Appendix C

Environmental

Appendix C-1

Environmental Supporting Documentation

Job No. TGL18185

APPENDIX C-1

DRAFT
ENVIRONMENTAL SUPPORTING DOCUMENT
FOR THE
COASTAL TEXAS PROTECTION
AND RESTORATION STUDY

Prepared for:

U.S. Army Corps of Engineers
and
Texas General Land Office

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Acronyms and Abbreviations

°F	degrees Fahrenheit
ADCIRC	ADvanced CIRCulation model
AdH	Adaptive Hydraulics model
BBEST	Bay Basin and Bay Expert Science Team
BEG	Bureau of Economic Geology
BSE	bay, sound, and estuary
CAA	Clean Air Act
CBBEP	Coastal Bend Bays and Estuaries Program
CEPRA	Coastal Erosion Planning and Response Act
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
cfs	cubic feet per second
CO	carbon monoxide
Coastal Texas Study	Coastal Texas Protection and Restoration Study
CSRM	coastal storm risk management
CSTORM-MS	Coastal Storm Modeling System
CWA	Clean Water Act
cy	cubic yards
dB	decibels
dBA	A-weighted sound level
DIFR-EIS	Draft Integrated Feasibility Report and Environmental Impact Statement
EFH	Essential Fish Habitat
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ER	ecosystem restoration
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
FWOP	future without-project
FWP	future with-project
GHG	greenhouse gases
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
Gulf	Gulf of Mexico
HCFCD	Harris County Flood Control District
HFPP	Hurricane Flood Protection Project
HGAC	Houston-Galveston Area Council

HGB	Houston-Galveston-Brazoria
HTRW	Hazardous, Toxic, and Radioactive Waste
IPCC	International Panel on Climate Change
L_{dn}	day-night noise level
L_{eq}	equivalent noise level
LNG	liquefied natural gas
MBTA	Migratory Bird Treaty Act
mcy	million cubic yards
MHHW	mean high high water
MLLW	mean low low water
MMPA	Marine Mammal Protection Act
mph	miles per hour
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
msl	mean sea level
NAAQS	National Ambient Air Quality Standards
NAVD 88	North American Vertical Datum of 1988
NEPA	National Environmental Policy Act
NFS	non-Federal sponsors
NHL	National Historic Landmarks
NMFS	National Marine Fisheries Service
NO_2	nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxides
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NRHP	National Register of Historic Places
NWR	National Wildlife Refuge
O_3	ozone
OMRR&R	Operations, Maintenance, Repair, Replacement, and Rehabilitation
Pb	lead
PCB	polychlorinated biphenyl
PM	particulate matter
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
PST	Petroleum Storage Tank
PWOP	present without-project
PWP	present with-project

RRC	Railroad Commission of Texas
RSL	relative sea level
RSLR	relative sea level rise
SAV	submerged aquatic vegetation
SH	State Highway
SIP	State Implementation Plan
SO_2	sulfur dioxide
STWAVE	Steady-state Wave model
TCEQ	Texas Commission on Environmental Quality
TCOON	Texas Coastal Ocean Observation Network
TDSHS	Texas Department of State Health Services
TNC	The Nature Conservancy
tpd	tons per day
TPWD	Texas Parks and Wildlife Department
tpy	tons per year
TSP	Tentatively Selected Plan
TWDB	Texas Water Development Board
TxDOT	Texas Department of Transportation
USACE	U.S. Army Corps of Engineers
USC	United States Code
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VOC	volatile organic compounds
WMA	Wildlife Management Area
WRDA	Water Resources Development Act
$\mu g/ft^3$	micrograms per cubic feet

2.0 EXISTING CONDITIONS (*NEPA REQUIRED)

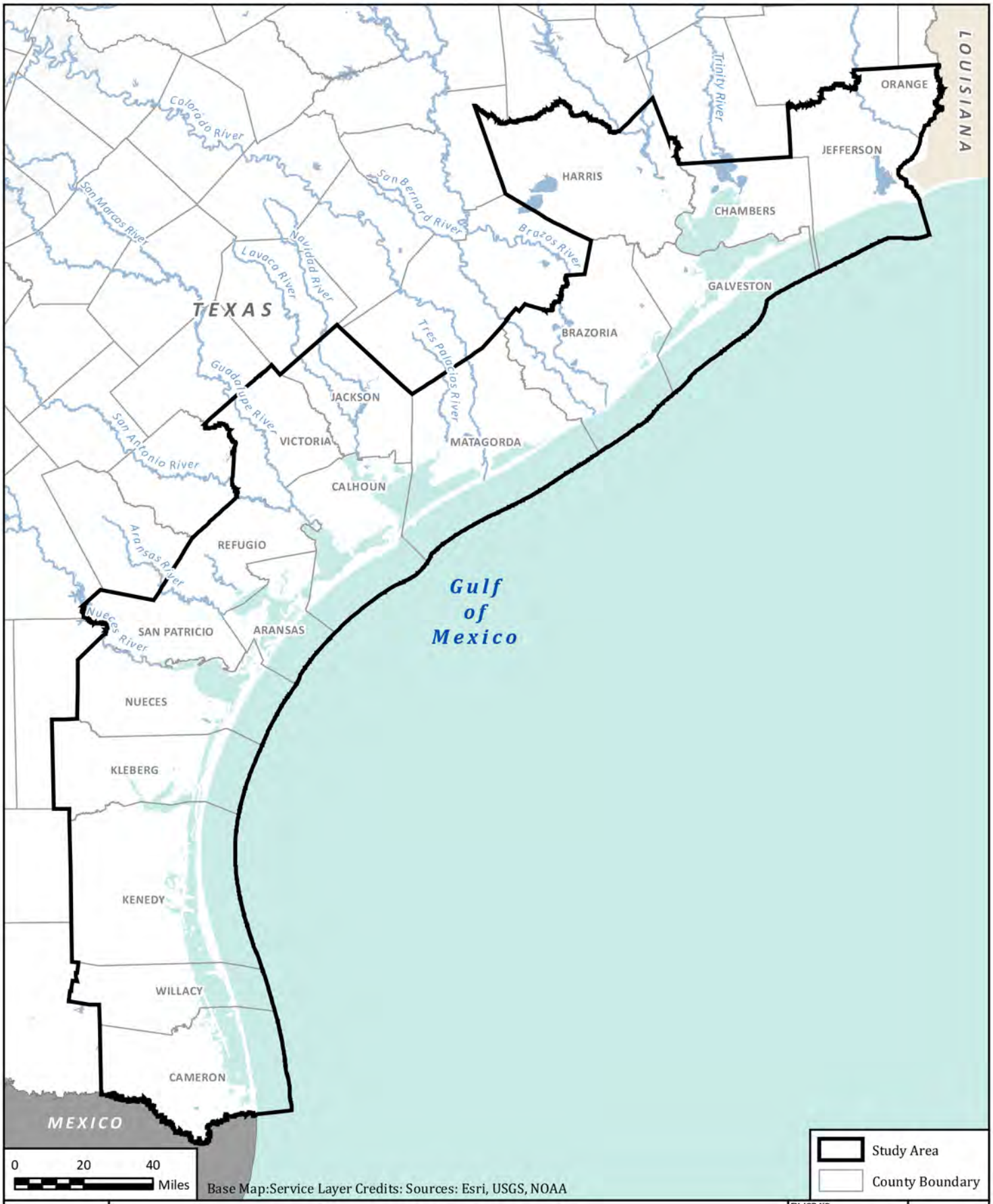
The purpose of the Existing Conditions section of this Draft Integrated Feasibility Report and Environmental Impact Statement (DIFR-EIS) is to provide a description of the existing environment in areas likely to be affected by the proposed Coastal Texas Protection and Restoration Study (Coastal Texas Study) and alternatives in a manner that allows effects to be better understood. In an effort to reduce the size of the document, descriptions are commensurate with the importance of the anticipated impact, with resources likely to not be impacted or that may be minimally impacted summarized, and a more-thorough description provided for resources more likely to be impacted. Sections within this environmental document appendix match the sections in the main DIFR-EIS report.

2.1 GENERAL SETTING

The study area consists of the entire Texas Gulf coast from the mouth of the Sabine River to the mouth of the Rio Grande and includes the Gulf of Mexico (Gulf) and tidal waters, barrier islands, estuaries, coastal wetlands, rivers and streams, and adjacent areas that make up the interrelated ecosystems along the coast of Texas (Figure 2-1). The study area encompasses 18 coastal counties along the Gulf coast and bayfronts. Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. Ecoregions serve as a spatial framework for the research, assessment, and management of ecosystem components and are also critical for structuring and implementing ecosystem management strategies. The study area closely corresponds to the U.S. Environmental Protection Agencies (EPA) level IV ecoregions (EPA, 2007) (Figure 2-2). Detailed maps of the Texas coastal area described in this document are shown on figures 2-3a–c.

The project area is defined as those areas that will be directly affected by construction or operation activities resulting from potential alternative plans of the Coastal Texas Study.

The upper coast occurs within Orange, Jefferson, Chambers, Galveston, Harris, and Brazoria counties, and includes two primary bay systems (Sabine Lake and Galveston Bay) and several large watersheds (Sabine, Neches, Trinity, San Jacinto, and Brazos rivers). The Galveston Bay area is recognized as nationally significant by Federal designation of the Galveston Bay National Estuary Program (1995). The broad range of salinities and flat topography allow the region to support a wide variety of habitats, including tidal and freshwater coastal marshes; shallow bay waters, which support seagrass beds, tidal flats, and reef complexes; coastal prairie with small wetland depressions; and forested riparian corridors. Extensive oyster reef habitat occurs in the southern part of Sabine Lake and throughout the Galveston Bay system. Areas of the Big Thicket National Preserve are spread across inland areas of the upper coast. Since roughly 75 percent of the bird species in North America either live in or pass through this area seasonally, the Big Thicket National Preserve was designated a Globally Important Bird Area by the American Bird Conservancy in 2001 (National Park Service [NPS], 2016a). A barrier peninsula (Bolivar) and island (Galveston) separate Galveston Bay from the Gulf, while the remainder of the upper coast is bounded by barrier headlands such as the Freeport area. Important large navigation channels in this region include the Sabine-Neches Waterway, Houston Ship Channel, and the Freeport Harbor Channel.



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Study Area

FN JOB NO	COH16388
FILE NAME	2-1Study_Area.mxd
DATE	8/21/2017
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DESIGNED	SSJ
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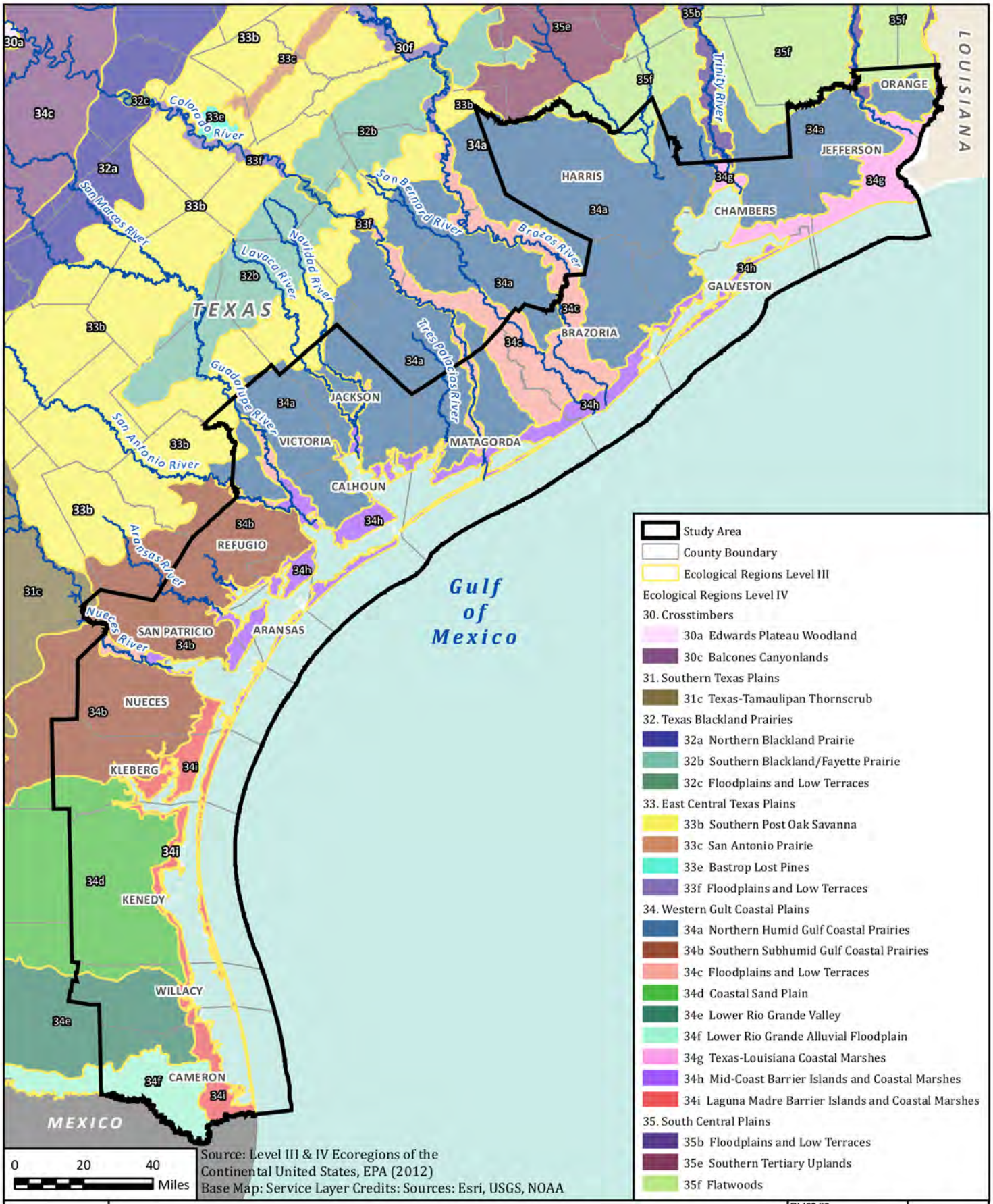
2-1

FIGURE

NAD 1983 Texas Centric Mapping System Albers



Source: Level III & IV Ecoregions of the Continental United States, EPA (2012)
Base Map: Service Layer Credits: Sources: Esri, USGS, NOAA

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Ecological Regions

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FIGURE

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NAD 1983 Texas Centric Mapping System Albers

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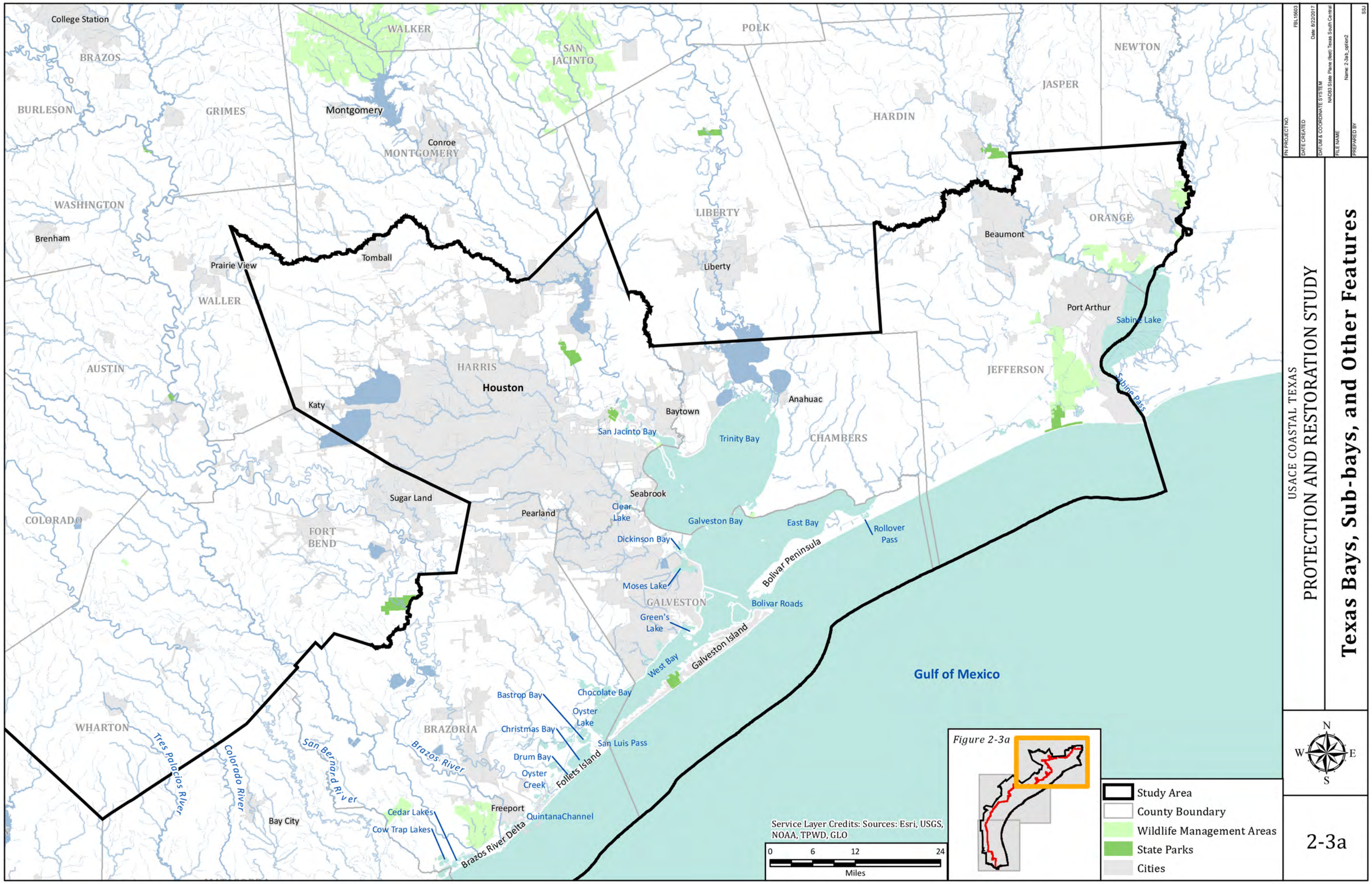

FN PROJECT NO. FBL15603

DATE CREATED Date: 6/22/2017

DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central

FILE NAME Name: 2-3ab_option2

PREPARED BY SSJ

USACE COASTAL TEXAS

PROTECTION AND RESTORATION STUDY

Texas Bays, Sub-bays, and Other Features

2-3a

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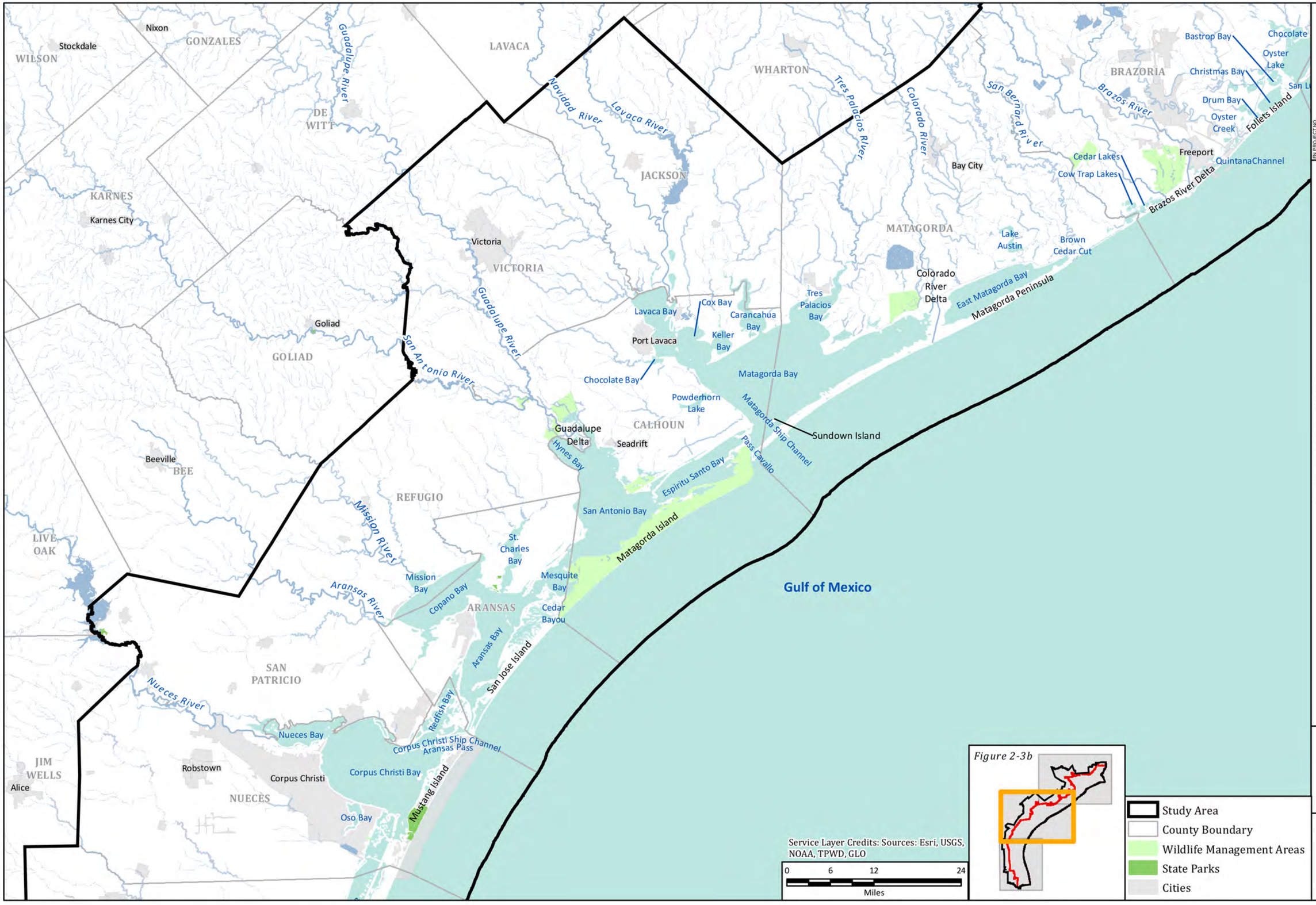

FN PROJECT NO. FBL15603

DATE CREATED Date: 8/22/2017

DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central

FILE NAME Name: 2-3ab_option2

PREPARED BY SSJ

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Texas Bays, Sub-bays, and Other Features

2-3b

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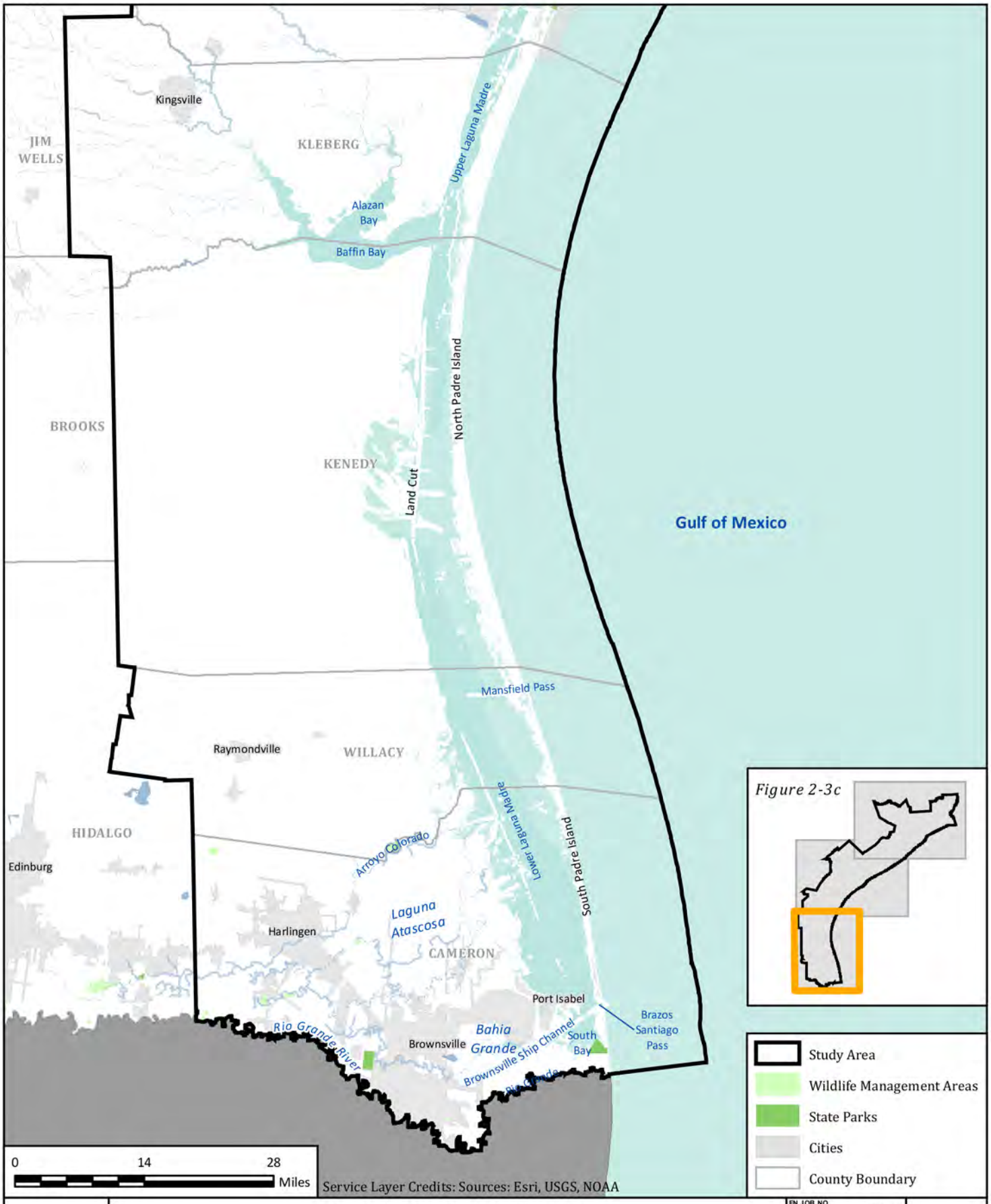

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Texas Bays, Sub-bays, and Other Features

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DATE	8/18/2017
SCALE	1:887,040
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2-3c

FIGURE

NAD 1983 Texas Centric Mapping System Albers

Matagorda, Jackson, Victoria, and Calhoun counties occur in the mid to upper Texas coast and include several bay systems (Matagorda Bay, Lavaca Bay, Espiritu Santo Bay, and parts of San Antonio Bay). Primary watersheds feeding these bays include the Colorado, Lavaca, and Guadalupe rivers, which form the boundary between the mid to upper coast; deltas of the Colorado and Guadalupe rivers also occur in the region. Matagorda Bay is the largest of the bay systems in the mid to upper coast and includes numerous minor estuaries. Notable features of the mid to upper coast include Half Moon Reef (a historic oyster reef that was successfully restored and continues to undergo additional restoration actions), Mad Island Preserve and Mad Island Wildlife Management Area (WMA), Matagorda Island State Park, and several National Wildlife Refuges (NWRs) (The Nature Conservancy [TNC], 2016a). Like many areas in the upper coast, the broad range of salinities and flat topography allow the region to support a wide spectrum of habitats, including tidal and freshwater coastal marshes; shallow bay waters that support seagrass beds, tidal flats, and reef complexes; coastal prairie with small wetland depressions; and forested riparian corridors. Extensive seagrasses and mangroves occur in Espiritu Santo Bay, near Pass Cavallo, and seagrass is also relatively prevalent immediately behind Matagorda Island and Matagorda Peninsula. Important large navigation channels in this region include the Matagorda Ship Channel and the Victoria Barge Canal.

The mid coast occurs within Aransas, Refugio, San Patricio, Nueces, and Kleberg counties, and includes several bay systems (Corpus Christi Bay, Copano Bay, Aransas Bay, Nueces Bay, portions of San Antonio Bay, and the Upper Laguna Madre, including Baffin Bay). Primary watersheds feeding these bays include the Mission River, Aransas River, Nueces River, and Los Olmos Creek (which forms the boundary between the mid to lower coast). This area includes the barriers of North Padre Island, San Jośe Island, Mustang Island, and portions of Matagorda Island. Padre Island National Seashore is owned and managed by the NPS and is the longest stretch of undeveloped barrier island in the world (NPS, 2016b). The Nueces River Delta is a unique resource found in the area that has many interest groups working to restore and conserve it and its ecological functions (Lloyd, 2016). Extensive seagrasses occur throughout the area, and unique hard reefs occur within Baffin Bay; these unique hard reefs were formed from either remnant beach rock or fossilized serpulid worm reefs. The Upper Laguna Madre is also a defining feature of the Texas coast as it is the northernmost portion of a hypersaline lagoon, described further below (Tunnell and Judd, 2002). Important large navigation channels in this region include the Corpus Christi Ship Channel and the La Quinta Channel.

The southernmost portions of the Texas coast occur within Kenedy, Willacy, and Cameron counties and is dominated by the Lower Laguna Madre, which is one of five hypersaline lagoons in the world. High overall temperatures and evaporation rates, combined with low rainfall and freshwater input, drive the high salinity (Tunnell and Judd, 2002). Average salinity along the Laguna Madre is 36 parts per thousand (ppt) (EPA, 1999). Main watersheds that flow into the Lower Laguna Madre include Arroyo Colorado and the Rio Grande. The Laguna Madre is shallow, averaging approximately 3.3 feet deep, and, including the South Bay and the Bahia Grande complex, contains approximately 180,000 acres of shallow flats (Tunnell and Judd, 2002). The main outlet into the Gulf for the southern reach of the Lower Laguna Madre is Brazos Santiago Pass, through which passes the deep-draft Brazos Island Harbor navigation channel.

Coastal, subtropical, desert, temperate, and tropical biomes converge in Cameron County near the Rio Grande (McMahan et al., 1984). Thornscrub forest and brush habitat occur on upland sites like fluvial riparian zones of resacas and the Rio Grande, and on lomas throughout the area. Resacas are relict oxbow lakes of the Rio Grande that provide unique aquatic habitat in this region. Similarly, unique lomas are brush-covered clay dunes situated within tidal and wind-tidal flats with abrupt topographic relief reaching 30 feet above surrounding flats (Jahrsdoerfer and Leslie, 1988). Impenetrable brush with a relatively closed canopy provides habitat and movement corridors for wildlife in the area.

Abundant tidal flats in this region provide important habitat for a variety of coastal wildlife from migratory waterfowl, shorebirds (like the Federally listed piping plover [*Charadrius melodus*] and rufa red knot [*Calidris canutus rufa*]), wading birds, and other estuarine-dependent species like shrimp and various finfish (White et al., 1986). These flats are usually barren except for large areas colonized by blue-green algae mats called algal flats. The unique processes that result in algal flat formation only exist in several locations worldwide, including the Persian Sea, Red Sea, and eastern Mediterranean Sea (Morton and Holmes, 2009).

The Gulf Intracoastal Waterway (GIWW) is a 1,100-mile man-made, shallow-draft canal that runs along the Gulf from St. Marks, Florida, to Brownsville, Texas, linking Texas Ports with the rest of the country. In Texas, the main channel of the GIWW is 379 miles long spanning from the Sabine River to Brownsville (Texas Department of Transportation [TxDOT], 2016a).

2.2 CLIMATE CHANGE

Weather is the atmospheric conditions over days to a few weeks, and climate is how the atmosphere "behaves" over relatively long periods of time (National Aeronautics and Space Administration, 2005). Climate is the atmospheric condition over part of the earth over an extended time, years to decades, and typically exhibits patterns that repeat, e.g., cold temperatures in the winter and warm temperatures in the summer. Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to climate variability (International Panel on Climate Change [IPCC], 2014).

Three factors have the most influence on Texas's Gulf coast climate (Nielsen-Gammon, 2016):

- The Gulf – provides moisture, winds, and moderates temperatures;
- Latitudinal position – ranging from subtropical along the border with Mexico to temperate along the upper coast; and
- El Niño and La Niña – the large-scale climate patterns resulting from warming and cooling of the central and east-central equatorial Pacific.

Rainfall is the main form of precipitation along the coast and tends to occur most frequently and in greatest amounts in the spring and late summer/early fall. Rainfall rates decrease, and temperatures increase moving south along the coast. Coastal relative humidity averages slightly more than 60 percent over the course of the year (Nielsen-Gammon, 2016).

During El Niño periods, when Pacific waters are warmer than normal, the Texas coast is typically wetter and cooler than normal in the winter. Freshwater inflows to estuaries may increase and bay salinities may decrease. When Pacific waters are cooler than normal, the La Niña pattern is in place, the winters are warmer and dryer than normal resulting in droughts, reduced freshwater inflows, and increased bay salinities (Tolan, 2007).

During the winter, rapid drops in temperature occur 10 to 20 times a year with the passage of fast-moving cold fronts called "blue northers." The rapid temperature drops, sometimes to below freezing, have caused massive fish and sea turtle mortality events along the coast. In some instances, dolphins have been affected. Freezing temperatures are relatively uncommon along the coast, but more likely to be experienced along the upper coast than the lower coast (Martin and McEachron, 1996). High velocity winds associated with these events cause "blow outs" of the bays when water levels may drop more than a foot below normal low tides. Low pressure systems can form in the Gulf during the winter causing long periods of steady rains along the coast. In rare cases these systems can strengthen, generating high winds and water levels substantially above high tide (Contreras, 2003). Prevailing southerly and southeasterly winds blow warm, humid air from the Gulf onshore much of the year. High temperatures in the 80 and 90 degrees Fahrenheit (°F) occur in the summer along the coast (Nielsen-Gammon, 2016).

The Southern Regional Climate Center (National Oceanic and Atmospheric Administration [NOAA], 2016a) summarized the climate for the Texas coast from 1981 to 2010 (Table 2-1).

Table 2-1
Annual Average Temperature and Total Rainfall for Texas Coastal Cities, 1981 to 2010

City	Average Temperature (°F)	Total Rainfall (inches)
Beaumont	68.59	60.42
Galveston	71.22	50.76
Port O'Connor	70.66	35.93
Corpus Christi	72.11	32.49
South Padre Island	74.28	25.83

Source: NOAA (2016a).

These conditions were influenced by a strong El Niño during 2016. Average temperatures in Texas coastal counties ranged from <1 to 3°F above normal. Rainfall in the Sabine Lake and Galveston areas was 16 to more than 20 inches above normal (NOAA, 2016a).

Coastal climate in Texas is characterized by episodic storms and unusual weather events that are documented in the monthly report, "Storm Data." During 2015 to 2016, unusual weather events along the Texas coast included temperatures below freezing for several hours in Kenedy County, severe hail storms in Harris and Jefferson counties, and tornadoes and severe flooding along most of the Texas coast caused by Hurricane Patricia, which crossed from the Pacific through Mexico during October 2015 (National Centers for Environmental Information, 2016).

2.3 PHYSICAL RESOURCES

2.3.1 Regional Geologic Setting

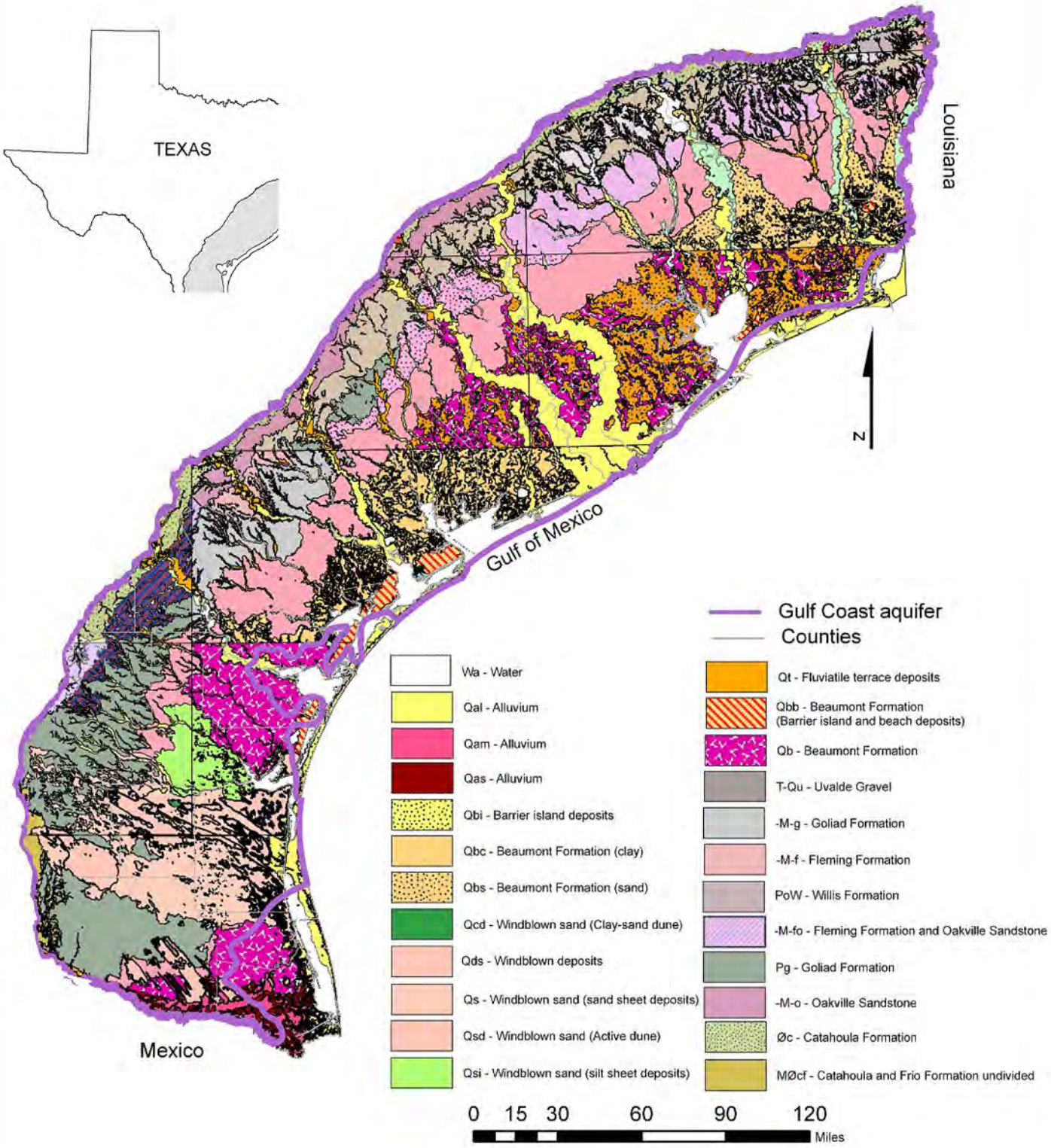
2.3.1.1 Geology

The geological setting of the Texas coastline and the major geomorphological features have been developed through a combination of fluvial, coastal, and marine processes occurring over the last 125,000 years (Anderson et al., 2016). Anderson et al. (2016) used sedimentary rock analysis including detailed lithological descriptions, identification of sedimentary structures, grainsize analysis, seismic stratigraphic analysis, macro- and micro-faunal analyses, magnetic susceptibility and clay mineralogy, hundreds of radiocarbon dates, oxygen isotope profiles, and micro-paleontological data to determine the geological record and reconstruct the evolution of the Texas coast. By evaluating relative age assignments of sea level transgressions and regressions, a geological record interpretation was developed for the depositional environments created during the sea level changes within the last 125,000 years. This analysis helped to develop the history of the geology and geomorphology of the Texas coast.

The Beaumont Formation, or Beaumont clays, is a Pleistocene formation present across the Texas coast composed of the oldest coastal deposits. Bernard et al. (1970) and Fisher et al. (1972) originally defined the Beaumont Formation as a fluvial delta with shallow marine deposits and barrier-strand plain-Chenier units that formed 35,000 to 400,000 years ago. The Beaumont Formation is present in large areas of the former coastal plains and continental shelf as presented on Figure 2-4. This figure shows the surficial geology of the coastal Texas aquifers illustrating the extension of the Beaumont clay throughout the Texas coast (Chowdhury and Turco, 2006).

Blum and Price (1998) dated the age of the Beaumont Formation using the nearby Colorado River system, showing that the representative period of the deltaic and fluvial deposition spanned from 85,000 to 400,000 years ago. These deposits consisted of multiple fluvial and deltaic cycles of river valley incision and filling as responses to sea level changes (Blum and Price, 1998). The Beaumont Formation also includes ancient barrier islands and beach deposits created over 35,000 years ago, which can be observed in Rockport, Port O'Connor, Ingleside, and on the north shorelines of West and East Galveston bays (Fisher et al., 1972).

According to Anderson et al. (2016), with the slowdown of sea level rise in the last 2,000 to 9,000 years, the current coastline became a mix of sandy barrier island environments, marsh-swamps, bay-estuary-lagoons, inlets and offshore shorefaces, and fluvial-deltaic systems that covered the Beaumont Formation. These new depositional environments consist of a wide range of sands, silts, and clays in different geomorphological environments. The post-Beaumont Formation coastal deposits correspond to reworked deposits from these alluvial, fluviatile, and aeolian processes being placed in the newly created coastal environments. Following the slowdown of sea level rise, the coastal environment has been characterized by sandy lowlands that are subject to severe shoreline retreat and limited sediment supply (Anderson et al., 2016).



Source: Chowdhury and Turco (2006)

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Geology of Coastal Texas Aquifers

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2-4

FIGURE

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NAD 1983 Texas Centric Mapping System Albers

The general geologic setting of the Texas coast described by Morton and Peterson (2005, 2006a, 2006b) is summarized below.

Sabine Pass to the Colorado River. This area is made up of two headlands that are flanked by a barrier island. The eastern portion of the headland extends from Sabine Pass to Bolivar Peninsula, and the western portion includes the Brazos River and delta complex extending from Follets Island to the eastern portion of Matagorda Peninsula. It is composed of deltaic sand and mud deposits transported by the Brazos and Colorado rivers, thus changing the orientation around the western headland. Broken shells and rock fragments, resulting from long-term erosion and altering of older deposits from the surf zone, make up the beach sediments along both headlands. A source of sediment for adjacent barrier islands (i.e., Bolivar Peninsula, Galveston Island, Follets Island, and Matagorda Peninsula) is long-term erosion of the headlands. When these barrier islands with numerous beach ridges formed, there was abundant sand supply and subsequent seaward advancement of the Gulf shoreline (Morton and Peterson, 2005).

Aransas Pass to Mansfield Channel. This area is characterized by wide, long, sandy barrier islands (Mustang and Padre islands) that are mostly undeveloped. Due to the abundant sand supplied by longshore currents in the Gulf, these islands have continued to increase in size. Wide beaches and densely vegetated high continuous dunes characterize the area except for north of Mansfield Channel. Two natural inlets (Aransas Pass and Packery Channel) occur in this area due to the low tidal range and high sand supply in the littoral system. Following the deepening of Aransas Pass for navigation in 1930, Packery Channel closed but was reopened in 2004 to allow small boats shorter access to the Gulf. Along this portion of the Texas coast, beaches change orientation from northeast to southwest to north-south and are composed of fine sand with some broken shell except in the area known as Big Shell Beach. Shells are concentrated here because the area falls in the zone of convergence of longshore currents, which flow from the northeast and south at different times, and the winds blow sand from the beach leaving the shell deposits (Morton and Peterson, 2006a).

Mansfield Channel to the Rio Grande. This area is mostly undeveloped and made up of South Padre Island, a long, narrow, sandy barrier island, and Brazos Island, a deltaic headland with a sandy beach. As sea level rose, these areas narrowed and retreated landward as the Rio Grande sand supply decreased, forming the Rio Grande delta and barrier island. The barrier island exhibits wide beaches, high, sparsely vegetated dunes, which are cut by numerous washover fans, and in some areas during droughts have migrated across the barrier island into the Laguna Madre. Brazos Santiago Pass is the only natural tidal inlet in the area due to the low tidal amplitude and evaporation commonly exceeding precipitation in the area. Beaches are composed of fine sand with some broken shells that erode from underlying deltaic sediments (Morton and Peterson, 2006b).

As natural conditions occur along the coastline, several factors indirectly impact the regional and local geologic settings including shoreline retreat or accretion, land loss due to relative sea level rise (RSLR), and subsidence. RSLR effects may be translated into higher water elevations, increased sediment transport, and exposure of new geologic stratigraphy to erosion altering the composition of the sedimentary environment. These geomorphic processes are described in detail in sections 2.3.2 and 2.3.3.

2.3.1.2 Sediment Transport

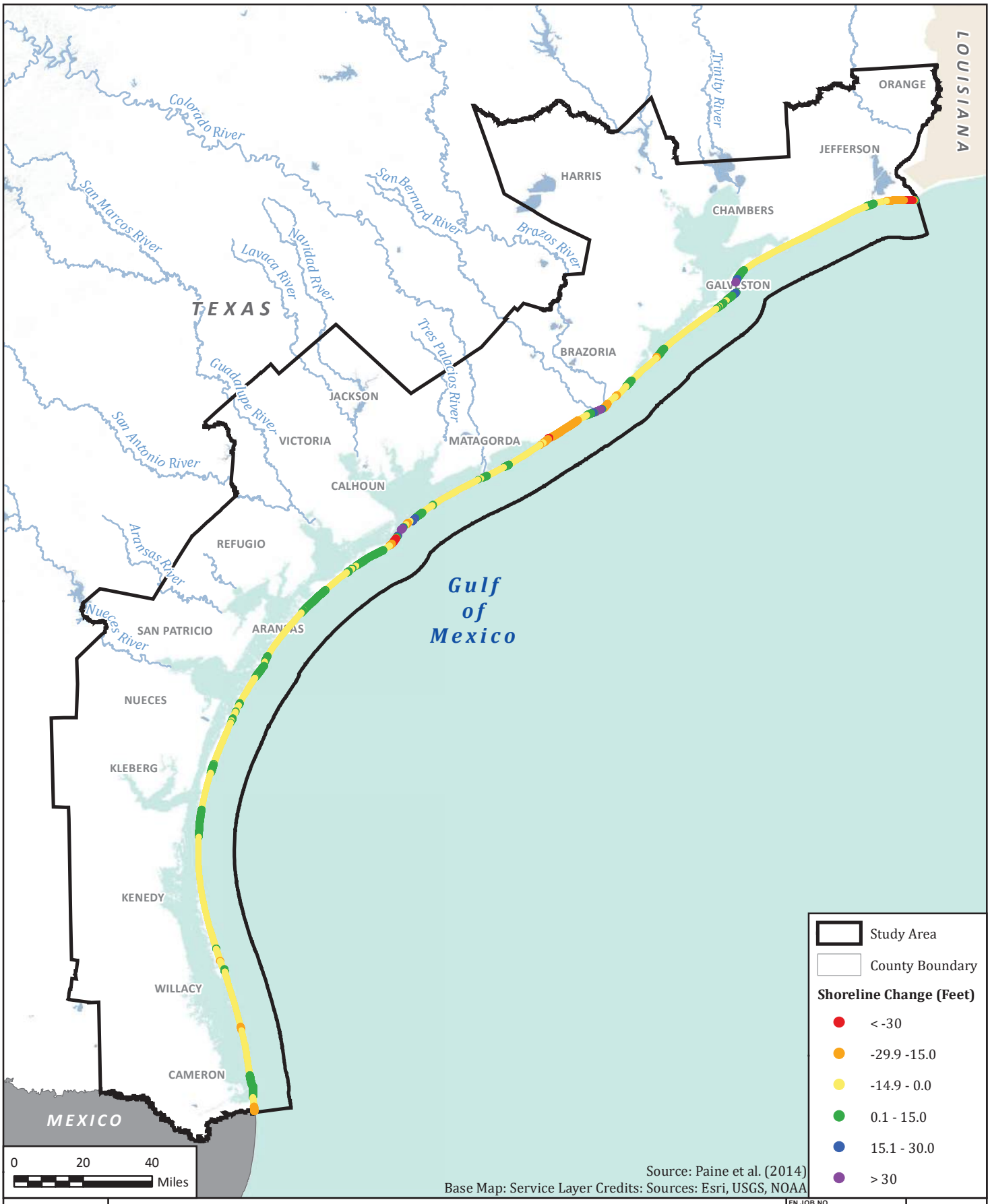
Local and regional natural geomorphic and hydrodynamic processes (including river processes, tides, storm surges, circulation eddies, and longshore drift transporting sand from river deltas to other locations along the coast), catastrophic or episodic storm events, and anthropogenic developments (navigation infrastructure or the presence of engineered structures or shorelines) act upon coastal sediment transport along Gulf shorelines to form and erode beaches, barrier islands, and peninsulas (Freese and Nichols, Inc., 2016).

Because of these processes, a common denominator to Gulf shorelines and bays are extensive rates of shoreline erosion due to reduced sediment supply to the coastal system. Typically, sediments that are deposited into the system tend to migrate toward the Gulf and then are carried in a southwesterly direction along the coast from Port Arthur to south of Corpus Christi via longshore drift (Dunn and Raines, 2001). An opposing current creates a zone of convergence and transports material in a northerly direction from the Mexico coastline toward Corpus Christi (Freese and Nichols, Inc., 2016). However, hard structures such as groins, jetties, and breakwaters, interfere with longshore drift and induce either shoreline erosion or accretion adjacent to these artificial structures (Morton et al., 2004; Freese and Nichols, Inc., 2016). The fluvial sediment supply that nourishes the Gulf has been highly altered due to extensive reservoir construction, changes in land use, and instream sand and gravel mining (Dunn and Raines, 2001). The removed sediment from bay shorelines results in regional sediment sinks, and this loss results in or causes the disintegration of marsh systems, deltas, inlets, bird island habitat, oyster reefs, and other eco-geomorphologic systems (Moya et al., 2012).

Maintenance dredging of navigation channels has historically resulted in sediments that were typically stored in dredge material placement areas or dumped into the Gulf via open placement (U.S. Army Corps of Engineers [USACE], 1975). Since the Texas coast is now considered a sediment-starved system, more opportunities to use dredge material beneficially are being considered for the construction of coastal protection and ecosystem restoration (ER) projects (Freese and Nichols, Inc., 2016).

2.3.1.3 Shoreline Change

The Texas coastal shoreline consists of a dynamic environment involving sea level rise, subsidence, sediment supply, littoral drift, and frequent and intense storms. Sediment supplies have been altered within most watersheds and coastal systems (Paine et al., 2014). Reservoir construction along major rivers has reduced the sediment supply that enters bays and nourishes coastlines thereby resulting in widespread shoreline erosion (Paine et al., 2012). Shoreline erosion threatens coastal habitats, recreation opportunities and qualities, and residential, transportation, and industrial infrastructure. Gulf shoreline erosion rates between the 1930s and 2012 averaged –4.1 feet per year of retreat. Rates of shoreline change are generally greater on the upper Texas coast (from the mouth of the Colorado River to Sabine Pass) than those in the mid to lower Gulf coast. The upper Texas coast retreat was calculated at –5.5 feet per year, and the mid to lower coast retreated an average of –3.2 feet per year (Paine et al., 2014) (Figure 2-5). Table 2-2 and Figure 2-5 show the net shoreline and land area change from the 1930s to 2012 for geomorphic areas and counties along the Texas Gulf shoreline.



Source: Paine et al. (2014)
Base Map: Service Layer Credits: Sources: Esri, USGS, NOAA

N W E S

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Shoreline Change 1930s to 2012

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DESIGNED	SSJ
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2-5
FIGURE

NAD 1983 Texas Centric Mapping System Albers

Table 2-2
Net Shoreline Change for the Texas Gulf Shoreline, 1930s to 2012*

Area	Number of Sample Sites	Net Rate of Retreat (feet/year)	Range of Retreat (acres/year)	Area Change Rate (acres/year)	Area Change (acres)
All Texas Sites	11,749	–4.1	–41.5 to 50.6	–177.8	–14,590
Geomorphic Areas:					
Sabine Pass to Rollover Pass	1,345	–9.7	–28.9 to 23.0	–48.9	–4,009
Bolivar Peninsula	543	1.4**	–4.4 to 36.1	+2.7	+227
Galveston Island	930	–0.9	–6.7 to 16.1	–3.2	–257
Brazos/Colorado Headland	1,258	–6.8	–32.1 to 50.6	–32.4	–2,648
Matagorda Peninsula	1,591	–3.3	–25.4 to 49.6	–19.5	–1,610
Matagorda Island	1,120	–2.4	–41.5 to 39.8	–10.1	–840
San José Island	620	–2.4	–4.0 to 1.0	–5.7	–467
Mustang Island	575	–1.1	–4.7 to 7.9	–2.5	–200
North Padre Island	2,404	–2.7	–11.1 to 2.7	–24.5	–1,996
South Padre Island	1,359	–7.5	–18.5 to 8.4	–38.0	–3,120
Counties:					
Jefferson	1,042	–10.9	–28.9 to 23.0	–43.0	–3,522
Chambers	36	–7.4	–6.2 to –4.7	–1.0	–82
Galveston	1,740	–0.8	–6.7 to 36.1	–5.2	–435
Brazoria	924	–1.4	–17.5 to 50.6	–4.9	–405
Matagorda	1,926	–6.5	–32.1 to 49.6	–47.2	–3,866
Calhoun	1,134	–2.4	–41.5 to 39.8	–10.1	–840
Aransas	609	–2.5	–4.0 to 1.0	–5.7	–467
Nueces	667	–1.2	–4.7 to 7.9	–3.0	–252
Kleberg	707	–1.71	-4.2 to 0.7	–4.4	–373
Kenedy	1,522	–2.62	–11.1 to 2.2	–15.1	–1,235
Willacy	428	–8.60	–11.1 to 9.1	–13.8	–1,136
Cameron	1,014	–7.42	–18.5 to 7.9	–28.4	–2,322

Source: Bureau of Economic Geology (BEG, 2016a); Paine et al. (2014).

* Data calculated using coastwide LiDAR data collected in February 2012. Rates include effects (erosion, deposition, and recovery) associated with Hurricane Ike (September 2008).

** Most of the Gulf shoreline along Bolivar Peninsula has been eroding at rates up to 6.4 feet per year. Four miles of shore from the Bolivar Roads north jetty to the east has accreted sediment impounded behind the jetty. Sediment added in this area results in a net positive rate of retreat even though most of the peninsula's shore is eroding.

According to Paine et al. (2014), areas undergoing significant net retreat (see Figure 2-5) include (1) the marshes on the upper Texas coast between High Island and Sabine Pass; (2) segments on the sandy barrier-island shoreline on Galveston Island; (3) most of the combined fluvial and deltaic headland constructed by the Brazos and Colorado rivers; (4) sandy, headland-flanking Matagorda Peninsula west of the Colorado River; (5) San José Island, a sandy barrier island on the mid Texas coast; and (6) the northern end and much of the southern half of Padre Island, a sandy barrier island on the lower coast. Significant net shoreline advance occurred (1) adjacent to the jetties that protect dredged channels at Sabine Pass, Bolivar Roads, and Aransas Pass; (2) near tidal inlets at the western ends of Galveston Island and Matagorda Peninsula; (3) at the mouth of the Brazos River; (4) along most of Matagorda Island; and (5) on central Padre Island (Paine et al., 2014).

2.3.2 Physical Oceanography

2.3.2.1 Tides

In Texas, three factors influence tidal exchange: astronomical (true tides), meteorological (i.e., mostly influenced by winds and barometric pressure), and density stratification. Meteorological tides can raise or lower water levels on Gulf beaches as much as 3 feet compared to astronomical tides, which exhibits how wind has significant tidal influence and accounts for substantial tidal exchange between the Gulf and estuaries (Armstrong et al., 1987). During winter, passage of strong fronts can dramatically change water levels in estuaries as water is “forced” out of the system by the northerly winds (Morton et al., 1994).

Tidal range (the difference in height between the highs and the lows) along the Texas coast is less than 2 feet on average. The Texas coast experiences week-long periods of diurnal tides (once-per-day high and low) followed by a week of semidiurnal tides (twice-per-day high and low) making them more unpredictable than other areas in the United States. In Texas, diurnal tides have a much greater range than semidiurnal (Amos, 2014).

Texas coast tide data are provided by NOAA and Texas Coastal Ocean Observation Network (TCOON) tide stations (NOAA, 2016b). These stations are established along the Texas coast and provide the most comprehensive assessment of tides, water levels, and general meteorological and physical oceanography data available. Table 2-3 shows the mean tide range (difference in height between mean high water and mean low water) for representative pass and bay stations starting from north moving to south along the Texas coast.

Table 2-3
Tide Ranges Within the Study Area

Station	Station ID	Mean Range of Tide (feet)
Sabine Pass North, Texas	8770570	1.09
Port Arthur, Texas	8770475	0.83*
Galveston Bay Entrance, North Jetty, Texas	8771341	1.16
Galveston Pier 21, Texas	8771450	1.02
Morgan's Point, Texas	8770613	1.12
San Luis Pass	8771972	0.90
Freeport, Texas	8772447	1.39
Sargent, Texas	8772985	0.57
Matagorda City, Texas	8773146	0.39
Matagorda Bay Entrance Channel, Texas	8773767	1.11
Port Lavaca, Texas (TCOON)	8773259	0.84*
Seadrift, Texas (TCOON)	8773037	0.32*
Port Aransas, Texas (TCOON)	8775237	0.87*
Nueces Bay, Texas (TCOON)	8775244	0.64*
Packery Channel, Texas	8775792	0.36*
South Padre Island Coast Guard Station, Texas (TCOON)	8779748	1.12*

Source: NOAA (2016b).

* Mean range of tide not available, value reported mean high water minus mean low water.

2.3.2.2 Currents and Circulation

The ocean current system of the North Atlantic Gyre consists of four interconnecting ocean currents: Gulf Stream Current, North Atlantic Current, Canary Current, and North Equatorial Current (Stott, 2017). This ocean current system consists of convection currents driven by temperature and saline differentials and the Coriolis Effect (NOAA, 2011). These strong currents transport energy and nutrients from the bottom of the ocean to the surface and distribute it globally. The Gulf Loop Current is a warm-water system that flows through the Yucatan Strait, flowing clockwise through the Gulf and out the Florida Strait into the Atlantic Ocean (NOAA, 2014a). The position of the Loop Current is variable based on ocean trends such as surface temperature, wind, and saline concentration. Occasionally portions of the loop can be pinched off and the resulting eddies of warm water can propagate westward towards the shoreline of Texas or Mexico (Gyory et al., 2013). Eddies and the Loop Current provide a deep layer of warm water, which can provide energy and strengthen hurricanes (Masters, 2016). Table 2-4 provides a summary of ocean currents and eddies influencing meteorological patterns within the Gulf region.

Table 2-4
Summary of Gulf of Mexico Ocean Currents and Eddies

Currents	Thermal Rating	Rotation	Features
North Atlantic Gyre	Warm and Cold	Clockwise	Interconnecting ocean currents: Gulf Stream, North Atlantic, Canary, and North Equatorial Currents
Gulf Loop Current	Warm	Clockwise	Ocean current flowing from Yucatan Strait to Florida Strait; thermal energy source for hurricanes to intensify
Gulf Eddies	Warm	Circular	Westward propagation to Texas; thermal energy source for hurricanes to intensify

Source: Masters (2016).

Because of the gently sloping nature of the Gulf continental shelf and low wave action, local winds can play a more active role in shaping shoreline dynamics such as tides and surface currents (King, 2007). Waves, which propagate across an ocean or bay expanse, obtain energy from the wind, delivering and transferring wave energy to nearshore coastal environments. Along Texas Gulf coast beaches as well as bay shorelines, these wind-generated waves induce longshore and cross-shore currents, which transport sediments. Longshore currents run parallel to the coastline and produce waves, which strike the shoreline at an angle. Longshore currents carry sediments along the coastline. Cross-shore currents are shore-perpendicular currents. Cumulatively these two current components effect physical changes to coastal and bay shorelines by accreting or eroding sediments. Wind direction, angle of wave approach, and the geographic orientation of the shoreline can influence the current direction and amount of sediment transportation from the beachhead (Grand Valley State University, 2016; NOAA, 2016c).

Five major bay systems occur in Texas: the Sabine, Galveston, Matagorda, Nueces, and Laguna Madre Systems (see figures 2-3a–c). The estuarine ecosystems within these bay systems are under threat by increased exchange with and exposure to Gulf waters and forces due to a combination of geomorphic changes to barrier islands, hydrologic modifications within the coastal watersheds, and RSLR. Increased exchange and exposure with the Gulf will change the tidal prism and salinity regime, impacting bay marsh vegetation and erosion, and placing existing infrastructure at greater risk to storm-induced damages. However, redundant and resilient levels of protection and restoration through the concept of multiple lines of defense can reduce the physical impacts of storm surges and winds that enter the bays. These lines of defense are provided first by Gulf-facing barrier islands, then by in-bay living shorelines, and finally by bay and estuarine marshes.

Sabine Lake System. The Sabine River is a 510-mile river between the Texas and Louisiana border. The river drains about 9,756 square miles, mostly in Texas (Sabine River Authority, 2016). The Neches River is 416 miles long and drains an area of 10,011 square miles (Texas Commission on Environmental Quality [TCEQ], 2016a). The outflow of the Sabine-Neches River Basin is through Sabine Pass into the Gulf. The deepening of the GIWW and the Sabine-Neches Waterway has allowed salt water to intrude into the historically freshwater lake, which has resulted in higher salinities in its upper and lower areas and lower salinities in its central portion (Louisiana Coastal Wetlands Conservation and Restoration Task Force, 2002). There are a few saltwater barriers along the

two rivers, which help mitigate the saltwater intrusion of the river system upstream (Trans-Texas Water Program, 1998).

Galveston Bay System. Galveston Bay receives flows from the San Jacinto and Trinity rivers. Together the two rivers provide the estuary with about 8 million acre-feet of fresh water annually. The Houston Ship Channel links the Port of Houston to Galveston Bay and the Gulf. The Port of Houston is the second busiest port in the United States, and expansion of the ship channel width and depth over the years has increased the amount of tidal circulation within the bay (Pulich, 2006).

Matagorda Bay System. The Matagorda Bay Estuary system is the second largest on the coast of Texas. From 1941 through 2003, Matagorda Bay received an annual average of 3,444,000 acre-feet of fresh water from its watershed and river basins. The Matagorda Ship Channel, constructed in 1966, connects Port O'Connor and Matagorda Bay to the Gulf. The Colorado River was diverted into the eastern portion of Matagorda Bay in 1991 by the USACE in an effort to increase freshwater inflows into the estuary (Lower Colorado River Authority et al., 2006).

Nueces Estuary System. The Nueces Estuary System consists of Nueces Bay, Corpus Christi Bay, and Oso Bay and spans 106,990 acres. The estuary receives an average of 587,000 acre-feet of fresh water from the Nueces River annually (Texas Water Development Board [TWDB], 2017a). Lake Corpus Christi and Choke Canyon Reservoir on the Nueces River have reduced inflows into the bay by 15 percent. Because of this, Corpus Christi Bay is not as well flushed compared to other bay systems on the Texas coast. The estuary is connected to the Gulf by Aransas Pass and the GIWW (Coastal Bend Bays and Estuaries Program [CBBEP], 1997).

Laguna Madre Estuary System. The Laguna Madre Estuary stretches for 280,910 acres and has an average depth of 4.5 feet. The estuary receives most of its 743,000 acre-feet of freshwater inflows from streams like San Fernando Creek and the Arroyo Colorado (TWDB, 2017b). The Laguna Madre's high evaporation rate and ephemeral streams create a hypersaline environment in the lagoon. The Laguna Madre is connected to the Gulf by the GIWW and Port Mansfield Channel (Texas Parks and Wildlife Department [TPWD], 2004).

2.3.2.3 Salinity

Estuaries are where freshwater rivers and streams mix with saline Gulf waters. A defining characteristic of these dynamic areas is salinity. Estuarine salinity is usually intermediate between salt levels of rivers and Gulf waters and tends to vary proportionally to the amount of freshwater entering the estuary from the land and the amount of Gulf waters entering through passes. Coastal wetlands and ecologically, recreationally, and commercially important species of fish and shellfish depend on these intermediate salinities for successful spawning, development, and growth.

Texas estuaries exhibit a wide range of salinity. Relatively high rainfall rates in the northeast region of the state, combined with the small size of Sabine Lake and its restricted exchange with the Gulf, create the estuary with the lowest salinity on the Texas coast. The south Texas coast is semiarid with less freshwater inflow, higher temperatures, and evaporation rates. Because of these dry conditions and relatively little tidal exchange, the

Laguna Madre exhibits salinities frequently exceeding those of the Gulf. The salinity characteristics of each estuary contribute to the differing biological communities up and down the coast (Longley, 1994).

Estuaries are typically freshest where the rivers drain into them and saltiest where the estuary meets the ocean. Every estuary on the Texas coast may experience hypersaline conditions (sometimes referred to as a "negative estuary") during droughts, when salinities can substantially exceed Gulf salinities of 34 ppt (Britton and Morton, 1989). During droughts, saltwater wedges may be pushed far upstream into tidal streams with salty water on the bottom, overlaid by fresh water on the surface. This vertical stratification of salinity is also observed in ship channels entering bays from the Gulf. Substantial differences between surface and bottom water salinities can create density differences with little vertical mixing of water, allowing oxygen levels to become depleted along the bay bottom.

Wet periods or storms with exceptionally high rainfall can flush nearly all saltwater from bays, dropping salinities to near 0 ppt. Prolonged exposure to salinity below 5 ppt may kill oysters. Although oysters may die, their primary predators and parasites, which tend to be healthier at salinities above 15 ppt, are also killed. Elimination of predators and parasites after these freshwater inflow events provides oyster populations an opportunity to rebound (Cake, 1983).

Sabine Lake. Salinities in upper Sabine Lake ranged from 0 to 17 ppt with a median salinity of 5.1 ppt. Salinities in lower Sabine Lake ranged from 0 to 30 ppt with a median salinity of 8.5 ppt (Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Expert Science Team [BBEST], 2009). The State of Texas conducted studies to recommend freshwater inflows to the Sabine-Neches Estuary, which would be necessary to provide the salinity regime, sediments, and nutrients to maintain the character of the ecosystem. Analysis was based on occurrence of six fish and shellfish species and existing wetland plant communities. Recommended inflows would maintain salinities in upper Sabine Lake from 0 to 15 ppt most of the time, between 1 to 15 ppt in mid Sabine Lake, and 2 to 20 ppt in lower Sabine Lake (Kuhn and Chen, 2005).

Galveston Bay. The TPWD and the TWDB collaborated in 2001 to produce freshwater inflow recommendations for Galveston Bay (Lee et al., 2001). The analysis estimated 5.2 million acre-feet per year of freshwater inflow, primarily in the spring, would maximize productivity of Eastern oysters (*Crassostrea virginica*), white and brown shrimp (*Litopenaeus setiferus* and *Farfantepenaeus aztecus*), blue crab (*Callinectes sapidus*), red drum (*Sciaenops ocellatus*), black drum (*Pogonias cromis*), and spotted seatrout (*Cynoscion nebulosus*). This inflow would create salinity zones ranging from <5 ppt in Trinity Bay to 10 to 20 ppt in portions of East and West bays (Lee et al., 2001).

From 1987 to 2009, average salinities in Galveston Bay remained unchanged; however, there was a significant decline in salinity of Galveston Bay tributaries over the same period, from an average of about 15 ppt in 1987 to about 10 ppt in 2009 (Lester and Gonzalez, 2011). During high salinity conditions, surface salinities range from 10 ppt in Trinity Bay to 30 ppt in in West Bay and near the Galveston Entrance Channel. During low-salinity conditions, surface salinities range from 0.5 ppt in upper Trinity Bay to 20 ppt in West Bay (Orlando et al., 1991).

The Trinity and San Jacinto BBEST (2009) developed freshwater inflow recommendations for the Galveston Bay system. These recommendations were intended to provide spring salinities in Trinity Bay ranging from 0 to 5 ppt to support germination and establishment of wild celery (*Vallisneria*) near the Trinity River Delta and protect *Rangia* clams near freshwater sources in other parts of the bay. An additional recommendation of the BBEST was that a high-flow event should occur at least once every 10 years, which drops the salinity below 5 ppt for at least 2 weeks and controls oyster predators and parasites.

Brazos River and Brazos-Colorado Coastal Basin. The Brazos and San Bernard rivers are riverine estuaries. The Brazos River Estuary (TCEQ Water Quality Segment 1201) extends 28 river miles upstream from its mouth at the Gulf to about 3 miles upstream of Farm to Market Road 521 (San Bernard Street) in Brazoria. Salinity varies inversely with river flow as does the distance the salinity wedge extends upstream along the bottom. At high flow, there may not be a salinity wedge, and when flows are low the salinity wedge may extend 27 river miles upriver. From November 2014 through May 2015, average surface salinity ranged from 1 to 17 ppt, while average bottom-water salinity over the same period ranged from 3 to 24 ppt (Bonner et al., 2015).

The San Bernard River, at the time of this report, does not reach the Gulf. Accumulated sediment blocks the river's mouth at the Gulf. The TWDB monitored salinity from 2007 to 2014 in the Cedar Lakes complex west of the San Bernard River, south of the GIWW, and inshore of the Gulf beach. Daily average salinity ranged from 0 to 40 ppt and averaged 19 ppt (TWDB, 2016a).

Matagorda/Lavaca Bay Complex. Evaluation of benthic macroinvertebrates in the Matagorda-Lavaca bay complex suggest the existence of three salinity zones: Lavaca Bay (12 to 19 ppt), part of Matagorda Bay (22 to 27 ppt), and a marine zone of Matagorda Bay (30 to 40 ppt). Changes in the benthic community structure appear to occur over changes of salinity from 18 to 22 ppt. The long-term average salinity for Matagorda Bay is 24 ppt and 15 ppt for Lavaca Bay. Freshwater inflow recommendations include maintaining a salinity range of 15 to 18 ppt in the eastern arm of Matagorda Bay containing the Colorado River Delta and maintaining salinity below 30 ppt in the Colorado River Delta during drought (Lower Colorado River Authority-San Antonio Water System, 2008).

From 1986 through 2006, salinity in upper Lavaca Bay ranged from 0 to 33 ppt. Desired salinity ranges for Lavaca Bay range from 21 to 30 ppt during drought and 11 to 20 ppt during wet years. One freshwater inflow recommendation included allowing salinity to drop below 5 ppt for up to 2 weeks every 5 to 10 years. The extended period of low salinity is expected to reduce concentrations of oyster parasites and predators in the system (Colorado-Lavaca BBEST, 2011).

San Antonio-Aransas Bay Complex. In the Mission-Aransas system, average salinity nearshore from 1982 to 2004 was 19 ppt while over the same time, average salinity in the open water was 21 ppt (TPWD, 2010). Basic salinity objectives were recommended for the Guadalupe-San Antonio and Mission-Aransas estuaries. These objectives were for spring salinities ranging from 2 to 10 ppt and summer salinities from 10 to 20 ppt to support important species (Guadalupe BBEST, 2011).

Nueces/Corpus Christi Bay Complex. Salinities in Nueces Bay range from <2 ppt during floods to over 45 ppt during dry conditions (USACE, 2012a). Average annual salinity is 25 ppt. The system is frequently a reverse estuary where salinities in the delta are higher than bay salinities and can reach concentrations exceeding 80 ppt (Hill et al., 2015).

The Nueces BBEST (2011) evaluated a variety of different organisms (plants, invertebrates, and fish) that could be used as indicator organisms to develop an ecologically sound salinity regime for Nueces Bay and would be protective of the bay's biological community. During dry periods with low or no freshwater inflow into the bay, salinity can exceed 40 ppt in the upper portions of the bay. When porewater salinities in the Nueces Delta exceed 25 ppt, the delta experiences substantial declines in cordgrass (*Spartina* spp.) marsh. The biomass of filter-feeding benthic macroinvertebrates is at its highest levels when bay salinities are about 20 ppt. Blue crab abundance declines when salinities exceed 20 ppt, while Atlantic croaker (*Micropogonias undulatus*) occurs from 8 to 22 ppt. Based on evaluation of the indicator organisms, the Nueces BBEST (2011) suggested an appropriate salinity in the bay during normal flows would be 18 ppt to maintain ecological health.

Laguna Madre. The annual mean salinity of the Upper Laguna Madre (which includes the Baffin Bay complex) is 38 ppt and 34 ppt for the Lower Laguna Madre (Schoenbaechler, 2016). Hypersaline conditions are common in the Upper Laguna Madre and Baffin Bay with salinities in the Upper Laguna Madre commonly reaching 45 ppt and 53 ppt in upper Baffin Bay. In the Lower Laguna Madre, salinities tend to be higher in the southern reach of the bay (south of the mouth of the Arroyo Colorado) and lower in the northern reach of the bay. The principal habitat in the Laguna Madre is seagrass used by a wide variety of estuarine and marine organisms (Tolan et al., 2004). Seagrasses tolerate salinities above 35 ppt but can be harmed when salinities are in the range of 6 to 13 ppt. Sustained, optimal growth of seagrass occurs when salinities are above 20 to 24 ppt ranging up to 37 to 40 ppt (Rio Grande BBEST, 2012).

Rio Grande. Like the Brazos River, the Rio Grande is a riverine estuary extending 48 river miles from its mouth at the Gulf. The tidal reach of the river frequently stratifies with a saltwater wedge sometimes extending 23 river miles upstream from the river's mouth. Salinity from 2008 to 2010 averaged 0.7 ppt at the upstream end of the tidal reach and 14 ppt about 2.5 river miles upstream from the mouth. Over the period from 2005 to 2011, salinity ranged from 0 to 34 ppt at the surface and from 0 to 40 ppt in the saltwater wedge (Rio Grande BBEST, 2012).

Portions of the tidal river exhibit daily variation in salinity with changing tides. At a sampling location 2.5 river miles above the mouth, the diurnal salinity range in salinity over one day was from 4 to 28 ppt. Tidal river salinity is substantially affected by river flow with lower salinities observed at higher river flows (Rio Grande BBEST, 2012).

2.3.3 Coastal Processes

2.3.3.1 Relative Sea Level Change

The USACE policy in Engineering Regulation 1100-2-8162 and Engineering Technical Letter 1100-2-1, Sea Level Change Considerations for Civil Works Programs, requires all studies to consider impacts from sea level

change (USACE, 2013a; 2014). Changes in local or RSLR reflect the integrated changes in global or eustatic sea level plus changes due to vertical land movement or subsidence.

Water level along the Texas coast fluctuates over hours and days with changing winds and the gravitational pull of the moon and earth among other factors. Sea level along the Texas coast tends to be higher in the spring and late summer/early fall when the moon is closer to the earth and lower in the summer and late fall/winter when the moon is farther from the earth.

Sea level changes also occur over hundreds and thousands of years. For at least the last 18,000 years, sea level rose more than 400 feet along the Texas coast. The rate of sea level rise has slowed over the last 3,500 years (Davis, 2011).

Sea level change or relative sea level (RSL) change is any change in sea level that occurs compared to a reference point on land (Rovere et al., 2016). RSL has been rising along the Texas coast over the period of measurement from 1908 to present, and the rate of RSLR has accelerated in recent years. Two factors are raising sea level on the Texas coast:

1. Eustatic sea level rise caused by increased volume of water in the oceans. Ocean volume is increased by addition of water from some melting glaciers and ice sheets. It is also increased by expansion of ocean water as it warms with increasing temperatures, and
2. Subsidence (sinking of land due to soil compaction and/or withdrawal of subsurface liquids).

The average absolute sea level (eustatic sea level rise) around the world has risen over 9 inches since 1880 (EPA, 2016a). El Niño events can measurably influence sea level changes over periods of months to a year or more (Johnson and Parsons, 2016). In this document, the terms “sea level change” or “relative sea level rise” refer to change in sea level caused by the combined effects of eustatic sea level rise and land subsidence.

Rising sea level has been accompanied by shoreline retreat, erosion, and habitat loss. Trends in sea level change are important because they impact “…coastal mapping, marine boundary delineation, coastal zone management, coastal engineering, sustainable habitat restoration design….” (NOAA, 2017b). Rising sea level also likely contributes to increased storm surges and tides and their impacts (IPCC, 2014).

The upper and middle Texas coast have had sea level rise more than 0.17 inch per year (inch/year) from 1957 to 2011 (NOAA, 2016d) (Table 2-5). The highest rate of RSLR, 0.26 inch/year, in these areas was measured at the Galveston Pleasure Pier (tide gauge 8771510). RSL has also been rising in the lower Texas coast at a lower rate, less than 0.16 inch/year. Higher rates of RSLR along the upper coast are generally attributed to higher rates of subsidence. Localized subsidence, ranging up to 10 feet from 1906 to 2000, has been highest in the Houston-Galveston area. The Harris-Galveston Subsidence District, created in 1975, regulates groundwater withdrawal. Reduced rates of groundwater withdrawal has considerably reduced the rate of subsidence in the area. NOAA does not report sea level trend data for any gauges in the Matagorda Bay area. Some localized subsidence continues in other parts of the coast, but nowhere has it been near rates in the Houston-Galveston area (NOAA, 2016d).

Table 2-5
Sea Level Trends along the Texas Coast

Gauge Station Name*	Tide Gauge Number	Sea Level Rise Rate (inch/year)
Sabine Pass (from 1958–2015)	8770570	0.22
Galveston Pleasure Pier (from 1957–2011)	8771510	0.26
Freeport (from 1972–2008)	8772440	0.17
Rockport (from 1937–2015)	8774770	0.21
Corpus Christi (from 1983–2015)	8775870	0.15
Port Mansfield (from 1963–2006)	8778490	0.08
Port Isabel (from 1944–2015)	8779770	0.15

Source: NOAA (2016d).

* The period of record for each gauge is in parentheses after the gauge name.

2.3.3.2 History of Severe Storms and Hurricanes

Severe storms and hurricanes in Texas originate in tropical seas (usually starting as a tropical wave off the Africa coast), and their landfall can alter Texas coastal areas for years. Hurricanes are important and have influenced the geologic history of the Gulf coastline, especially barrier islands (Britton and Morton, 1989). These storms occur seasonally from June through November with a peak mid August to late October. On average from 1970 to 2010 for the Atlantic, Caribbean, and Gulf, 11 tropical storms developed, 6 of which became hurricanes. While hurricanes pose a threat to life and property, intense storms (tropical storms and depressions) can result in flooding due to heavy rains, high winds, tornadoes, and extensive loss of life (NOAA, 2013a).

The probability of hurricane landfall on the Texas coast is about one every 6 years along any 50-mile stretch. Annual probabilities of a landfall range from 31 percent at Sabine Pass to 41 percent at Matagorda Bay. The annual average occurrence of a tropical storm or hurricane is about 0.8 per year or three every 4 years (Table 2-6). Hurricane frequency is inconsistent; a 10-year hurricane-free period occurred from 1989 to 1999, the longest since 1829, while four hurricanes struck the Texas coast during the 1886 season and during the 1885 to 1888 season, one or more occurred each year. The busiest decade for hurricanes and tropical storms was during the 1940s where 14 total storms struck the Texas coast, followed by the 1880s with 11, and the 2000s with 10 (Roth, 2010).

Hurricane strength is measured by the Saffir-Simpson Hurricane Wind Scale, which characterizes storm intensity relative to the sustained wind speed and estimates potential property damage. Storms are classified from Category 1 (lowest) to Category 5 (highest) (Table 2-7). Because of their potential for significant loss of life and damage, Category 3 and higher storms are considered major hurricanes; Category 1 and 2 storms are still considered dangerous with damaging winds and require preventative measures (NOAA, 2013a).

The greatest threat to life and property occurs from storm surge and tides during a hurricane landfall. Hurricane winds produce an abnormal rise in water causing a storm surge, which can reach heights over 20 feet and cover hundreds of miles of coast. The more intense and larger the hurricane, the larger the storm surge. Storm tides are a combination of astronomical tide and storm surge raising the water level during a storm. The combination of

storm tide, high winds, and waves can cause severe damage to the coast resulting in loss of life, beach and dune erosion, destruction of infrastructure, and saltwater intrusion into bays and estuaries, capable of traveling several miles inland. In addition, hurricanes and tropical storms can also produce tornadoes, high winds, heavy rainfall, and rip currents, all capable of causing severe damage (NOAA, 2013a).

Table 2-6
Annual Average Occurrence of Hurricanes and Tropical Storms in Texas

Decade	Hurricanes	Tropical Storms	Total
1850s	3	1	4
1860s	4	1	5
1870s	2	4	6
1880s	8	3	11
1890s	3	3	6
1900s	4	2	6
1910s	7	1	8
1920s	2	3	5
1930s	5	4	9
1940s	8	6	14
1950s	2	5	7
1960s	3	3	6
1970s	2	7	9
1980s	5	4	9
1990s	1	4	5
2000s	5	5	10
Total	64	56	120
Average Annual	0.4	0.4	0.8

Source: Roth (2010).

Table 2-7
Saffir-Simpson Hurricane Wind Scale

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	75–95 mph	Very dangerous winds will produce some damage
2	96–110 mph	Extremely dangerous winds will cause extensive damage
3 (major)	111–129 mph	Devastating damage will occur
4 (major)	130–156 mph	Catastrophic damage will occur
5 (major)	157 mph or higher	Catastrophic damage will occur

Source: NOAA (2013a).

mph = miles per hour

Texas has been affected by several hurricanes and severe storms during the last century. Table 2-8 summarizes the Texas hurricane events by coastal area (upper, mid, and lower) starting in the 1850s whose tracks made landfall. The most active coastal area for hurricanes over the past 160 years is the upper Texas coast with 28 landfall events, followed by the mid Texas coast with 26 landfall events, and lastly the lower Texas coast with 15 landfall events.

Table 2-8
Texas Hurricane Events by Coastal Areas

Coastal Area	Named Hurricanes (Year, Name, and Landfall Strength)	Unnamed Hurricanes (Year and Landfall Strength)	Total Number
Upper Texas Coast	1957 – Audrey (H4) 1959 – Debra (H1) 1963 – Cindy (H1) 1971 – Edith (H2) 1983 – Alicia (H3) 1986 – Bonnie (H1) 1989 – Chantal (H2) 1989 – Jerry (H3) 2005 – Rita (H2) 2007 – Humberto (H1) 2008 – Ike (H2)	1865 (H2), 1871 (H1), 1879 (H2), 1886 (H2), 1886 (H3), 1897 (H1), 1900 (H4), 1909 (H3), 1915 (H4), 1932 (H4), 1938 (H1), 1940 (H2), 1941 (H3), 1942 (H1), 1943 (H2), 1947 (H1), 1949 (H2)	28
Mid Texas Coast	1961 – Carla (H4) 1970 – Celia (H3) 1971 – Fern (H2) 2003 – Claudette (H1) 2017 – Harvey (H3)	1851 (H1), 1854 (H2), 1866 (H2), 1869 (H2), 1875 (H3), 1881 (H3), 1886 (H4), 1888 (H1), 1891 (H2), 1902 (H1), 1910 (H2), 1912 (H2), 1913 (H1), 1916 (H4), 1919 (H4), 1921 (H1), 1929 (H1), 1934 (H2), 1936 (H1), 1942 (H3), 1945 (H2)	26
Lower Texas Coast	1954 – Alice (H1) 1955 – Gladys (H1) 1957 – Beulah (H3) 1980 – Allen (H3) 1988 – Gilbert (H4) 1999 – Bret (H4) 2008 – Dolly (H2)	1857 (H2), 1880 (H4), 1886 (H2), 1887 (H2), 1895 (H2), 1909 (H3), 1933 (H2), 1933 (H3)	15
Texas Coast	Not available	1867 (H2), 1877 (H1)	2

Source: NOAA (2017a), Roth (2010).

In Texas, two main hurricane tracks exist: (1) enter from the southeast and curve northward and northeastward through eastern and central portions, and (2) westward track. Storms on the lower coast and lower mid coast tend to stay on a more westward track including an unnamed hurricane (1919), Celia (1970), Allen (1980), tropical storm Charley (1998), Bret (1999), and Dolly (2008). Westward tracks are due to circulation around the Mexican Plateau and a subtropical ridge that is present during the summer months in the Southern Plains. Northerly to

northeasterly track storms occur early and late in the season when cold fronts from the north drive winds southerly (Roth, 2010).

The costliest storms to strike Texas from 1900 to 2010 are shown in Table 2-9. As of the end of the 2017 Hurricane season, Hurricane Harvey (2017) was the costliest storm in Texas history and tied with Hurricane Katrina as the Nation's costliest storm at $125 billion (NOAA, 2018a). The top four costliest for Texas have all occurred since 2000, one of which only reached tropical storm status (Blake et al., 2011; NOAA, 2018a).

Table 2-9
Costliest Texas Storms, 1900 to 2017*

Name	Year	Category	Landfall	Cost of Damage
Harvey	2017	3	Rockport	$125.0 billion
Ike	2008	2	Galveston	$29.5 billion
Rita	2005	3	Sabine Pass	$12.0 billion
Allison	2001	TS	Freeport	$9.0 billion
Alicia	1983	3	Galveston	$2.0 billion
Dolly	2008	1	South Padre Island	$1.1 billion
Celia	1970	3	Corpus Christi	$930 million
Allen	1980	5	South Padre Island	$700 million
Carla	1961	5	Port O'Conner	$300 million

Source: Blake et al. (2011), Handbook of Texas Online (2017), NOAA (2018a).
* Not adjusted for inflation and include adjusted National Flood Insurance Program flood damage amounts beginning in 1995.
TS = tropical storm

2.3.3.3 Storm Surge Effects

Storm surge is an abnormal rise of water level over and above the predicted astronomical tides resulting from tropical storms and hurricanes; storm surges present some of the costliest natural disaster damages to life and property in the United States. Many of the more extreme and damaging hurricane events have occurred along the U.S. Gulf coast (Needham and Keim, 2012). The hurricane that struck Galveston Island, Texas, in 1900 and Hurricane Harvey that struck Rockport, Texas, in 2017 are examples of the costly extreme hurricane events as described above (NOAA, 2108a; Rappaport and Fernandez-Partagas, 1995). Extremely high water levels associated with storm surges at coastal locations are an important public concern and a factor in coastal hazard assessment, navigational safety, and ecosystem management.

The coastal environment is dramatically affected when impacted by surges from extreme hurricane events. The affects may result in significant morphological changes to barrier islands, destruction of forests, agricultural lands, critical infrastructure, inundation of coastal shorelines with salt water, and severe damages to essential wildlife habitat (Needham and Keim, 2012). For example, Hurricane Beulah (1997) made landfall with an 18-foot storm surge that inundated South Padre Island and made 21 cuts completely through the island causing significant devastation to the island's sensitive ecosystem, dramatically altering the landscape (Sugg and Pelissier, 1968).

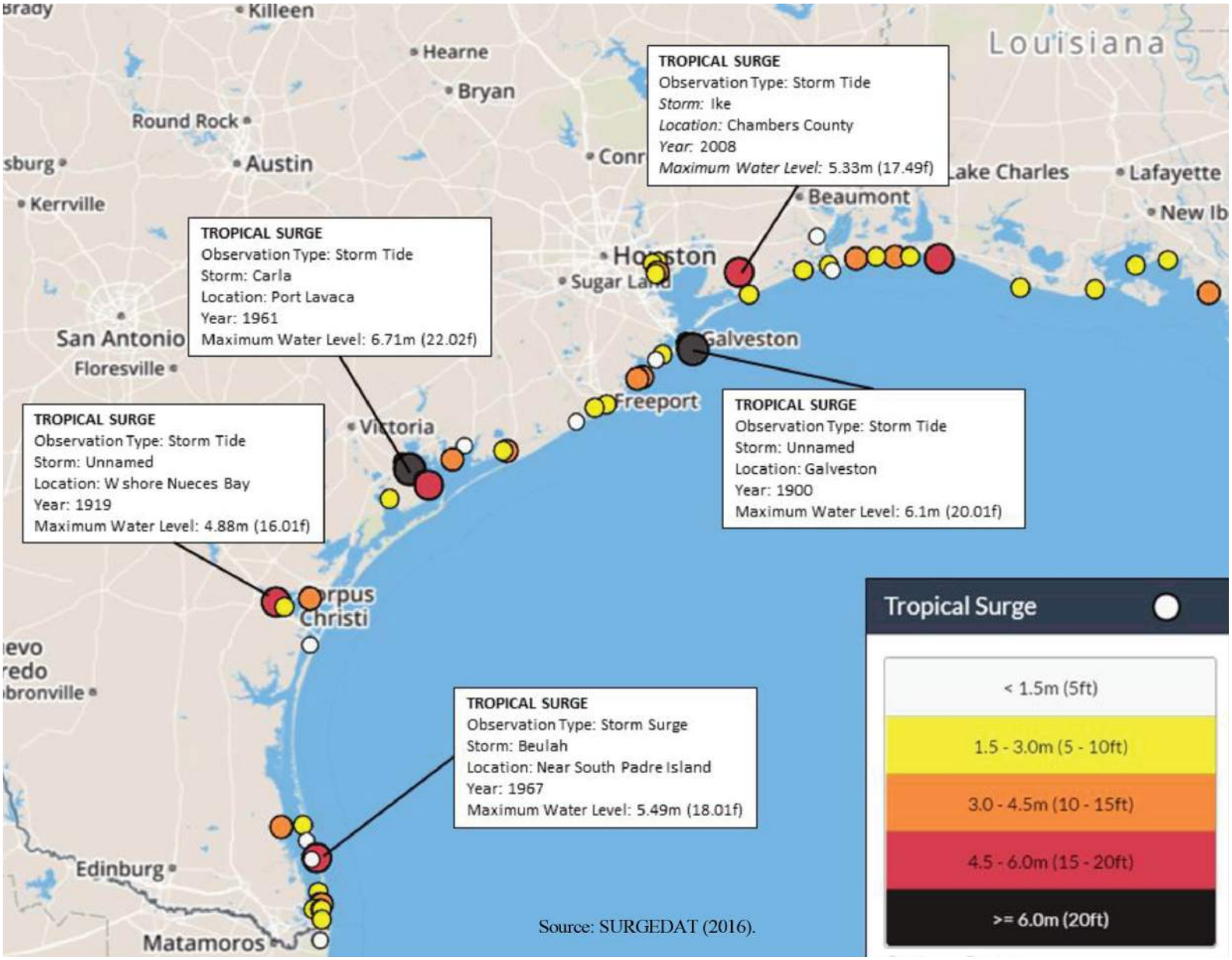
Additionally, hurricane storm surge and waves induce barrier island rollover or landward migration of islands (Stone et al., 1997).

The SURGEDAT (2016) Gulf of Mexico Peak Surge Database provides storm surge (peak height) and location of storms since 1880. Figure 2-6 displays storm surge magnitudes occurring in the study area (SURGEDAT, 2016). The figure provides estimated locations of maximum storm surge; however, storm surges typically inundate larger areas of a coastline greatly beyond the peak surge location. As an example, Berg (2009) reported Hurricane Ike produced a maximum storm surge of 14.5 feet in Chambers County, but surge effect of the hurricane was experienced for most of the U.S. Gulf coastline, with more than 124 miles of coastline being inundated by more than 6.6 feet of storm surge. In addition, the inland extent of Hurricane Ike's storm surge was considerable, where the surge reached a distance of approximately 30 miles from the Gulf at Lake Charles, Louisiana, with a water level of 2.14 feet (Berg, 2009).

2.3.3.4 Attenuation of Storm Surge Impacts by Coastal Wetlands and Barrier Islands

It is generally believed that coastal wetlands provide critical protection against incoming hurricane storm surges, and that restoration of lost wetlands should be a key component of any strategy to protect vulnerable regions such as the Texas coast. However, few studies have evaluated the value of wetlands in protecting against storm surge in Texas, where most of Texas's 7.6 million acres of wetlands are concentrated along the coast (U.S. Geological Survey [USGS], 1997). Gently sloping beachfronts like those found in Texas tend to experience larger storm surges than ones with a steeper continental shelf such as those found in eastern Florida (NOAA, 2017c).

Storm surges can both benefit and impact these ecosystems (e.g., sediment deposition, erosion, saltwater stress, loss of vegetation, change in vegetation, creation of habitat through disturbance, loss of habitat through disturbance, etc.). Dense vegetation of saltgrass (*Distichlis* sp.), cordgrass, bulrush (*Seirpus* spp.), mangrove forest, or sea oats (*Uniola paniculata*) can dissipate wave energy and reduce the severity of storm surges. Generally, wetland loss could result in reduced frictional resistance and increased wind fetch, which can allow storm surges to readily propagate through low areas (Ebersole et al., 2015). Similarly, dunes and dune vegetation act to slow down wave momentum and energy, protecting the leeward side of the dunes (Feagin et al., 2010). Barrier islands such as those found along the southern Texas Gulf coast act as a physical barrier against incoming storms and can redirect surge pathways through inlets and bays. According to the USACE (2015a), coastal wetlands can contribute to storm surge attenuation by reducing the height of an incoming storm surge at a rate of 1 foot for every 2.7 miles of wetland traversed. Recent studies have shown that this could vary depending on many factors including the storm trajectory, presence or absence of levees, vegetation density, and the traveling speed of the storm. In 2005, Hurricane Rita flooded wetlands and made them ineffective at reducing the storm surge, because the effect of this hurricane was also compounded by the Mississippi River levee system (which increased the surge) (Resio and Westerink, 2008).



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Texas Coast Storm Surge Locations and Magnitudes

FN JOB NO	COH16388
FILE NAME	2-3TX_Coast_Storm_Surge.mxd
DATE	10/9/2018
SCALE	Not to Scale
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2-6

FIGURE

NAD 1983 Texas Centric Mapping System Albers

Wamsley et al. (2010) determined that the destruction of wetlands correlates with the increase in storm surge. The results showed that marsh degradation would allow for surge propagation and height to increase by 10 to 15 percent. While the attenuation rate for wetlands remains highly variable and dependent on multiple factors, there still remains a quantitative benefit to the effects of wetland and marsh ecosystems.

The effect of wetlands in attenuating storm surge is situationally dependent. Wetlands can attenuate surge in many situations but may also be largely irrelevant in others. The effect of specific marsh restoration or preservation measures cannot be determined without studies and modeling based on fundamental underlying physics, forcing and dissipation mechanisms, adequate specification of the system geometry, and the evaluation of a wide array of storms, varying in direction, speed, and size (Resio and Westerink, 2008).

2.3.4 Water and Sediment Quality

Water and sediment quality along the Texas coast are measured by a variety of organizations. The TCEQ monitors water and sediment quality of bays and estuaries throughout the State with support from the EPA. The EPA, NOAA, and U.S. Fish and Wildlife Service (USFWS) joined with academia and State agencies to conduct synoptic surveys of coastal ecosystem health through the EPA's National Coastal Assessment, which was first conducted in 2001 and most recently sampled in 2010 (EPA, 2017a). The Texas Department of State Health Services (TDSHS) samples fish tissues and bacteriological quality of water to determine suitability for human consumption. The USACE collects data associated with its maintenance dredging responsibilities.

Section 305(b) of the Federal Clean Water Act (CWA) requires states to report the quality of their surface waters every 2 years. The TCEQ's most recent completed report was done in 2014, covering data collected from December 1, 2005, to November 30, 2012 (TCEQ, 2015a). These reports compare monitored water quality to water quality criteria established by the state, which are intended to ensure the State's waters are fishable and swimmable in accordance with goals of the CWA. Criteria are published in the State's water quality standards, which are approved by the EPA, and include values of chemicals that should not be exceeded and desirable uses (e.g., recreation and aquatic life protection). Water quality standards provide the guidelines by which the chemical concentrations in regulated discharges are controlled. Reports focus on water-quality issues created by regulated discharges of treated wastewater but in recent years have also focused on impacts from stormwater runoff and habitat modification. The focus of monitoring on impacts from regulated discharges and activities limits the utility of water quality data to evaluate impacts of wetland loss, habitat modification, and sea level change.

The following discussion provides an overview of coastal water quality in the context of water quality standards and the past focus on monitoring impacts of regulated discharges. Information about waterbodies discussed below is derived primarily from comparison of water quality monitoring conducted by the state and its partners to established criteria and screening concentrations (TCEQ, 2015a). These categories of water quality impacts are included in the water quality descriptions that follow:

- **Bacteria levels that are elevated or exceed criteria (TCEQ, 2014)**: Water quality criteria for bacteria are set to protect humans from encountering pathogenic organisms while engaged in recreational activities in, on, or around waterbodies (EPA, 2001). These criteria are also set to prevent humans from

ingesting pathogenic organisms with the consumption of oysters and other shellfish. Although these criteria are used to regulate disinfection of municipal treated wastewater and nonpoint source pollution from animal production facilities, elevated bacteria levels may have natural causes associated with warm-blooded wildlife using waterbodies.

- **Nutrients, nitrates, and phosphorus**: The TCEQ has not established water quality criteria for nutrients in estuaries, but it has identified screening-level concentrations intended to indicate possible nutrient enrichment (TCEQ, 2012, 2014). Concern for elevated nutrients is based on their potential contribution to harmful algal blooms, phytoplankton blooms that lead to low dissolved oxygen conditions, and epiphytic growths of algae that can smother seagrasses (EPA, 2001).

- **Dissolved oxygen criteria (TCEQ, 2014)**: Bacterial utilization of ammonia and carbonaceous compounds from treated wastewater and nonpoint sources of pollution can depress oxygen concentrations in waterbodies to levels harmful to aquatic life (EPA, 2001).

- **Toxic substances**: Water quality criteria (TCEQ, 2014) have been established for a wide variety of heavy metals and synthetic organic compounds to prevent toxicity in water to aquatic organisms and minimize the bioaccumulation of these contaminants to levels hazardous to aquatic biota and humans. Fish consumption advisories are included below, which have been issued by the TDSHS. Fish consumption advisories remain in effect until adequate data have been collected and analyzed indicating there is no longer a threat to human health.

2.3.4.1 Upper Coast

Water quality criteria, desired uses, and nutrient and chlorophyll *a* screening criteria were generally met in water and sediment samples throughout the Sabine and Neches coastal system. Bacterial levels exceeded criteria at some locations, and dissolved oxygen in some coastal waters was below criteria. The Neches River Tidal had one measurement of the pesticide malathion exceeding its criterion in water (TCEQ, 2015a). A fish consumption advisory has been issued for the area that recommends limiting consumption of gafftopsail catfish (*Bagre marinus*) due to polychlorinated biphenyls (PCBs) contamination (TDSHS, 2011). Fish consumption advisories remain in effect until the state evaluates new data indicating pollutant concentrations are below levels believed hazardous to humans.

The GIWW between Sabine Lake, Galveston Bay, and the Sabine-Neches Ship Channel each exceeded bacteria criteria on one occasion. The tidally influenced reach of Taylor Bayou in the same area also exceeded bacteria criteria on one occasion and chlorophyll *a* criteria in several samples. Lead in sediment higher than recommended criteria was detected in nine samples in Alligator Bayou (TCEQ, 2015a).

Gulf nearshore waters in Jefferson and Chambers counties had some bacteria and chlorophyll *a* measurements above criteria (TCEQ, 2015a).

The Trinity River and San Jacinto River watersheds and the coastal basin between the San Jacinto and Brazos rivers contribute flow to much of the north end of the Galveston Bay system. Elevated nutrients, chlorophyll *a*, and bacteria were found in some of these tidal streams, particularly near urbanized watersheds. The tidal reach of Greens Bayou had elevated pesticide levels (DDT and DDD) in sediment. Patrick Bayou, in its tidally influenced reach, had toxic sediments and mercury and hexachlorobutadiene in sediment above criteria. The tidal reach of Vince Bayou also had toxicity measured in sediments (TCEQ, 2015a).

The Galveston Bay ecosystem experiences a variety of water-quality issues. During the assessment period, many of the primary bays, secondary bays, and tidal streams had elevated bacteria, chlorophyll *a*, nutrients, bacteria above suitable levels for oyster-harvest waters, and depressed oxygen levels. High copper in water was also found in Clear Lake. Elevated concentrations of nutrients and low oxygen appeared most frequently in estuaries near urbanized watersheds (TCEQ, 2015a). Protected and restored wetlands may play a role in managing pollutant loading from increasingly urbanized watersheds (Novitzki et al., 1997). Bays farther from human development (i.e., Christmas Bay) had high nutrients and bacteria less frequently. Although concentrations of nutrients and chlorophyll *a* exceed screening criteria used by TCEQ, ammonia, total phosphorus, and chlorophyll *a* declined from 1987 to 2009 in the Galveston Bay system (Lester and Gonzalez, 2011).

The tidally influenced reach of the Brazos River experienced some chlorophyll *a* measurements above screening criteria. The San Bernard River where it is tidally influenced had bacteria and chlorophyll *a* levels above criteria. The tidal waters of Caney Creek in the Sargent area exhibited low oxygen and elevated bacteria levels (TCEQ, 2015a).

Two widespread fish consumption advisories have been issued for the Galveston Bay system:

- Fish and Shellfish Consumption Advisory 50 applies to all portions of the Galveston Bay system in Brazoria, Chambers, Galveston, and Harris counties because of dioxins and PCBs in all catfish species, spotted seatrout, and blue crab in Upper Galveston Bay and dioxins and PCBs in all species of catfish in Galveston Bay including Chocolate Bay, East Bay, Trinity Bay, and West Bay (TDSHS, 2013a).
- Fish and Shellfish Consumption Advisory 55 applies to the Houston Ship Channel and adjoining waters including the San Jacinto River below Lake Houston in Harris County because of dioxins and PCBs in all fish species and blue crab (TDSHS, 2015).

2.3.4.2 Middle to Upper Coast

East Matagorda Bay had bacteria above suitable levels for oyster-harvest waters while no water or sediment quality issues were identified in the Matagorda Bay/Powderhorn Lake complex. In the Tres Palacios Bay area, low oxygen was detected in Tres Palacios Harbor. Bacteria above suitable levels for oyster-harvest waters and bacteria above the recreational assessment criteria were also found. Water or sediment issues were not identified around the Lavaca and Chocolate bay systems except for some areas with bacteria above suitable levels for oyster-harvest waters. Keller Bay also had some bacteria measurements above suitable levels for oyster-harvest waters. Low oxygen was measured in the tidal reach of Garcitas Creek. Carancahua Bay exhibited some measurements

with elevated bacteria, total phosphorus, chlorophyll *a*, and bacteria above suitable levels for oyster-harvest waters. West Carancahua Creek in its tidal reach had some oxygen levels below criteria (TCEQ, 2015a).

The tidally influenced reach of the Colorado River had nitrate levels above screening levels. Oxygen levels were occasionally depressed, and chlorophyll *a* was sometimes high in Tres Palacios Creek's tidal reach (TCEQ, 2015a).

The TDSHS (2000) issued a revised fish consumption advisory for a portion of Lavaca Bay prohibiting the take of all fish and crabs because of mercury contamination. Concentrations of mercury in water were below the TCEQ human health criterion for saltwater fish in the 2.5 square mile portion of Lavaca Bay included in the TDSHS advisory during sampling conducted in 2002 and 2003 (Gill, 2004).

2.3.4.3 Middle Coast

San Antonio Bay to the Aransas Bay complex including Espiritu Santos Bay in the east and Copano Bay to the west did not exhibit water-quality issues. Bacteria above suitable levels for oyster-harvest waters were occasionally high in San Antonio, Hynes, Guadalupe, Copano, Port, and Mission bays (TCEQ, 2015a).

Elevated chlorophyll *a* was detected in Little Bay. St. Charles Bay exhibited occasional depressed oxygen levels. Some recreational beaches in Corpus Christi Bay had bacteria levels above criteria. Elevated copper in water was detected in Nueces Bay and Conn Brown Harbor. The Corpus Christi Inner Harbor, with limited mixing, sometimes had nitrates and ammonia above screening criteria. Oso Bay and Oso Creek on the south side of Corpus Christi Bay had high bacteria, nitrates, total phosphorus, and chlorophyll *a* and low oxygen levels at times. The Victoria Barge Canal had several measurements of chlorophyll *a* and nitrates above screening levels (TCEQ, 2015a).

The Guadalupe River's tidal reach had some measurements of elevated nitrates. The tidal portions of the Mission and Aransas rivers each had one bacteria sample exceeding the recreational criterion. The tidally influenced part of the Nueces River experienced elevated chlorophyll *a* on several occasions (TCEQ, 2015a).

2.3.4.4 Lower Coast

The tidal reach of the Arroyo Colorado has more water-quality issues than other estuarine waters in this region. Extensive stretches of the Arroyo have elevated bacteria, nitrates, and chlorophyll *a* contributing to low oxygen levels (TCEQ, 2015a). This area has extensive row crop agriculture and some of its tributaries also exhibit occasional elevated ammonia, nitrates, chlorophyll *a*, and bacteria (Arroyo Colorado Watershed Partnership, 2007). Petronila Creek where it is influenced by tides experiences high concentrations of bacteria, pH, total phosphorus, and chlorophyll *a*. The tidal Rio Grande had occasional chlorophyll *a* and nitrates above screening concentrations (TCEQ, 2015a).

The Laguna Madre north of the Arroyo Colorado sometimes has low oxygen and chlorophyll *a* above screening criteria. Near its confluence with the Arroyo Colorado, the Laguna Madre had measurements of bacteria,

including bacteria above suitable levels for oyster-harvest waters, chlorophyll *a*, nitrates, and ammonia above criteria. The Laguna Madre south of the Arroyo Colorado has also had episodes of depressed oxygen. The Baffin Bay complex has had high levels of chlorophyll *a*. Tidal tributaries to that complex have had elevated bacteria, chlorophyll *a*, total phosphorus, and nitrates. The Brownsville Ship Channel occasionally has had low oxygen levels and elevated bacteria. The Port Isabel Fishing Harbor also had elevated bacteria levels (TCEQ, 2015a).

2.3.4.5 Gulf- and Coastwide

Mercury contamination of edible fish tissue led the TDSHS (2013b) to issue a fish consumption advisory for all waters off the Texas coast from the Sabine River in the north to the Rio Grande in the south. This advisory includes blackfin tuna (*Thunnus atlanticus*), blue marlin (*Makaira nigricans*), little tunny (bonito) (*Euthynnus alletteratus*), king mackerel (*Scomberomorus cavalla*), all species of shark (Chondrichthyes), swordfish (*Xiphias gladius*), and wahoo (*Acanthocybium solandri*).

2.3.4.6 Gulf of Mexico Coastal Condition

The EPA (2012) conducted an intensive biological, chemical, and physical sampling at 879 sites across Gulf coastal ecosystems from 2003 to 2006. There were no discernible Gulf-wide trends in any of the parameters over the period of analysis. The following summarizes the results of this study:

- *Water Quality Index*: A water quality index was developed with dissolved inorganic nitrogen, dissolved inorganic phosphorus, chlorophyll *a*, water clarity, and dissolved oxygen. Low water transparency was frequently observed in Texas relative to other Gulf states. Dissolved oxygen concentrations were generally good. Most Texas sites receiving an overall poor water quality index rating were in the upper and mid Texas coast (primarily the Galveston Bay system).

- *Sediment Quality Index*: Sediment toxicity, contaminant concentrations, and total organic carbon data were combined into a sediment quality index. Sediment quality ranged from poor to good along the entire Texas coast with most poor values occurring in upper Galveston Bay and the Laguna Madre. The report speculated that relatively high sediment toxicity in the Laguna Madre may have resulted from high salinity impacts on the toxicity test rather than toxicity of contaminants from human sources.

- *Benthic Index*: Benthic macroinvertebrate communities were evaluated with a condition index. Benthic communities in Texas ranged from poor to good along the entire Texas coast with no poor index values from the Lower Laguna Madre to the Rio Grande.

- *Coastal Habitat Index*: The Gulf coast from Florida to Texas lost 41,800 acres of coastal wetlands between 1998 and 2004. Loss was attributed to coastal development, sea level rise, subsidence, and tropical storms/hurricanes.

- *Fish Tissue Contaminants Index*: Fish with contaminated tissues were collected from the Sabine Lake, Galveston Bay, Lavaca Bay, Aransas Bay, and Baffin Bay systems; however, contaminants were below

guidance levels in most samples. Tissues exceeding guidance levels were found most frequently in Atlantic croaker and hardhead catfish (*Arius felis*). Total polyaromatic hydrocarbons, PCBs, DDT, mercury, and arsenic were the most commonly encountered pollutants in fish tissue.

2.3.5 Freshwater Inflow

Freshwater inflows mix with saline Gulf waters along the coast to create estuaries. Fresh water originates from streams draining the estuary's watershed, irrigation and wastewater return flows, rainfall, and groundwater seepage. It plays a key role in determining ecological health of estuaries by diluting seawater salinities while carrying sediment and nutrients from coastal watersheds. Variations in amounts, seasonal distribution, and manner of delivery of fresh water create unique estuarine ecosystems (Longley, 1994; Powell et al., 2002). Significant changes in freshwater inflow regimes can affect the ecological health of estuaries. Growing demand for water may threaten estuaries with reduced freshwater inflow, sediments, and nutrients. Reduced freshwater inflow can allow salinities to increase, impacting wetland vegetation communities and the fauna that rely on them. Reduced sediment transport with freshwater inflow can allow sediment compaction in marshes and shoreline erosion to accelerate. Changes in nutrient loading can impact the types of marsh vegetation and transitions between aquatic plants and the microscopic plants in the open water.

Volumes of freshwater inflow to Texas estuaries reflect the pattern of decreasing rainfall rates from east to west across the state (Table 2-10). Sabine Lake, the estuary on the eastern border of the state, receives more freshwater inflow than any other estuary in the state. The Laguna Madre in south Texas is one of a handful of hypersaline lagoons in the world where evaporation rates frequently exceed freshwater inflow (Tunnell and Judd, 2002). The ecological condition of each estuary has evolved with the pattern of freshwater inflow from its watershed. For estuaries in watersheds with high rainfall rates, freshwater inflow would not be considered ecologically sound with significant, long-term reductions in freshwater inflow, and conversely, estuaries in semiarid and arid watersheds would not be considered ecologically healthy with significant, long-term increases in freshwater inflow.

The State of Texas first recognized the importance of understanding relationships between freshwater inflow and estuarine health in 1967 (TWDB, 1967). Dramatic swings in freshwater inflow and sediment and nutrient loading occur in Texas estuaries. Extended droughts with reduced freshwater inflow are punctuated by episodic severe flooding from tropical storms and hurricanes, which tend to occur in late summer and early fall. Since that time, the State of Texas has studied freshwater inflows into its estuaries and has estimated how much fresh water is being delivered to each estuary (Table 2-10).

The Sabine and Neches rivers are the major sources of freshwater inflow to Sabine Lake (Kuhn and Chen, 2005). Highest flows typically occur in February and March with lowest inflows from August to October (TWDB, 2016b). The Trinity and San Jacinto rivers provide 71 percent of the freshwater inflow to the Galveston Bay system. As in Sabine Lake, lowest inflows are from August to October, but highest inflows usually occur in May and June (Lee et al., 2001; TWDB, 2016b).

Table 2-10
Freshwater Inflow to Texas Estuaries*

Estuary/Period of Record	Lowest Annual Inflow	Highest Annual Inflow	Median Annual Inflow
Sabine Lake (Sabine and Neches rivers) (1941–2010)	3.2	29.0	14.0
Galveston Bay (1941–2011)	1.5	22.0	11.1
Brazos Estuary (1977–2009)	1.2	19.6	5.6
San Bernard Estuary (1977–2009)	0.2	1.5	0.6
Matagorda Bay (including Lavaca and coastal basins) (1941–2009)	0.4	14.9	3.1
East Matagorda Bay (1977–2009)	0.06	1.2	0.5
Lavaca Bay (1941–2003)	0.3	0.02	1.4
San Antonio Bay (1941–1987)	0.3	7.7	2.1
Mission-Aransas Bay (1941–2009)	0.007	1.6	0.4
Nueces Estuary (1941–2009)	0.04	2.7	0.3
Upper Laguna Madre (1977–2010)	0.04	1.0	0.3
Lower Laguna Madre (1977–2010)	0.2	2.7	0.5
Rio Grande (1934–2006)	0.03	2.6	1.5 (average)

Source: Guthrie (2010), International Boundary and Water Commission (2006), Lower Colorado River Authority (2006), Schoenbaechler and Guthrie (2011a–f), TWDB (2016b).

* Units are in millions of acre-feet

The Brazos River Estuary receives highest freshwater inflows from the Brazos River during May with relatively high flows during the late winter and early spring. The San Bernard River Estuary does not have a direct connection with the Gulf at the time of this report because accumulated sediment blocks its mouth at the Gulf. Freshwater inflow comes from the San Bernard River with some fresh water from the Brazos River flowing through the GIWW into the San Bernard Estuary. The San Bernard does not exhibit any distinct seasonal freshwater inflow patterns (TWDB, 2016b).

There is no direct freshwater inflow from streams into East Matagorda Bay, and 98 percent of fresh water comes from adjacent coastal lands (Schoenbaechler and Guthrie, 2011b). In the Matagorda/Lavaca Bay complex, 45 percent of fresh water enters from the Colorado River, and 26 percent is delivered to Lavaca Bay by the Lavaca River. Coastal watersheds without flow gauges on streams contribute the remaining fresh water to the system. Freshwater flows are highest in May and June and lowest in July and August (Lower Colorado River Authority, 2006).

Freshwater inflows to the San Antonio Bay system come primarily from the San Antonio and Guadalupe rivers and tend to peak in May and June with a secondary peak in September and October. Lowest quantities of fresh water enter the bay in July and August. In the Mission-Aransas Estuary, peak inflows, primarily from the Mission and Aransas rivers have been recorded in September and October with a secondary peak in inflow in May and June (Guadalupe BBEST, 2011).

The Nueces Estuary experiences relatively slight peaks in freshwater inflow during June and September with low rates of inflow from November through March (Nueces BBEST, 2011). The Nueces River contributes about 90 percent of the freshwater inflow to the estuary. The semiarid nature of the watershed is reflected in evaporation having exceeded the combination of precipitation and Nueces River flow in 31 of the 69 years from 1941 to 2009 (Schoenbaechler and Guthrie, 2011d).

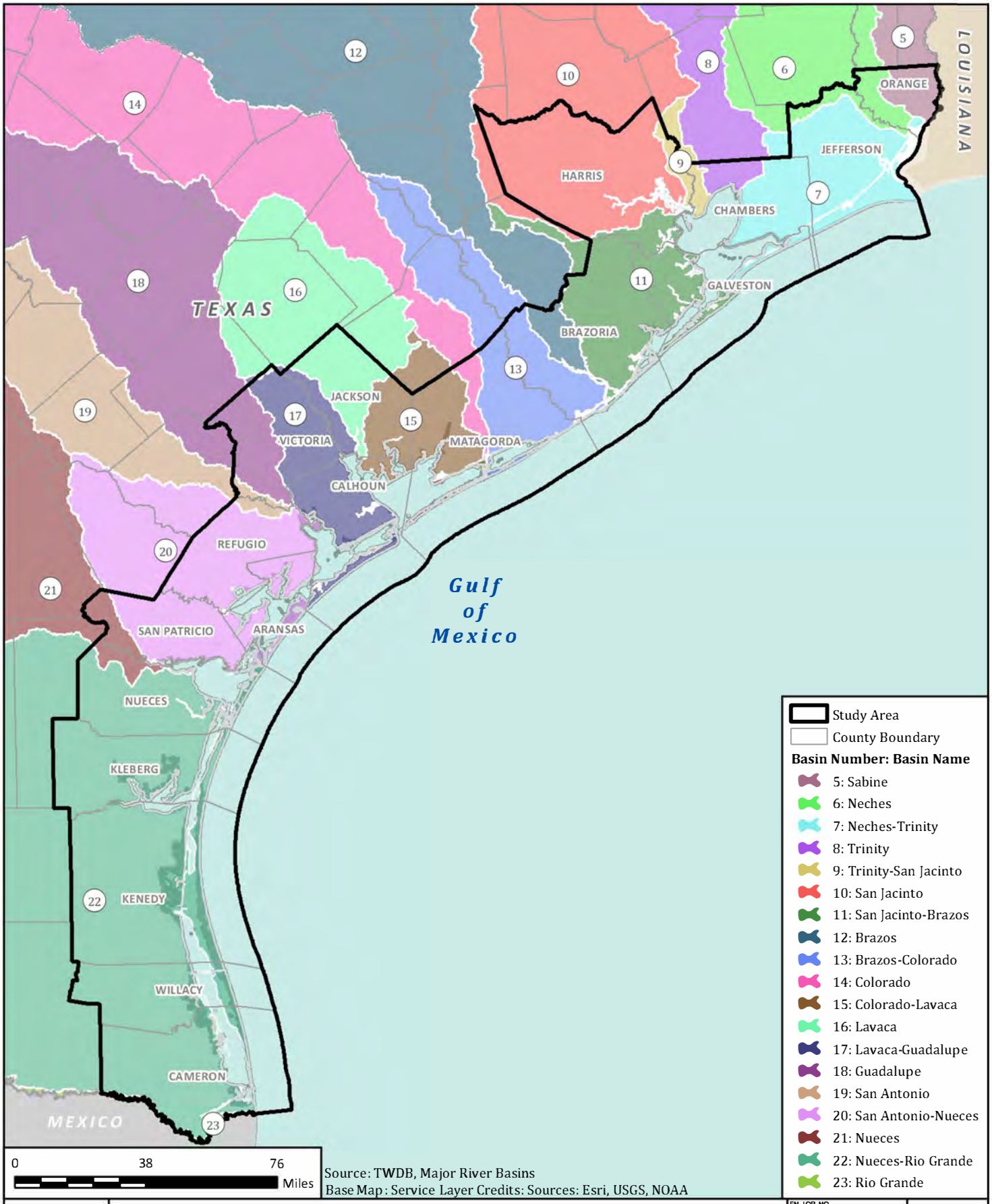
Ninety-seven percent of fresh water to the Upper Laguna Madre comes from the surrounding coastal watershed (Schoenbaechler and Guthrie, 2011e). Combined precipitation and stream flow were exceeded in 15 out of 34 years. The relatively high evaporation rate in this arid region of Texas combined with low rates of precipitation and inflow contribute to frequent hypersaline conditions in the Upper Laguna Madre. Inflows peak in September and October with a secondary peak in May and June. Freshwater inflows are lowest in August and winter (TWDB, 2016b).

Discharges from constructed floodways contribute 98 percent of the freshwater inflow to the Lower Laguna Madre (Schoenbaechler and Guthrie, 2011e). Irrigation return flows combined with municipal and industrial wastewater discharges to the Arroyo Colorado make it the primary source of day-to-day freshwater addition to the Lower Laguna Madre. Floodwaters from the lower Rio Grande are diverted into three floodways flowing into the Lower Laguna Madre to avoid flooding communities along the river. Over the 34 years from 1977 to 2010, evaporation exceeded the addition of fresh water from precipitation and stream flows to the Lower Laguna Madre. This subtropical, semiarid watershed contributes relatively little fresh water to the estuary, creating episodic hypersaline conditions like those in the Upper Laguna Madre. This area receives floodwaters caused by tropical storms and hurricanes impacting the watershed from both the Gulf and the Pacific Ocean (Rio Grande BBEST, 2012).

Like the Brazos River, the Rio Grande is a riverine estuary extending 48 miles upstream from its mouth at the Gulf. The annual flow from the Rio Grande to its estuary averaged 1.5 million acre-feet per year from 1934 to 2006 although it has not exceeded that amount since 1993. Flow from the Rio Grande into its estuary is largely controlled through releases from Falcon Dam on the river and diversions from the river by water users from Mexico and the U.S. In 2006, freshwater flows entering the estuary were largest in September and October with a smaller peak in flow in April and May. On at least two occasions in the past 17 years, freshwater inflows provided by the Rio Grande have been insufficient to keep the mouth of the estuary open at the Gulf (Mathis, 2006).

2.3.6 Hydrology

The study area spans the entire Gulf coast from the mouth of the Sabine River to the mouth of the Rio Grande. It encompasses several major Texas river basins and eight coastal basins with each coastal basin named according to the major river basins that border them. Figure 2-7 presents the major Texas rivers, river basins, and coastal basins within the study area. These river and coastal basins include:



Source: TWDB, Major River Basins
Base Map: Service Layer Credits: Sources: Esri, USGS, NOAA

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Major Water Basins

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FIGURE

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- **Upper Coast River and Coastal Basins:** Sabine River Basin, Neches River Basin, Neches-Trinity Coastal Basin, Trinity River Basin, Trinity-San Jacinto Coastal Basin, San Jacinto River Basin, San Jacinto-Brazos Coastal Basin, Brazos River Basin, and the Brazos-Colorado Coastal Basin;
- **Middle Coastal River Basins:** Brazos-Colorado River Basin (western portion), Colorado River Basin, Colorado-Lavaca River Basin, Lavaca River Basin, Lavaca-Guadalupe River Basin, Guadalupe River Basin, a portion of the San Antonio River Basin, and a small portion of the San Antonio-Nueces River Basin; and
- **Lower Coast Basins:** Nueces-Rio Grande River Basin and the Rio Grande River Basin. The river basins vary greatly in size, length, flow, and precipitation making the Texas coast a diverse hydrologic environment. Table 2-11 below summarizes a few key hydrologic parameters of the major river basins connected to the Texas coastal zone. Figure 2-8 shows the major non-contributing and contributing water basins occurring in Texas.

Table 2-11
Texas River Basin Average Flows and Average Annual Precipitation

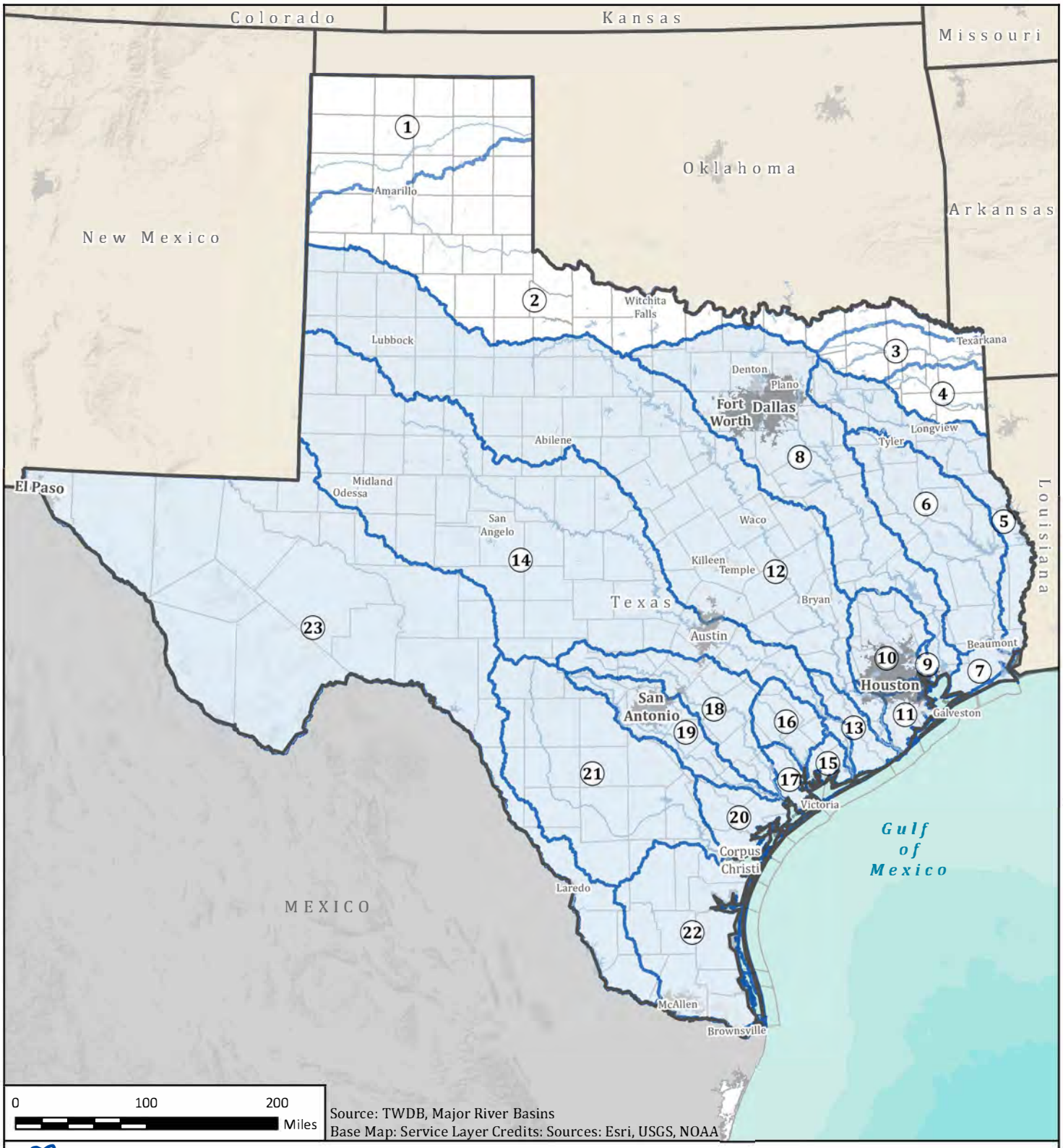
River Basin	Basin Area (square miles)	River Length (miles)	Average Flow (acre-feet per year)	Average Annual Precipitation (inches per year)
Sabine	9,756	360	5,864,000	60 at coast, range of 40–61
Neches	9,937	416	4,323,000	60 at coast, range of 41–60
Trinity	17,913	550	5,727,000	55 at coast, range of 29–60
San Jacinto	3,936	85	1,365,000	55 at coast, range of 44–56
Brazos	45,573	840	6,074,000	50 at coast, range of 17–54
Colorado	42,318	865	1,904,000	45 at coast, range of 13–41
Lavaca	2,309	117	277,000	45 at coast, range of 36–46
Guadalupe	5,953	409	1,422,000	35 at coast, range of 27–39
San Antonio	4,180	238	562,700	40 at coast, range of 27–39
Nueces	16,700	315	539,700	30 at coast, range of 22–31
Rio Grande	182,215	1,896	645,500	25 at coast, range of 8–21

Source: TWDB (2016c, 2016d).

2.3.6.1 Upper Coast River and Coastal Basins

2.3.6.1.1 Sabine River Basin

The Sabine River Basin straddles the Texas and Louisiana border. The basin is approximately 360 miles in length and has a total contributing area of 9,756 square miles with 76 percent of the river basin residing in Texas, and the remaining area residing in Louisiana (Sabine River Authority, 2016). In Texas, the Sabine River Basin begins in Hunt County, flows southeasterly to Grocer Lake at the Texas-Louisiana border, and then flows southward to the Sabine-Neches Estuary, commonly referred to as Sabine Lake (TWDB, 2016e). The Sabine Lake Estuary is part of the Neches-Trinity Coastal Basin and is formed by the confluence of the Sabine and Neches rivers. The Sabine Lake Estuary's 5-mile tidal outlet at Sabine Pass connects the lake to the Gulf, allowing for upstream



Source: TWDB, Major River Basins
Base Map: Service Layer Credits: Sources: Esri, USGS, NOAA

Major Water Basins of Texas
Contributing Water Basins
Rivers of Texas
Existing Reservoirs

Non-Contributing Water Basins

1. Canadian

Contributing Water Basins

2. Red
3. Sulphur
4. Cypress
5. Sabine
6. Neches
7. Neches-Trinity
8. Trinity
9. Trinity-San Jacinto
10. San Jacinto
11. San Jacinto-Brazos
12. Brazos
13. Brazos-Colorado
14. Colorado
15. Colorado-Lavaca
16. Lavaca
17. Lavaca-Guadalupe
18. Guadalupe
19. San Antonio
20. San Antonio-Nueces
21. Nueces
22. Nueces-Rio Grande
23. Rio Grande

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Contributing and Non-Contributing Water Basins

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FIGURE

NAD 1983 Texas Centric Mapping System Albers

drainage of flows from the Sabine River into the Gulf. The average annual precipitation within the Sabine River Basin ranges from 40 to 60 inches, with approximately 61 inches of precipitation per year received at the coast (TWDB, 2016d). The major contributing stream systems within the basin are the Sabine River, Lake Fork Creek, Big Sandy Creek, and Big Cow Creek. The major reservoirs in the basin are Lake Fork Reservoir, Lake Tawakoni, and Toledo Bend Reservoir. Toledo Bend Reservoir is the largest of the lakes with a surface area of 181,619 acres, with a normal impoundment capacity of 4,447,000 acre-feet (Sabine River Authority, 2016). The water level within the Toledo Bend Reservoir fluctuates between approximately 1 and 5 feet (TPWD, 2016a).

The Sabine River Tidal segment is contained within Orange County and extends from the confluence with Sabine Lake to Morgan Bluff. The tidal segment is 29 miles long, and no water quality concerns have been identified by the TCEQ within this intertidal area. About midway upstream of the tidal segment is Blue Elbow Swamp. Canals and ditches, which were constructed in the early 1900s, have changed natural flow patterns within Blue Elbow Swamp, including the Little Cypress Bayou, which has been channelized through the swamp to the Sabine River for the purpose of reducing floods in developed areas (TCEQ, 2016b). On the south end of the tidal segment, the mouth of the Sabine River has the largest volume of water discharged of any Texas river, which is about 46.2 percent of the total annual mean inflow into the Sabine Lake Estuary of 14 million acre-feet (Sabine and Neches BBEST, 2009). Additional details of the Sabine Lake Estuary's influence on the Texas coast is provided in Section 2.3.6.1.3.

The sediment yield of the entire Sabine Lake Estuary region (including the Sabine and Neches rivers) is calculated to be approximately 14 tons per square mile per year. Most of the materials are likely to be organics, sediments derived from shoreline erosion, bedload sediments, sediments transported by marine and coastal processes, and fluvial inputs from local watersheds (Phillips and Slattery, 2007).

In 2012, the Sabine River Basin experienced extreme drought, which caused low lake and reservoir levels and low flows within the river and creeks throughout the basin but resulted in minor water restrictions and elevated bacteria levels (Sabine River Authority, 2012; Texas Water Resources Institute, 2017).

2.3.6.1.2 Neches River Basin

The Neches River Basin is approximately 416 miles long and has a drainage area of 9,937 square miles (TWDB, 2016e). Beginning in southwestern Van Zandt County, the river flows southeasterly through the pinewoods of east Texas, into highly industrialized areas in Orange and Jefferson counties, to its confluence with the Sabine River at the Sabine Lake Estuary and to the Gulf. The average annual precipitation ranges from 41 to 60 inches across the basin, and averages approximately 60 inches of precipitation per year at the coast (TWDB, 2016d). The major stream systems within the basin are the Neches River, the Angelina River, Attoyac Bayou, Village Creek, and Pine Island Bayou. There are four major reservoirs within the basin: Lake Palestine, B.A. Steinhagen Lake, Lake Tyler, and Sam Rayburn Reservoir, with the first two being along the Neches River itself (TCEQ, 2016a). Sam Rayburn Reservoir is the largest reservoir in the basin with a surface area of 114,500 acres and a maximum depth of 80 feet. The water level of the reservoir fluctuates by an average of 7 feet annually, which is more than any other major reservoir within the Neches River Basin (TPWD, 2016b). The Neches River Tidal segment runs

from the confluence with the Sabine Lake Estuary to just upstream of Interstate Highway 10 in Orange County. The average discharge in the Neches River near the upper end of the tidally influenced river segment was 3,625 cubic feet per second (cfs) in 2014 (USGS, 2016a).

The Sabine Lake Estuary acts as the main link between the Neches River and the Gulf. Additional details of the Sabine Lake Estuary's influence on the Texas coast is provided in Section 2.3.6.1.3.

2.3.6.1.3 Neches-Trinity Coastal Basin

The Neches-Trinity Coastal Basin consists of a total drainage area of 769 square miles and a length of 132 miles. The basin is situated in eastern Texas, located in Jefferson and Chambers counties. The average annual precipitation in the basin is approximately 60 inches. Waterbodies within the basin include Taylor Bayou, Shallow Prong Lake, the GIWW, Alligator Bayou, Hillebrandt Bayou, and Willow Marsh Bayou. The Intracoastal Waterway Tidal segment stretches from the confluence with Galveston Bay in Galveston County to the confluence with the Sabine-Neches/Port Arthur Canal in Jefferson County. The tidal section includes the Taylor Bayou Tidal, 4.8 miles downstream of State Highway (SH) 73 in Jefferson County (TWDB, 2016d).

The Sabine Lake Estuary has an average salinity of 5 ppt, the lowest average salinity of any major Texas estuary. It receives freshwater inflows from its major rivers, the Sabine and Neches rivers, as well as from runoff from the surrounding coastal watersheds summing to approximately 14 million acre-feet per year on average (Sabine and Neches BBEST, 2009). Precipitation near the Sabine Lake Estuary ranges from approximately 54 to 60 inches per year and drains from an area of 45,320 acres (TWDB, 2016e). The water quality of the Sabine Lake Estuary is generally good (Sabine and Neches BBEST, 2009).

The Sabine-Neches Canal Tidal segment runs from the confluence with Sabine Pass at the southern tip of Pleasure Island to the Sabine Lake Seawall at the northern tip of Pleasure Island (Lower Neches Valley Authority, 2010). The dredging of canals and ditches in the area, such as the Sabine-Neches Waterway, has resulted in a disruption of the natural patterns of water flow in swamps. These navigation channels have also made it possible for salt water to intrude on the fresh water upstream. The Sabine-Neches Waterway extends from the Gulf through a channel to the cities of Port Arthur, Beaumont, and Orange, and continues through the Sabine River Channel (USACE, 2012b).

2.3.6.1.4 Trinity River Basin

The Trinity River Basin begins near the Dallas-Fort Worth area, drains southeastward to Trinity Bay and eventually into the Gulf (TWDB, 2016f). The Trinity River Basin is approximately 550 miles long and drains approximately 17,913 square miles including the large metropolitan areas of the city of Dallas, Fort Worth, and Houston. The major river systems in the basin include Cedar Creek, Clear Fork Trinity River, East Fork, Elm Fork Trinity River, Lower Trinity River, Main Stem Trinity River, Mountain Creek, Village Creek, Richland Creek, and West Fork Trinity River (Trinity River Authority, 2010).

The Trinity River Basin flow is highly variable. Precipitation in the lower portion of the basin is approximately 53 inches annually. During the summer months, flows in various streams throughout the basin are low, sometimes dry. The flows can be largely influenced by effluent discharge from industrial facilities and municipal wastewater plants as well as by releases from reservoirs (Trinity River Authority, 2010).

Water control features along the Trinity River include reservoirs such as Benbrook, Grapevine, Lavon, Lewisville, Navarro Mills, Bardwell, Joe Pool, Ray Roberts, and Lake Livingston. Additional water diversions include exports to adjacent basins. An estimated 1,114 million gallons per day are taken from the Trinity River and exported to adjacent basins to meet increasing municipal and industrial water demands (Trinity River Authority, 2010).

Most upstream sediment loads are captured by Lake Livingston and the Lake Livingston Dam. Lake Livingston surveys show sediment yields of 2 to 387 tons per square miles per year, with a mean of 275. The lower Trinity River has a high rate of alluvial sediment storage and acts as a bottleneck for sediment material to the river mouth (Phillips et al., 2004).

2.3.6.1.5 Trinity-San Jacinto River Basin

The Trinity-San Jacinto River Basin is a relatively small coastal plain with an area of 247 square miles from the headwaters in Walker County and flows southward to Galveston County. Precipitation in the basin ranges from 50 to 60 inches per year (TWDB, 2016d). The area receives inflows from its major rivers, the Trinity and San Jacinto rivers, as well as surface runoff from the surrounding coastal watersheds (TCEQ, 2016c). Another major source of fresh water to this basin is Goose Creek, which had an average discharge of 13.5 cfs in 2014 (USGS, 2016b).

2.3.6.1.6 San Jacinto River Basin

The San Jacinto River Basin is approximately 85 miles long and drains approximately 3,936 square miles, including the large metropolitan area of the city of Houston. The San Jacinto River Basin begins in Walker County and drains southeastward to Galveston Bay (TCEQ, 2016d). The major river systems in the basin include the East and West forks of the San Jacinto River; Caney, Cypress; Peach and Spring Creek; and Luce and Buffalo bayous. Precipitation in the lower San Jacinto River Basin near the Gulf is estimated between 50 and 55 inches annually (TWDB, 2012, 2016b). Water-control features along the San Jacinto River include reservoirs and lakes such as Addicks Reservoir, Barker Reservoir, Lake Conroe, Lake Houston, Lewis Creek Reservoir, Sheldon Reservoir, and Gulf Coast Water Authority Reservoir (TWDB, 2016g). Flow within the upper San Jacinto River Basin is controlled by releases from Lake Conroe and flows in the lower end of the basin are influenced by Lake Houston and Buffalo Bayou.

2.3.6.1.7 San Jacinto-Brazos River Basin

The San Jacinto-Brazos Basin is located between the San Jacinto and Brazos river basins and drains approximately 1,440 square miles. The main river systems within the basin include Armand Bayou, Bastrop Bayou, Chocolate

Bayou, Clear Creek, Dickinson Bayou, Oyster Creek, and the Old Brazos River Channel. The San Jacinto-Brazos River Basin drains to various bays including West Bay, Clear Lake, Moses Lake, Chocolate Bay, Bastrop Bay, Christmas Bay, Drum Bay, Texas City Ship Channel, Bayport Channel, and Lower Galveston Bay. Annual precipitation in the basin is estimated between 35 and 70 inches (TWDB, 2016d). Sources of inflow to the streams in the basin include treated wastewater, industrial discharge, and urban runoff (TWDB, 2016d, 2016g).

2.3.6.1.8 Brazos River Basin

The Brazos River Basin begins in Lubbock County and flows to the Gulf near Freeport. The entire Brazos River Basin stretches 840 miles and drains approximately 45,573 square miles, which is the largest drainage area of all the basins in Texas (TCEQ, 2016e; TWDB, 2016h). Salt Fork, Double Mountain Fork, and Clear Fork are three of the major river systems that join the main stem of the Brazos River. The Brazos River itself has the largest average annual flow volume of the rivers in Texas, as shown in Table 2-11. The Brazos River Authority Reservoir System includes Possum Kingdom Lake, Lake Granbury, and Lake Limestone. A fourth reservoir for the system, Allens Creek, is in the planning stages. There are several more lakes in the basin whose primary purpose is flood control: Proctor, Whitney, Aquila, Belton, Stillhouse Hollow, Georgetown, Granger, and Somerville lakes. The levels of the lakes fluctuate based on water needs and climatic conditions (Brazos River Authority, 2016).

The Brazos River Tidal section runs approximately 25 miles from its confluence with the Gulf to SH 322 in Brazoria County. Flow just downstream of Lake Whitney averaged 3,516 cfs in 2015, and flow just downstream of Proctor Lake averaged 419 cfs in 2015 (USGS, 2016c, 2016d). The amount of suspended sediments has decreased since the mid-1980s due to dam and reservoir construction, changes in land use, and sand and gravel mining (Dunn and Raines, 2001).

2.3.6.1.9 Brazos-Colorado River Basin

The Brazos-Colorado River Basin is a region of flat coastal plains located between the Brazos and Colorado river basins. The basin drains approximately 1,850 square miles. The river systems within the basin are the San Bernard River and Caney Creek (TCEQ, 2016f).

2.3.6.2 Middle Coastal River Basins

2.3.6.2.1 Colorado River Basin

The Colorado River Basin begins in Dawson County and drains southeastward toward Matagorda Bay, eventually draining into the Gulf. It drains approximately 42,318 square miles. The Colorado River flows approximately 865 miles before draining into Matagorda Bay. Reservoirs and lakes along the Colorado River include Inks Lake, Lake Marble Falls, Lake Austin, Lake Travis, Lake Buchanan, and Lady Bird (formerly Town) Lake (TPWD, 2016c). The major river systems within the Colorado River Basin include the Concho River, Llano River, Pedernales River, San Saba River, Pecan Bayou, Beals Creek, Champion Creek, Elm Creek, Oak Creek, Onion Creek, and Redgate Creek (TWDB, 2016i). Precipitation in the Lower Colorado River Basin is estimated at over 45 inches in the Gulf Coast Plain near the Gulf (TWDB, 2012, 2016d). The stability of the ecosystems within

Matagorda Bay rely predominantly on freshwater inflows from the Colorado River, Lavaca River, Navidad River, Tres Palacios Creek, and Lavaca Bay.

2.3.6.2.2 Colorado-Lavaca River Basin

The Colorado-Lavaca River Basin is located between the Colorado and Lavaca river basins. The basin drains approximately 939 square miles from Wharton County down to Tres Palacios Bay. The basin is primarily used for agriculture, urbanization, and industrialization. The main tributary within the basin is Tres Palacios Creek (TWDB, 2010).

2.3.6.2.3 Lavaca River Basin

The Lavaca River Basin begins in Fayette County, continues through the southern part of Jackson County, eventually making its way to Lavaca Bay. Precipitation in the basin is around 40 inches per year (TWDB, 2012). The two major river systems are the Lavaca and Navidad rivers. The Navidad River upstream of Lake Texana had an average discharge of 558.9 cfs in 2015 (USGS, 2016e). The Lavaca River Basin has the smallest area in Texas (2,309 square miles) and the second shortest length, spanning 74 miles (TWDB, 2016c). The major reservoir within the Lavaca River Basin is Lake Texana, which has a surface area of 9,727 acres and maximum depth of 58 feet. The lake fluctuates up to 15 feet and has a tannin stained to muddy clarity (TPWD, 2016d).

The Lavaca River Tidal segment is 23 miles long and stretches from the confluence with Lavaca Bay in Calhoun/ Jackson County to a point 5.3 miles downstream of U.S. Highway 59 in Jackson County (TCEQ, 2017a).

2.3.6.2.4 Lavaca-Guadalupe River Basin

The Lavaca-Guadalupe River Basin begins along the border of DeWitt and Victoria counties and flows in a southeastern direction to its confluence with San Antonio Bay in Calhoun County. Average annual precipitation is approximately 42 inches (TWDB, 2016d). The major river systems within the basin include the Guadalupe River, Garcitas Creek, Victoria Barge Canal, Marcado Creek, and Arenosa Creek. The basin has a drainage area of 998 square miles including the principal drainage system, the Victoria Barge Canal (TWDB, 2016c).

2.3.6.2.5 Guadalupe River Basin

The Guadalupe River Basin begins in southwestern Kerr County and flows southeasterly to Guadalupe Bay, which is part of the San Antonio Bay system. The average annual precipitation in the basin is approximately 35 inches on the Texas coast (TWDB, 2016d). The major river systems within the basin are the Guadalupe River, Blanco River, San Marcos River, Plum Creek, and Coleto Creek (TCEQ, 2016g). The Guadalupe River Basin stretches 409 miles and has a drainage area of 5,953 square miles (BEG, 1996). The two major reservoirs along the Guadalupe River are Canyon Lake and Coleto Creek Reservoir (TCEQ, 2016g). Canyon Lake is the larger of the two reservoirs with a surface area of 8,308 acres and a maximum depth of 125 feet. The lake is also spring fed and lake levels fluctuate moderately (TPWD, 2016e).

The Guadalupe River Tidal segment stretches from the confluence with Guadalupe Bay in Calhoun/Refugio County to the Guadalupe-Blanco River Authority Salt Water Barrier, 0.4 mile downstream of the confluence of the San Antonio River in Calhoun/Refugio County. The average discharge in the Guadalupe River just upstream of the Salt Water Barrier was 619.2 cfs in 2014 (USGS, 2016f).

The Eagle Ford Shale, a geologic formation that is being tapped to extract oil and natural gas, lies underneath DeWitt and Gonzales counties within the Guadalupe River Basin (Eagle Ford Shale, 2017). The concentration of oil and gas wells along the shale requires the consumption of large amounts of water during the recovery of petroleum resources. Consequently, water demands have been affected by the hydraulic fracturing industry within the watershed (Guadalupe-Blanco River Authority, 2013).

2.3.6.2.6 San Antonio River Basin

The San Antonio River Basin begins in Kerr and Medina counties and drains southeastward toward the Gulf. The entire San Antonio River Basin drains approximately 4,180 square miles, including the large metropolitan area of the city of San Antonio. The major river systems include the San Antonio River, Medina River, Leon Creek, Salado Creek, and Cibolo Creek. The longest river in the basin is the San Antonio River, which flows approximately 240 miles before it drains into the Guadalupe River, upstream of San Antonio Bay (Lower San Antonio River Sub-Basin Study Design Workgroup, 2009). Water diversions along the San Antonio River include reservoirs and lakes such as Calaveras Lake, Medina Lake, Olmos Reservoir, and Victor Braunig Lake (USGS, 2001).

Precipitation in the Lower San Antonio River Basin near the Gulf is estimated between 35 and 40 inches annually (TWDB, 2012, 2016d). Based on USGS gauge data from 1924 to 2017, it is estimated that the San Antonio River (at USGS Gauge 8188500) has had an average discharge of 1,079 cfs (USGS, 2016g). Flows from the San Antonio River Basin ultimately drain into San Antonio Bay. The stability of the ecosystems within the bay rely predominantly on freshwater inflows from the San Antonio and Guadalupe rivers. TPWD data indicate that recent heavy drought in Texas has led to an increase in salinity within the bay (Stanzel and Dodson, 2014). Water in the bay flows to the Gulf through Pass Cavallo, Aransas Pass, and Cedar Bayou (USGS, 2001).

2.3.6.2.7 San Antonio-Nueces River Basin

The San Antonio-Nueces River Basin is located between the San Antonio and Nueces River basins. The basin drains approximately 3,100 square miles from Karnes County down to Copano Bay and Aransas Bay along the Gulf coast. The two largest river systems within the basin are the Aransas and Mission rivers, which flow approximately 28 miles and 41 miles, respectively. Additional tributaries include Aransas Creek and Poesta Creek (Nueces River Authority, 2010).

2.3.6.2.8 Nueces River Basin

The Nueces River Basin extends from Edwards County to Nueces Bay in the Gulf near Corpus Christi. The main river systems within the basin include the Atascosa and Frio rivers, which converge into the Nueces River.

Branching from these major rivers are tributaries, such as San Miguel Creek, Hondo Creek, Sabinal River, and Leona River. The basin stretches 315 miles and has a drainage area of 16,700 square miles. The major reservoirs along the Nueces River include Choke Canyon Reservoir and Lake Corpus Christi covering 47,891 surface acres (TCEQ, 2016h). Choke Canyon Reservoir is the largest of the two reservoirs, receiving an average of 49.8 cfs from San Miguel Creek and 187.9 cfs from the Frio River (USGS, 2016h, 2016i).

The Nueces River Tidal section starts at the confluence with Nueces Bay in Nueces County for 12 miles to Calallen Dam in Nueces/San Patricio County. Part of the Nueces and its tributaries flow into the crevices of the Edwards Aquifer Balcones Fault Zone resulting in stream flows that consists mostly of stormwater downstream of the recharge zone (TCEQ, 2016h). The water levels in the artesian zone have decreased due to drought and water demand, negatively impacting habitats that rely on flows from the San Marcos and Comal springs (USACE, 2012c).

2.3.6.3 Lower Coast Region

2.3.6.3.1 Nueces-Rio Grande Basin

The Nueces-Rio Grande Basin is located between the Nueces River and the Rio Grande basins. The basin drains approximately 10,442 square miles from Webb County down to the Laguna Madre, Baffin Bay, and Oso Bay along the Gulf coast. The two largest river systems in the basin are Petronila Creek and Arroyo Colorado River, which flow approximately 58 miles and 89 miles, respectively (Nueces River Authority, 2010).

2.3.6.3.2 Rio Grande Basin

The Rio Grande Basin begins as snow melt in the southern Colorado Rockies and drains southeastward towards the Gulf. The Rio Grande Basin is approximately 1,901 miles long and drains approximately 333,500 square miles, including areas within Mexico (International Boundary and Water Commission, 2016). The Rio Grande is split into three main reaches: Upper Rio Grande, Middle Rio Grande, and Lower Rio Grande (New Mexico Office of the State Engineer, 2016a). The Lower Rio Grande extends from Elephant Butte Dam to the Gulf. Contributing ephemeral streams include Las Animas Creek, Cuchio Negro, and Percha Creek. Flows in the Lower Rio Grande are controlled by releases from Elephant Butte and Caballo reservoirs (New Mexico Office of the State Engineer, 2016b). Water diversion between Mexico and the United States between Elephant Butte and Fort Quitman, south of El Paso, utilizes all the available surface water in the section of the Rio Grande. Flow south of Fort Quitman comprises predominantly surface runoff from the surrounding basin (U.S. Bureau of Reclamation and Rio Grande Regional Water Authority, 2013).

Precipitation within the basin ranges from approximately 10 inches per year in the Trans-Pecos region in west Texas to over 25 inches in the Lower Rio Grande Valley near the Gulf (TWDB, 2012).

Primary demands on the water within the river come from municipal and agricultural use. Approximately 75 percent of the water in the Rio Grande is currently allocated for agricultural use (International Boundary and Water Commission, 2016). Several segments of the Rio Grande have been listed as Section 303(d) impaired

streams. Along with water quality concerns, increasing demand on water and abundance of invasive aquatic species in the Rio Grande has jeopardized the stability of ecosystems along the river, particularly those supporting endangered species (New Mexico Office of the State Engineer, 2016c).

2.3.6.4 Gulf Coast Aquifer

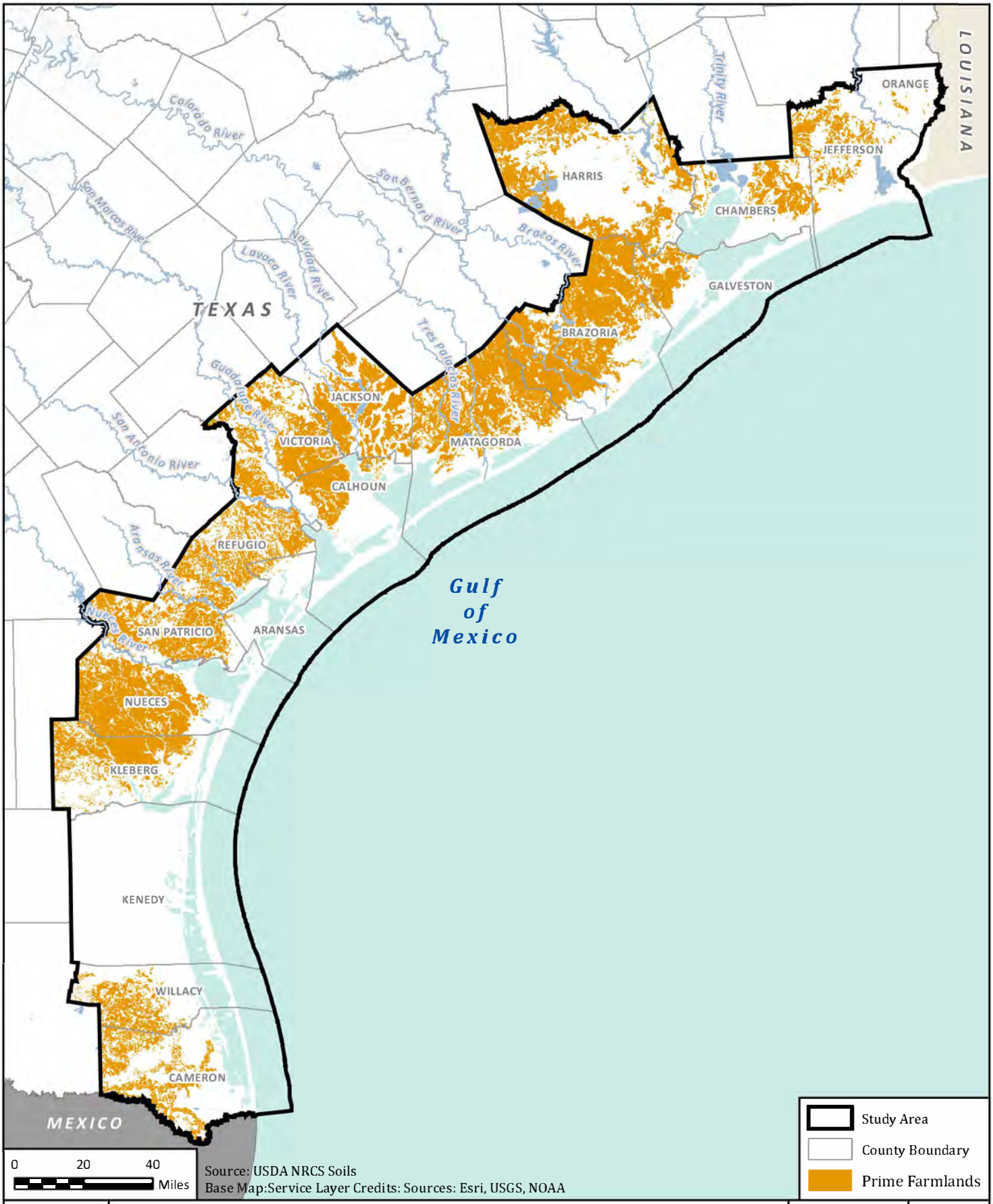
The major aquifer spanning the Texas coast from the Louisiana border to the Mexico border is the Gulf Coast Aquifer. The Gulf Coast Aquifer comprises three main aquifers: the Chicot, the Evangeline, and the Jasper aquifers (TWDB, 2016j). The Gulf Coast Aquifer covers an area of approximately 41,879 square miles. Availability of fresh water in 2010 was approximately 1,825,976 acre-feet per year. Rapid growth in the region has caused an increase in withdrawal of water from the aquifer, reducing water levels up to 350 feet and causing subsidence throughout the aquifer (Trinity River Authority, 2010).

2.3.7 Soils (Prime and Other Important Unique Farmland)

The following describes the soils and prime and unique farmlands found in the study area (Figure 2-9).

Upper Coast. The soils located in the northern extents of Orange County are associated with the western coastal plain and flatwoods soil types. The deep soils, Otanya-Kirbyville-Evadale, occur on low-relief uplands and flat plains. These areas are generally wet and have poor drainage. These soils are characteristic of the southern tertiary uplands. Similar upland soils consisting of Woodtell-Pinetucky-Conroe can be found in northern Harris County. These are deep soils found on interstream divides and low ridges. The Gulf coast prairie soils are the largest proportion of soils found in the upper Texas coast. Beaumont-League-Labelle soils are found in Orange and Jefferson counties; while the Katy-Wockley-Gessner soils are found in north central Harris County. Lake Charles-Bernard-Edna soils occur in southern Harris County, northern Galveston County, and northern Brazoria County. The band along the coastline is the Gulf coast saline prairie consisting of Harris-Surfside-Francitas soils. These soils are formed in nearly level quaternary sediments on coastal lowland plains (Natural Resources Conservation Service [NRCS], 2008).

Most of the prime farmlands in this area are found in historic alluvial terraces, flatwoods, wet plains, and woodlands (NRCS, 2006). The prime farmland soil associations in the six-county region are Aris fine sandy loam, Asa silt-clay loam, Bernard-Edna clay loam, Bissonet loam, Brazoria clay, Clemville silty clay loam, Katy fine sandy loam, Lake Charles clay, Mocarey loam, Mocarey-Algoa complex, Mocarey-Cieno complex, Mocarey-Leton complex, Norwood silty loam, Pledger clay, Spurger fine silty loam, Texla silty loam, and Vamont clay. Agricultural crops include corn, cotton, grain, and sorghum. Pastures and hayfields include adapted bahiagrass and bermudagrass (Soil Conservation Service [now the NRCS], 1976).



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Prime Farmlands

FN JOB NO	COH16388
FILE NAME	2.10EIS_PF_Soils.mxd
DATE	8/21/2017
SCALE	1:2,377,085
DESIGNED	SSJ
DRAFTED	SSJ

2-9
FIGURE

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Middle to Upper Coast. This area consists of the floodplains, Gulf coast prairie, and Gulf coast saline marshes. The coastline is separated into two distinct saline prairie types. The coastline of Matagorda County is Harris-Surfside-Francitas soils, while the coastline of Calhoun County is Mustang-Daggerhill-Barrada soils (NRCS, 2001a). Central Matagorda County along the Colorado River and other freshwater drainages are floodplain soils: Pledger-Brazoria-Norwood. Floodplain soils are formed in the nearly level alluvium of streams and are subject to inundation during floods. Norwood soils have an irregular distribution of organic material. Brazoria and Pledger soils are heavy clays with high shrink swell potential. Southern Victoria and Jackson counties and northern Calhoun and northwestern Matagorda counties have Gulf coast prairie soils of the Laewest-Dacosta-Edna series (NRCS, 2008).

The prime farmlands soil associations for this area are Asa silty loam, Brazoria clay, Clemville silty clay loam, Dacosta-Contee complex, Dacosta sandy clay loam, Edna fine sandy loam, Faddin loam, Faddin fine sandy loam, Fulshear fine sandy loam, Inez fine sandy loam, Katy fine sandy loam, Laewest clay, Laewest silty clay, Norwood silty clay loam, Pledger clay, Telferner fine sandy loam, and Texana fine sandy loam. These soils are primarily used to grow rice, soybeans, corn, pecans, and sorghum. The lands are also used to grow turfgrass like St. Augustine and bermudagrass and pastures for dallisgrass, common bermudagrass, coastal bluestem, kleingrass, Pensacola bahiagrass, and native hay meadows (NRCS, 2001a).

Mid Coast. The northern reaches of Aransas County and the soils of the eastern half of Refugio County are the Laewest-Dacosta-Edna soils of the Gulf coast prairie. The majority of San Patricio and Nueces counties is in the Gulf coast plain with dominant soils being in the Victoria-Orelia-Edroy series (NRCS, 2008). The Victoria clay has a high shrink-swell potential and in undisturbed areas, forms gilgai depressions (Soil Conservation Service, 1988). The southwestern corner of Nueces and western half of Kleberg counties also lie within the Rio Grande plain but are dominated by Nueces-Sarita-Falfurrias soils. Central Kleberg County lies in the upland Gulf coast plain also containing Victoria-Orelia-Edroy soil. The Gulf coast saline prairie of the mid coast is dominated by Mustang-Daggerhill-Barrada soils, which are on low coastal terraces and plains along the barrier islands (NRCS, 2001b).

The mid coast is predominantly open grassland and used for rangelands and wildlife habitat. Most of the prime farmlands in this area reside on historic open grassland areas with scattered trees and shrubs. Prime farmland soil classes in the area include Banquete clay, Calallen sandy clay loam, Clareville loam, Clareville clay loam, Colmena fine sandy loam, Cranell sandy clay loam, Czar sandy clay loam, Monteola clay, Odem fine sandy loam, Orelia fine sandy loam, Palalote sandy loam, Pharr fine sandy loam, Raymondville clay loam, Raymondville complex, Sinton loam, Sinton clay, Victoria clay, and Willacy fine sandy loam. Because of the slope and fine soil, erosion is a major problem. Corn, sorghum, and cotton are important agricultural crops in the region (Soil Conservation Service, 1979, 1988).

Lower Coast. The area is bisected by the dry Rio Grande plain to the west and Gulf coast saline prairie to the east. The Rio Grande plains of the lower coast contain Nueces-Sarita-Falfurrias soils in Kenedy County and McAllen-Hidalgo-Brennan soils in Willacy and Cameron counties. The Nueces-Sarita association is from aeolian sand deposits and is relatively flat and well draining. Mustang-Daggerhill-Barrada soils are found along the

coastline as part of the Gulf coast saline prairie in the lower coast (NRCS, 2008). The Rio Grande series consists of well-drained calcareous soils with little slope on the floodplains of the Rio Grande. The Willacy and Willamar series are saline soils on deltas and coastal terraces (Soil Conservation Service, 1977).

Irrigated lands in this area are used to grow cotton, sorghum, corn, grapefruit, oranges, sugarcane, onions, potatoes, cabbage, lettuce, and beets. Common bermudagrass, coastal bermudagrass, African stargrass, and angleton bluestem are grown to feed livestock. Examples of prime farmland soil types are Camargo silty clay loam, Cameron sandy clay loam, Hidalgo sandy clay loam, Laredo silty clay loam, Laredo-Reymosa complex, Matamoros silty clay, Matamoros-Rio Grande complex, Olmitos silty clay, Racombes sandy clay loam, Raymondville clay loam, Rio Grande silty clay loam, and Willacy fine sandy loam. Wind erosion of fine sandy sediments is a large concern in the region (Soil Conservation Service, 1977).

2.3.8 Energy and Mineral Resources

Texas leads the United States in overall energy production including oil and gas exploration and production, power generation, and renewable and sustainable energy generation. The Texas Gulf coastal zone, specifically the upper Texas coast, has been developed for oil and gas exploration since the late 1800s to early 1900s when drilling began in the upper Texas coast area (Handbook of Texas Online, 2016). Oil and gas exploration and production bolstered the economies of many coastal cities and increased the development of the coastal region with service, supply, and manufacturing facilities associated with oil and gas production. The opening of the Houston Ship Channel in 1914 further enticed large oil refineries to the Houston area. Similarly, the development of the Corpus Christi Ship Channel in 1926 boosted oil and gas exploration and production-related facilities in Corpus Christi, Refugio, and Port Lavaca.

In recent times, the energy sector along the Texas coast has increased its renewable energy production as well. Two coastal wind farms, located in south Texas, provide renewable energy from wind power contributing to Texas's 12,000-megawatt wind power capacity. Supporting wind power generation, several large wind equipment manufacturing facilities have been built in the Houston region (State of Texas, 2014).

The presence of energy production activities along the Texas coast including oil and gas exploration and production facilities has resulted in a large pipeline network within the coastal zone. While intricate pipeline networks are associated with each oil or natural gas field, several large-diameter transmission pipelines cross the coastal bays and GIWW. The upper and mid Texas coast contains the densest network of oil and gas pipelines beginning in Orange County and ending in Nueces County. Oil and gas pipelines in south Texas are generally located in or near Brownsville, Texas, in Cameron County (American Petroleum Institute, 2014; U.S. Energy Information Administration [EIA], 2016).

Widespread mineral mining for sulfur, silica, sand and gravel, salt, stone, heavy metals, perlite, gypsum, and clay is present along the entire Texas Gulf coast; however, it is more prevalent in the upper coast around the cities of Beaumont, Port Arthur, Houston, and Freeport. Mining activities are distributed sparsely throughout the mid and southern coast. Most mineral mining in these areas is within the areas of Port Lavaca, Corpus Christi, and Brownsville. Mining activities are near more-developed cities and ports along the Texas coast (BEG, 2016b).

2.3.9 Hazardous, Toxic, and Radioactive Waste

The presence of potential Hazardous, Toxic, and Radioactive Waste (HTRW) concerns along the Texas coast including hazardous materials, hazardous waste, and potential contamination by current or past industrial or other activities are discussed below. Potential HTRW concerns were identified through a review of State and Federal databases cataloguing permitted facilities and activities regulated by these agencies, such as the TCEQ and the EPA. In addition, port activities are discussed below.

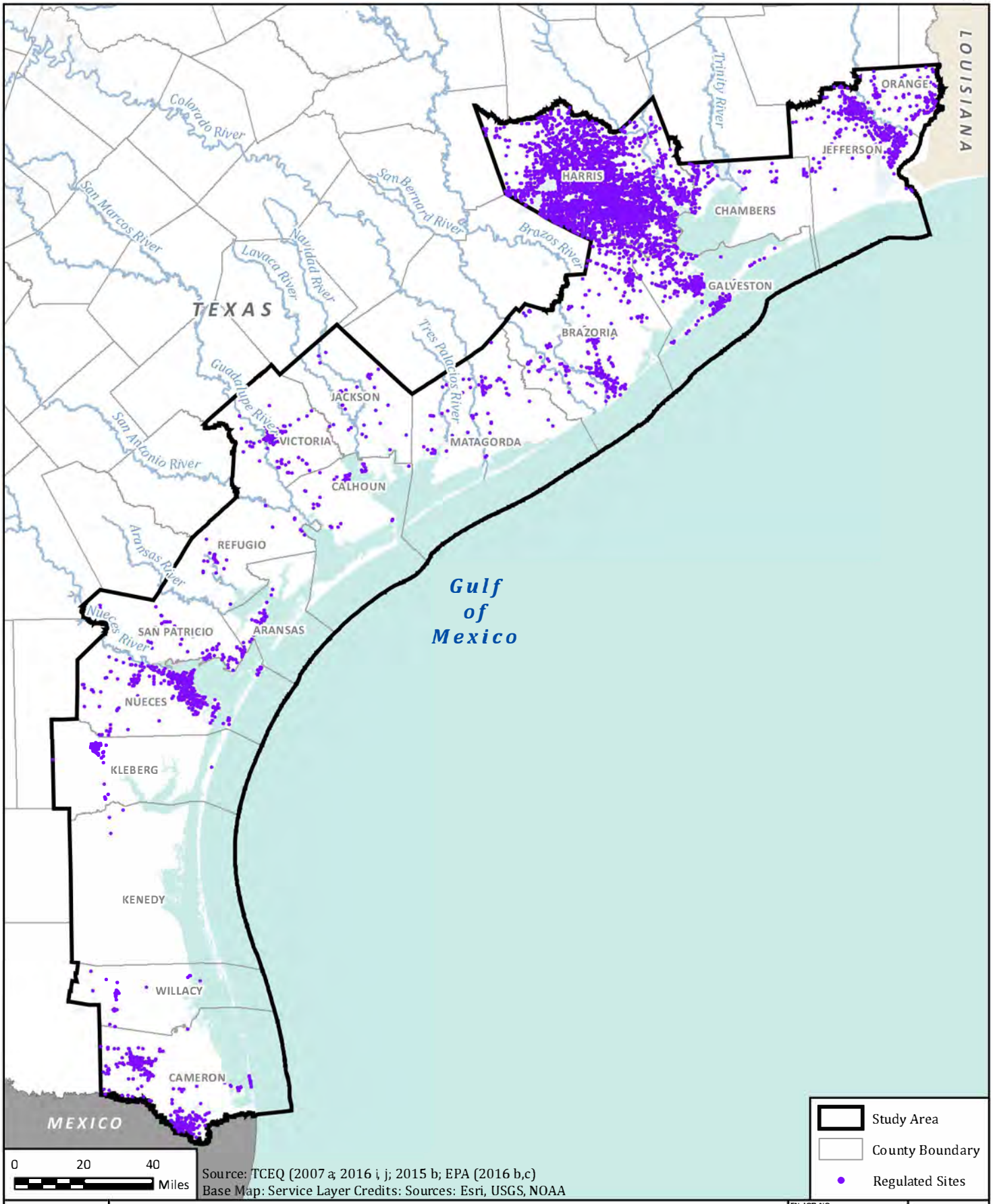
Engineer Regulation 1165-2-132 provides guidance for Civil Works projects regarding consideration of issues and problems associated with potential HTRW, which may be located within project boundaries or may affect or be affected by USACE Civil Works projects. HTRW includes any material listed as a "hazardous substance" under the Comprehensive Environmental Response, Compensation and Liability Act, 42 United States Code (USC) 9601 et seq.

Potential HTRW concerns will be identified following the selection of the Tentatively Selected Plan (TSP) in October 2018. A desktop HTRW assessment will be conducted to identify the existence of, and potential for, HTRW contamination, which could impact or be impacted by the TSP. This assessment will follow guidance provided by Engineer Regulation 1165-2-132 and consists of a review of recent and historic aerial photographs and a review of Federal, State, and local regulatory agency database information.

2.3.9.1 Upper Coast

The Texas coast from Orange and Jefferson counties along the Texas-Louisiana border south to Brazoria County is a highly urbanized region with major industrial and commercial development along the coastal zone. According to the TCEQ and EPA, these commercial and industrial activities and associated HTRW concerns are centered around the coastal cities and ports of Orange, Beaumont, Port Arthur, Houston, Galveston, Pasadena, Baytown, Deer Park, La Porte, Texas City-La Marque, Dickinson, League City, Friendswood, and Freeport (Figure 2-10) (EPA, 2016b, 2016c; TCEQ, 2007a, 2015b, 2016i, 2016j).

Sabine Lake, in Orange and Jefferson counties, contains three ports: Orange, Beaumont, and Port Arthur. The Port of Orange, on the Sabine River, is dominated by numerous petrochemical facilities, shipbuilding yards, and tug, barge, and offshore petroleum drilling platform repair facilities. The Port of Beaumont is located along the Neches River upstream of Sabine Lake. The port includes a petroleum terminal that receives crude oil by rail and truck as well as several industrial facilities for the shipping and receiving of military equipment, forestry products, steel, crude oil, cargo, aggregate, bulk grain storage, and potash. Port Arthur is located 19 miles to the north of the Gulf and contains several petroleum and chemical facilities (Gulf South Research Corporation, 2015; TxDOT, 2014a).



Source: TCEQ (2007 a; 2016 i, j; 2015 b; EPA (2016 b,c)
Base Map: Service Layer Credits: Sources: Esri, USGS, NOAA

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Locations of HTRW Sites

FN JOB NO	COH16388
FILE NAME	2.11EIS_HTRW_Sites.mxd
DATE	8/22/2017
SCALE	1:2,377,085
DESIGNED	SSJ
DRAFTED	SSJ

2-10

FIGURE

NAD 1983 Texas Centric Mapping System Albers

Galveston Bay has shoreline in Chambers, Harris, and Galveston counties. Highly industrialized areas within the cities of Houston, Pasadena, Baytown, Deer Park, La Porte, Texas City-La Marque, Dickinson, League City, and Friendswood contain numerous petrochemical facilities and oil storage facilities. Refining and petrochemical activities are most prominent in eastern portions of Harris County along the Houston Ship Channel (Lester and Gonzales, 2011). The Port of Houston, a 25-mile-long complex located along the Houston Ship Channel, has the world's second largest petrochemical complex and the Nation's busiest port regarding foreign tonnage (Port of Houston, 2018a).

The Port of Freeport industrial complex consists of aggregate facilities, petrochemical sites, petroleum processing and refining plants, natural gas gathering systems, and chemical manufacturing plants (USACE, 2012d). Imports to the Port of Freeport include aggregates, chemicals, crude oil, and liquefied natural gas (LNG). Exports from the port include chemicals, resins, and LNG (TxDOT, 2014a).

2.3.9.2 Middle to Upper Coast

South of Brazoria County, the Texas coast along Matagorda, Jackson, Victoria, and Calhoun counties are less densely developed for industrial and commercial purposes. According to the TCEQ and EPA, these commercial and industrial activities and associated HTRW concerns are most prominent in the cities located throughout Matagorda and Calhoun counties with Port Lavaca and Palacios containing the highest volume of regulated sites (see Figure 2-10) (EPA, 2016b, 2016c; TCEQ, 2007a, 2015b, 2016i, 2016j).

Matagorda Bay is home to the Port of Bay City and the Port of Palacios. Located along the Colorado River southwest of Bay City, Texas, the Port of Bay City is predominantly utilized for the shipping and receiving of cargo (Port of Bay City Authority, 2016). To the west, the Port of Palacios consists mainly of commercial fishing; however, recent industrial growth includes tugboat and barge manufacturing, recreational vessel manufacturing, and bulk transportation of fertilizer, grain, gravel, and building materials (Matagorda County Navigation District No. One, 2016). In addition, several inland industrial facilities including chemical manufacturing, plastics production and refining, and pipe manufacturing are located within Matagorda County (Matagorda County Economic Development Corporation, 2016).

Point Comfort and Port Lavaca are along the shoreline of Lavaca Bay at the mouth of the Lavaca River in Calhoun County. The Calhoun Port Authority facilities, in Point Comfort, include liquid cargo facilities that support chemical and petrochemical activities. The top commodities of the port are chemicals, fertilizers, petroleum products, and bauxite (TxDOT, 2014a). Industrial activities surrounding Port Lavaca and Point Comfort consist of chemical, plastic resin, and petrochemical production and metals manufacturing (City of Port Lavaca, 2015).

The Port of West Calhoun is located along the eastern shoreline of San Antonio Bay. Port facilities at the Port of West Calhoun include commercial seafood production and oil and natural gas exploration (TxDOT, 2014a).

2.3.9.3 Middle Coast

Industrial and commercial development increases along the Texas coast from San Antonio Bay to Baffin Bay, which includes Aransas, Refugio, San Patricio, Nueces, and Kleberg counties. Refugio, San Patricio, and Nueces counties contain the largest volume of regulated sites, which are centrally located around the cities of Rockport, Aransas Pass, Port Aransas, Portland, and Corpus Christi. According to the TCEQ and EPA, these commercial and industrial activities and associated HTRW concerns are most prominent along the coast between Rockport and Corpus Christi, which contain the highest volume of regulated sites (see Figure 2-10) (EPA, 2016b, 2016c; TCEQ, 2007a, 2015b, 2016i, 2016j).

The Port of Corpus Christi is the fifth largest U.S. port and includes cargo shipping and receiving facilities for offshore drilling, wind turbine production, steel and steel pipe production, and heavy machinery. In addition, several facilities in and around the port contribute to increasing volumes of chemicals, crude oil, and petroleum products (Port of Corpus Christi, 2016).

Industrial activities in Corpus Christi and the surrounding area consist of steel pipe production and iron ore, shale oil, and natural gas production including five petroleum refineries (Corpus Christi Regional Economic Development Corporation, 2016).

2.3.9.4 Lower Coast

The southernmost section of the Texas coastline includes Kenedy, Willacy, and Cameron counties. According to the TCEQ and EPA, HTRW concerns are most prominent in Port Isabel and the Port of Brownsville. Fewer regulated facilities are present near Harlingen and Port Mansfield in Cameron and Willacy counties, respectively (see Figure 2-10) (EPA, 2016b, 2016c; TCEQ, 2007a, 2015b, 2016i, 2016j).

Port Isabel's top commodities are concrete, sand, and aggregate; however, the port also serves oil service vessels, concrete manufacturers, and boat construction and repair facilities (TxDOT, 2014a).

The Port of Brownsville's top commodities consist of steel products, iron ore, petroleum products, and lubricants (TxDOT, 2014a). Industrial activities in Brownsville and the surrounding area consist of advanced and heavy manufacturing, automotive production, medical equipment production, and aviation services (Brownsville Economic Development Council, 2016). As part of the Rio South Texas Economic Council, the Port of Brownsville also serves as a gateway to both domestic and international industrial centers. Numerous advanced manufacturing and aerospace design facilities are located in the area and in neighboring cities of Reynosa and Matamoros in Mexico (Rio South Texas Economic Council, 2010).

2.3.10 Air Quality

2.3.10.1 Regulatory Context

The Clean Air Act of 1970 (CAA) requires the EPA to set National Ambient Air Quality Standards (NAAQS; 40 Code of Federal Regulations [CFR] part 50) for pollutants considered harmful to public health and the

environment. The CAA identified two types of NAAQS: primary standards provide public health protection, including protecting the health of "sensitive" populations, such as asthmatics, children, and the elderly; and secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings (EPA, 2016d). The EPA established NAAQS for six criteria pollutants including carbon monoxide (CO), nitrogen dioxide (NO_2), lead (Pb), sulfur dioxide (SO_2), fine particulate matter (PM_{10} and $PM_{2.5}$), and ozone (O_3) (Table 2-12).

Table 2-12
EPA's 2015 National Ambient Air Quality Standards

Pollutant		Primary/Secondary	Averaging Time	Level
Carbon Monoxide (CO)		primary	8 hours	9 ppm
			1 hour	35 ppm
Lead (Pb)		primary and secondary	Rolling 3-month average	0.004 μg/ft^3
Nitrogen Dioxide (NO_2)		primary	1 hour	100 ppb
		primary and secondary	1 year	53 ppb
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm
Particulate Matter (PM)	$PM_{2.5}$	primary	1 year	0.34 μg/ft^3
		secondary	1 year	0.42 μg/ft^3
		primary and secondary	24 hours	0.99 μg/ft^3
	PM_{10}	primary and secondary	24 hours	4.25 μg/ft^3
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb
		secondary	3 hours	0.5 ppm

Source: EPA (2016d).
ppm = parts per million; μg/ft^3 = micrograms per cubic feet; ppb = parts per billion

CO is a colorless, odorless gas released from the incomplete combustion of fuels. The primary sources of CO are from fossil fuel burning vehicles and industrial processes such as coal-fired power plants and boilers. CO can temporarily accumulate at the ground level during windless conditions and atmospheric inversions (EPA, 2016e).

NO_2, nitric oxide, and other nitrogen compounds are grouped together as nitrogen oxides (NO_x). NO_x is formed through the combustion of fossil fuels. Emissions from cars, trucks, power plants, and industrial engines contribute to the release of NO_x. NO_x is considered an O_3 precursor. The photoreaction of volatile organic compounds (VOCs) with NO_x creates O_3 (EPA, 2016f).

Lead is a toxic metal that may be found in particulate dust and gas. Constant exposure to lead can cause neurological, cardiovascular, renal, and reproductive problems. Since the United States has switched to using unleaded gas and removed lead-based paints, the amount of lead in the atmosphere has decreased significantly. Lead can still be found in industrial processes such as smelting, steel production, and battery manufacturing (EPA, 2016g).

The largest source of SO_2 is from the combustion of fossil fuels or high sulfur coal from power plants and other industrial facilities. SO_2 can harm the respiratory system, reduce landscape visibility by creating haze, and contribute to acid rain formation (EPA, 2016h).

PM_{10} and $PM_{2.5}$ are fine, inhalable particulate matter ≤10 and 2.5 microns. These particulates can enter the respiratory tract and get lodged deep within the alveolar region of the lungs. This can impair breathing and may cause cardiovascular and respiratory illness. These particles can come from a variety of natural and artificial sources such as soil-dust erosion, construction sites operations, roadways, fires, and industrial smokestacks (EPA, 2016i).

Ground-level O_3 is created from the chemical reaction of NO_x, VOCs, and sunlight. Since O_3 is not directly emitted from a source, O_3 reduction is accomplished by limiting its component compounds. Breathing O_3 can cause chest pains, coughing, and airway inflammation. Long-term exposure can lead to decreased lung functions and damaged lung tissues (EPA, 2016j).

The EPA categorizes individual regions or counties into two levels of compliance with the NAAQS for criteria pollutants: "attainment areas" and "nonattainment areas." Attainment areas are districts or areas that meet NAAQS; nonattainment areas exceed the NAAQS and must have and implement a plan to meet the NAAQS (EPA, 2017b). O_3 nonattainment areas are further classified as moderate, serious, and severe. Nonattainment areas with more serious air quality issues must implement additional control measures. There are currently 18 counties in Texas that exceed the O_3 standard (TCEQ, 2016k). Of these nonattainment counties, Chambers, Galveston, Brazoria, and Harris counties are within the study area (Table 2-13). Jefferson, Orange, Victoria, Nueces, and San Patricio counties are categorized by the TCEQ as "special inventory," meaning that although emissions do not exceed the NAAQS O_3 standard, it remains under close supervision. These classifications are subject to change, however, and in October 2015 the EPA lowered the O_3 standard from 0.075 to 0.070 parts per million (EPA, 2016d).

Table 2-13
TCEQ's Current Designation for Counties Within the Study Area

Designation	Counties	
Nonattainment	Brazoria	Galveston
	Chambers	Harris
Attainment/ Special Inventory	Jefferson	Kleberg
	Orange	Nueces
	Calhoun	Refugio
	Jackson	San Patricio
	Matagorda	Cameron
	Victoria	Kenedy
	Aransas	Willacy

Source: TCEQ (2016k).

The TCEQ is responsible for developing a comprehensive plan to maintain NAAQS compliance. In cooperation with county officials, local city governments, and other State agencies, the TCEQ submits a State Implementation Plan (SIP) to the EPA for approval. The SIP contains background information, action plans, contingency measures, schedules, and reporting requirements for reducing and maintaining air quality standards (TCEQ, 2017b).

2.3.10.2 Conformity of Federal Actions

Established under the CAA (section 176(c)(4)), the General Conformity Rule (40 CFR Part 51, subpart 54) ensures that Federal actions conform to the appropriate SIP. To proceed with a Federally funded project, a General Conformity program requires an emissions inventory to ensure that increased air pollution from the activities subject to the General Conformity Rule will not negatively affect the state's emissions budget and conform with its respective SIP.

The CAA prohibits Federal agencies from funding, permitting, constructing, or licensing any project that does not conform to an applicable SIP. Under the General Conformity Rule, Federal agencies must consult with State and local air quality districts to help assure these regulatory entities know about the expected impacts of the Federal action and can include expected emissions in their SIP emissions budget.

The General Conformity Rules are applicable to projects located in nonattainment areas (Ref: 40 CFR 93, Subpart B). Counties in the study area currently in nonattainment include Chambers, Galveston, Brazoria, and Harris. Therefore, the General Conformity requirements are applicable, and a General Conformity Determination will be required (TCEQ, 2016k).

2.3.10.3 Air Quality Baseline Condition

The 2014 emissions total shown in Table 2-14 is provided by the EPA's National Emissions Inventory (EPA, 2016k, 2016l). Emissions inventory data are compiled and submitted by the TCEQ from annual emissions inventory questionnaires, mobile and area source emissions programs, and technical data (TCEQ, 2017c). The 2014 National Emissions Inventory contains the most recent available data and compiles emissions from point source, area, highway, and off-highway sources. The table is categorized by the county and criteria pollutants.

According to the TCEQ, Galveston, Harris, Chambers, Fort Bend, Liberty, Montgomery, Waller, and Brazoria counties are currently categorized as "moderate" nonattainment area under the 2008 8-hour O_3 NAAQS (TCEQ, 2018a). The air quality in the region around Galveston Bay (Galveston, Harris, Brazoria, and Chambers) is currently categorized as "attainment" for all other criteria pollutants: Pb, CO, NO_2, SO_2, and $PM_{2.5}$ and PM_{10}. There are currently 13 air monitoring stations managed by the TCEQ used to monitor for air quality around the coastal storm risk management (CSRM) project area (TCEQ, 2017d). Monitoring stations are located around industrial facilities and large population centers. There is one air quality monitoring station located on Galveston Island, seven monitoring stations located around Texas City, one monitoring station located on Smith Point, two monitors near Seabrook, and three monitoring stations located near La Porte-Baytown.

Table 2-14
Summary of Air Emissions Inventory for Counties Along the Texas Coast, 2014

County	CO (tpy)	NO_X (tpy)	PM_{10} (tpy)	$PM_{2.5}$ (tpy)	SO_2 (tpy)	VOC (tpy)
Orange	15,697	10,903	1,087	974	4,436	6,978
Jefferson	28,936	19,643	3,016	2,641	13,754	16,975
Chambers	10,384	4,746	661	564	272	5,907
Harris	383,358	85,027	15,650	12,185	11,673	67,582
Galveston	28,403	14,898	2,192	1,901	2,721	8,788
Brazoria	30,574	12,695	2,856	2,466	819	10,522
Matagorda	9,494	3,554	620	513	63	4,575
Jackson	3,432	2,086	155	130	37	2,436
Victoria	12,225	6,065	597	488	109	3,208
Calhoun	8,615	7,116	780	667	491	3,980
Aransas	6,385	2,822	144	125	79	2,681
Refugio	2,253	1,605	89	78	8	3,957
San Patricio	9,704	5,982	543	451	137	4,744
Nueces	34,129	14,146	2,468	2,111	1,042	12,806
Kleberg	3,680	1,386	134	119	17	2,792
Kenedy	1,518	1,728	37	32	8	1,297
Willacy	2,264	981	82	71	5	1,190
Cameron	32,065	6,109	684	527	125	5,193

Source: EPA (2016k, 2016l).
tpy = tons per year

Jefferson and Orange counties monitors have shown decreases in O_3 levels and are currently in attainment. Victoria County is in special inventory and currently meets Federal standards for O_3 and all other NAAQS and is designated attainment by the TCEQ (2016k). Nueces County is currently meeting Federal standards for all NAAQS and is in attainment. Cameron County is currently meeting Federal standards for O_3 and all other NAAQS and is in attainment (TCEQ, 2016k).

2.3.10.4 Greenhouse Gas Emissions

Greenhouse gases (GHG) include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3) (EPA, 2017c). The combustion of fossil fuels from the operation of electric generating power plants, transportation vehicles, industrial and residential sources, and agriculture has resulted in an increase in GHG emissions (EPA, 2017d).

2.3.11 Noise

The Noise Control Act of 1972 (42 USC §4901) initiated a program to regulate noise pollution to promote for all Americans an environment free from noise that jeopardizes their health and welfare. The primary responsibility for control of noise rests with State and local governments. The State of Texas recognizes noise as potentially harmful and has given municipalities the freedom to enact laws on a case-by-case basis.

Noise is defined as unwanted sound that disrupts or interferes with normal activities or that diminishes the quality of the environment. Noise is usually caused by human activity and is added to the natural or ambient, acoustic setting of an area. The effects of noise can range from annoyance to adverse physiological responses, including permanent or temporary loss of hearing, and other types of disturbance to humans and animals. Noise is publicly significant because of the public's concern for the potential annoyance and adverse effects of noise on humans and wildlife.

Human reaction to loudness, or sound pressure, is measured in terms of sound pressure levels and expressed in terms of decibels (dB). Decibels are measured on a logarithmic scale in order to compress the wide range between the lower threshold of human hearing and the loudness at which pain occurs. A sound level of 0 dB is approximately the threshold of human hearing and is barely audible under extremely quiet listening conditions. Normal speech has a sound level of approximately 60 dB. Sound levels of approximately 120 dB begin to be felt inside the ear as discomfort and increases to pain at higher levels (EPA, 1976). Sounds of the same pressure but different frequencies are not perceived by the human ear as equally loud. The human ear is less sensitive to low and extremely high frequencies and most sensitive to the mid-range frequencies that correspond with human speech. Therefore, to measure sound in a manner similar to human perception, an adjustment known as "A-weighting" is used. Regulatory agencies involved in assessing community noise or establishing noise standards typically require that measurements and analysis be performed using the A-weighted sound level (dBA). Common sound/noise levels that an individual may encounter daily are listed in Table 2-15.

Table 2-15
Common Sound/Noise Levels

Outdoor	dBA	Indoor
Air Horn	110	Rock/Blues Band
Jet Flyover at 1,000 feet		Baby Crying
Leaf Blower	100	Subway
Gas Weed Eater		Fire Alarms
Riding Lawn Mower	90	Blender
Gas Edger		Crowded Restaurant
Police Whistle	80	Disposal at 3 feet
Air Conditioner Compressor		Shouting at 3 feet
	70	
		Normal Conversation at 3 feet
Normal Conversation at 3 feet	60	Clothes Dryer at 3 feet
Babbling Brook		Large Business Office
Quiet Urban (daytime)	50	Refrigerator
Quiet Urban (nighttime)	40	Quiet Office/Library
Wilderness	30	
	20	Recording Studio
	10	Threshold of Hearing

Source: TxDOT (2011).

Although A-weighted sound measurements indicate the level of noise at a given moment, community noise levels vary constantly over a period of time. Many descriptors have been developed to evaluate the effects of noise on the human environment over time, but the two most commonly used descriptors are the equivalent noise level (L_{eq}) and the day-night noise level (L_{dn}). Both the L_{eq} and L_{dn} are single number indicators that describe the average noise level over a specified time period. L_{eq} provides a way to describe the average sound level in decibels for any given time period under consideration. L_{dn} is the 24-hour average sound level obtained after the addition of a 10-dB penalty for sound levels that occur during nighttime hours (10:00 p.m. to 7:00 a.m.) in order to account for heightened sensitivity to noise during that period. L_{dn} is the community noise metric recommended by the EPA and has been adopted by most Federal agencies. A L_{dn} of 65 dBA is the level most commonly used for noise planning purposes and represents a compromise between community impact and the need for activities like construction. Many Federal agencies, including the EPA, Department of Defense, and Department of Housing and Urban Development, have adopted this descriptor in assessing environmental impacts. Studies indicate that outdoor noise environments across the United States range from approximately 40 L_{dn} in rural residential areas, to nearly 60 L_{dn} in older urban residential areas, to as much as 90 L_{dn} in congested urban settings (EPA, 1974).

Sound pressure levels of two separate sources are not directly additive. Therefore, as shown in Table 2-16, if a sound of 60 dBA is added to another sound of 60 dBA, the resulting noise level is 63 dBA, not 120 dBA. For example, if the noise level of a riding lawnmower is measured at 90 dBA at 10 feet and the noise level of a gas weed eater is measured at 85 dBA at 10 feet, the combined noise level of both would be approximately 91 dBA at 10 feet.

Table 2-16
Decibel Addition[1]

Difference Between Two Sources	Example	Add to the Higher Level	Resultant Sound Level[2]
0 dB	60 and 60 dB	3 dB	63 dB
1 dB	60 and 61 dB	3 dB	64 dB
2 dB	60 and 62 dB	2 dB	64 dB
3 dB	60 and 63 dB	2 dB	65 dB
4–9 dB	60 and 65 dB	1 dB	66 dB
10 or more	60 and 70 dB	0 dB	70 dB

Source: TxDOT (2011).

[1] Only represents approximations of the logarithmic function of decibel addition.

[2] Accurate within 1 dB.

There are many different sources of noise that contribute to the ambient noise environment throughout the study area. Waterborne transportation activities that contribute to the ambient noise environment include ship traffic, barges, commercial fishing/shrimping vessels, sport and recreation boats, and dredging vessels. Other forms of transportation that contribute to the ambient noise environment include automobiles, trucks, recreational vehicles, and airplanes. Noise sources related to recreation and commercial enterprises include public beaches, restaurants and nightclubs, retail stores, marinas, and hotels. Multiple types of industry also contribute to the existing noise

environment including heavy industry such as petroleum refineries, light industry such as manufacturers of consumer electronics and clothing, and port activities like importing and exporting cargo.

Noise-sensitive receptors are facilities or areas where excessive noise may disrupt normal human or wildlife activities, cause annoyance, or loss of business. Land uses such as residential, religious, educational, passive recreational, and medical facilities are more sensitive to increased noise levels than are commercial and industrial land uses. Common examples of noise-sensitive receptors in the study area include residential communities, schools, motels and hotels, parks and other outdoor recreation areas, and coastal wildlife areas such as habitat for colonial nesting birds.

2.4 ECOLOGICAL AND BIOLOGICAL RESOURCES

2.4.1 Ecoregions

The study area is located entirely within the Western Gulf coastal plain, which is a low-elevation area adjacent to the Gulf (EPA, 2011). Due to its nutrient-rich soils and abundance of rain, much of the land has been converted to cropland and pastures for livestock. About a third of the State's population resides within 100 miles of the coast along with a large part of the State's industry. The large expanses of intact wetlands and coastal marshes along the coast are also important rest stops and wintering habitats for waterfowl and migrating birds. The warm Gulf waters are home to a variety of fish and shellfish, while the marshes and wetlands provide an abundance of habitat for birds and migrating waterfowl (Griffith et al., 2007).

The Western Gulf coastal plain can be categorized further into nine distinct level IV ecoregions (Griffith et al., 2007). These ecoregions are divided based on similarities of soils, vegetation, climate, geology, wildlife, and human factors and include the following.

Texas-Louisiana Coastal Marshes. This ecoregion contains vast, flat tracts of freshwater and saltwater coastal marshes with many rivers, lakes, bayous, and tidal channels. This part of Texas receives the most annual precipitation, 48 to 54 inches per year, and remains humid year-round. The land below is rich in oil and gas reserves. The coast lacks the barrier islands found farther south along the Texas coast. Cordgrass (*Spartina spartinae*, *S. alternaflora*, and *S. patens*) is the dominant vegetation type. Coastal protected lands such as the Anahuac, McFaddin, and Moody NWRs provide habitat for wintering waterfowl, American alligators (*Alligator mississippiensis*), and migrating bird species (Griffith et al., 2007). The coastal marshes are also an important commercial fishery for brown shrimp, blue crab, eastern oyster, and red drum.

Northern Humid Gulf Coastal Prairies. The gently sloping land was once dominated by coastal grassland prairies of little bluestem (*Schizachyrium scoparium*), yellow Indiangrass (*Sorghastrum nutans*), and switchgrass (*Panicum virgatum*). Today most of the native tallgrass coastal prairies have been converted to croplands, livestock pastures, urban, and industrial land. The relatively flat topography and clay subsoils, with an abundance of rain (37 to 58 inches annually), retain moisture and keep the area wet for most of the year. Rice, soybean, cotton, hay, and corn production are the main agricultural commodities within the region using supplemental upstream water provided by canals and irrigation ditches. The conversion of prairie to pasturelands and industrial

trade has brought along a string of invasive species such as red imported fire ants (*Solenopsis invicta*), Chinese tallow (*Triadica sebifera*), Macartney rose (*Rosa bracteata*), and King Ranch bluestem (*Bothriochloa ischaemum*) resulting in detrimental effects to native prairie species like the Attwater's prairie chicken (*Tympanuchus cupido attwateri*). Oak mottes and woodlots still exist in a lesser capacity (Griffith et al., 2007). Throughout the year but peaking in the fall and winter, birds and waterfowl can be found utilizing the remaining coastal plains, croplands, and altered habitat to their wintering grounds on the Gulf coast or South America.

Mid Coast Barrier Islands and Coastal Marshes. Stretching from Galveston Bay to Corpus Christi Bay, this ecoregion generally receives less annual precipitation than the Texas-Louisiana marshes. This region is characterized by barrier islands, tidal marshes, dunes, and salt/brackish/freshwater marshes. Cordgrass, saltgrass, and sedges (*Cyperaceae* spp.) are typically found in the marsh habitats, while seacoast bluestem (*Schizachyrium scoparium*) and sea oats are found on sandy barrier islands. During the fall, endangered whooping cranes (*Grus americana*) migrate to the brackish marshes of Aransas NWR to feed on blue crabs (Griffith et al., 2007). Commercial and sport fishing is also popular along the coast.

Floodplains and Low Terraces. This ecoregion consists of Holocene floodplains and alluvial deposits. Bottomland forests are the dominant vegetation type in this region consisting of pecan (*Carya illinoinensis*), live oak (*Quercus virginiana*), elm (*Ulmus* spp.), hackberry (*Celtis occidentalis*), cottonwood (*Populus* spp.), and bald cypress (*Taxodium distichum*) along streams. Large swaths of these floodplain woodlands have been converted to cropland, pastures, and forests. Freshwater flows through these historic floodplains have also been redirected for municipal, industrial, and agricultural uses. Combined with recent droughts in Texas and the Southwest, the Nueces, Brazos, Colorado, and other rivers have experienced greatly diminished flows, which affect the salinity and productivity of downstream estuaries and bays (Griffith et al., 2007).

Southern Subhumid Gulf Coastal Prairies. Generally drier than the northern humid Gulf Coastal Prairie, this region only receives about 26 to 37 inches of rain annually. The regional soil temperature is hyperthermic meaning it stays above 71.6°F. Decades of fire suppression, overgrazing, and other disturbances have led to an increased abundance of woody and thorny-scrub plants such as honey mesquite (*Prosopis glandulosa*), huisache (*Acacia farnesiana*), blackbrush (*Vachellia rigidula*), and granjeno (*Celtis pallida*). Prairie grassland species such as little bluestem, Gulf muhly (*Muhlenbergia capillaris*), and switchgrass (*Panicum virgatum*) can still be found but in less abundance than described in historical records (Griffith et al., 2007).

Coastal Sand Plains. These sandy plains were formed from Holocene-era sand dune deposits blown inshore by Gulf winds. The co-dominant habitat types are mesquite-live oak-prickly pear savannahs and tall coastal grasslands with bluestem and switchgrass. Most of the area is used for cattle grazing, which can lead to land degradation and erosion. The land is semiarid, receiving on average 24 to 27 inches of rain per year. As dry as it may seem, seasonal tropical storms can provide enough moisture to sustain sizable wetland ecosystems in sandy depressions and swales. Saline wetlands are found closer to the coast and contain Gulf cordgrass (*Spartina spartinae*) and seashore saltgrass (*Distichlis spicata*) (Griffith et al., 2007). These are productive habitats that support a variety of nesting birds and waterfowl. Private landholdings, like the King Ranch, are used for hunting, raising livestock, agriculture, bird watching, and wildlife tourism.

Lower Rio Grande Valley. This ecoregion was once an expanse of native grassland and woodland habitat but now much of this region has been converted into cropland, pasture, and urban landscapes. Decades of livestock management have led to the invasion of mesquite (*Prosopis* spp.), granjeno, and other species of scrub brush and soil erosion. The 320 days of freeze-free temperatures and a network of drainage canals and irrigation ditches make the area ideal for growing grains, vegetables, melons, sugar cane, and a variety of citrus plants. The agricultural fields also provide nesting habitat and forage for game species such as mourning dove (*Zenaida macroura*), white-winged dove (*Zenaida asiatica*), white-tailed deer (*Odocoileus virginianus),* and white-fronted goose (*Anser albifrons*) (Griffith et al., 2007).

Lower Rio Grande Alluvial Floodplain. The lower portions of the Rio Grande were historically dominated by Texas palmetto (*Sabal mexicana*) and floodplain forests. Much of these plains have been converted to cropland and urban areas. Some of the major agricultural crops in the Lower Rio Grande region include cotton, citrus, sorghum, sugar cane, vegetables, and melons. Water diversion, crop irrigation, and human activity have led to water scarcity and an increase in river salinity. The Rio Grande and other bodies of water in Texas have been victims to invasive plant species such as hydrilla (*Hydrilla verticillata*) and water hyacinths (*Eichhornia crassip*es). Unchecked, these plants grow rapidly, often depleting dissolved oxygen levels and clogging waterbodies. Despite these issues, the Lower Rio Grande Valley remains a biological hot spot for wildlife. The Laguna Atascosa NWR provides a haven for many rare species at the northernmost extent of their range such as ocelots (*Leopardus pardalis*), Gulf coast jaguarundis (*Herpailurus yagouaroundi cacomistles*), and Texas indigo snakes (*Drymarchon corais*). The southern tip of Texas acts as a converging point for both the Central and Mississippi migratory bird flyways, and as many as 500 different bird species have been documented along the Lower Rio Grande Valley (Griffith et al., 2007).

Laguna Madre Barrier Island and Coastal Marshes. Adjacent to the Gulf, this ecoregion is categorized by tidal mud flats, barrier island, seagrass meadows, and hypersaline lagoons. Seagrass meadows grow in the shallow, clear waters along the Laguna Madre. The seagrass beds serve as a productive nursery habitat for red drum, and grazing for sea turtles and redhead ducks (*Aythya americana*). Padre Island is the longest barrier island in the world. Seacoast bluestem, sea oats, and other grassy vegetation can be found along the 113-mile-long island. Ponds and marshes are populated with cordgrass, cattails (*Typha* spp.), and bulrush. Sea turtles including the leatherback (*Dermochelys coriacea*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and Kemp's ridley (*Lepidochelys kempii*) are dependent on the sandy barrier islands for nesting habitat. The South Padre National Seashore protects most of the barrier island and is under the jurisdiction of the NPS. The park has documented 380 species of birds and 81 species of butterflies and moths (Griffith et al., 2007).

2.4.2 Wetlands

The Texas Gulf coast is highly complex and ecologically diverse, with obvious differences in geomorphology between the upper, mid, and lower coast. Within the upper Texas coast (Sabine Lake to the Galveston Bay system), wetland systems are like southwestern Louisiana marshes, where the elevational gradients are gradual, freshwater inflows are relatively higher, and salinity gradients are extended (with freshwater wetlands inland

transitioning into brackish and intermediate marsh, and the gradient ending in the tidal salt marshes within the bays) (Moulton et al., 1997).

The mid Texas coast (Galveston Bay system to Corpus Christi Bay) is also characterized by large bays and estuaries, with river inflows. Freshwater inflows in the mid Texas coast decrease from north to south, where more fresh water contributes to Galveston and Matagorda bays, and less freshwater inflow is experienced in Corpus Christi Bay. The fresh water to salt marsh gradient is typically reduced in the mid Texas coast relative to the upper Texas coast. Additionally, coastal prairie becomes more dominant, with less forested wetlands, as compared to the upper Texas coast (Moulton et al., 1997).

The lower Texas coast is characterized by the Upper and Lower Laguna Madre, which is one of the few hypersaline lagoons in the world. Wind-tidal flats, lower rainfall, low and flat elevation, the Rio Grande delta, and arid rangeland are also defining characteristics of the lower Texas coast (Tunnell and Judd, 2002).

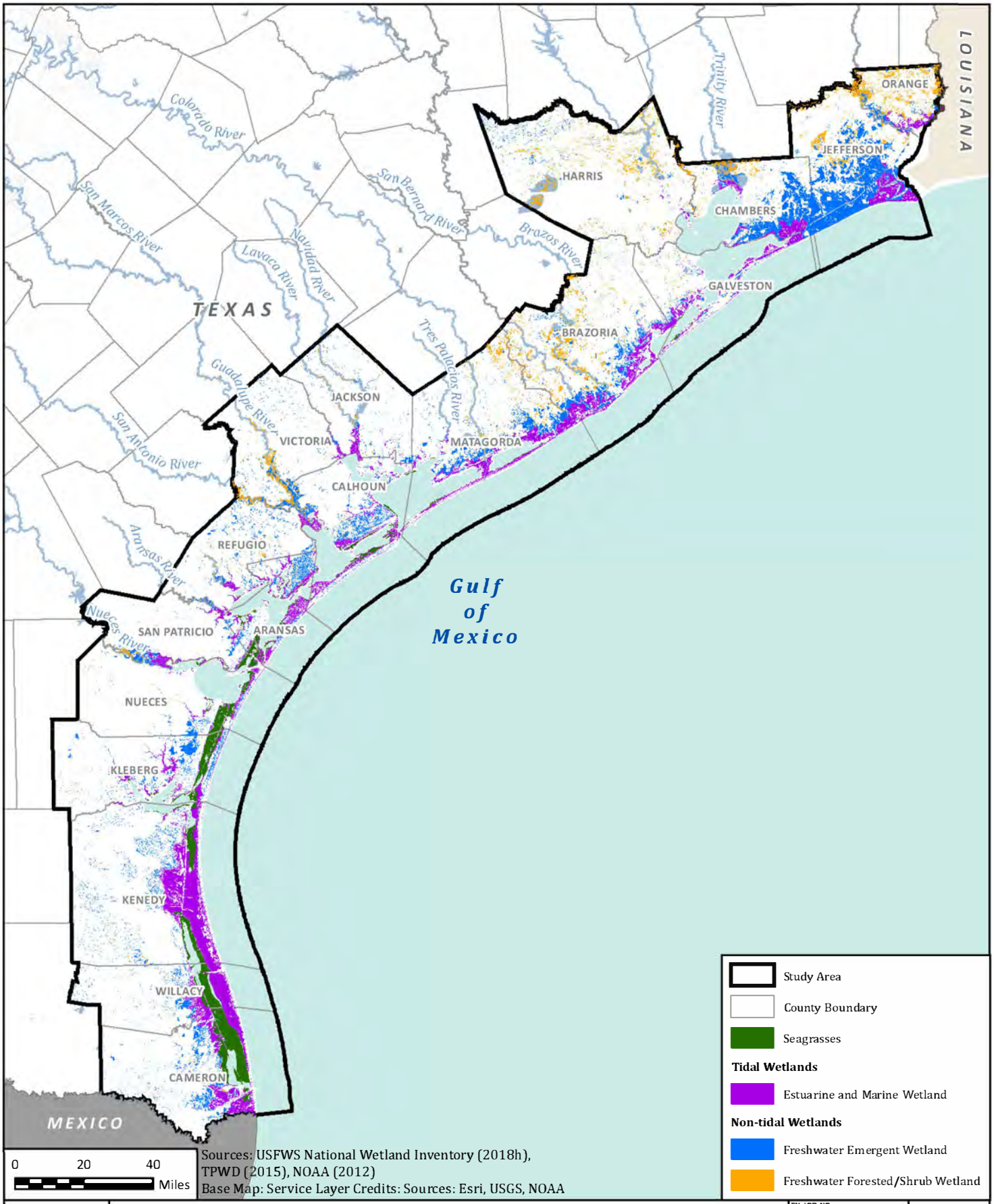
Wetlands within the study area encompass the full range of conditions exhibited in the upper, mid, and lower Texas coast, both tidal and non-tidal (Figure 2-11). Types of wetlands include:

- Non-tidal Wetlands (Freshwater)
  - Riverine Forested Wetlands
  - Prairie Potholes and Marshes
  - Texas Coastal Sand Sheet Wetlands
- Tidal Wetlands (Brackish, Intermediate, and Salt Marshes)
  - Estuarine or Tidal Fringe Wetlands
  - Barrier Island Interior Wetlands

2.4.2.1 Non-tidal Wetlands (Freshwater)

Riverine Forested Wetlands

Riverine forested wetlands are found on the floodplains of rivers and large streams. The main source of water for this habitat is from overtopped riverbanks and flooding. Within the upper Texas coast from east Houston to Louisiana, swamps are the wettest type of forested wetlands and are typically persistently inundated (Mitsch and Gosselink, 2007). The dominant vegetation is bald cypress, water tupelo (*Nyssa aquatica*), water hickory (*Carya aquatica*), planertree (*Planera aquatic*), and willow oak (*Q. phellos*). Yaupon (*Ilex vomitoria*), sugarberry (*Celtis laevigata*), dwarf palmetto (*Sabal minor*), and elm can be found in the understory. Bottomland hardwood forests are also part of this complex and are flooded less frequently than swamps. Bottomland hardwood forests are dominated by willow oak, water oak (*Q. nigari*), overcup oak (*Q. lyrata*), cherrybark oak (*Q. pagoda*), laurel oak (*Q. laurifolia*), green ash (*Fraxinus pennsylvanica*), red maple (*Acer rubrum*), black willow (*S. nigra*), water tupelo, and others. Understory vegetation often consists of dwarf palmetto, Cherokee sedge (*Carex cherokeensis*),



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Texas Coastal Wetlands

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NAD 1983 Texas Centric Mapping System Albers

deciduous holly (*Ilex decidua*), yaupon, and many others. On the mid coast, pecan hickory, elms, water oak, live oak, green ash, common hackberry (*Celtis occidentalis*), sugarberry, and sycamore (*Platanas occidentalis*) often dominate the forests; the understory is like that of the upper coast. Salamanders (Urodela), bald eagles (*Haliaeetus leucocephalus*), white-tailed deer, barred owls (*Strix varia*), American beavers (*Castor canadensis*), river otters (*Lutra canadensis*), swamp rabbits (*Sylvilagus aquaticus*), and bass and sunfishes (Centrarchidae) feed, nest, and roost in this habitat. Agriculture, timber harvesting, swamp draining, human development, and changes to hydrology have decreased forested wetlands. Forested wetlands are one of the most threatened ecosystem. Since the 1950s Texas has lost more than 96,000 acres (about 11 percent) (Texas A&M AgriLife Extension, 2017a).

Coastal flatwood wetlands are unique forested wetlands found between the Louisiana border and the Houston area. Longleaf and loblolly pines (*Pinus palustris* and *P. taeda*, respectively) and hardwood trees are commonly found within the drier parts of the wetland, while willow (*Salix* spp.), laurel oak, swamp chestnut oak (*Q. michauxii*), and dwarf palmetto are found in wetter areas. The soil is typically loamy with a claypan subsoil below 30 inches. Precipitation and run-off inundate the wetlands keeping soils wet during the winter and early spring and dry the rest of the year. Historically, these wet and upland areas experience regular fire to maintain pine dominance. The biggest threats to these wetlands are from the timber industry, which can overharvest pine trees and hardwoods (Texas A&M AgriLife Extension, 2017b).

The lower coast riparian wetlands are unique forested wetlands associated with riverine areas from the San Antonio River to southern Texas. These freshwater, depressional wetlands are maintained by river runoff and regular flooding events and provide habitat for belted kingfishers (*Megaceryle alcyon)*, rails (Rallidae), green treefrogs (*Hyla cinerea*), rare ocelots, and Gulf coast jaguarundis. Plants found within the riparian areas are common hackberry, retama (*Parkensonia accumulata*), huisache, Texas ebony (*Ebonopsis ebano*), and dwarf palmetto. The riparian corridors are threatened due to overgrazing, channel dredging, water diversion, damming of rivers upstream, and invasive plant species (Texas A&M AgriLife Extension, 2017c).

Prairie Potholes and Marshes

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 prairies were once wetlands. The difference between a pothole and a marsh is mainly size; marshes occur in larger and generally less-well-defined depressions than potholes. On the upper coast, potholes and marshes occur in complexes with pimple mounds (small hummocks 1 to 2 feet tall) and intermound flats. This complex pattern, formed thousands of years ago by ancient rivers and bayous, has been modified through time by climatic (especially wind) and biotic forces. Potholes and marshes maintain their hydrology through direct precipitation, runoff from adjacent flats, and occasionally local groundwater. Prairie potholes and pimple mounds provide habitat for a variety of wildlife and plants such as cattails, buttonbush (*Cephalanthus occidentalis*), black willow, water lilies (*Nymphaea* spp.), American alligator, American bullfrogs (*Rana catesbeiana*), ribbon snakes (*Thamnosis* spp.), wading birds, shorebirds, waterfowl, butterflies (Lepidoptera), and dragonflies (Odonata). During periods of drought, wildlife can be found concentrated around the potholes. Today urban sprawl and

agricultural fill threaten prairie potholes and marshes. Since the 1950s, more than 29 percent (235,000 acres) of freshwater marshes have been lost (Texas A&M AgriLife Extension, 2017d).

Texas Coastal Sand Sheet Wetlands

The coastal sand sheet that covers parts of Kleberg, Kenedy, and Willacy counties was formed from sand blown in from the Gulf coast and shaped by the wind. The topography of the area is generally flat but with rolling vegetated dunes, blowouts, and wetlands (Carr, 2007). Because of the dry climate, most of the water supplied to the wetlands is from groundwater percolating through the sandy soils. These wetlands support plant assemblages that reflect the range of salinity found in these depressions. The fresher wetlands have species like California bulrush (*Schoenoplectus californicus*), common three-square bulrush (*Scirpus pungens*), spikerushes (*Eleocharis* spp.), flatsedges (*Cyperus* spp.), cattails, white-topped sedge (*Rhyncospora coloratum*), paspalum grasses (*Paspalum* spp.), Gulf cordgrass, and other water-tolerant grasses. The more saline wetlands have more salt-tolerant species like shoregrass (*Distichlis littoralis*), saltgrass, sea oxeye daisy (*Borricchia frutescens*), Carolina wolfberry (*Lycium carolinensis*), seablight (*Sueda maritima*), and Gulf cordgrass. Most of the sand sheet region is used for livestock grazing and hunting. The sandy wetlands also support black-bellied whistling ducks (*Dendrocygna autumnalis*), mottled ducks (*Anas fulvigula*), least grebes (*Tachybaptus dominicus*), Virginia opossums (*Didelphis virginiana*), toads (Bufonidae), and livestock. Development and livestock overgrazing currently threaten the sand sheet wetlands (Texas A&M AgriLife Extension, 2017e).

2.4.2.2 Tidal Wetlands

Estuarine Wetlands

Estuarine wetlands are tidally influenced wetlands that occur throughout the Texas Gulf coast; however, estuarine wetlands are on a declining trend due to sea level rise, subsidence, and hydrological modifications (Mitsch and Gosselink, 2007; Moulton et al., 1997). Estuarine or tidal wetlands can range from being vegetated marshes, to unvegetated mud and barren sand flats found on the bay side of the coastal barrier islands (Texas A&M AgriLife Extension, 2017f). Estuarine emergent wetlands are mostly concentrated at the upper and mid Texas coast; estuarine shrub-scrub wetlands were most abundant in the mid Texas coast in Espiritu Santo Bay, south of Port O'Connor, and at the southern end of South Padre Island (Moulton et al., 1997). Estuarine unvegetated flats are more common around the lower Texas coast in the Lower Laguna Madre. Some of these tidal wetlands are subject to daily tidal ranges (i.e., low salt marsh), where others are only subject to tidal influence during high tides or storm events (i.e., high salt marsh); the upper and lower limits of the tidal range control the extent and location of estuarine wetlands. Freshwater inflows and sea water also maintain the salinity of the marsh and influence plant community composition (NOAA, 2017d). These wetlands can be a few feet wide where the intertidal range is thin due to shoreline geomorphology or can occupy large areas covering thousands of acres (Texas A&M AgriLife Extension, 2017f). Relative to the tidal range and salinity gradients transitioning from fresh to saline, marsh types include brackish and intermediate, which occur at tidal elevations between the mean high-water line and the annual high tide line, and salt marsh, which occur at tidal elevations between the mean tide line and the mean high tide line (NOAA, 2017d).

Brackish and intermediate marshes grade inland from salt marshes. The dominant species in brackish and intermediate marshes can include saltmarsh bulrush (*Scirpus robustus*) or bulrush (*Juncus* spp.); seashore saltgrass and saltmeadow cordgrass are co-dominant species. Brackish and intermediate marshes are subjected to periodic pulses of salt water, but saline influences are attenuated by high fresh water influences (Mitsch and Gosselink, 2007). Salinity ranges in brackish and intermediate marshes can be from 3 to 10 ppt (Louisiana Department of Wildlife and Fisheries, 2005). They dominate the interior marshes of the Sabine, Galveston Bay, and Matagorda Bay systems (USACE, 2015a). Brackish and intermediate marshes are generally more productive and diverse relative to salt marshes (Mitsch and Gosselink, 2007).

Salt marshes are located along the bay shorelines and higher salinity areas of the estuarine systems. Subjected to regular tidal inundation, low saline marsh is dominated by smooth cordgrass (*Spartina alterniflora*) and often accompanied by seashore saltgrass, blackrush (*Juncus romerianus*), saline marsh aster (*Aster tenuifolius*), and saltmeadow cordgrass (*S. patens*). The dominant species in high salt marsh, which is subject to less-frequent tidal inundation, is often glasswort (*Salicornia* spp.) and shoregrass (USACE, 2015a). Black mangrove (*Avicennia germinans*) is also becoming a more common salt marsh species along the Texas coast and can persist in both low and high salt marsh areas (Armitage et al., 2015).

Fringing the Laguna Madre are unique tidal wetland areas consisting of broad, nearly unvegetated wind-tidal flats. These wind-tidal flats are not regularly flooded by tides. They are only occasionally flooded when strong winds push shallow water from the Laguna onto the low flats, or during annual high tides. The cycle of irregular flooding and drying causes salt to build up on the surface of the flats (Tunnell and Judd, 2002). These wind-tidal flats are inhospitable to most vascular plants but are often covered by vast mats of blue-green algae. These habitats may look barren, but they support rich invertebrate populations that, in turn, attract large numbers of shorebirds and wading birds (Texas A&M AgriLife Extension, 2017f). They are considered a “Special Aquatic Site” under 40 CFR 230. The unique processes that result in wind-tidal formations only exist in several locations worldwide, including the Persian Sea, Red Sea, and eastern Mediterranean Sea (Morton and Holmes, 2009).

Barrier Island Interior Wetlands

The Texas barrier islands were created about 4,000 years ago from wave action and sediment deposition from rivers and creeks. Coastal winds and waves created ridges, troughs, and flats between sand dunes where water could collect. Padre Island is the longest undeveloped barrier island in the world. Island interior wetlands provide an important source of fresh water for species. Although these wetlands are primarily fresh water, storm events and extreme tides occasionally introduce salt into these barrier island wetlands. Wetland plants are similar to those found in other freshwater marshes but may include some brackish-water species due to elevated soil salinity and occasional tidal inundation in some areas. Typical species include saltmeadow cordgrass, cattails, bulrushes, coastal water-hyssop (*Bacopa monnieri*), pennywort (*Hydrocotyle* spp.), spikerushes, flatsedges, sedges (*Carex* spp.), burhead (*Echinodorus* spp.), marsh fimbry (*Fimbristylis castanea*), white-topped sedge, frogfruit (*Phyla nodiflora*), seashore paspalum (*Paspalum vaginatum*), bushy bluestem (*Andropogon glomeratus*), and other grasses. The availability of fresh water attracts species of frogs (Ranidae), turtles (Testudines), raccoons (*Procyon* sp.), feral pigs (*Sus scrofa*), waterfowl, wading birds, and shorebirds (Texas A&M AgriLife Extension, 2017g).

2.4.2.3 Seagrass

Seagrass can be found along the Texas Gulf coast between the coastal barrier islands and mainland. There is approximately 235,000 acres of seagrass in Texas (TPWD, 1999). Although seagrass occur throughout the entire coast, about 75 percent of seagrass occur within the Laguna Madre on the lower Texas coast (Handley et al., 2007). Shoalgrass (*Halodule wrightii*), turtlegrass (*Thalassia testudinum*), manateegrass (*Syringodium filiforme*), widgeongrass (*Ruppia maritima*), and clovergrass (*Halophilia engelmannii*) can all be found in shallow (generally <5 feet water depth depending on water clarity) Texas coastal water (TPWD, 1999). Although seagrasses are generally declining in most parts of the Texas coast, seagrass beds within the Upper Laguna Madre and Corpus Christi Bay have been generally expanding or are stable. For example, between the 1950s and 2002 to 2004 within the Texas Barrier Island Coastal Bend, seagrass beds increased in area at Harbor Island and North Padre Island by 70 percent and 78 percent, respectively (Moulton et al., 1997; Table 2-17).

Table 2-17
Seagrass Information for Bays Along the Texas Coast

Location	Seagrass (acres)	Trends
Sabine Lake System	minimal to none	–
Galveston Bay	519	decreasing
Matagorda Bay	2,716	decreasing
San Antonio Bay System	10,638	decreasing
Corpus Christi Bay	6,346	fluctuates with inflow, stable
Upper Laguna Madre	55,456	increase since 1950s
Lower Laguna Madre	114,095	decrease since 1950s

Source: Handley et al. (2007), TPWD (1999).

Seagrass plays an important part in stabilizing the seafloor substrate and nutrient accumulation. Seagrass communities are an important part of the ecosystem generating high primary productivity and acting as nurseries for recreational and commercial fisheries such as red drum, brown shrimp, and black drum and foraging habitat for manatees, sea turtles, herons, and egrets. Threats to seagrass meadows include natural disturbances such as hurricanes and strong currents, and human impacts such as dredging channels, propeller damage from boats, urbanization, and pollution runoff (Texas Statewide Seagrass Monitoring Program, 2015a, 2015b).

2.4.2.4 Wetland Trends

The estuarine gradients and freshwater inflows can vary in each coastal ecoregion, and these variables affect the type and extent of wetlands present. Similarly, seagrasses can vary across each coastal ecoregion. The Texas Gulf coast has generally been losing estuarine (saltwater) intertidal wetlands since wetlands were first mapped in the 1950s, although some gains have been observed near the San Bernard NWR region (Moulton et al., 1997; White et al., 2006). Losses of estuarine emergent wetlands (marshes) are due to subsidence, RSLR, ecological succession to estuarine intertidal scrub-shrub (mangrove) wetlands, and conversion to open water or upland. Losses approached approximately 1,600 acres per year from 1955 to 1992. Table 2-18 summarizes the changes in

estuarine intertidal wetlands, including emergent scrub-shrub and non-vegetated (tidal flats) from 1955 to 1992 (Moulton et al., 1997).

Table 2-18
Estuarine Intertidal Wetland Loss and Gain Trends on the Texas Gulf Coast

Year	Intertidal Emergent (approximate acres)	Intertidal Scrub-Shrub (approximate acres)	Intertidal Non-Vegetated (approximate acres)
1955	387,211	2,563	236,414
1992	355,632	4,966	205,972
Net Change	–31,579	+2,403	–30,442
Average Loss or Gain per Year	–853	+65	–823

Source: Moulton et al. (1997).

White et al. (2006) provides additional information that also indicates regional differences in wetland trends from the 1950s to 2002. General wetland trends data by region include:

- Approximately 30 percent loss of estuarine marsh within the Brazos River Delta region;
- Approximately 27 percent increase of estuarine marsh within the San Bernard NWR region;
- Approximately 31 percent loss of estuarine marsh within the Caney Creek area; and
- Slight increase in estuarine marsh within the Laguna Madre system.

2.4.3 Aquatic Resources

2.4.3.1 Freshwater Habitats and Fauna

Some freshwater fish species use estuarine systems, particularly when salinities are less than 5 ppt. Conversely some estuarine and marine fish live in freshwater systems. Because many estuaries extend miles upstream into tidal rivers there can be overlap between freshwater and estuarine nekton (fish and swimming invertebrates) communities.

Sampling nekton communities of 16 tidal streams from the Sabine River Basin south to the Nueces River tidal indicated salinity is the parameter with the greatest effect on nekton in tidal streams (Tolan, 2008). Over 105 species of nekton were sampled with seines and otter trawls. Species typically found in these tidal streams included bay anchovy (*Anchoa mitchelli*), western mosquitofish (*Gambusia affinis*), Gulf menhaden (*Brevoortia patronus*), white shrimp (*Litopenaeus setiferus*), grass shrimp (*Palaemonetes* sp.), silversides (*Menidia* sp.), blue catfish (*Ictalurus furcatus*), Atlantic croaker, and blue crab. Blue catfish tend to inhabit larger rivers and can be found in estuaries with salinities up to 15 ppt (Hendrickson and Cohen, 2015).

Recreational freshwater fish species commonly found in brackish waters of estuaries include largemouth bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), and crappie (*Pomoxis* spp.). A few species considered to be freshwater fish, gizzard shad (*Dorosoma cepedianum*) and alligator gar (*Atractosteus spatula*),

live in streams with salinities of 0 ppt and can be common in estuaries where salinities exceed 30 ppt (Hendrickson and Cohen, 2015). Some marine species, striped mullet (*Mugil cephalus*), hogchokers (*Trinectes maculatus*), skipjack herring (*Alosa chrysochloris*), and Atlantic needlefish (*Strongylura marina*), move over 100 river miles upstream in rivers connected to the coast (pers. comm. David Buzan, 2017).

Other species migrate from fresh water into or through the estuary to spawn. American eels (*Anguilla rostrata*) leave estuaries and freshwater systems hundreds of miles from the coast after decades of maturing in fresh water to spawn in the Atlantic Ocean (Hendrickson and Cohen, 2015). Larval American eels migrate through the Atlantic to enter estuaries and rivers in Texas. Freshwater prawns, *Macrobrachium*, also migrate downstream to spawn in estuaries with young prawns swimming back upstream for tens to hundreds of miles (Reimer et al., 1974).

2.4.3.2 Estuarine Habitats and Fauna

Seven major estuaries occur along the Texas coast: Sabine-Neches (Sabine Lake), Trinity-San Jacinto (Galveston Bay), Colorado-Lavaca (Matagorda Bay), Guadalupe (San Antonio Bay), Mission-Aransas (Aransas Bay), Nueces (Corpus Christi Bay), and Laguna Madre (Upper Laguna Madre, Baffin Bay, Lower Laguna Madre). These systems form an intricate assemblage of interacting habitats that are greatly influenced by the Gulf and have a total water surface area of 2,408 square miles (Armstrong et al., 1987). They provide important nursery habitat for numerous commercially and recreationally important estuarine-dependent fish and shellfish species and for marine mammals, reptiles, resident birds, wintering waterfowl, shorebirds, and other avian species (Armstrong et al., 1987; Britton and Morton, 1989; Tunnell and Judd, 2002). The following sections describe the dominate types of estuarine habitat present within the Coastal Texas Study area.

2.4.3.2.1 Open Bay

The open bay comprises of phytoplankton and nekton. Phytoplankton (microscopic algae) are the major primary producers (plant life) in the open bay, taking up carbon through photosynthesis and nutrients for growth. Phytoplankton are fed upon by zooplankton (small crustaceans), fish, and benthic consumers. Nekton assemblages (organisms that swim freely in the water column) consist mainly of secondary consumers, which feed on zooplankton and smaller nekton (Armstrong et al., 1987; Britton and Morton, 1989). Diverse and abundant phytoplankton and nekton communities occur throughout the entire study area and are discussed below.

Plankton Assemblages

Sabine Lake. Phytoplankton in Sabine Lake comprise primarily both freshwater and marine diatoms and green algae. Species composition changes seasonally with minimum abundance occurring in the winter and maximum in the summer. Zooplankton are most abundant during the summer and early fall, coinciding with higher salinities. The dominant species is the copepod *Acartia tonsa*, with several other marine copepods also present. Commensurate with higher salinities, the higher numbers are found in the lowest reaches of the estuary. Freshwater species, including rotifers and cladocerans, are the dominant taxa near the mouth of the rivers.

Abundance of zooplankton is lowest in the winter and spring and highest in the summer and fall, which is the opposite in other estuaries (with the exception of Galveston Bay) (Armstrong et al., 1987).

Galveston Bay. Galveston Bay has the highest primary productivity of all Texas bays (Armstrong et al., 1987). Phytoplankton, including diatoms, green algae, blue-green algae, dinoflagellates, euglenoids, cryptophytes, and golden-brown algae are the primary producers of the open bay. They take up carbon by photosynthesis and pass it through the food chain to the primary consumers, zooplankton and phytoplanktivorous (plant-eating) fishes (Armstrong et al., 1987; Lester and Gonzalez, 2011; Sheridan et al., 1989). Zooplankton consists mainly of copepods, cladocerans, chaetognaths, and larval stages of fish, shrimp, and crabs. They are important because they are the basis of the food chain and are the source of food for all larval and juvenile fish. Zooplankton are limited by turbidity (which limits the phytoplankton production and therefore food availability) and currents that can carry them out to sea and away from concentrated food masses. It appears that zooplankton production in Galveston Bay is also directly related to water temperature and inversely related to salinity (Armstrong et al., 1987).

Matagorda Bay Area. In Lavaca Bay, phytoplankton species composition changes seasonally with maximum abundance occurring in the winter and minimum in the summer, dominated by diatoms. Zooplankton are most abundant during the spring, with the minimum occurring in the fall. The dominant species are the copepod *Acartia tonsa* and barnacle nauplii. They are important because they are important food for larval and juvenile fish. Zooplankton are limited by turbidity (which limits the phytoplankton production and therefore food availability) and currents, which can carry them out to sea and away from concentrated food masses (Armstrong et al., 1987). It is expected that plankton assemblages in Matagorda Bay would be similar to those of Lavaca Bay.

Corpus Christi Bay Area and Upper Laguna Madre. In Aransas Bay, diatoms make up the majority of phytoplankton assemblages composed mainly of *Coscinodiscus* spp. in the winter and *Rhizosolenia alata* in the summer. Blue-green and green algae dominate the upper portions of the Mission-Aransas Estuary, whereas diatoms dominate the lower. Diatoms (*Thalassionema nitzschioides*, *Thalassiothrix frauenfeldii*, and *Chaetoceros* spp.) make up over 70 percent of the phytoplankton community in Corpus Christi Bay. In Nueces Bay and the Upper Laguna Madre, the same diatoms dominate abundance, especially during the winter months, followed by the dinoflagellate *Ceratium furca* (Tunnell et al., 1996). Areas of the Upper Laguna Madre, where salinities exceeded 60 ppt, had few to no plankton present (Armstrong et al., 1987).

Lower Laguna Madre. Due to the lack of freshwater inflow and the resulting high salinities, the Lower Laguna Madre is relatively phytoplankton free. Diatoms dominate phytoplankton collections in the Lower Laguna Madre with highest densities at stations with lower salinities and lowest densities at stations with salinities above 30 ppt (Armstrong et al., 1987; Tunnell and Judd, 2002). In the Bahia Grande, dominant plankton assemblages consist of green algae, such as diatoms and cyanobacteria, which are highest in the winter and spring (Hicks et al., 2010). Red algae and floating *Sargassum* are also common in the Lower Laguna Madre (Tunnell and Judd, 2002).

Nekton Assemblages

Texas bay systems support a diverse nekton population including fish, shrimp, and crabs. Some of these are resident species, spending their entire life in the bay, whereas others are migrant species spending only a portion of their life cycle in the estuary (Armstrong et al., 1987). Many of these species are estuarine dependent, migrating through passes of the Gulf to use the submerged aquatic vegetation (SAV) of the estuarine systems in the bay system as nursery habitat (Tunnell and Judd, 2002). With respect to the Upper and Lower Laguna Madre, the hypersaline waters can affect fish osmotic balance and decrease dissolved oxygen; however, fish occupying these areas are euryhaline (able to tolerate a wide range of salinities) and better able to cope with the harsh conditions (Gunter, 1967).

Dominant nekton species inhabiting Texas estuaries include blue crab, white shrimp, brown shrimp, pink shrimp (*Farfantepenaeus duorarum*), Atlantic croaker, bay anchovy, code goby (*Gobiosoma robustum*), black drum, Gulf menhaden, hardhead catfish, pinfish (*Lagodon rhomboides*), sheepshead (*Archosargus probatocephalus*), silversides, southern flounder (*Paralichthys lethostigma*), spot (*Leiostomus xanthurus*), and spotted seatrout (Nelson et al., 1992; Pattillo et al., 1997). These species are ubiquitous along the Texas coast and are unaffected by salinity changes. Seasonal differences occur in abundance, with the fall usually the lowest in biomass and number. Newly spawned fish and shellfish begin migrating into the bays in winter and early spring with the maximum biomass during the summer (Parker, 1965).

2.4.3.2.2 Open-Bay Bottom

The open-bay bottoms in Texas bay systems include all unvegetated subtidal areas with various sediment types. They are open systems that greatly interact with the overlying waters and adjacent habitats (Armstrong et al., 1987; Tunnell and Judd, 2002). Benthic organisms are divided into two groups: epifauna, such as crabs and smaller crustaceans that live on the surface of substrate, and infauna, such as mollusks and polychaetes that burrow into the substrate (Green et al., 1992). Mollusks and other infaunal organisms are filter feeders that strain suspended particles from the water column. Other infauna, such as polychaetes, feed by ingesting sediments and extracting nutrients. Many of the epifauna and infauna feed on plankton, which are fed upon by numerous fish and birds (Armstrong et al., 1987; Lester and Gonzales, 2011).

The Beaumont-Port Arthur area bay system includes Sabine Lake. Mud and sandy mud are the dominant sediment types in the system. Generally, muds occupy the slightly deeper eastern half of Sabine Lake, whole sandier sediments occur in the western half. Benthic macroinvertebrates found in these sediments are primarily polychaetes, bivalves, gastropods, and crustaceans (White et al., 1987).

The Galveston-Houston area bay system includes the Galveston, Trinity, East, and West bays. Mud and sandy mud are the dominant sediment types in this system, with sand at bay margins. Sandy sediments are associated with flood-tidal deltas at Bolivar Roads and San Luis Pass and with modern barrier islands. Benthic macroinvertebrates found in these sediments are primarily polychaetes, bivalves, gastropods, and crustaceans (White et al., 1985).

The Bay City-Freeport area bay system includes Matagorda, East Matagorda, and Tres Palacios bays. Mud and sandy mud are the dominant sediment types in this system, with sandier sediments occupying the bay margins of Matagorda Peninsula and locally along bay margins. Benthic macroinvertebrates found in these sediments are primarily polychaetes, bivalves, gastropods, and crustaceans (White et al., 1988).

The Port Lavaca area bay system includes Powderhorn Lake and Matagorda, Carancahua, Lavaca, Keller, Cox, Chocolate, Espiritu Santo, San Antonio, Hynes, Guadalupe, Mesquite, and Aransas bays. Mud and sandy mud are the dominant sediment types in this bay-estuary-lagoon system. Benthic macroinvertebrates found in these sediments are primarily polychaetes, bivalves, gastropods, and crustaceans (White et al., 1989a).

The Corpus Christi area bay system includes the Laguna Madre and Corpus Christi, Nueces, Oso, Redfish, Aransas, Copano, Port, and Mission bays. Mud is the dominant sediment type throughout this bay-estuary-lagoon system; however, sandier sediments occur along bay margins and are found in higher abundance in the Laguna Madre and Redfish Bay. Benthic macroinvertebrates found in the sediments of this bay-estuary-lagoon system are primarily pelecypods, gastropods, crustaceans, and polychaetes (White et al., 1983).

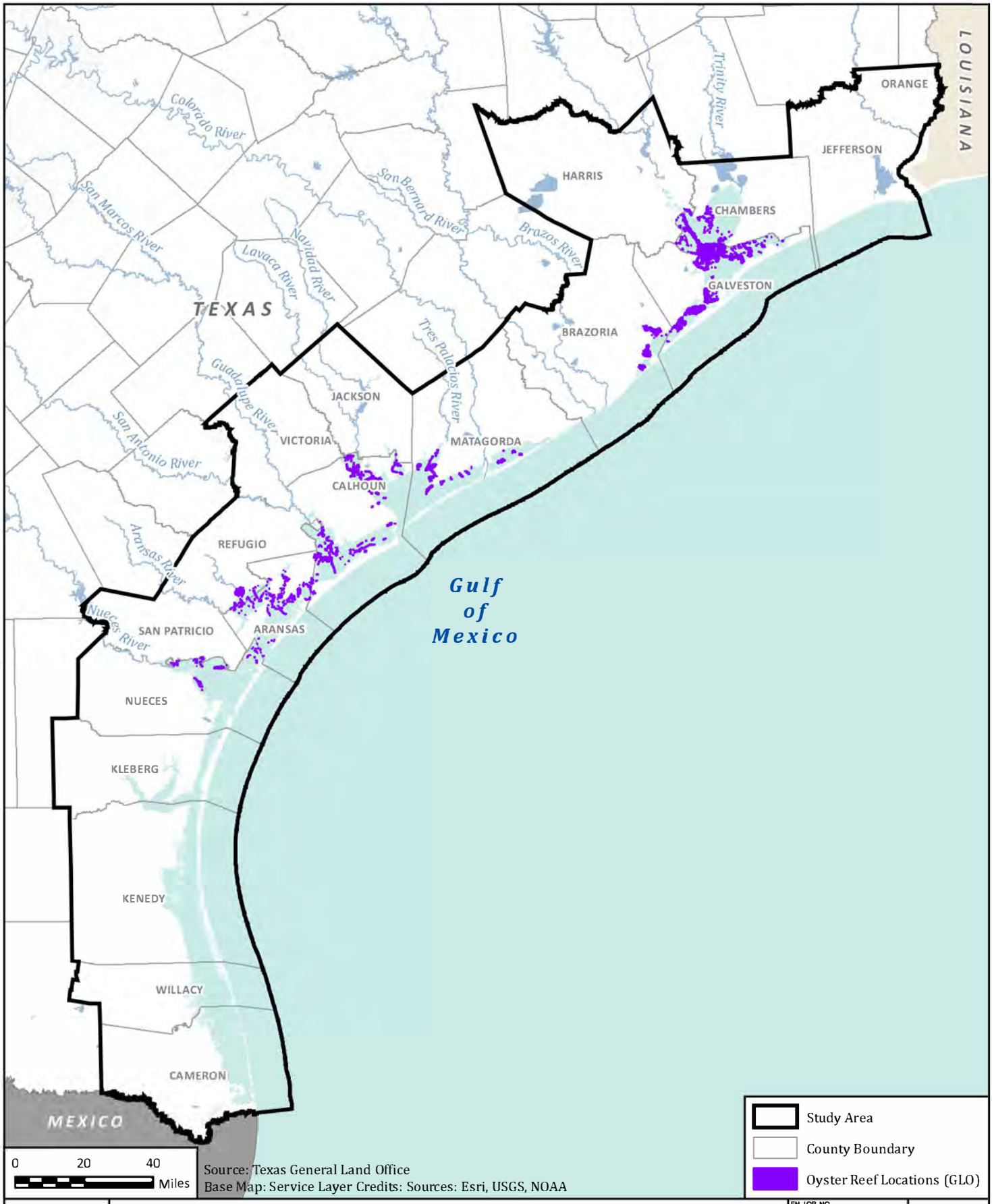
The Kingsville area bay system includes the Laguna Madre, Baffin Bay, and Alazan Bay. Mud, sand, and muddy sand are the dominant sediment types. Benthic macroinvertebrates found in the sediments of the bay-estuary-lagoon system are primarily polychaetes, bivalves, gastropods, and crustaceans (White et al., 1989b).

The Lower Laguna Madre and South Bay systems include flat areas of mud and sand that contribute large quantities of nutrients and food, making these substrates some of the most important components of this habitat type. The distribution of the benthic macroinvertebrates is primarily influenced by bathymetry and sediment type. Benthic macroinvertebrates found in the sediments of the Lower Laguna Madre are primarily polychaetes, bivalves, gastropods, and crustaceans (White et al., 1986).

2.4.3.2.3 Oyster Reef

Eastern oysters are present in all bay systems from Sabine Lake to Corpus Christi Bay, and South Bay and provide ecologically important functions (Figure 2-12). Few oysters are present in the Upper Laguna Madre, Baffin Bay, or Lower Laguna Madre. Oyster reefs are formed where a hard substrate and adequate currents are plentiful. Currents carry nutrients to the oysters and take away sediment and waste filtered by the oysters. Most oyster reefs are subtidal or intertidal and found near passes, cuts, and along the edges of marshes. Oysters can filter water 1,500 times their own volume per hour, which, in turn, influences water clarity and phytoplankton abundance (Lester and Gonzalez, 2011; Powell et al., 1992). Due to their lack of mobility and their tendency to bioaccumulate pollutants, oysters are an important indicator for detecting contamination (Lester and Gonzalez, 2011).

While oysters can survive in salinities ranging from 5 to over 40 ppt, they thrive from 10 to 25 ppt, which is the level where pathogens and predators are limited. The lower salinity is critical for osmotic balance. Oysters can survive brief periods of salinities less than 5 ppt by remaining tightly closed. Oysters will remain closed until



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Oyster Reef Locations

FN JOB NO	COH16388
FILE NAME	213EIS_Oyster_Reef.mxd
DATE	8/18/2017
SCALE	1:2,377,085
DESIGNED	SSJ
DRAFTED	SSJ

2-12

FIGURE

NAD 1983 Texas Centric Mapping System Albers

normal salinities return or until they deplete their internal reserves and perish. In contrast, oyster drills (*Thais haemastoma*), welks (Buccinidae), and crabs prey on oysters during long periods of high salinities. *Perkinsus marinus* (Dermo) is the most common and deadly oyster pathogen in the bays and is a primary factor affecting habitat suitability (Cake, 1983).

Many organisms, including mollusks, barnacles, crabs, gastropods, amphipods, polychaetes, and isopods, live on oyster reefs, forming a very diverse community (Sheridan et al., 1989). Oyster reef communities are dependent upon food from the open bay and marshes. Many organisms feed on oysters including black drum, crab, and gastropods, such as the oyster drill (Lester and Gonzales, 2011; Sheridan et al., 1989). When oyster reefs are exposed during low tides, shore birds will use the reef areas for resting (Armstrong et al., 1987).

In Texas, all molluscan shellfish must be harvested from areas that have been approved or conditionally approved as designated by the TDSHS (2016). This status is subject to change to prohibited or restricted by the TDSHS at any time due to extreme weather conditions, oil spills, and red tides. Currently, oysters are approved for harvesting from the following bay systems: Galveston, West Galveston, Freeport area, East Matagorda, Matagorda, Lavaca, San Antonio, Espiritu Santo, Copano, Aransas, Mesquite, Corpus Christi, Lower Laguna Madre, and South bays (TDSHS, 2016). However, the majority (over 90 percent) of oysters harvested commercially and recreationally come from the Galveston, Matagorda, and San Antonio bay systems (TPWD, 2016f).

The eastern oyster populations living in South Bay are genetically distinct from other oysters inhabiting the Texas coast and have adapted to the hypersaline conditions (Tunnell and Judd, 2002). This population is thought to be a remnant from when the Rio Grande flowed into the area (White et al., 1986).

Globally, an estimated 85 percent of oyster habitat has been lost with the remaining populations in poor condition, and in the last 100 years there has been an estimated 88 percent decline in oyster biomass in the United States (Baggett et al., 2014). Gulf oyster landings are the highest in the world; however, overall oyster biomass and abundance has suffered serious declines (Beck et al., 2011; Zu Ermgassen et al., 2012). This decline has been mainly due to overharvesting; however, other factors include coastal development and dredging causing habitat loss or degradation, diseases, sedimentation, and pollution (Baggett et al., 2014; Beck et al., 2011; Coen and Luckenbach, 2000). Galveston Bay is an example where historically oyster shell was commercially harvested as construction material to build roads. Oyster shells were removed from the bay, some of which were live, greatly reducing the oyster reef habitat area. This practice was prohibited in 1969 and oyster reefs have been increasing since. In response to the decline in oyster populations, restoration activities have increased to help prevent further loss of these habitats. Additionally, in 2008 Hurricane Ike covered 60 percent of oyster reef habitat in Galveston Bay as the storm surge moved through; it is still unknown how long it will take reefs to recover (Lester and Gonzales, 2011).

Table 2-19 shows the historic and current extent of oyster reefs in Texas bays. There has been a decline in oyster reef habitat in all bay systems, except for Sabine Lake which has increased, with Matagorda Bay having the greatest loss (Baggett et al., 2014).

Table 2-19
Historic and Current Oyster Reef in Texas

Location	Historic Reef (acres)	Current Reef (acres)	Difference (acres)
Sabine Lake*	640	1,186	546
Galveston Bay	31,987	26,664	–5,322
Matagorda Bay	41,197	5,506	–35,691
San Antonio Bay	6,397	5,313	–1,084
Corpus Christi Bay	8,316	716	–7,600
Laguna Madre (Upper and Lower, Baffin Bay)	1,919	168	–1,751

Source: Baggett et al. (2014).

* Includes Texas and Louisiana.

2.4.3.2.4 Offshore Sands

There are few seagrasses or attached algae found in the offshore sands due to the strong currents and unstable sediments. Most of the bottom surface is populated with macroinfauna such as an occasional hermit crab (Paguroidea), portunid crab (Portunidae), or ray (Batoidea). Even though there is little life on the sand surface itself, the overlying waters are highly productive. Phytoplankton are abundant, including microscopic diatoms, dinoflagellates, and other algae (Britton and Morton, 1989).

Much of the faunal diversity lies buried in the sand and relies on phytoplankton for food. Bivalves found in offshore sands include the blood ark (*Anadara ovalis*), incongruous ark (*Anadara brasiliana*), southern quahog (*Mercenaria campechiensis*), giant cockle (*Dinocardium robustum*), disk dosinia (*Dosinia discus*), pen shells (*Atrina serrata*), common egg cockle (*Laevicardium laevigatum*), cross-barred venus (*Chione cancellata*), tellins (*Tellina* spp.), and the tusk shell (*Dentalium texasianum*). The most common species occurring in the shallow offshore sands are the sand dollar (*Mellita quinquiesperforata*) and several species of brittle stars (*Hemipholis elongata*, *Ophiolepis elegans*, and *Ophiothrix angulata*). Many gastropods are common, including the moon snail (*Polinices duplicatus*), ear snail (*Sinum perspectivum*), Texas olive (*Oliva sayana*), Atlantic auger (*Terebra dislocata*), Salle's ager (*Terebra salleano*), scotch bonnet (*Phalium granulatum*), distorted triton (*Distorsio clathrata*), wentletraps (*Epitonium* sp.), and whelks (*Busycon* spp.). Crustaceans inhabit these waters including white and brown shrimp (both commercially sought species), rock shrimp (*Sicyonia brevirostris*), blue crabs, mole crabs (*Albunea* spp.), speckled crab (*Arenaeus cribrarius*), box crab (*Calappa sulcata*), calico crab (*Hepatus epheliticus*), and pea crab (*Pinotheres maculatus*). The most abundant infaunal organisms, with respect to the number of individuals, are the polychaetes (Capitellidae, Orbiniidae, Magelonidae, and Paraonidae) (Britton and Morton, 1989).

2.4.3.3 Commercial and Recreational Fisheries

The TPWD Rockport Marine Laboratory collects commercial and recreational fisheries data for the Texas coast. Ten years of data (2006 to 2015) for the commercial and recreational fisheries were obtained from Darin Topping

and Mark Fisher at the Rockport Marine Laboratory in October 2016. Species included in the commercial fisheries data are black drum, flounder, sheepshead, mullet, and other. Shellfish include blue crab, eastern oyster, brown and pink shrimp, white shrimp, and other. Species included in the recreational fisheries data are spotted seatrout, red drum, southern flounder, red snapper (*Lutjanus campechanus*), and king mackerel.

2.4.3.3.1 Commercial Fisheries

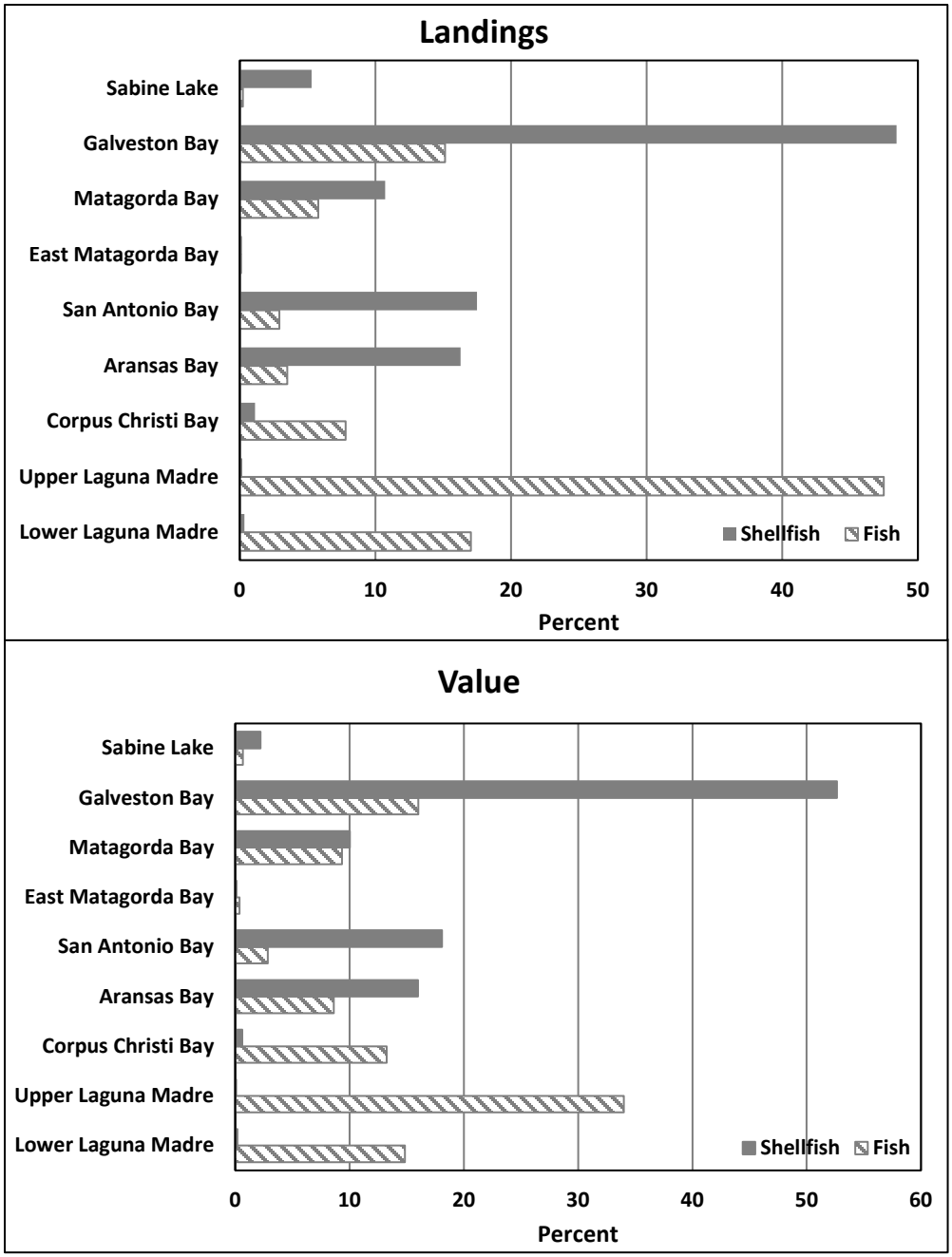
In Texas, commercial landings in the bays from 2006 to 2015 averaged 20.6 million pounds of fish with an average value of $28.0 million and 95.5 million pounds of shellfish with an average value of $232.4 million. Table 2-20 and Figure 2-13 show TPWD commercial landings and value (ex-vessel value) for all Texas bay systems from 2006 to 2015. The Upper Laguna Madre, Lower Laguna Madre, and Galveston Bay produce the highest commercial finfish harvest from all Texas bay systems, representing 47.5, 17.3, and 15.1 percent, respectively, of the total finfish landings, while East Matagorda Bay and Sabine Lake produce the least with 0.1 and 0.2 percent, respectively. The Upper Laguna Madre produced 9.7 million pounds with a value of $9.5 million. Black drum is the most commercially caught species in Corpus Christi Bay, Upper Laguna Madre, and Lower Laguna Madre, representing 44.6, 97.9, and 74.3 percent of the total catch. Mullet is the only other fish species collected in large numbers from the Lower Laguna Madre at 12.4 percent (pers. com. D. Topping [TPWD], 2016).

Table 2-20
Commercial Landings and Values by Texas Bay System, 2006 to 2015

	Fish		Shellfish		Total Combined	
Bay System	Pounds	Value	Pounds	Value	Pounds	Value
Sabine Lake	45,272	$188,038	5,064,516	$5,143,620	5,109,788	$5,331,658
Galveston Bay	3,106,632	$4,488,176	46,268,367	$122,359,116	49,374,999	$126,847,292
Matagorda Bay	1,188,943	$2,619,944	10,230,949	$23,301,144	11,419,892	$25,921,088
East Matagorda Bay	19,786	$104,550	154,525	$252,068	174,311	$356,618
San Antonio Bay	598,265	$800,409	16,703,598	$42,022,980	17,301,863	$42,823,389
Aransas Bay	718,988	$2,418,969	15,560,727	$37,154,255	16,279,715	$39,573,224
Corpus Christi Bay	1,601,657	$3,712,742	1,067,999	$1,462,062	2,669,656	$5,174,804
Upper Laguna Madre	9,746,031	$9,521,444	175,014	$215,833	9,921,045	$9,737,277
Lower Laguna Madre	3,558,791	$4,158,333	322,126	$468,619	3,880,917	$4,626,952

Source: Personal communication with Darin Topping (October 19, 2016) from TPWD, Rockport Marine Lab, Rockport, Texas.

From 2006 to 2015, Galveston, San Antonio, Aransas, and Matagorda bays produced the highest commercial shellfish harvest from all Texas bay systems, representing 48.4, 17.5, 16.3, and 10.7 percent, respectively, of the total shellfish landings while the least is from East Matagorda Bay (0.2 percent), Upper Laguna Madre (0.2 percent), Lower Laguna Madre (0.3 percent), and Corpus Christi Bay (1.1 percent). Galveston Bay produces 43.3 million pounds with a value of $122.4 million (pers. com. D. Topping [TPWD], 2016).



Source: Personal communication with Darin Topping (October 19, 2016) from TPWD, Rockport Marine Lab, Rockport, Texas.

Figure 2-13. Percent of Commercial Landings and Value of Fish and Shellfish by Texas Bay System, 2006–2015

Table 2-21 shows the percent total landings of shellfish and finfish by bay system. Most blue crab harvest comes from Galveston (33.4 percent), Aransas (17.8 percent), and San Antonio (17.7 percent) bays, and Sabine Lake (17.2 percent). Almost half the eastern oysters are harvested from Galveston Bay (48.9 percent), with San Antonio, Aransas, and Matagorda bays making up the remaining harvest. Galveston Bay produces over half (52.2 percent) of the brown, pink, and white shrimp harvest (76.4 percent). Most black drum are collected from the Upper Laguna Madre (55.7 percent), flounder from East Matagorda Bay (25.3 percent) and Aransas Bay (22.4 percent). Sheepshead are harvested mainly from Galveston, Matagorda, and East Matagorda bays and mullet from the Lower Laguna Madre and Galveston Bay (pers. com. D. Topping [TPWD], 2016).

Table 2-21
Percent of Total Shellfish and Finfish Landings by Texas Bay System, 2006 to 2015

Bay System	Blue Crab	Eastern Oyster	Brown/ Pink Shrimp	White Shrimp	Black Drum	Flounder	Sheeps-head	Mullet
Sabine Lake	17.2	0	0.5	0.8	0.1	0	0.2	2.2
Galveston Bay	33.4	48.9	52.2	76.4	14.0	6.2	34.9	27.3
Matagorda Bay	10.3	8.5	21.5	13.3	2.3	25.3	21.0	0.4
East Matagorda Bay	0.4	0.1	0	0	0	0.3	0	0.4
San Antonio Bay	17.7	22.4	11.8	3.4	2.7	13.5	20.9	0.2
Aransas Bay	17.8	20.1	8	4.7	1.8	22.4	11.7	4.8
Corpus Christi Bay	1.5	0	6	1.3	6.8	11.2	8.3	4.3
Upper Laguna Madre	0.6	0	0	0	55.7	2.7	0.6	1.5
Lower Laguna Madre	1.1	0	0	0	16.5	18.4	2.4	58.9

Source: Personal communication with Darin Topping (October 19, 2016) from TPWD, Rockport Marine Lab, Rockport, Texas.

The TPWD divides the Gulf off Texas into five grid zones (17 through 21 from north to south). From 2006 to 2015, a total of 24.1 million pounds of fish and 55,500 pounds of shellfish were commercially harvested from all Gulf grid zones combined, with a total value combined of $76.1 million. Commercially harvested species include black drum, flounder, sheepshead, mullet, and other. Shrimp are also commercially harvested from this area of the Gulf; however, the data are only available Gulfwide, not by grid zone through TPWD. Snapper make up the majority of the commercial Gulf harvest, followed by grouper (Serranidae) then cobia (*Rachycentron canadum*) (pers. com. D. Topping [TPWD], 2016).

Gulf shrimp landings data by Texas ports were obtained through the National Marine Fisheries Service (NMFS) Annual Commercial Landings Statistics. From 2006 to 2015, a total of 767.8 million pounds of shrimp were commercially harvested in the Gulf with a value of $1.7 billion. Brown shrimp comprised the majority of the commercial shrimp harvest in the Gulf, 526.2 million pounds with a value of $1.1 billion, followed by white shrimp at 240.8 million pounds with a value of $635.9 million (NMFS, 2016a).

2.4.3.3.2 Recreational Fisheries

Recreational fishing is economically and biologically important in all Texas bay systems. Bay anglers primarily sought spotted seatrout (18 percent of trips), red drum (14 percent), southern flounder (2 percent), a combination of spotted seatrout and red drum (38 percent) or a combination of spotted seatrout, red drum, and southern flounder (4 percent), while many anglers sought no particular species (18 percent) (pers. com. M. Fisher [TPWD], 2016). From 2006 to 2015, annual bay private boat (i.e., those using privately owned and rental boats, including fishing tournaments) fishing pressure was greatest from Galveston Bay, followed by Aransas Bay, Upper Laguna Madre, Matagorda Bay, Lower Laguna Madre, San Antonio Bay, Sabine Lake, and Corpus Christi Bay (Table 2-22). Party-boat fishing (i.e., those using a professional fishing guide with 10 or fewer people) is greatest from Galveston Bay, followed by Aransas Bay, Upper Laguna Madre, Corpus Christi Bay, Matagorda Bay, Lower Laguna Madre, San Antonio Bay, and Sabine Lake (Table 2-22) (pers. com. M. Fisher [TPWD], 2016; Green and Campbell, 2010).

Table 2-22
Percent of Angler Effort for Texas Bays and Gulf, 2006 to 2015

System	Private Boat	Party Boat
Bay:		
Sabine Lake	8.1	2.1
Galveston Bay	29.4	28
Matagorda Bay	10.9	8.6
San Antonio Bay	8.8	4.7
Aransas Bay	12.8	23.1
Corpus Christi Bay	6.9	10.3
Upper Laguna Madre	12.7	17.5
Lower Laguna Madre	10.4	5.7
Gulf:		
Gulf off Sabine Lake	5.6	0
Gulf off Galveston	26.8	26.9
Gulf off Port O'Connor	21.7	32.5
Gulf off Port Aransas	36.6	30.9
Gulf off Port Isabel	9.5	9.6

Source: Personal communication with Mark Fisher (October 26, 2016) from TPWD, Rockport Marine Lab, Rockport, Texas.

Offshore recreational fishing is also popular along the Texas coast. Gulf anglers primarily sought red snapper (25 percent), king mackerel (22 percent), or a combination of red snapper and king mackerel (8 percent), while many anglers sought no particular species (26 percent) (pers. com. M. Fisher [TPWD], 2016). From 2006 to 2015, private boat fishing pressure from ports was greatest off Port Aransas, followed by Galveston Bay, Port O'Connor, Port Isabel, and Sabine Lake (see Table 2-22). From 2006 to 2015, the greatest private boat effort from the Gulf was from Port Aransas, followed by Sabine Lake and Galveston, Port O'Connor, and Port Isabel (see Table 2-

22). Party-boat effort was greatest from Port O'Connor, followed by Port Aransas, Galveston, and Port Isabel (pers. com. M. Fisher [TPWD], 2016; Green and Campbell, 2010).

2.4.4 Wildlife Resources

Blair (1950) categorizes Texas into seven biotic provinces: the Austroriparian, Texan, Tamaulipan, Chihuahuan, Navahonian, Kansan, and Balconian. The study area is located within the Austroriparian (upper Texas coast), Texan (upper to mid Texas coast), and Tamaulipan (lower Texas coast) biotic provinces.

The Austroriparian Biotic Province is situated on the eastern border of Texas and extends southward to Galveston County on the Gulf coast. Habitat in this province is typically wetter and more forested than the lower Gulf coast. According to Blair (1950), at least 47 mammal species, 29 snake species, 10 lizard species, 2 land turtle species, 17 anuran (frogs and toads) species, and 18 urodele (salamanders and newts) species occur within the region.

The Texan Biotic Province stretches from Galveston Bay to western Calhoun County (Blair, 1950). Regional climate is moist subhumid with some excess rainfall. Wildlife habitats include beach, shell ramp-barrier flats, dredged material, saltwater marsh, brackish to freshwater marsh, fresh to brackish lakes, inland freshwater marsh, grassland, and riparian forest (McGowen et al., 1976). The Texan Biotic Province supports a diverse fauna composed of a mixture of species common to neighboring provinces. At least 49 species of mammals are known to have occurred in the Texan province in recent times, in addition to over 300 avian species, 39 snake species, 16 lizard species, 2 land turtle species, 18 anuran species, and 5 urodele species (Blair, 1950).

The Tamaulipan Biotic Province regional climate is semiarid and hot with little moisture for plant growth. The vertebrate fauna of the region is typified by neotropical and plains species. Wildlife habitats include upland prairies, salt marshes, tidally influenced lowlands, barrier islands, saline lagoons, and coastal prairies. According to Blair (1950) there are 61 mammalian species, over 300 avian species, 38 species of snakes, 19 species of lizards, and at least 5 species of amphibians.

2.4.4.1 Amphibians

Amphibians common to marsh habitats are the green treefrog (*Hyla cinerea*), American bullfrog, eastern narrow-mouthed toad (*Gastrophryne carolinensis*), Great Plains narrow-mouthed toad (*G. olivacea*), Blanchard's cricket frog (*Acris crepitans blanchardi*), squirrel treefrog (*H. squirella*), bronze frog (*R. clamitans*), and the southern leopard frog (*R. sphenocephala*). Amphibian species that are common to the upland grasslands include the Gulf coast toad (*Bufo nebulifer*), upland chorus frog (*Pseudacris feriarum feriarum*), Hurter's spadefoot (*Scaphiopus hurterii*), Rio Grande chirping frog (*Syrrhophus cystignathoides*), and the northern spring peeper (*Pseudacris crucifer crucifer*). Amphibian species that are commonly found in forest habitats include the gray treefrog (*H. versicolor*) and the Eastern green toad (*A. debilis*). Salamanders and newts (Urodele) fauna that could occur in the study area include the small-mouthed salamander (*Ambystoma texanum*), eastern tiger salamander (*A. tigrinum tigrinum*), central newt (*Notophthalmus viridescens louisianensis*), and western lesser siren (*Siren intermedia nettingi*), all of which are restricted to moist bottomland or hydric habitats (Herps of Texas, 2017a, 2017b).

2.4.4.2 Reptiles

Snakes known to inhabit wet, forested habitats are the Texas ratsnake (*Elaphe obsoleta*), rough green snake (*Opheodrys aestivus*), eastern hog-nosed snake (*Heterodon platirhinos*), eastern garter snake (*Thamnophis sirtalis sirtalis*), western cottonmouth (*Agkistrodon piscivorous leucostoma*), Texas coral snake (*Micrurus tener*), diamond-backed watersnake (*Nerodia rhombifer rhombifer*), southern copperhead (*Agkistrodon contortrix contortrix*), speckled kingsnake (*Lampropeltis getula holbrooki*), Gulf saltmarsh snake (*N. clarkii clarkii*) and Gulf Coast ribbonsnake (*T. proximus orarius*). Snakes common to upland grasslands include prairie kingsnake (*L. calligaster calligaster*), western coachwhip (*Masticophis flagellum testaceus*), eastern yellow-bellied racer (*Coluber constrictor flaviventris*), and the western diamond-backed rattlesnake (*Crotalus atrox*). Turtles include the snapping turtle (*Chelydra serpentina*), common musk turtle (*Sternotherus odoratus*), Mississippi mud turtle (*Kinosternon subrubrum*), red-eared slider (*Trachemys scripta elegans*), three-toed box turtle (*Terrapene carolina triunguis*), ornate box turtle (*T. ornata ornata*), Texas spiny softshell (*Apalone spinifera emoryi*), Rio Grande cooter (*Pseudemys gorzugi*), and diamond-backed terrapin (*Malaclemys terrapin*). Lizards found in the coastal area include the green anole (*Anolis carolinensis*), prairie lizard (*Sceloperus consobrinus*), eastern six-lined racerunner (*Aspidoscelis sexlineata sexlineata*), Texas spotted whiptail (*A. gularis gularis*), little brown skink (*Scincella lateralis*), Mediterranean gecko (*Hemidactylus turcicus turcicus*), Western slender glass lizard (*Ophisaurus attenuatus attenuatus*), Great Plains skink (*Plestiodon obsoletus*), Texas spiny lizard (*S. olivaceus*), Texas rose-bellied lizard (*S. variabilis marmoratus*), and Texas tree lizard (*Urosaurus ornatus ornatus*). The American alligator is also known to occur in the study area (Herps of Texas, 2017c, 2017d, 2017e).

2.4.4.3 Mammals

Mammals using the coastal fields and forests of the area include the Virginia opossum, least shrew (*Cryptotis parva*), eastern mole (*Scalopus aquaticus*), hoary bat (*Lasiurus cinereus*), eastern red bat (*L. borealis*), Brazilian free-tailed bat (*Tadarida brasiliensis*), evening bat (*Nycticeius humeralis*), nine-banded armadillo (*Dasypus novemcinctus*), eastern cottontail (*S. floridanus*), black-tailed jackrabbit (*Lepus californicus*), swamp rabbit, eastern gray squirrel (*Sciurus carolinensis*), eastern fox squirrel (*S. niger*), Attwater's pocket gopher (*Geomys attwateri*), hispid pocket mouse (*Chaetodipus hispidus*), American beaver, Gulf coast kangaroo rat (*Dipodomys compactus*), fulvous harvest mouse (*Reithrodontomys fulvescens*), white-footed mouse (*Peromyscus leucopus*), hispid cotton rat (*Sigmodon hispidus*), marsh rice rat (*Oryzomys palustris*), eastern woodrat (*Neotoma floridana*), nutria (*Myocastor coypus*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), common gray fox (*Urocyon cinereoargenteus*), ringtail (*Bassariscus astutus*), northern raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), bobcat (*Lynx rufus*), feral pig, and white-tailed deer (Davis and Schmidly, 1994; Schmidly, 2004).

2.4.4.4 Birds

Common year-round avian species along the Gulf coast include great blue heron (*Ardea herodias*), turkey vulture (*Cathartes aura*), red-tailed hawk (*Buteo jamaicensis*), black-bellied whistling-duck, willet (*Tringa semipalmata*), laughing gull (*Leucophaeus atricilla*), black skimmer (*Rynchops niger*), killdeer (*Charadrius vociferus*), mourning dove (*Zenaida macroura*), belted kingfisher (*Megaceryle alcyon*), blue jay (*Cyanocitta*

cristata), American crow (*Corvus brachyrhynchos*), tufted titmouse (*Baeolophus bicolor*), Carolina wren (*Thryothorus ludovicianus*), little blue heron (*Egretta caerulea*), sanderling (*Calidris alba*), least sandpiper (*C. minutilla*), white ibis (*Eudocimus albus*), roseate spoonbill (*Platalea ajaja*), royal tern (*Sterna maxima*), sandwich tern (*S. sandvicensis*), northern mockingbird (*Mimus polyglottos*), northern cardinal (*Cardinalis cardinalis*), lark sparrow (*Chondestes grammacus*), red-winged blackbird (*Agelaius phoeniceus*), eastern meadowlark (*Sturnella magna*), great-tailed grackle (*Quiscalus mexicanus*), brown-headed cowbird (*Molothrus ater*), northern bobwhite (*Colinus virginianus*), and house sparrow (*Passer domesticus*) (Lockwood and Freeman, 2004; Sibley, 2000; Texas Bird Records Committee, 2017).

Texas is located within the Central Flyway corridor, which is used by millions of migratory bird species in the spring and fall. Winter residents and migrants include blue-winged teal (*Anas discors*), mallard (*A. platyrhynchos*), gadwall (*A. strepera*), green-winged teal (*A. crecca*), greater white-fronted goose (*Anser albifrons*), Ross's goose (*Chen rossii*), Canada goose (*Branta canadensis*), wood duck (*Aix sponsa*), cackling goose (*Branta hutchinsii*), snow goose (*Chen caerulescens*), northern pintail (*A. acuta*), ring-necked duck (*Aythya collaris*), lesser scaup (*Aythya affinus*), common merganser (*Mergus merganser*), northern flicker (*Colaptes auratus*), ruby-crowned kinglet (*Regulus calendula*), cedar waxwing (*Bombycilla cedrorum*), yellow-rumped warbler (*Dendroica coronata*), chipping sparrow (*Spizella passerina*), field sparrow (*S. pusilla*), vesper sparrow (*Pooecetes gramineus*), savannah sparrow (*Passerculus sandwichensis*), white-throated sparrow (*Zonotrichia albicollis*), dark-eyed junco (*Junco hyemalis*), and American goldfinch (*Carduelis tristis*). Summer residents expected to occur in the study area include the yellow-billed cuckoo (*Coccyzus americanus*), chuck-will's widow (*Caprimulgus carolinensis*), common nighthawk (*Chordeiles minor*), chimney swift (*Chaetura pelagica*), eastern kingbird (*Tyrannus tyrannus*), scissor-tailed flycatcher (*T. forficatus*), purple martin (*Progne subis*), barn swallow (*Hirundo rustica*), summer tanager (*Piranga rubra*), indigo bunting (*Passerina cyanea*), painted bunting (*P. ciris*), and dickcissel (*Spiza americana*) (Lockwood and Freeman, 2004; Sibley, 2000; Texas Bird Records Committee, 2017).

2.4.4.5 Insects

Common insect species found along the Gulf coast include the field cricket (*Gryllus* spp.), American cockroach (*Periplaneta americana*), wheel bug (*Arilus cristatus*), leaf-footed bug (*Leptoglossus phyllopus*), dog-day cicada (*Tibicen* spp.), green lacewing (*Chrysoperla* spp.), ground beetle (*Scarites subterraneus*), June beetle (*Phyllophaga* spp.), firefly (*Photinus* spp.), blister beetle (*Epicauta* spp.), boll weevil (*Anthonomous grandis*), Asian tiger mosquito (*Aedes albopictus*), deer fly (*Chrysops* spp.), house fly (*Musca domestica*), blow fly (*Calliphora* spp.), giant swallowtail (*Heraclides cresphontes*), cloudless sulphur (*Phoebis sennae eubule*), snout butterfly (*Libytheana* spp.), checkered skipper (*Pyrgus communis*), prairie alligator (*Anisomorpha ferrunginea*), common termite (*Reticulitermes claripennis*), yucca moth (*Tegeticula yuccasella*), monarch butterfly (*Danaus plexippus*), honey bee (*Apis mellifera*), paper wasp (*Polistes carolina*), and the red imported fire ant (Drees and Jackman, 1998).

2.4.5 Protected Resources

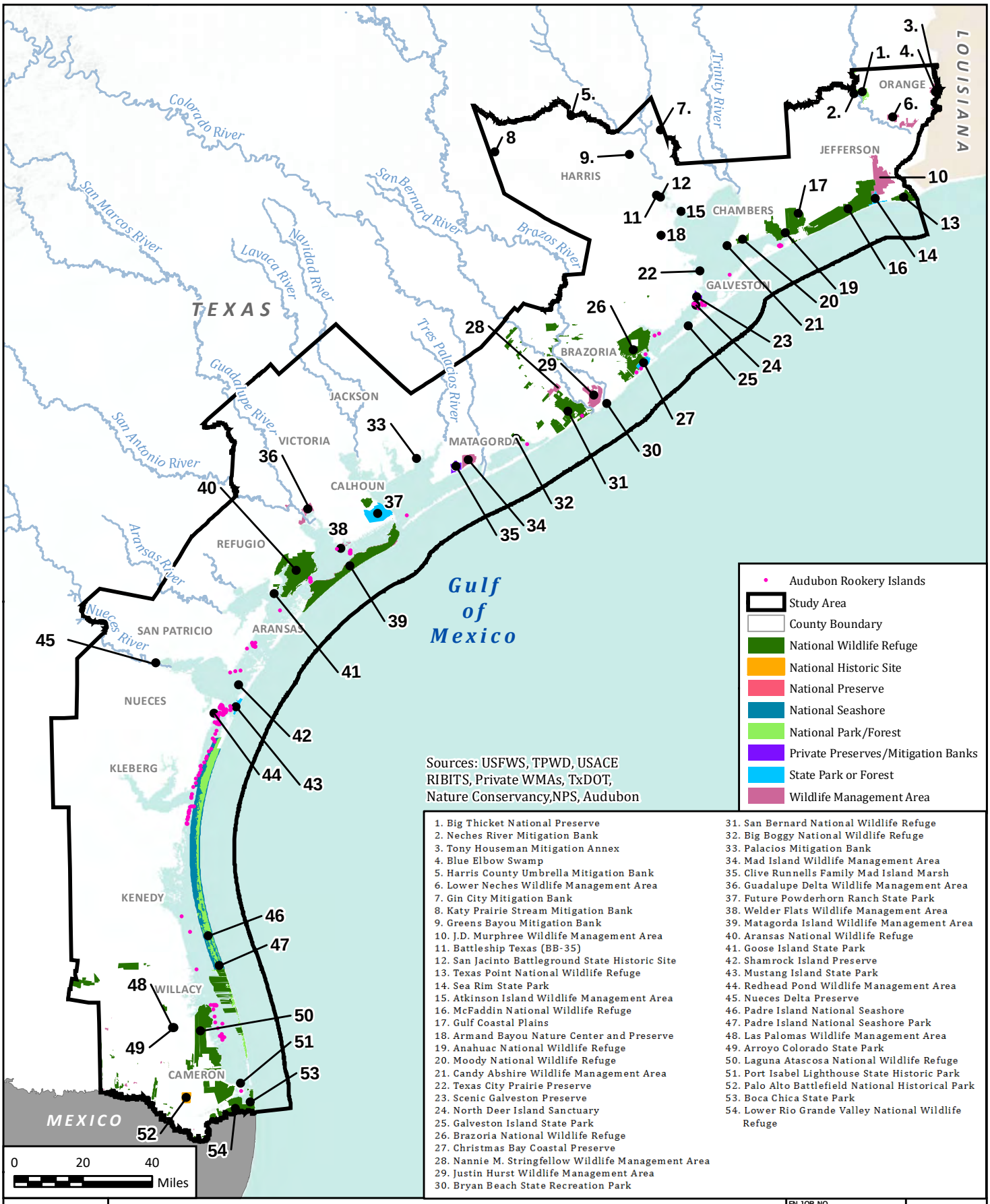
2.4.5.1 Protected Lands

Numerous protected lands have been established along the Texas Gulf coast and within the study area that demonstrate the ecological, cultural, and recreational diversity of Texas (Figure 2-14). Some of these areas were created to provide opportunities for hunting, fishing, wildlife viewing, and environmental education. Administration of these areas is provided under Federal and State governance or by private organizations. The USFWS manages 11 NWRs: McFaddin, Texas Point, Anahuac, Moody, Brazoria, San Bernard, Trinity River, Big Boggy, Aransas, Laguna Atascosa, and Lower Rio Grande Valley. The NPS manages Padre Island National Seashore, Palo Alto Battlefield National Historical Park, and the Big Thicket National Preserve. State-protected lands include 13 WMAs (J.D. Murphree, Lower Neches, Tony Houseman, Atkinson Island, Candy Abshier, Justin Hurst, Nannie M. Stringfellow, Mad Island, Matagorda Island, Welder Flats, Guadalupe Delta, Redhead Pond, and Las Palomas), 11 state parks (Goose Island, Mustang Island, Boca Chica, Battleship Texas, San Jacinto Sate Historical Park, Sea Rim, Galveston Island, Bryan Beach, Arroyo Colorado, Powderhorn Ranch, and Port Isabel Lighthouse State Historic Site), and Christmas Bay Coastal Preserve. Harris County Flood Control District (HCFCD) protected lands include the Greens Bayou Mitigation Bank and the Harris County Umbrella Mitigation Bank. Privately protected lands include the Armand Bayou Nature Center and Preserve, Scenic Galveston Preserve, CBBEP's Nueces Delta Preserve, TNC's Clive Runnells Family Mad Island Marsh Preserve, TNC's Shamrock Island Sanctuary, TNC's Sundown Island, the Houston Audubon Society's North Deer Island Sanctuary, and High Island Sanctuaries. There are four privately owned mitigation banks: Gulf Coastal Plains, Gin City, Palacios Wetlands, and Katy Prairie. Table 2-23 provides a brief description of the protected areas as well as the managing group.

2.4.5.2 Threatened and Endangered Species

The Endangered Species Act (ESA) of 1973, as amended, was enacted to provide a program for the preservation of threatened and endangered species and to provide protection for the ecosystems upon which the species depend for their survival. All Federal agencies are required to implement protection programs for these designated species and use their authorities to further the purpose of the ESA. The USFWS and NMFS are the primary agencies responsible for implementing the ESA. The USFWS is responsible for terrestrial flora and fauna, including freshwater species, while the NMFS is responsible for non-bird marine species.

The USFWS and NMFS have identified 31 Federally listed threatened and endangered species as potentially occurring in the study area (Table 2-24). The ESA defines a threatened species as "a species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range" and an endangered species as "a species that is in danger of extinction throughout all or a significant portion of its range" (50 CFR 424.02; USFWS, 2015a). Species are listed in Table 2-24 and discussed briefly in the following sections. Inclusion on the list does not imply that a species occurs in the study area, but only acknowledges the potential for its occurrence in those counties.



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Protected Lands

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2-14
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NAD 1983 Texas Centric Mapping System Albers

Table 2-23
Protected Lands Within the Study Area

Refuge Name	Management	Acreage	County	Types of Habitat	General Description
Upper Texas Coast					
Goose Island State Park	State (TPWD)	321	Aransas	estuarine marsh; oak mottes; tidal flats	This park boasts fishing, camping and boating. The "Big Tree" at the park is more than 1,000 years old and one of the largest live oak trees in the Nation.
Brazoria NWR	National (USFWS)	44,413	Brazoria	wetlands; prairies; woody thickets; salt and mud flats; lakes and streams	This refuge boasts 400 species of birds, 95 species or reptiles and amphibians, and 130 species of butterflies and dragonflies.
Bryan Beach State Recreation Park	State (TPWD)	885	Brazoria	coastal prairie	The park is regularly maintained by the City of Freeport. Recreation activities include sunbathing, camping, birding, and fishing.
Christmas Bay Coastal Preserve	State (GLO/TPWD)	4,831	Brazoria	prairies; salt marshes; oyster reefs	The preserve contains about 250 acres of seagrass beds and has minimal man-made alterations to the landscape.
Justin Hurst WMA	State (TPWD)	15,612	Brazoria	coastal dunes; Gulf shoreline; bay	The WMA is part of the Central Coast Wetlands Ecosystem Project, which provides research on biological conservation, outdoor demonstrations, and public hunting.
Nannie M. Stringfellow WMA	State (TPWD)	3,664	Brazoria	coastal bottomland hardwood forest	The WMA is part of the Coastal Bottomlands Mitigation Bank to improve the forest and grasslands as wildlife habitat.
San Bernard NWR	National (USFWS)	57,698	Brazoria, Matagorda	salt and freshwater marshes; ponds; coastal prairies; bottomland forests	The Columbia bottomland forest contains some of the largest live oak stands in Texas and provides habitat for wintering and nesting birds. The refuge was designated an "Internationally Significant Shorebird Site" and popular for waterfowl hunting and fishing.
Guadalupe Delta WMA	State (TPWD)	7,410	Calhoun, Victoria, Refugio	coastal marsh; man-made wetlands; riparian forest	The freshwater discharge of the Guadalupe River contributes to the low salinity of the bay system. The wetland habitat provides food and forage for wildlife such as white-faced ibis, herons, white-tailed hawk, and peregrine falcons.

Refuge Name	Management	Acreage	County	Types of Habitat	General Description
Boca Chica State Park	State (TPWD)	1,055	Cameron	sandy beaches and dunes	The TPWD signed a 50-year lease agreement with the USFWS; the park is now a part of the Lower Rio Grande Valley NWR. SpaceX is currently in the process of building a private spaceport adjacent to the state park.
Anahuac NWR	National (USFWS)	34,400	Chambers	brackish and saline marshes; coastal prairie and woodlands; Chenier plains	This refuge is used as a stopover along the Central Flyway for millions of migrating birds. The refuge contains one of the last remnants of native coastal tallgrass prairie in the United States and is known for its abundance of large American alligators.
Candy Abshier WMA	State (TPWD)	207	Chambers	live oak woodlots; freshwater ponds; bay shoreline	This WMA was recently rewarded with a grant from the National Fish and Wildlife Foundation to construct 2,660 feet of breakwater barriers to stabilize the eroding shoreline. The observation platform on site is used from August to November to count and observe migrating hawks along the coast.
Gulf Coastal Plains	(Private)	1,850	Chambers	coastal plains; prairies	Not available
Moody NWR	National (USFWS), perpetual non-development conservation easement	3,517	Chambers	estuarine marsh; bay shoreline	The tract is under a conservation easement under private ownership and has no public access. The NWR contains numerous shell middens and archeological sites.
Trinity River NWR	National (USFWS)	25,000	Chambers, Liberty	cypress-tupelo swamp; bottomland hardwood forest; wet pastures; lakes; rivers	The refuge is home to one of the largest maternal colonies of Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) in the world. The refuge contains more than 650 different species of plants and 400 types of butterflies and moths.
Galveston Island State Park	State (TPWD)	2,000	Galveston	coastal prairie; wetlands	One of the last undeveloped public lands on Galveston Island, this park is popular for swimming, fishing, camping, and hiking. The state park is still in the process of recovering from damages from Hurricane Ike in 2008.

Refuge Name	Management	Acreage	County	Types of Habitat	General Description
North Deer Island Sanctuary	National Audubon Society, Houston Audubon Society	144	Galveston	upland salt marsh	This island is one of the most productive waterbird colonies in the Galveston Bay with up to 40,000 breeding pairs during the season. It was recently a part of a shoreline restoration project where 6,450 feet of breakwater was installed to prevent shoreline erosion from natural wave action and barge traffic.
Scenic Galveston Preserve	Scenic Galveston (private)	3,200	Galveston	restored marsh	This tract is part of a conservation easement. The marshes are currently under clean-up restoration by volunteer groups.
Texas City Prairie Preserve	TNC (Private)	2,303	Galveston	coastal prairie; marsh	Donated by ExxonMobil, this preserve is partnered with the GLO, USFWS, and the Galveston Bay Estuaries Program to implement a series of living shoreline projects to protect and provide resiliency.
Armand Bayou Nature Center and Preserve	Armand Bayou Nature Center (Private)	2,800	Harris	brackish water bayou; riparian hardwood forest; remnant coastal prairie	Located outside of Houston, the center specializes in outdoor education, community outreach programs, canoeing, and hiking.
Atkinson Island WMA	State (TPWD)	150	Harris	brackish marsh; woodlot	Donated by Conoco Inc., this wildlife preserve is mainly used for wetland restoration research on dredged materials.
Battleship Texas State Historic Site	State (TPWD)	1	Harris	historic ship	This decommissioned World War I and World War II battleship now serves as a floating museum and war memorial. The battleship is located along the Houston Ship Channel and adjacent to the San Jacinto Battleground site.
Gin City Mitigation Bank	Gin City Restoration (Private)	500	Harris	freshwater wetlands	Restored rice fields include 300,000 trees and locally collected plants. The site provides 1,170 wetland credits.
Greens Bayou Mitigation Bank	County (HCFCD)	961	Harris	ponds; marshes; forests	One of the largest mitigation banks in the Texas Gulf coast region. The mitigation bank provides habitat, naturally filters urban runoff, and stores stormwater during rain events.
Harris County Umbrella Mitigation Bank	County (HCFCD)	66	Harris	wetland; stream channel	Restored sand and gravel mining pit now includes 25 acres of wetland and 2,000 linear feet of stream channel.

Refuge Name	Management	Acreage	County	Types of Habitat	General Description
Katy Prairie Stream Mitigation Bank	Warren Family, Katy Prairie Conservancy, Restoration Systems LLC (Private)	500	Harris	wetland; stream channel; prairie	Houston's first and the largest permitted stream mitigation bank in the United States (12,000+ linear feet).
San Jacinto Battleground State Historical Site	State (TPWD)	1,109	Harris	coastal prairie; tidal marsh; bottomland forest	This park sits on the site of one of the most important battles of the Texas Revolution. The park now contains the San Jacinto monument, a reflecting pool, and hosts annual battle reenactments.
JD Murphree WMA	State (TPWD)	24,250	Jefferson	fresh, intermediate and brackish marsh; Chenier plain	This site has a been a waterfowl banding location since the 1960s and provides valuable information on the population of mottled ducks, geese, and other birds. There are several continuous studies conducted by university staff and students related to the wetlands and other wildlife.
McFaddin NWR	National (USFWS)	58,861	Jefferson	freshwater and intermediate marsh; Gulf shoreline dune system	The refuge is home to the largest concentration of American alligators in Texas. The refuge serves as an important stopover for migrating songbirds and wintering grounds for geese and other waterfowl.
Neches River	Wetlands Mitigation Replacement of Southeast Texas (private)	541	Jefferson	cypress-tupelo swamp; emergent marsh mitigation bank	The area is a privately owned mitigation bank.
Sea Rim State Park	State (TPWD)	4,141	Jefferson	gulf prairie and marsh	This park was damaged after Hurricanes Rita and Ike and recently reopened. The park is a popular destination for birdwatching, beach recreation and kayaking.
Texas Point NWR	National (USFWS)	8,952	Jefferson	coastal wetlands	A primitive refuge with no paved trail or vehicle access. Designated by the American Bird Conservancy as a “Globally Important Bird Area of the United States.”
Blue Elbow Swamp Mitigation Bank	State (TxDOT)	2,737	Orange	cypress-tupelo swamp	The tract is located right behind the Texas Travel information center along SH 10 and provides visitors with a quick look at a marsh ecosystem.

Refuge Name	Management	Acreage	County	Types of Habitat	General Description
Big Thicket National Preserve	National (NPS)	112,501	Orange, Hardin, Jefferson	cypress-tupelo swamp; bottomland hardwood forest; freshwater marsh	This preserve boasts an incredible amount of biodiversity and has been designated a United Nations Educational, Scientific and Cultural Organization Biosphere Reserve. The preserve is home to 4 species of carnivorous plants and more than 1,000 different species of flowering plants, ferns, and orchids.
Mid to Upper Texas Coast					
Aransas NWR/ Matagorda Island WMA	National (USFWS), State (TPWD)	114,657	Calhoun, Aransas, Refugio	salt, brackish and freshwater marsh; coastal woodlots; tidal flats; Gulf beaches	This refuge is the winter migration stop of the endangered whooping cranes. The Matagorda island unit of the refuge is a nesting ground for Kemp's ridley sea turtles and piping plovers. The portion of Matagorda Island is jointly shared with USFWS and TPWD where the refuge has the lead responsibility for wildlife and habitat management, and TPWD is responsible for public use management.
Big Boggy NWR	National (USFWS)	4,526	Matagorda	brush and flat coastal prairie; freshwater and saltwater marsh; uplands	Only opened to the public during waterfowl hunting season, this refuge serves as a stop along the Central Flyway and as a breeding colony for herons, pelicans, spoonbills, and many other birds.
Clive Runnells Family Mad Island Marsh	TNC (Private)	7,063	Matagorda	coastal marsh; wetlands; upland prairie; barrier island	The preserve is ranked within the top 5 annual Christmas Bird Counts in the Nation and is home to nearly 250 different species of birds. Efforts are currently under way to restore freshwater inflows, freshwater wetlands, and upland prairies.
Mad Island WMA	State (TPWD)	7,281	Matagorda	fresh to brackish marsh land; coastal prairie	The WMA is well known for duck hunting in the fall and winter.
Palacios Mitigation Bank	Private	2,564	Matagorda	Wetlands	The largest environmental bank in Texas. The area was previously corn and sorghum fields. The bank is important habitat for migratory birds and wildlife.
Mustang Island State Park	State (TPWD)	3,954	Nueces	coastal barrier island; sand dune	The park is used as nesting grounds for the Atlantic green and Kemp's ridley sea turtles. There has also been reintroduction efforts for the endangered aplomado falcon inside of the park.

Refuge Name	Management	Acreage	County	Types of Habitat	General Description
Lower Neches WMA	State (TPWD)	7,998	Orange	open water marsh	Donated by philanthropist Nelda Childers Stark, this area was used by the Atakapan Indians for centuries. Hunting, wildlife viewing, and fishing activities are offered.
Mid-Texas Coast					
Redhead Pond WMA	State (TPWD)	37	Nueces	freshwater wetland	A freshwater pond in downtown Corpus Christi provides winter habitat for waterfowl.
Shamrock Island Preserve	TNC (Private)	110	Nueces	island	The island is utilized by 19 different species of birds as a nesting site and for roosting. The TNC has developed a long-term habitat restoration program for the island.
Nueces Delta Preserve	CBBEP (Private)	10,500	Nueces	grasslands; thornscrub; wetlands; marsh delta	The preserve contains limited trails, a learning, and visitor center for outdoor classrooms. Land management programs include re-establishing a prairie wetland, invasive species control, prescribed burns, and tree plantings.
Tony Houseman WMA	State (TPWD)	3,313	Orange	cypress-tupelo swamp	The site has a 600-foot boardwalk running through the center of the swamp. The WMA offers public hunting, hiking, canoeing, and fishing.
Lower Texas Coast					
Powderhorn Ranch State Park	State (TPWD)	17,351	Calhoun	shrubland; pasture; grassland; wetlands; open water	The newest Texas state park features 6 different types of plant species, including wetlands and shoreline for migratory birds. There are also plenty of recreational opportunities such as paddling, hiking, birdwatching, and hunting. The park is not yet open to the public.
Welder Flats WMA	State (GLO/TPWD)	1,480	Calhoun	Submerged coastal wetlands	The shallow seagrass shoreline provides a foraging area for waterfowl and whooping cranes. The San Antonio Bay shoreline is used by bay hatcheries to stock the area with red drum and spotted sea trout.
Lower Rio Grande Valley NWR	National (USFWS)	90,788	Cameron	riparian woodlands; saline flats; resacas and mesquite savannahs	The refuge contains several historical landmarks. The NWR provides habitat for 17 Federally listed threatened and endangered species such as ocelots, Kemp's ridley sea turtles, and aplomado falcons.
Palo Alto Battlefield National Historical Park	National (NPS)	3,364	Cameron	resacas; grassland prairie; scrub woodlands	The historic park contains many landmarks and battle sites from the Mexican War. The site remains an important place for Texas tortoise conservation.

Refuge Name	Management	Acreage	County	Types of Habitat	General Description
Port Isabel Lighthouse State Historical Site	State (TPWD)	2	Cameron	historic building	This lighthouse is the only lighthouse open to the public. The site also features a small museum and visitor center.
Laguna Atascosa NWR	National (USFWS)	97,007	Cameron, Willacy	tidally affected lagoon system; wetlands; sandy beaches; dunes; tidal mud flats; brackish marsh; freshwater ponds	One of the few places in the United States where ocelots and jaguarundis are found. The refuge also has the most recorded species of birds (417) than any other in the national refuge system.
Padre Island National Seashore	National Parks Service	130,434	Kleberg, Kenedy, Willacy	coastal prairie; dune system; tidal flats; hypersaline lagoon	North Padre Island is the longest undeveloped barrier island in the world. The seashore is an important nesting site for the endangered Kemp's ridley sea turtle and migratory bird species.
Arroyo Colorado State Park	State (TPWD)	1,005	Willacy, Cameron	freshwater stream	The unit is part of the coastal birding trail and an important fishery area.
Las Palomas WMA	State (TPWD)	754	Willacy, Cameron	restored grasslands; wetlands	This WMA lies along the U.S.-Mexican border. Some of the units were formerly farm field that have not been restored for white-winged dove breeding habitat.

Source: Armand Bayou Nature Center (2016), Brazosport (2017), CBBEP (2009), Dotzour and Manning (2002), HCFCD (2017), Houston Audubon (2016), Mitigation Solutions (2017), NPS (2016b, 2017a, 2017b), Restoration Systems LLC (2017), Scenic Galveston (2016), TxDOT (1995), TNC (2016b, 2016c, 2017), TPWD (2014, 2016g–u, 2017a–g), USACE et al. (1999); USFWS (2013a–f, 2018a–f).

GLO = Texas General Land Office

Table 2-24
Federally Endangered, Threatened, or Candidate for Listing
Species of Potential Occurrence in the Study Area

Common Name	Scientific Name	Federal Status
PLANTS		
Black lace cactus	*Echinocereus reichenbachii* var. *albertii*	E
Slender rush-pea	*Hoffmannseggia tenella*	E
South Texas ambrosia	*Ambrosia cheiranthifolia*	E
Texas ayenia	*Ayenia limitaris*	E
Texas prairie dawn-flower	*Hymenoxys texana*	E
BIRDS		
Attwater's prairie chicken	*Tympanuchus cupido attwateri*	E
Interior least tern	*Sterna antillarum*	E
Northern aplomado falcon	*Falco femoralis septentrionalis*	E
Piping plover	*Charadrius melodus*	T
Rufa red knot	*Calidris canutus rufa*	T
Red-cockaded woodpecker	*Picoides borealis*	E
Red-crowned parrot	*Amazona virdigenalis*	C
Whooping crane	*Grus americana*	E
MAMMALS		
Gulf coast jaguarundi	*Herpailurus yagouaroundi cacomitli*	E
Ocelot	*Leopardus pardalis*	E
Blue whale	*Balaenoptera musculus*	E
Fin whale	*Balaenoptera physalus*	E
Humpback whale	*Megaptera novaeangliae*	T
Sei whale	*Balaenoptera borealis*	E
Sperm whale	*Physeter macrocephalus*	E
West Indian manatee	*Trichechus manatus*	T
REPTILES		
Atlantic hawksbill sea turtle	*Eretmochelys imbricata*	E
Kemp's ridley sea turtle	*Lepidochelys kempii*	E
Leatherback sea turtle	*Dermochelys coriacea*	E
Loggerhead sea turtle	*Caretta caretta*	T
FISHES		
Largetooth sawfish	*Pristis pristis*	E
AMPHIBIAN		
Houston toad	*Bufo houstonensis*	E
MOLLUSKS		
Golden orb	*Quadrula aurea*	C
Smooth pimpleback	*Quadrula houstensis*	C
Texas fawnsfoot	*Truncilla macrodon*	C
Texas pimpleback	*Quadrula petrina*	C

Source: NMFS (2016b); USFWS (2017a, 2018g)

E – Endangered; T – Threatened; C – Candidate for Federal listing

2.4.5.2.1 Plant Species

Black lace cactus. The Federally endangered black lace cactus (*Echinocereus reichenbachii* var. *albertii*) is a small, columnar cactus with pink flowers. It is only found in three counties in south Texas (Kleberg, Refugio, and Jim Wells) in open mesquite brush habitat and saline soils. The population of the cactus has been in decline due to the invasion of non-native grasses, collection by horticulturalists, destruction of habitat for agriculture, and residential development (USFWS, 2009). It is likely the black lace cactus would occur in the study area.

Slender rush-pea. The Federally endangered slender rush-pea (*Hoffmannseggia tenella*) is a small, perennial legume with compound leaves and delicate yellow-orange flowers (TPWD, 2016v). It is found in two Texas counties, Kleberg and Nueces, in coastal prairie habitat. The largest population can be found at the St. James cemetery in Bishop. Much of its historical range has been converted to croplands, and individuals must compete with non-native grasses such as the Kleberg bluestem (*Dichanthium annulatum*) and King Ranch bluestem (USFWS, 2006a). Populations of the slender rush-pea are likely found within the study area.

South Texas ambrosia. The Federally endangered south Texas ambrosia (*Ambrosia cheiranthifolia*) is a perennial herbaceous plant with gray-green leaves and yellow inflorescence flowers. They are associated with native grasses such as Texas grama (*Bouteloua rigidiseta*) and buffalograss (*Bouteloua dactyloides*) in native grasslands and savannah habitats (TPWD, 2016w). The primary threat to the south Texas ambrosia is habitat loss, agricultural conversion of prairie, competition with non-native grasses, and urban development (USFWS, 2010a). South Texas ambrosia can be found in Nueces and Kleberg counties and is likely to be found within the study area.

Texas ayenia. The Federally endangered Texas ayenia (*Ayenia limitaris*) or the "Tamaulipan kidneypetal" is a medium-sized, flowering shrub endemic to three counties in south Texas (Cameron, Hidalgo, and Willacy) with additional populations in Mexico. Populations are typically found inhabiting riverine terraces and floodplains in close associations with Texas ebony and snake-eyes (*Phaulothamnus spinescens*) (TPWD, 2016x). The primary threat to the Texas ayenia is habitat conversion for agriculture and urban development (USFWS, 2014a). Pilot reintroduction programs have been successful on tracts in the Lower Rio Grande Valley NWR. Populations of the Texas ayenia are likely found within the study area.

Texas prairie dawn-flower. The Federally endangered Texas prairie dawn-flower (*Hymenoxys texana*) is a small, annual plant with a yellow flower head that blooms in early spring (TPWD, 2016y; USFWS, 2015b). They are commonly found on fine sandy loam soils at the base of pimple mounds. The main threat to the Texas prairie dawn-flowers are habitat conversion and degradation, heavy cattle grazing, and urbanization (USFWS, 2015b). The Texas prairie dawn-flower is found in five counties in eastern Texas (Fort Bend, Gregg, Harris, Trinity, and Waller). Populations of the prairie dawn-flower are likely to be found within the study area.

2.4.5.2.2 Bird Species

Attwater's prairie chicken. The Federally endangered Attwater's prairie chicken is a medium-sized, strongly barred, grouse species native to Texas. True to their name they are typically found in coastal grassland prairies.

Prairie chickens are known for their distinctive springtime breeding displays where males would congregate in leks, inflate their air sacs, and produce a low "booming" call. Once numbering in the millions, the population has declined to a few hundred due to the loss of coastal grassland habitats and the introduction of invasive species such as red imported fire ants and Macartney rose (Campbell, 2003). Historically found in all counties along the Texas-Louisiana Gulf coast, there are presently only two populations of Attwater's prairie chickens in Texas: the Attwater Prairie Chicken NWR in Colorado County and at release sites in Goliad, Refugio, and Victoria counties (Williams and Harrell, 2009). The Attwater's prairie chicken is rare and unlikely to be found in the study area.

Interior least tern. The Federally endangered interior least tern (*Sterna antillarum*) is a subspecies of the least terns commonly found along the coast. They generally nest greater than 50 miles inland. They are the smallest North American tern species. Adult least terns have a thin yellow bill, black cap and eye stripe, and a forked tail. They are colonial birds and together nest along riverine systems on gravel sandbars, shell beaches, and reservoir shorelines. Populations of interior least terns have been in decline due to channelization of rivers, reduced sediment loads due to river impoundment, pollution, and recreational use of sandbars and gravel pits (Campbell, 2003). It is likely that interior least terns are found within the study area.

Northern aplomado falcon. The Federally endangered Northern aplomado falcon (*Falco femoralis septentrionalis*) is a medium-sized grassland bird of prey. They have a distinct dark "cummerbund," a dark crescent facial mark, and steely gray dorsal plumage. The falcons are strong fliers and have been observed exhibiting cooperative hunting techniques. Breeding pairs do not construct nests but instead utilize old or newly built nests from other falcons and corvids. Reasons for their decline can be attributed to degradation of habitat due to overgrazing, prairie dog control, and pesticide usage (Campbell, 2003). There has been a reintroduction effort to bring back populations of aplomado falcons to south Texas; sightings have been noted in Willacy County and along the coast to Port O'Connor (eBird, 2016a). Populations of the aplomado falcon are likely to occur within the study area.

Piping plover. The Federally threatened piping plover is a small shorebird that inhabits coastal beaches and tidal flats (Elliott-Smith and Haig, 2004). Approximately 35 percent of the known global population of piping plovers winters along the Texas Gulf coast, where they spend 60 to 70 percent of the year (Campbell, 2003). The piping plover population that winters in Texas breeds on the northern Great Plains and around the Great Lakes. The species is a rare to uncommon migrant and winter resident in coastal areas of south Texas (Lockwood and Freeman, 2004). The piping plover is likely to occur within the study area.

Rufa red knot. The Federally threatened rufa red knot is a medium-sized, stocky, short-necked sandpiper with a rather short straight bill. The *rufa* subspecies, one of three subspecies occurring in North America, has one of the longest distance migrations known, travelling between its breeding grounds in the central Canadian Arctic to wintering areas that are primarily in South America (USFWS, 2014a). During migration and winter in Texas, rufa red knots may be found feeding in small groups, on sandy, shell-lined beaches, and to a lesser degree, on flats of bays and lagoons (Oberholser, 1974). It is an uncommon to common migrant along the coast, and rare to casual inland, primarily in the eastern half of the State. Rufa red knots are very rare summer visitors and are rare and local winter residents on the coast (Lockwood and Freeman, 2004). The wintering population in Texas is

estimated to be approximately 2,000 individuals (USFWS, 2007a, 2015c). The rufa red knot is likely to occur in the study area.

Red-cockaded woodpecker. The red-cockaded woodpecker (*Picoides borealis*) is a Federally listed species typically found in old growth pine forests. Woodpeckers excavate holes in live pines to create resin wells, which serve as a barrier against egg-eating snakes. The southeastern longleaf pine forests that the red-cockaded woodpeckers primarily nest in have been greatly reduced to 3 percent of their historic range (USFWS, 2006b). The primary reason for the decline of the population is due to habitat loss and fire suppression. The red-cockaded woodpecker range in Texas is limited to the long leaf and loblolly pine forests on the eastern side of the state (eBird, 2016b). The red-cockaded woodpecker is unlikely to occur within the study area.

Red-crowned parrot. The red-crowned parrot (*Amazona virdigenalis*), a Federal candidate for listing, is a medium-sized green parrot with a distinctive red forehead. They are typically native to northeastern Mexico. Populations have recently been established in urban areas along the Lower Rio Grande Valley around McAllen, Harlingen, and Brownsville (eBird, 2016c). Threats to these birds include the destruction of forest habitat and capture for the exotic pet trade (BirdLife International, 2016). Populations of the red-crowned parrot are likely to occur within the study area.

Whooping crane. Federally endangered whooping cranes are tall, white birds with a medium-sized bill and black primary feathers. Whooping cranes migrate during the daytime and roost at night in croplands and wetland areas on their 2,400-mile journey to the Texas Gulf coast. During the winter, the cranes are found along the Gulf coast wetlands and uplands feeding on blue crabs, clams, and wolfberry (Campbell, 2003). The population of whopping cranes has rebounded within the last decade up to 329 individuals wintering along the Texas coast in 2015–2016 (USFWS, 2016a). Current threats to wild cranes include powerline collisions, shooting, disease, loss of habitat, and severe weather (USFWS, 2010b). Populations of whooping cranes are likely to occur in the study area.

2.4.5.2.3 Mammal Species

Gulf coast jaguarundi. Federally endangered jaguarundi is one of the rarest cats in Texas typically found in shrubby habitats and grasslands with dense canopy cover. They are slightly larger than the domestic housecat and have a dark-brown, black, or rusty-colored coat. Population of jaguarundis in Texas has been in decline due to habitat destruction of their native thorn brush scrublands, pasture conversion, and human development (Campbell, 2003). The last confirmed jaguarundi sighting was in 1986 in Brownsville (USFWS, 2013g). The population of the jaguarundi is unlikely to occur within the study area.

Ocelot. Federally endangered ocelots are medium-sized, spotted cats found in thorny scrub and oak-grassland habitat of south Texas (Campbell, 2003). In addition to Texas, they are found in 22 countries from Central to South America (International Society for Endangered Cats, 2016). Ocelots are nocturnal hunters and prefer woodlands with thick canopy cover. The fragmentation of habitat by roadways has led to increased collision mortalities and reduced dispersal rates (USFWS, 2016b). The population of the ocelot is likely to occur in the study area.

Blue whale. The blue whale (*Balaenoptera musculus*) is the largest whale species in the world and can weigh over 330,000 pounds. They are found worldwide and migrate thousands of miles between foraging areas where they feed primarily on krill (NMFS, 2016c). There are only two documented records of blue whales in the Gulf. The only documented Texas record was an individual stranding between Freeport and San Luis Pass in 1940 (Schmidly, 2004). The blue whale is not expected to occur in the study area.

Fin whale. The Federally listed fin whale (*Balaenoptera physalus*) is the second largest whale in the world. Fin whales are typically found in higher latitudes during the summer and spring, migrating several thousand miles south to warmer equatorial waters to mate and calve. They are found year-round in the Gulf although there has only been one recorded incidence in Texas in 1951 (Schmidly, 2004). They were historically hunted but nowadays face threats such as collisions with vessels, habitat degradation, and reduced prey abundance from overfishing (NMFS, 2015a). The fin whale is not expected to occur in the study area.

Humpback whale. The humpback whale (*Megaptera novaeangliae*) has one of the longest migration routes of any whale species, travelling as much as 3,000 miles in the span of 36 days. Because of the ban on commercial whaling, the population of humpbacks has been steadily increasing. They still face threats from ship strikes and entanglement in fishing gear (NMFS, 2016d). The only documented observation of a humpback in Texas waters was in 1992 near the Bolivar Jetty in Galveston. The species is rare in the Gulf (Schmidly, 2004). This species is unlikely to occur in the study area.

Sei whale. This migratory species can commonly be found in higher latitudes during the summer and equatorial waters in the winter and fall. Sei whales (*Balaenoptera borealis*) are protected under the Marine Mammal Protection Act (MMPA) of 1972 and the ESA; they currently face threats from ship collisions, entanglement with fishing gear, and habitat degradation (NMFS, 2015b). Sei whales can be found in the Gulf and Caribbean but no records exist for Texas (Schmidly, 2004). Sei whales are not expected to occur in the study area.

Sperm whale. Sperm whales (*Physeter macrocephalus*) are proficient divers and often spend most of their time in deep waters feeding. The average dive can last for 35 minutes and can reach depths of over 1,312 feet (NMFS, 2015c). Sperm whales are the most common species of whale in the Gulf. Sightings and stranding occur regularly along the Texas Gulf coast. Although sperm whales are known to occur in the Gulf, they typically inhabit deep offshore waters (Schmidly, 2004). The sperm whale is not likely to occur in the study area.

West Indian manatee. The Federally threatened West Indian manatee (*Trichechus manatus*) is an aquatic mammal that inhabits brackish water bays, large rivers, and salt water, and feeds upon submergent, emergent, and floating vegetation with the diet varying according to plant availability (Davis and Schmidly, 1994; USFWS, 2008, 2017a). Historically, the manatee inhabited the Laguna Madre, Gulf, and tidally influenced portions of rivers. Currently manatees are extremely rare in Texas waters and the most recent sightings are likely individuals migrating or wandering from Mexican waters. Historical records from Texas waters include Cow Bayou, Sabine Lake, Copano Bay, Bolivar Peninsula, and the mouth of the Rio Grande (Davis and Schmidly, 1994). The West Indian manatee could occur within the study area, but likely as a transient and not a resident.

2.4.5.2.4 Reptile Species

Atlantic hawksbill sea turtle. The Federally endangered Atlantic hawksbill sea turtle is widely distributed in the Caribbean and western Atlantic Ocean, with representatives of at least some life history stages regularly occurring in southern Florida and the northern Gulf (especially Texas), south to Brazil (NMFS, 2015d). The hawksbill generally inhabits coastal reefs, bays, rocky areas, passes, estuaries, and lagoons, where it occurs at depths of less than 70 feet (Mortimer and Donnelly, 2008). Like some other sea turtle species, hatchlings are sometimes found floating in masses of marine plants (e.g., *Sargassum* rafts) in the open ocean. In the continental United States, the hawksbills typically occur in Florida and Texas. Most of these sightings involve post-hatchlings and juveniles and are primarily associated with stone jetties. These small turtles are believed to originate from nesting beaches in Mexico (NMFS, 2015d). The only documented nest on the Texas coast was found in 1998 at the South Padre Island National Seashore and remains the only recorded nest in Texas (NPS, 2016c). The Atlantic hawksbill sea turtle is likely to occur in the study area.

Kemp's ridley sea turtle. The Federally endangered Kemp's ridley sea turtle inhabits shallow coastal and estuarine waters, usually over sand or mud bottoms where prey can be found. Adults are primarily restricted to the Gulf, although juveniles may range throughout the Atlantic Ocean since they have been observed as far north as Nova Scotia (USFWS, 2015d). Kemp's ridley occurs in Texas in small numbers, and in many cases, may be in transit between crustacean-rich feeding areas in the northern Gulf and breeding grounds in Mexico. Almost the entire population of Kemp's ridley nests on a 16-mile stretch of coastline near Rancho Nuevo, Tamaulipas, Mexico, approximately 190 miles south of the Rio Grande. Nesting in Texas occurs on a much smaller scale but makes up the majority of the nests (NMFS, 2015e; NPS, 2015a). As of 2015, a total of 159 nests have been documented along the entire Texas coast with the majority occurring at the Padre Island National Seashore. Nests have been documented in Brazoria County (north of Surfside), Surfside Beach, and Quintana Beach (NPS, 2016c). This species is likely to occur within the study area.

Leatherback sea turtle. The Federally endangered leatherback sea turtle is probably the most wide-ranging of all sea turtle species. It occurs in the Atlantic, Pacific, and Indian oceans; as far north as British Columbia, Newfoundland, Great Britain, and Norway; as far south as Australia, Cape of Good Hope, and Argentina (USFWS, 2015e). The leatherback is mainly pelagic, inhabiting the open ocean, and seldom approaches land except for nesting, reproduction, or when following concentrations of jellyfish, when it can be found in inshore waters, bays, and estuaries (NMFS, 2015f; TPWD, 2015). They can dive to depths of 4,200 feet and stay down for up to 85 minutes. Leatherbacks nest primarily in tropical regions and only sporadically in some of the Atlantic and Gulf states of the continental United States (NMFS, 2015f). In the Atlantic and Caribbean, the largest nesting assemblages occur in the U.S. Virgin Islands, Puerto Rico, and Florida (NMFS, 2015c; NPS, 2015b). Until 2008, leatherback nests had not been recorded in Texas for 80 years when one nest was located at Padre Island National Seashore (NPS, 2016c). Leatherbacks are rare along the Texas coast and tend to keep to deeper offshore waters where their primary food source, jellyfish, occurs (NPS, 2015b; TPWD, 2015). Currently, there are no documented leatherback nests on the Texas coast (NPS, 2016c). Since leatherback sea turtles are mainly pelagic, this species is unlikely to occur in the study area.

Loggerhead sea turtle. The Federally endangered loggerhead sea turtle (*Caretta caretta*) is widely distributed in tropical and subtropical seas, being found in the Atlantic Ocean from Nova Scotia to Argentina, the Gulf of Mexico, the Mediterranean Sea, and the Indian and Pacific oceans (although it is rare in the eastern and central Pacific) (NMFS, 2015g; USFWS, 2015f). In the continental United States, loggerheads nest along the Atlantic coast from Florida to as far north as New Jersey and sporadically along the Gulf coast, including Texas (NMFS, 2015g; NPS, 2015c). Loggerhead populations have been in decline due to humans (shrimp trawling) and predators (NPS, 2015c). They prefer shallow inner continental shelf waters, occurring very infrequently in the bays. They can often be seen around offshore oil rig platforms, reefs, and jetties where they feed on crabs, mollusks, jellyfish, and Portuguese man-o-war (NMFS, 2015g; NPS, 2015c). Currently, eight loggerhead nests have been documented on the Texas coats, although all south of the study area (NPS, 2016c). Due to their habitat preference, it is unlikely that the loggerhead sea turtle would occur in the study area.

2.4.5.2.5 Fish Species

Largetooth sawfish. Largetooth sawfish (*Pristis pristis*) are generally restricted to brackish, shallow waters in coastal estuaries and bays. Largetooth and smalltooth sawfish had historically inhabited U.S. waters but have not been seen in more than 50 years. Current Atlantic populations are found around the Caribbean Ocean, Costa Rica, and Brazil (NMFS, 2015h). It is unlikely this species would occur in the study area.

2.4.5.2.6 Amphibian Species

Houston toad. The Houston toad (*Bufo houstonensis*) is a Federally listed, medium-sized toad found typically in sandy soils with woodlands interspersed with grassy areas or coastal prairies (USFWS, 2011a). Individuals burrow into the sand to hibernate during the winter. They emerge and congregate around sandy ponds and ditches in early spring to breed. Males have a high, clear trill call. Populations of the Houston toad have been in decline due to habitat destruction, invasion of the red imported fire ant, and the use of chemical pesticides (TPWD, 2016z). The population of Houston toad is unlikely to occur within the study area.

2.4.5.2.7 Mollusk Species

Golden orb. The golden orb (*Quadrula aurea*), a Federal candidate for listing, is an endemic freshwater mussel species found only in the Guadalupe-San Antonio and Nueces-Frio drainage basins. Shell color ranges from yellow-brown, gold, orange-brown, dark brown, or black. They are typically found in firm mud, sand, and gravel (Howells, 2014). Populations of golden orbs have been in decline mainly due to river impoundment, which restricts the dispersal of their host species, increases sedimentation, and reduces water flow (USFWS, 2015a). Because of the higher salinity of the lower river systems, it is unlikely for populations of the golden orb to occur within the study area.

Smooth pimpleback. The smooth pimpleback (*Quadrula houstonensis*), a Federal candidate for listing, is a freshwater mussel that is native only to the Colorado and Brazos river drainages. Shell coloration tends to range from tan, light and dark brown, chestnut, to black (Howells, 2002). They are typically found in creeks, rivers, and some reservoirs with a slow to moderate flow in mud, sand, or gravel bottoms (Howells, 2002, 2014). Due to

increased runoff and land management, this species has seen a dramatic reduction in distribution and abundance. Species in the Brazos River and its tributaries have been found to still be abundant (Karatayev and Burlakova, 2008). Because of the higher salinity of the lower river systems near the bay, it is unlikely for populations of smooth pimpleback to be found in the study area.

Texas fawnsfoot. The Texas fawnsfoot (*Truncilla macrodon*), a Federal candidate for listing, is extremely rare and endemic to the Brazos and Colorado rivers of Central Texas (Karatayev and Burlakova, 2008). Shell coloration tends to range from green, tan, yellow-brown, or reddish brown. Due to the rarity of this species, little is known about its life history and habitat requirements (Howells, 2014). A recent study by Howells (2014) found live species from the lower Brazos River in an area characterized by steep vegetative banks in a shallow pool area with soft sandy sediment. The population of the Texas fawnsfoot is unlikely to occur in the study area.

Texas pimpleback. The Texas pimpleback (*Quadrula petrina*), a Federal candidate for listing, is a large species of freshwater mussel endemic to the Guadalupe, San Antonio, and Colorado rivers. Its shell coloration can range from yellow to tan, brown to black with faint green rays, and concentric blotches. Populations are found in medium to larger rivers in mud, sand, and gravel bottoms (Howells, 2014). Texas pimplebacks have seen dramatic declines in their populations due to river impoundments, modified stream flows, and sedimentation (USFWS, 2015a). Because of higher salinity in the lower river system, it is unlikely for the population of the Texas pimpleback to occur within the study area.

2.4.5.2.8 Critical Habitat

The USFWS, in Section 3(5)(A) of the ESA, defines critical habitat as (i) the specific areas within the geographical area occupied by the species, at the time that it is listed in accordance with the ESA, on which are found those physical or biological features that are essential to the conservation of the species and that may require special management considerations or protection; and (ii) specific areas outside the geographical area occupied by a species at the time it is listed, upon a determination that such areas are essential for the conservation of the species.

Critical habitat for the Federally listed piping plover exists within South Bay, Boca Chica, Queen Isabella Causeway in Cameron County; Padre Island in Cameron, Willacy, Kenedy, and Kleberg counties; Lower and Upper Laguna Madre in Cameron, Willacy, and Kleberg counties; Mollie Beattie Coastal Habitat, Newport Pass/Corpus Christi Pass Beach, Mustang Island Beach, Fish Pass Lagoons, Shamrock Island, Mustang Island, Blind Oso, East Flats and adjacent to the Naval Air Station-Corpus Christi in Nueces County; Sunset Lake in San Patricio County; North Pass, San Jose Beach, Allison's Bight, and Cedar Bayou/Vinson Slough in Aransas County; Matagorda Island Beach, Ayers Point, and Panther Point to Pringle Lake in Calhoun County; Decros Point in Matagorda/Calhoun counties; West Matagorda Peninsula Beach, Western and Eastern Matagorda Peninsula Flats, Colorado River Diversion Delta, East Matagorda Bay, Brown Cedar Cut, and Northeast Corner East Matagorda Bay in Matagorda County; San Bernard NWR Beach in Matagorda/Brazoria counties; Gulf Beach between Brazos and San Bernard Rivers/Bryan Beach in Brazoria County; San Luis Pass in Brazoria/Galveston counties; and Big Reef, Bolivar Flats, and Rollover Flats in Galveston County (USFWS, 2001).

Critical habitat for the endangered whooping crane in Texas encompasses Aransas NWR and Matagorda Island in Refugio and Aransas counties (USFWS, 1978).

2.4.5.3 Essential Fish Habitat

This DIFR-EIS will serve to initiate Essential Fish Habitat (EFH) consultation under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). Congress enacted amendments to the MSFCMA (Public Law 94-265) in 1996 that established procedures for identifying EFH and required interagency coordination to further the conservation of Federally managed fisheries. The MSFCMA is necessary to prevent overfishing, to rebuild overfished stocks, to ensure conservation, to facilitate long-term protection of EFH, and to realize the full potential of the Nation's fishery resources. The MSFCMA protects fish and shellfish that occur in U.S. waters, the highly migratory species of the high seas, the species that dwell on or in the continental shelf appertaining to the United States, and the anadromous species, which spawn in U.S. rivers or estuaries and constitute valuable and renewable natural resources (U.S. Department of Commerce, 2007). Rules published by the NMFS (50 CFR sections 600.805–600.930) specify that any Federal agency that authorizes, funds or undertakes, or proposes to authorize, fund, or undertake an activity that could adversely affect EFH is subject to the consultation provisions of the above-mentioned act and identified consultation requirements.

EFH is defined as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” EFH is separated into estuarine and marine components. The estuarine component is defined as “all estuarine waters and substrates (mud, sand, shell, rock, and associated biological communities); subtidal vegetation (seagrasses and algae); and adjacent intertidal vegetation (marshes and mangroves).” The marine component is defined as “all marine waters and substrates (mud, sand, shell, rock, and associated biological communities) from the shoreline to the seaward limit of the Exclusive Economic Zone” (200 nautical miles from the coast) (Gulf of Mexico Fisheries Management Council, 2004). Adverse effect to EFH is defined as, “any impact, which reduces quality and/or quantity of EFH…” and may include direct, indirect, site-specific or habitat impacts, including individual, cumulative, or synergistic consequences of actions.

Within areas identified as EFH, Habitat Areas of Particular Concern may be designated in order to focus conservation priorities on areas that are important to the life cycles of Federally managed species and may warrant more-targeted protection measures. Designation of specific Habitat Areas of Particular Concern is based on ecological function, habitats sensitive to human-induced environmental degradation, stressors of development activities, and habitat rarity (Dobrzynski and Johnson, 2001). No Habitat Areas of Particular Concern are designated in the study area (NOAA, 2016e).

Table 2-25 lists the species that NMFS and the Gulf of Mexico Fisheries Management Council identify in the study area as EFH. The categories of EFH that occur within the study area include estuarine water column, estuarine mud and sand bottoms (unvegetated estuarine benthic habitats), estuarine shell substrate (oyster reefs and shell substrate), estuarine emergent wetlands, seagrasses, and mangroves.

Table 2-25
Species Identified as Essential Fish Habitat in the Study Area

Common Name*	Species Name*	Coastal Region		
		Upper	Mid	Lower
Brown shrimp	*Farfantepenaeus aztecus*	X	X	X
Pink shrimp	*Farfantepenaeus duorarum*	X	X	X
White shrimp	*Litopenaeus setiferus*	X	X	X
Blacknose shark	*Carcharhinus acronotus*	X	X	X
Atlantic angel shark	*Squatina dumeril*			X
Spinner shark	*Carcharhinus brevipinna*	X	X	X
Silky shark	*Carcharhinus falciformis*		X	X
Finetooth shark	*Carcharhinus isodon*		X	X
Bull shark	*Carcharhinus leucas*	X	X	X
Blacktip shark	*Carcharhinus limbatus*	X	X	X
Dusky shark	*Carcharhinus obscurus*		X	
Tiger shark	*Galeocerdo cuvier*	X	X	X
Lemon shark	*Negaprion brevirostris*	X	X	X
Atlantic sharpnose shark	*Rhizoprionodon terraenovae*	X	X	X
Scalloped hammerhead shark	*Sphyrna lewini*	X	X	X
Great hammerhead shark	*Sphyrna mokarran*	X	X	X
Bonnethead shark	*Sphyrna tiburo*	X	X	X
Red grouper	*Epinephelus morio*	X	X	X
Gag grouper	*Mycteroperca microlepis*	X	X	X
Scamp	*Mycteroperca phenax*	X	X	X
Cobia	*Rachycentron canadum*	X	X	X
Dolphin	*Coryphaena hippurus*		X	X
Greater amberjack	*Seriola dumerili*	X	X	X
Lesser amberjack	*Seriola fasciata*	X	X	X
Red snapper	*Lutjanus campechanus*	X	X	X
Gray snapper	*Lutjanus griseus*	X	X	X
Lane snapper	*Lutjanus synagris*	X	X	X
Vermilion snapper	*Rhomboplites aurorubens*	X	X	X
Red drum	*Sciaenops ocellatus*	X	X	X
Little tunny	*Euthynnus alletteratus*	X	X	X
King mackerel	*Scomberomorus cavalla*	X	X	X
Spanish mackerel	*Scomberomorus maculatus*	X	X	X
Sailfish	*Istiophorus platypterus*		X	X
Blue marlin	*Makaira nigricans*			X

Source: NMFS (2009); NOAA (2013b, 2016e).

* Species according to Page et al. (2013).

Tables 2-26 through 2-28 describe the relative abundance and adult and juvenile presence of each EFH managed species occurring in the study area. Relative abundance is defined as follows (Nelson et al., 1992):

- Highly Abundant: Species numerically dominant relative to others
- Abundant: Species often encountered in substantial numbers relative to others
- Common: Species generally encountered but not in large numbers and not evenly distributed over specific salinity zones
- Rare: Species present but not frequently encountered
- Not Present: Species not found in area

2.4.5.4 Migratory Birds

The Migratory Bird Treaty Act (MBTA) of 1918 makes it illegal to kill, possess, transport, buy, sell, or trade any migratory bird parts, nest, or eggs unless a valid Federal permit is issued (USFWS, 2017b).

There are several NWRs, WMAs, parks, dredge islands, and protected areas along the Texas Gulf coast that provide nesting habitat and support rookeries for migratory birds. The USFWS has listed 59 migratory species that may use or have the potential to use the islands and other land areas near the study area (Table 2-29) (USFWS, 2018g). Twenty-one of the 59 species are found year-round such as the American kestrel (*Falco sparverius paulus*) and reddish egret (*Egretta rufescens*). Seventeen species such as the long-billed curlew (*Numenius americanus*) and red knot winter along the Gulf coast. Twelve species including elf owl (*Micrathene whitneyi*) and prothonotary warbler (*Protonotaria citrea*) have breeding ranges along the coast. There are nine migrant species such as the cerulean warbler (*Dendroica cerulea*) and hudsonian godwit (*Limosa haemastica*) that migrate through the study area.

2.4.5.5 Marine Mammals

The MMPA of 1972 was established to prevent the decline of marine mammal species and populations. It prohibits the taking (harassment, injury, killing) and importing of marine mammals and products into the United States. The MMPA applies to all marine mammal species and implementation is shared with NMFS (whales, dolphins, seals, and sea lions) and the USFWS (polar bear, sea otters, marine otter, walrus, and manatees) (NOAA, 2017e).

During the initial phase of preparing the DIFR-EIS both agencies (NMFS and USFWS) were contacted, as cooperating agencies, to solicit information on marine mammals inhabiting the proposed project area and identify data gaps and potential risks based on general information provided to these agencies regarding possible project alternatives. The USACE Project Delivery Team will continue to coordinate with NMFS and USFWS in order to further refine the understanding of the effects that the various project alternatives would have on marine mammals and how these can be minimized.

Table 2-26
Species Adult and Juvenile Presence in the Upper Texas Coast for Identified Essential Fish Habitat

Common/Scientific Name*	Estuarine								Marine	
	Sabine Lake		Galveston Bay		Brazos River		Matagorda Bay			
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
Brown shrimp (*Farfantepenaeus aztecus*)	abundant July–Oct common Nov–Mar major nursery area	common Apr-Oct	abundant year-round major nursery area	common Apr–Oct	abundant year-round major nursery area	not present	common to highly abundant year-round major nursery area	common to highly abundant Apr-July	spawning area year-round	major adult area spring, summer, fall
Pink shrimp (*Farfantepenaeus duorarum*)	nursery area summer and fall	not present	nursery area summer and fall	not present to rare	common Nov–June	not present	nursery area summer and fall	common Feb-May	nursery area summer and fall	present year-round spawning area in summer
White shrimp (*Litopenaeus setiferus*)	highly abundant Apr–Dec nursery area	highly abundant Aug-Mar common Apr-July	highly abundant Apr–Dec common Jan–Mar nursery area	rare to common year-round	highly abundant July–Oct abundant Nov–June nursery area	common Apr–June	highly abundant Feb–Nov rare to not present Dec–Jan nursery area	abundant March common Apr–June, Aug–Nov	not present	present year-round spawning Mar–Oct
Blacknose shark (*Carcharhinus acronotus*)	not present		not present		not present		not present		not present	present
Spinner shark (*Carcharhinus brevipinna*)	not present		present	not present	not present		present	not present	present	not present
Finetooth shark (*Carcharhinus isodon*)	not present		not present		not present		not present		present	
Bull shark (*Carcharhinus leucas*)	rare Mar–Oct	not present	common Mar–Nov	not present	present		present	not present	present	
Blacktip shark (*Carcharhinus limbatus*)	not present		present	not present	not present		present	not present	present	

Common/Scientific Name*	Estuarine								Marine	
	Sabine Lake		Galveston Bay		Brazos River		Matagorda Bay			
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
Tiger Shark (*Galeocerdo cuvier*)	not present		not present		not present				present	
Lemon shark (*Negaprion brevirostris*)	not present		not present	present	not present		present		present	
Atlantic sharpnose shark (*Rhizoprionodon terraenovae*)	not present		present		not present		present		present	
Scalloped hammerhead shark (*Sphyrna lewini*)	not present		present	not present	not present		present	not present	present	not present
Great hammerhead shark (*Sphyrna mokarran*)	not present		not present		not present		not present		present	
Bonnethead shark (*Sphyrna tiburo*)	not present		present	not present	not present		present		present	
Red grouper (*Epinephelus morio*)	not present		not present		not present		not present		nursery area year-round	adult occurrence
Gag grouper (*Mycteroperca microlepis*)	not present		not present		not present		not present		not present	adult occurrence
Scamp (*Mycteroperca phenax*)	not present		not present		not present		not present		not present	adult occurrence
Cobia (*Rachycentron canadum*)	not present		nursery area year-round	adult area summer	nursery area year-round	not present	nursery area year-round	not present	nursery area year-round	present summer
Greater amberjack (*Seriola dumerili*)	not present		not present		not present		not present		present year-round	adult and spawning area year-round
Lesser amberjack (*Seriola fasciata*)	not present		not present		not present		not present		not present	present

Common/Scientific Name*	Estuarine								Marine	
	Sabine Lake		Galveston Bay		Brazos River		Matagorda Bay			
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
Red snapper (*Lutjanus campechanus*)	not present		nursery area year-round	not present	nursery area year-round	not present	nursery area year-round	not present	nursery area year-round	not present
Gray snapper (*Lutjanus griseus*)	not present		nursery area	major adult area year-round	not present		nursery area	major adult area year-round	not present	major adult area year-round spawn June–Aug
Lane snapper (*Lutjanus synagris*)	nursery area	not present	nursery area	not present	nursery area	not present	nursery area	not present	nursery area	not present
Vermilion snapper (*Rhomboplites aurorubens*)	not present		not present		not present		not present		nursery area	not present
Red drum (*Sciaenops ocellatus*)	common year-round nursery area	present year-round	common year-round nursery area	present year-round	common year-round nursery area	common year-round	nursery area year-round	common year-round	not present	present year-round spawning area fall and winter
Little tunny (*Euthynnus alletteratus*)	not present		not present		not present		not present		present	
King mackerel (*Scomberomorus cavalla*)	not present		nursery area year-round	present year-round	nursery area year-round	present year-round	not present		nursery area year-round	present year-round spawning area May–Nov
Spanish mackerel (*Scomberomorus maculatus*)	rare to not present	common Apr–June	common May–Oct nursery area	not present	rare to not present	present year-round	nursery area year-round	common July–Oct rare Nov-June	nursery area year-round	present year-round spawning area summer and fall

Source: Nelson et al. (1992); NMFS (2009); NOAA (2013b, 2016e); pers. com. R. Swafford (NMFS, 2018).

* Species according to Page et al. (2013).

Table 2-27
Species Adult and Juvenile Presence in the Mid Texas Coast for Identified Essential Fish Habitat

Common/Scientific Name*	Estuarine								Marine	
	San Antonio Bay		Aransas Bay		Corpus Christi/ Upper Laguna Madre		Baffin Bay			
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
Brown shrimp (*Farfantepenaeus aztecus*)	common to highly abundant year-round major nursery area	abundant May–June common April, July–Sept	abundant July–Mar abundant to highly abundant Apr–June major nursery area	not present	common July–Mar common to highly abundant Apr–June major nursery area	present Mar–May	highly abundant May–July abundant Aug–May major nursery area	not present	spawning area year-round	major adult area spring, summer, fall
Pink shrimp (*Farfantepenaeus duorarum*)	common Feb-Apr	common Mar-June	common Aug–Apr	common Mar–Apr	common Aug-June	not present	common Nov–Mar abundant Apr–June	present spring	nursery area summer and fall	present year-round spawning area in summer
White shrimp (*Litopenaeus setiferus*)	highly abundant May–July common to abundant Aug–May nursery area	highly abundant Sept common to abundant May–Aug, Oct–Dec	abundant June–Nov common Dec	common Sept-Nov, Apr–May	abundant July–Oct common Nov-June nursery area	abundant Aug–Mar common Apr–June	common Nov–Jul abundant Aug–Oct nursery area	present summer	not present	present year-round Aransas and Corpus Christi bays present summer Upper Laguna Madre and Baffin Bay present year-round spawning Mar–Oct
Blacknose shark (*Carcharhinus acronotus*)	not present		present	not present	present	not present	present	not present	present	
Spinner shark (*Carcharhinus brevipinna*)	present	not present	not present		not present		not present		present	
Finetooth shark (*Carcharhinus isodon*)	not present		not present		not present		not present		present	
Bull shark (*Carcharhinus leucas*)	common Mar–Nov	not present	common Mar–Nov	not present	common Mar–Oct	not present	present		present	

Common/Scientific Name*	Estuarine								Marine	
	San Antonio Bay		Aransas Bay		Corpus Christi/ Upper Laguna Madre		Baffin Bay			
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
Blacktip shark (*Carcharhinus limbatus*)	present		present		present		present		present	
Dusky shark (*Carcharhinus obscurus*)	not present		not present		not present		not present		present	
Tiger shark (*Galeocerdo cuvier*)	not present		present		present		not present		present	
Lemon shark (*Negaprion brevirostris*)	present		not present	present	not present	present	not present		present	
Atlantic sharpnose shark (*Rhizoprionodon terraenovae*)	present		present		present		not present		present	
Scalloped hammerhead shark (*Sphyrna lewini*)	present	not present	present	not present	present	not present	present	not present	present	
Great hammerhead shark (*Sphyrna mokarran*)	not present		not present		present		not present		present	
Bonnethead shark (*Sphyrna tiburo*)	present		present		present		present		present	
Red grouper (*Epinephelus morio*)	not present		not present		not present		not present		nursery area year-round	adult occurrence
Gag grouper (*Mycteroperca microlepis*)	not present		not present		not present		not present		not present	adult occurrence
Scamp (*Mycteroperca phenax*)	not present		not present		not present		not present		not present	adult occurrence
Cobia (*Rachycentron canadum*)	nursery area year-round	not present	nursery area year-round	not present	nursery area year-round	not present	nursery area year-round	not present	nursery area year-round	present summer
Dolphin (*Coryphaena hippurus*)	not present		not present		not present		not present		present year-round	

Common/Scientific Name*	Estuarine								Marine	
	San Antonio Bay		Aransas Bay		Corpus Christi/ Upper Laguna Madre		Baffin Bay			
	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
Greater amberjack (*Seriola dumerili*)	not present		not present		not present		not present		present year-round	adult and spawning area year-round
Lesser amberjack (*Seriola fasciata*)	not present		not present		not present		not present		not present	present
Red snapper (*Lutjanus campechanus*)	nursery area year-round	not present	nursery area year-round	not present	nursery area year-round	not present	not present		nursery area year-round	not present
Gray snapper (*Lutjanus griseus*)	nursery area	major adult area year-round	nursery area	major adult area year-round	nursery area	major adult area year-round	nursery area	major adult area year-round	not present	major adult area year-round spawn June-August
Lane snapper (*Lutjanus synagris*)	nursery area	not present	nursery area	not present	nursery area	not present	nursery area	not present	nursery area	not present
Vermilion snapper (*Rhomboplites aurorubens*)	not present		not present		not present		not present		nursery area	not present
Red drum (*Sciaenops ocellatus*)	common year-round nursery area	present year-round	common year-round nursery area	present year-round	common year-round nursery area	present year-round	common year-round nursery area	present year-round	not present	present year-round spawning area fall and winter
Little tunny (*Euthynnus alletteratus*)	not present		not present		not present		not present		present	
King mackerel (*Scomberomorus cavalla*)	not present		not present		not present		not present		nursery area year-round	present year-round spawning area May–Nov
Spanish mackerel (*Scomberomorus maculatus*)	nursery area year-round	present year-round	nursery area year-round	present year-round	nursery area year-round	present year-round	nursery area year-round	present year-round	nursery area year-round	present year-round spawning area summer and fall
Sailfish (*Istiophorus platypterus*)	not present		not present		not present		not present		not present	present

Source: Nelson et al. (1992); NMFS (2009); NOAA (2013b, 2016e); pers. com. R. Swafford (NMFS), 2018.

* Species according to Page et al. (2013).

Table 2-28
Species Adult and Juvenile Presence in the Lower Texas Coast for Identified Essential Fish Habitat

Common/ Scientific Name*	Estuarine		Marine	
	Lower Laguna Madre			
	Juvenile	Adult	Juvenile	Adult
Brown shrimp (*Farfantepenaeus aztecus*)	common June–July abundant Aug–Nov major nursery area	common Mar–May	spawning area year-round	major adult and spawning area year-round
Pink shrimp (*Farfantepenaeus duorarum*)	common to abundant Sept–April nursery area year-round	common Mar–April adult and spawning area year-round	nursery area summer and fall	present year-round spawning area in summer
White shrimp (*Litopenaeus setiferus*)	common to abundant May–Nov nursery area	common Mar–May spawn Mar–Oct	not present	present year-round spawning area Mar–Oct
Blacknose shark (*Carcharhinus acronotus*)	not present		present	not present
Atlantic angel shark (*Squatina dumeril*)	not present		present	
Spinner shark (*Carcharhinus brevipinna*)	present	not present	present	
Silky shark *Carcharhinus falciformis*)	present		present	
Finetooth shark (*Carcharhinus isodon*)	not present		present	
Bull shark (*Carcharhinus leucas*)	present		present	
Blacktip shark (*Carcharhinus limbatus*)	present		present	
Tiger shark (*Galeocerdo cuvier*)	not present	present	not present	present
Lemon shark (*Negaprion brevirostris*)	present	not present	present	not present
Atlantic sharpnose shark (*Rhizoprionodon terraenovae*)	present		present	

Common/ Scientific Name*	Estuarine		Marine	
	Lower Laguna Madre			
	Juvenile	Adult	Juvenile	Adult
Scalloped hammerhead shark (*Sphyrna lewini*)	present	not present	present	
Great hammerhead shark (*Sphyrna mokarran*)	not present		present	
Bonnethead shark (*Sphyrna tiburo*)	present		present	
Red grouper (*Epinephelus morio*)	not present		nursery area year-round	adult occurrence
Gag grouper (*Mycteroperca microlepis*)	not present		not present	adult occurrence
Scamp (*Mycteroperca phenax*)	not present		not present	adult occurrence
Cobia (*Rachycentron canadum*)	nursery area spring-fall	not present	nursery area spring-fall	present spring-fall
Dolphin (*Coryphaena hippurus*)	not present		present year-round	
Greater amberjack (*Seriola dumerili*)	not present		present year-round	adult and spawning area year-round
Lesser amberjack (*Seriola fasciata*)	not present		not present	present
Red snapper (*Lutjanus campechanus*)	nursery area year-round	not present	nursery area year-round	not present
Gray snapper (*Lutjanus griseus*)	nursery area	major adult area year-round	not present	major adult area year-round spawning area June-Aug
Lane snapper (*Lutjanus synagris*)	nursery area	not present	nursery area	adult and spawning area year-round
Vermilion snapper (*Rhomboplites aurorubens*)	not present		nursery area	not present
Red drum (*Sciaenops ocellatus*)	common year-round nursery area	present year-round	not present	present year-round spawning area fall and winter

Common/ Scientific Name*	Estuarine		Marine	
	Lower Laguna Madre			
	Juvenile	Adult	Juvenile	Adult
Little tunny (*Euthynnus alletteratus*)	not present		present	
King mackerel (*Scomberomorus cavalla*)	not present		nursery area year-round	present year-round spawning area May–Nov
Spanish mackerel (*Scomberomorus maculatus*)	nursery area year-round	present year-round	nursery area year-round	present year-round spawning area summer and fall
Sailfish (*Istiophorus platypterus*)	not present		present	not present
Blue marlin (*Makaira nigricans*)	present	not present	not present	

Source: Nelson et al. (1992); NMFS (2009); NOAA (2013b, 2016e); pers. com. R. Swafford (NMFS), 2018.

* Species according to Page et al. (2013).

Table 2-29
Migratory Birds Listed by the USFWS That May Be Found within the Study Area

Common Name	Scientific Name	Season(s)
Altamira Oriole	*Icterus gularis*	Year-round
American Golden Plover	*Pluvialis dominica*	Migrant
American Kestrel	*Falco sparverius paulus*	Year-round
American Oystercatcher	*Haematopus palliatus*	Year-round
Audubon's Oriole	*Icterus graduacauda audubonii*	Year-round
Audubon's Shearwater	*Puffinus Iherminieri*	Migrant
Band-rumped Storm-petrel	*Oceanodroma castro*	Migrant
Bewick's Wren	*Thryomanes bewickii*	Year-round
Black Rail	*Laterallus jamaicensis*	Year-round
Black Skimmer	*Rynchops niger*	Year-round
Botteri's Sparrow	*Aimophila botterii*	Breeding
Bridled Tern	*Onychoprion anaethetus recongnitus*	Migrant
Buff-breasted Sandpiper	*Tryngites subruficollis*	Migrant
Burrowing Owl	*Athene cunicularia*	Year-round
Cassin's Sparrow	*Aimophila cassinii*	Year-round
Cerulean Warbler	*Dendroica cerulea*	Migrant
Chestnut-collared Longspur	*Calcarius ornatus*	Migrant
Clapper Rail	*Rallus longirostris*	Year-round
Curve-billed Thrasher	*Toxostoma curvirostre*	Year-round
Dunlin	*Calidris alpina hudsonia*	Wintering
Eastern Whip-poor-will	*Antrostomus vociferus*	Breeding
Elf Owl	*Micrathene whitneyi*	Breeding
Gull-billed Tern	*Gelochelidon nilotica*	Year-round
Harris's Hawk	*Parabuteo unicinctus*	Year-round
Harris's Sparrow	*Zonotrichia querula*	Wintering
Henslow's Sparrow	*Ammodramus henslowii*	Breeding
Hooded Oriole	*Icterus cucullatus*	Breeding
Hudsonian Godwit	*Limosa haemastica*	Migrant
Kentucky Warbler	*Oporornis formosus*	Breeding
King Rail	*Rallus elegans*	Year-round
Lark Bunting	*Calamospiza melanocorys*	Wintering
Le Conte's Sparrow	*Ammodramus leconteii*	Wintering
Least Tern	*Sterna antillarum*	Year-round
Lesser Yellowlegs	*Tringa flavipes*	Wintering
Long-billed Curlew	*Numenius americanus*	Wintering
Magnificent Frigatebird	*Fregata magnificens*	Migrant
Marbled Godwit	*Limosa fedoa*	Wintering

Common Name	Scientific Name	Season(s)
Mountain Plover	*Charadrius montanus*	Wintering
Nelson's Sparrow	*Ammodramus nelsoni*	Wintering
Prairie Warbler	*Dendroica discolor*	Breeding
Prothonotary Warbler	*Protonotaria citrea*	Breeding
Red Knot	*Calidris canutus*	Wintering
Red-headed Woodpecker	*Melanerpes erythrocephalus*	Year-round
Reddish Egret	*Egretta rufescens*	Year-round
Ruddy Turnstone	*Arenaria interpres morinella*	Wintering
Rufous-crowned Sparrow	*Aimophila ruficeps*	Year-round
Seaside Sparrow	*Ammodramus maritimus*	Year-round
Semipalmated Sandpiper	*Calidris pusilla*	Wintering
Short-billed Dowitcher	*Limnodromus griseus*	Wintering
Smith's Longspur	*Calcarius pictus*	Wintering
Snowy Plover	*Charadrius alexandrinus*	Year-round
Sprague's Pipit	*Anthus spragueii*	Wintering
Swallow-tailed Kite	*Elanoides forficatus*	Breeding
Varied Bunting	*Passerina versicolor*	Breeding
Whimbrel	*Numenius phaeopus*	Wintering
Whooping Crane	*Grus Americana*	Wintering
Willet	*Tringa semipalmata*	Year-round
Wilson's Plover	*Charadrius wilsonia*	Breeding
Wood Thrush	*Hylocichla mustelina*	Breeding
Yellow Rail	*Coturnicops noveboracensis*	Wintering

Source: Audubon (2017); USFWS (2018g).

Bays, estuaries, and nearshore waters of Texas are home to the common bottlenose dolphin (*Tursiops truncatus truncatus*). No other species of marine mammal regularly inhabits these waters as part of their natural range. However, the Federally threatened West Indian manatee (*Trichechus manatus*) occurs as an occasional vagrant within these waters. While a total of 27 other cetacean species inhabit the Northern Gulf, few are likely to interact with the shoreline in a way that would risk direct impact from the implementation of the Coastal Texas Study (Würsig, Jefferson, et al., 2000).

2.4.5.5.1 West Indian Manatee (*Trichechus manatus*)

Manatee occur primarily in Florida within the northern Gulf, though historically they were known to occur more often throughout the northern Gulf and were even considered common in south Texas (Gunter, 1941). Minimum population estimates for the single Florida stock of manatee as of January 2011 was 4,834, and trends are considered stable or increasing, prompting a recent downlisting from “endangered” to “threatened” under the ESA (USFWS, 2014b). Fertl et al. (2005) provides a review of manatee sightings west of Florida dating through August 2004 and attributes an increase in sightings outside of their traditional range to a combination of dispersal and increased public awareness. The authors report 66 records (53 sightings, 8 carcasses, and 5 captures) in Texas

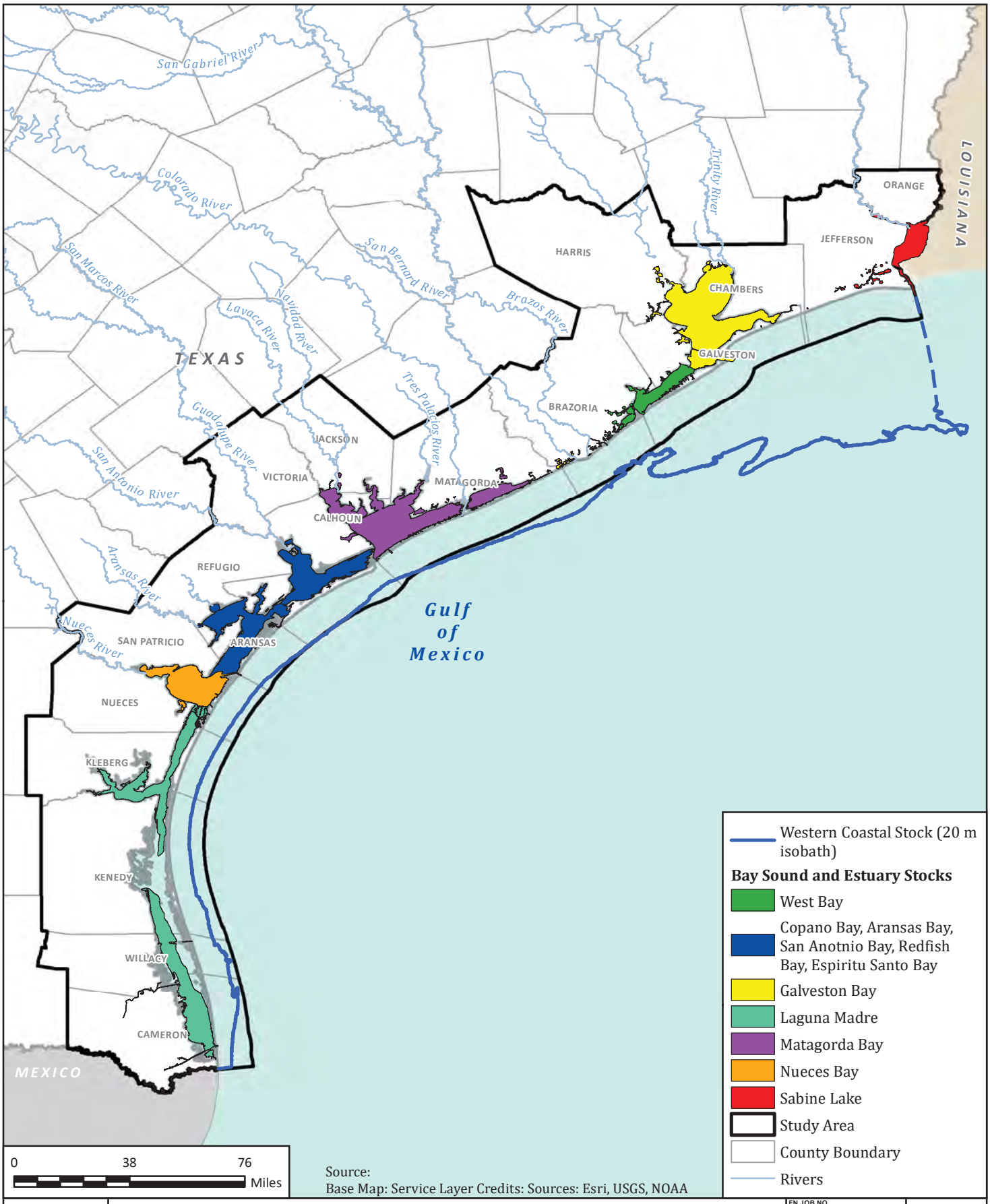
dating back to 1912. Manatee in Texas may stray from populations in either Florida or Mexico as an extension of their natural seasonal migration in warm weather or possibly in response to Gulf conditions during notably active hurricane seasons (Fertl et al., 2005). They are typically found in estuarine habitats in search of seagrasses, sources of fresh water, and warm water effluents in winter. Top threats to manatee include vessel collisions, cold water, and loss of seagrass foraging habitats (Runge et al., 2012).

2.4.5.5.2 Common Bottlenose Dolphin (*Tursiops truncatus truncatus*)

Stock Status, Distribution, and Seasonality. The MMPA defines a stock as "a group of marine mammals of the same species or smaller taxa in a common spatial arrangement that interbreed when mature." Bottlenose dolphins inhabiting bay, sound, and estuary (BSE) habitats of the northern Gulf are divided by the NMFS into 31 geographically defined stocks for management purposes (Hayes et al., 2017; Waring et al., 2016). Six of these BSE stocks are found in Texas, and a seventh stock straddles the Texas-Louisiana border including 1) Laguna Madre, 2) Corpus Christi and Nueces bays, 3) Redfish, Aransas, Copano, San Antonio, and Espiritu Santo bays, 4) Lavaca, Tres Palacios, and Matagorda bays, 5) West Bay, 6) Galveston Bay, and 7) Sabine Lake (Figure 2-15). Abundance estimates for Texas BSE stocks are mostly based on outdated aerial surveys from the early 1990s (a method now generally considered insufficient for finding dolphins in BSE environments). Abundance estimates for all stocks are currently considered "unknown" for management purposes (Hayes et al., 2017).

Some information concerning the distribution and seasonality of the BSE stocks in Texas are known, for example: mixing of inshore and non-residents has been seen at San Luis Pass, fall/winter increases in abundance are thought to occur in Matagorda Bay and Aransas Pass, and spring/summer increases in abundance are thought to occur in Galveston Bay. Additionally, it is thought that there is not enough estuarine habitat to support a demographically independent population of bottlenose dolphins between Matagorda Bay and West Bay although some usable habitat does exist in that stretch. Also, a number of geographically and socially distinct subgroupings of dolphins in Aransas Pass and Matagorda Bay have been identified but the importance of these distinctions to the stock designations remains undetermined (Hayes et al., 2018). There have also been some common anthropogenic stressors documented by Hayes et al. (2018) for bottlenose dolphins inhabiting BSE habitats along the Texas coast, and they include: potential injury from shrimp trawls, risk of entanglement with lines from commercial and recreational blue crab pots, risk of injury from gillnets used for research purposes, potential injury from interaction with commercial and recreational hook and line tackle, and potential injury or death caused by individuals with firearms or archery equipment. Since 1990, there have been 13 bottlenose dolphin die-offs in the northern Gulf; 6 of these involved stocks along the Texas coast. While the causes of these die-offs remain unknown, it is thought that harmful algal bloom toxins may have played a role in many of the events (Hayes et al., 2018).

Only four of the defined BSE stocks have individual stock assessment reports (Waring et al., 2016). The latest stock assessment report for the northern Gulf BSE stocks includes information up through 2017 (Hayes et al. 2018). Hayes et al. (2018) stated that the NMFS is in the process of writing individual stock assessment reports for each of the 31 BSE stocks of common bottlenose dolphins in the Gulf. Recent communications with NOAA staff confirm that updated estimates for Galveston Bay and West Bay are in process (pers. com. K. Mullin [NOAA



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Common Bottlenose Dolphin Stock Locations

FN JOB NO	COH16388
FILE NAME	2_16_Marine_Mammals.mxd
DATE	8/2/2018
SCALE	1:2,700,000
DESIGNED	SSJ
DRAFTED	SSJ

2-15
FIGURE

GCS WGS 1984

Southeast Fisheries Science Center], 2018). Until this effort is completed, basic information for Texas bay and estuary stocks will continue to be reported under the Northern Gulf of Mexico BSE Stocks section of the stock assessment report (Hayes et al. 2018).

The Final 2017 Marine Mammal Stock Assessment reports are now available (NOAA, 2018b). Examination of the draft document indicates the stock assessment report for the Texas BSE stocks will not be formally updated. Therefore, the next revision to the stock assessment report for BSE stocks including Galveston and West Bay stocks will not likely be released until 2019.

Bordering Texas BSE stocks is the Western Coastal Stock, a nearshore coastal stock inhabiting a geographically defined region from the barrier islands to the 20-meter isobath, extending from the southern tip of Texas to the Mississippi River Delta (see Figure 2-15). This coastal region represents a management zone where genetically distinct offshore and coastal/nearshore ecotypes could potentially coexist and where coastal and BSE populations may overlap (Waring et al., 2013). While the Western Coastal Stock is currently not classified "strategic," all Texas BSE stocks are considered "strategic" due to unknown abundance estimates and evidence that most of these stock sizes are likely small and demographically distinct from adjacent and sometimes overlapping stocks. Due to these factors, it is predicted that relatively low levels of human-caused mortality have the potential to exceed potential biological removal and bring populations below optimum sustainable population size (Hayes et al., 2017; Waring et al., 2013).

A strategic stock is defined by the MMPA as a marine mammal stock 1) for which the level of direct human-caused mortality exceeds the potential biological removal level; 2) which, based on best available scientific information, is declining and is likely to be listed as a threatened species under the ESA within the foreseeable future; or 3) which is listed as a threatened or endangered species under the ESA, or is designated as depleted under the MMPA. Although geographically defined stocks have been established, delineating biologically meaningful boundaries between and within coastal and BSE bottlenose dolphin stocks is difficult due to the fluid and complex social system of the species. Research supports the division of relatively discrete "communities" of dolphins within BSEs that show long-term site fidelity, a high degree of internal social interactions, and genetic differentiation from adjacent communities (Hubard and Swartz, 2002; Rosel et al., 2011; Scott et al., 1990; Wells et al., 1987). Emphasis is placed on protecting stable resident communities that would be at greatest risk from localized impacts. However, fine-scale characterization of Texas stocks remains insufficient to delineate biologically significant boundaries or to determine population abundance trends (Waring et al., 2013).

Seasonal distribution patterns are evident throughout Texas in bays, inlets, and nearshore waters. The likely differential use of some habitats by multiple stocks or communities of dolphins along the coast complicates defining these patterns, and seasonal changes likely reflect a combination of within-bay and coastal movements. Seasonal changes in density have been attributed to a combination of north-south migration along the coast influenced by water temperature and more localized shifts in distribution influenced by prey movements in and out of the estuary during different times of the year (Weller, 1998). Lynn and Würsig (2002) provide a review of Texas dolphin movement patterns and tentatively hypothesize that while small localized communities of Texas dolphins exhibiting high site fidelity to individual bays may be more susceptible to anthropogenic threats, these

populations may have the ability to recover due to the presence of transients and migratory individuals traveling between bays. They stress the unknown aspect of genetic mixing in these communities and the need for additional research.

Critical Behaviors. It is widely reported along the western Gulf coast that high concentrations of bottlenose dolphins regularly utilize deep channels and passes where estuarine and Gulf waters meet (Barham et al., 1980; Gruber, 1981; Jones, 1988; Leatherwood and Reeves, 1983; McHugh, 1989; Moreno, 2005; Ronje et al., 2017; Würsig and Lynn, 1996). These areas are likely to be mixing zones, including dolphins from multiple adjacent stocks that may display frequent movements between bay and Gulf environments. In the Galveston Bay region, high densities of dolphins concentrate in Bolivar Roads, the Houston Ship Channel, the Galveston Ship Channel, and just off beaches close to the inlet (Fazioli et al., 2018; Jones, 1988; Moreno, 2005; Ronje et al., 2017). Studies have shown that distinctive patterns of distribution and high-density "hot spots" are related to foraging behavior and that submarine habitat characteristics such as steep seabed gradients and deeper waters may be significant factors in foraging efficiency (Hastie et al., 2004; Moreno, 2005). Moreno (2005) specifically concluded that 94 percent of feeding groups within the lower Galveston Bay area occurred in Bolivar Roads or the Galveston Ship Channel, even though these areas constituted just 20 percent of the survey area. This, along with other evidence from research conducted within the Galveston Bay estuarine system, along the Texas coast, and in similar estuaries around the world leads to the conclusion that the inlet to Galveston Bay at Bolivar Roads is likely important dolphin foraging habitat.

Bottlenose dolphins exhibit a wide variety of prey preferences and have often been referred to as opportunistic feeders (Gaskin, 1982; Leatherwood, 1975; Shane et al., 1986); however, studies have shown that some populations exhibit selective feeding (Berens-McCabe et al., 2010; Corkeron et al., 1990; Santos et al., 2001). Soniferous (sound-producing) fishes from the family Sciaenidae (drums, trout, and croakers) are important prey sources for BSE bottlenose dolphins in Florida, North Carolina, and Texas (Barros and Odell, 1990; Berens-McCabe et al., 2010; Gannon and Waples, 2004). Dolphins may benefit energetically from passive listening to soniferous fishes to locate prey (Berens-McCabe et al., 2010; Gannon and Waples, 2004). Members of the fish family Sciaenidae and Mugilidae (mullets) are among the most abundant fishes in the northern Gulf inshore waters (Hoese and Moore, 1998). Dominant nekton species present in stomach contents from dolphins in Texas are Atlantic croaker, sand seatrout (*Cynoscion arenarius*), silver perch (*Bairdiella chrysoura*), Atlantic brief squid (*Lolliguncula brevis*), spot, and striped mullet (Barros and Odell, 1990; Gunter, 1941).

Dolphins in Galveston Bay are often associated with areas of human impact and anthropogenic activities. It is likely that the advantages of utilizing foraging strategies in these areas outweigh the disadvantages of disturbance. In addition to foraging in deep shipping channels, dolphins' association with shrimp trawlers is well documented in Galveston Bay (Fazioli et al., 2015; Fertl, 1994a; Henningsen and Würsig, 1992). Tolerance of these activities is evidence of the adaptive nature of bottlenose dolphins; however, studies show that vessel activity does alter dolphin behavior and whistle vocalizations in Galveston Bay (Candelaria-Ley, 2001; Pennacchi, 2013; Piwetz and Würsig, 2015). Evidence from other similar industrial environments indicates that vessel disturbance can lead to a reduction in foraging behavior and that an increase in vessel activity can lead to an avoidance response or

habitat displacement, even when dolphins are tolerant of high baseline levels of disturbance (Bejder, Samuels, Whitehead, Gales, Mann, et al., 2006; Pirotta et al., 2013, 2015).

Predator avoidance may play an important role in dolphin behavior, distribution, and habitat use patterns, with studies suggesting that foraging dolphin distributions reflect a trade-off between predation risk and food availability (Heithaus and Dill, 2002). Little is known about predator interactions in Galveston Bay, though shark bite scars have been noted in the population (Fertl, 1994b; Fazioli et al., 2018; Henningsen and Würsig, 1991). Sharks in the family Carcharhinidae, such as the bull shark (*Carcharhinus leucas*) and tiger shark (*Galeocerdo cuvier*), are common in the nearshore waters and coastal estuaries of the Gulf and are known to prey on dolphins (Froeschke et al., 2013; Hoese and Moore, 1998; Shane et al., 1986).

Calving in bottlenose dolphins may occur year-round but tends to show strong seasonal peaks. In Texas, evidence indicates this peak to be in March, with a smaller peak in November (Fazioli et al., 2018; Fernandez and Hohn, 1998; Urian et al., 1996). Scott et al. (1990) suggests that females may select sheltered habitats for newborn calves such as shallow enclosed secondary bays. While specific calving habitat has not yet been identified in Galveston Bay, known mom-calf groups tend to shift their distribution from upper to lower Galveston Bay, often in the eastern portions located away from the Houston Ship Channel, during November through April (Fazioli et al., 2018). Mothers with neonate calves appear to return to upper Galveston Bay in the late spring.

Bottlenose dolphins will travel frequently between important habitat areas and at times travel widely throughout their range, which for BSE stocks is believed to be more limited than for offshore stocks. Travel in and out of estuaries may occur regularly as dolphins utilize inshore, pass, and nearshore beach habitats. The frequency and importance of these movements for each stock utilizing Bolivar Roads is not well known; however, Jones (1988) noted apparent daily movements in and out of Bolivar Roads, with summer/fall movements from the pass to the beach and winter movements from the pass to the bay. Maze and Würsig (1999) documented West Bay resident dolphins moving seasonally in and out of San Luis Pass, primarily using inshore estuarine waters during summer months and Gulf and pass waters during winter months. In mid Texas bays, Lynn and Würsig (2002) found that resident dolphins left the bay system very infrequently, and McHugh (1989) found no evidence that the same dolphins utilized both inshore and offshore habitats.

Travel, rest, and social behaviors are important aspects of dolphin energy budgets in addition to foraging behavior. Evaluation of energy budgets and habitat use in relation to behavior provides insight into critical needs of the population and may help to delineate between communities with overlapping ranging patterns. For example, Henderson and Würsig (2007) found distinct differences in behavior patterns indicating habitat partitioning of adjacent communities of West Bay resident dolphins and Gulf coastal dolphins utilizing San Luis Pass.

Health. Health data for Texas dolphins are primarily gathered through the Texas Marine Mammal Stranding Network in cooperation with the NOAA Marine Mammal Health and Stranding Response Program. Bimodal stranding peaks occur in late fall/early winter with a larger peak during late February to early May, coinciding with dolphin calving seasons for the region. Bottlenose dolphin strand from offshore, coastal, and BSE stocks. Unusual mortality events with increased stranding occurrences for the region have been documented in 1990,

1992, 1994, 2007, 2008, and 2012 (Litz et al., 2014). Some unusual mortality events are Gulf-wide or affect mainly offshore or coastal stocks. However, the BSE population in Matagorda Bay was involved in both the 1990 and 1992 unusual mortality events. The causes of these events remain officially undetermined. The 1990 event coincided with a larger Gulf event attributed to morbillivirus, though a hard freeze caused abnormally low sea surface temperatures in Matagorda Bay and may have contributed to deaths in this region. In 1992, record rainfall leading to low salinity combined with pesticide runoff and morbillivirus exposure are thought to be possible contributing factors (Colbert et al., 1999; Litz et al., 2014).

Evidence suggests that dolphins residing within industrial coastal regions carry increased toxicant loads in their tissue and are subject to adverse effects on reproduction, endocrine function, and immune function (Ross, 2000; Schwacke et al., 2002; Stein et al., 2003). These health conditions, when combined with other environmental stressors, could cause immunosuppression, making dolphins more susceptible to disease (DeGuise et al., 2003; Fair and Becker, 2000; O'Shea et al., 1998; Schwacke et al., 2012; Stein et al., 2003). Contamination of water, sediment, and biological resources within Galveston Bay where there is a history of industrial contamination, including polynuclear aromatic hydrocarbons, PCBs, dioxin, chlorinated pesticides, and heavy metals is a current cause for heightened concern. Currently there is at least one known historical source of dioxins located at a Superfund site within the Galveston Bay system (EPA, 2018a). The TDSHS has issued seafood consumption advisories throughout the Galveston Bay system, and the TCEQ has initiated total maximum daily load projects for bioaccumulating pollutants including PCBs and dioxins in the Houston Ship Channel and upper Galveston Bay (Houston-Galveston Area Council [HGAC], 2012).

Bottlenose dolphins are physiologically adapted to inhabit brackish to oceanic coastal waters with salinities that typically range from 18 to 35 ppt. As such, they conserve freshwater through osmoregulation and are subject to negative health consequences and even death during prolonged exposure to low salinity environments (less than 10 ppt) (Colbert et al., 1999; Ewing et al., 2017). In addition to electrolyte imbalances resulting in changes to blood chemistry, several studies have documented the development of skin lesions characterized by degradation and ulceration of the epidermis accompanied by secondary infections from opportunistic pathogens (Colbert et al., 1999; Ewing et al., 2017; Mullin et al., 2015). While dolphins sometimes make short forays into riverine environments, or withstand short bouts of exposure to low salinity, current evidence suggests a candidate salinity threshold for establishing suitable dolphin habitat is less than or equal to 11 ppt (Ewing et al., 2017; Hornsby et al., 2017). Since 2015, the Galveston Bay Dolphin Research and Conservation Program has documented frequent cases of skin lesions consistent with documented prolonged freshwater exposure among dolphins in the Galveston Bay estuary (Fazioli et al., 2018). Much of the upstream portion of the Galveston Bay estuary is likely marginal habitat regarding salinity. Dolphins in this area may be impacted by prolonged low salinity exposure caused by increased freshwater runoff and flood events.

Catastrophic weather events, such as hurricanes, may impact dolphins indirectly through critical habitat damage, decreased prey availability, and water quality changes (salinity, hypoxia, and exposure to toxins) or directly through physical injury and habitat displacement (Bassos-Hull and Wells, 2007; Rosel and Watts, 2007). "Out of habitat" dolphins documented after hurricanes are sometimes trapped in areas outside their normal range in locations where they are likely to perish due to surrounding environmental conditions or lack of resources (Rosel

and Watts, 2007). After Hurricane Rita's landfall in Louisiana, seven bottlenose dolphins were found in various locations including flooded roadside ditches, borrow pits, larger canals, shallow flooded fields, and natural creeks. These locations were located 2.5 to 11 kilometers inland where salinities ranged from 10 to 15 ppt (Rosel and Watts 2007). The displaced animals were carried inland by the 15-foot storm surge accompanying the hurricane and were left stranded in areas that retained water longest as waters receded. From 2005 to 2017, a total of nine bottlenose dolphins were reported as "out of habitat" in Texas. Of these, four were reported as likely to be caused by storm surge: one during Tropical Storm Eduardo (2008), one during Hurricane Ike in 2008, and two during Hurricane Harvey in 2017 (NOAA, 2018c). Observations indicate that dolphins may change short-term distribution patterns in response to hurricanes (Fazioli et al., 2018), and one population in the Bahamas exhibited long-term post-hurricane changes to population structure (Elliser and Herzing, 2011). Bassos-Hull and Wells (2007) found no long-term impacts to the dolphin population in Charlotte Harbor, Florida, after Hurricane Charley devastated the shoreline.

Phillips and Rosel (2014) developed a process for prioritizing common dolphin stocks for stock assessment research based on an evaluation of the stressors faced by each stock, and the availability and quality of basic information on stock structure, abundance, and mortality for each stock. They found that the cumulative stressors of a heavily urbanized and industrialized watershed pose a high risk to the health of dolphins residing in Galveston Bay. A threat assessment performed by Phillips and Rosel (2014) identified the highest ranked risk factors to be chemical pollution, commercial and recreational fisheries, dredging and construction, algal blooms, hypoxia, adverse weather, freshwater inflows, and habitat loss. These risks when combined with virtually no data available on population structure, abundance, or mortality for this stock led NOAA to assign Galveston Bay a "high priority" ranking for stock assessment research and the highest risk score for the Texas coast in the assessment.

2.5 CULTURAL RESOURCES

The human landscape was examined over a broad study area encompassing over 18,000 square miles of the Texas Gulf coast across 18 counties. Over 5,200 cultural resources have been documented along the Texas coast within this study area. These resources include prehistoric and historic archeological sites, historic buildings and structures, historic and archeological districts, and cemeteries. Properties listed on the National Register of Historic Places (NRHP) include 506 properties, of which 14 are National Historic Landmarks (NHL) (Table 2-30).

Table 2-30
Cultural Resources in the Study Area

Area	Sites	NRHP Properties	NRHP Districts	Cemeteries
Upper Coast	2,097	311	34	418
Mid to Upper Coast	577	117	1	121
Mid Coast	950	17	4	79
Lower Coast	390	16	6	94
Totals	4,014	461	45	712

2.5.1 Upper Texas Coast

This region comprises the upper Texas coast (Orange, Jefferson, Chambers, Harris, Galveston, and Brazoria counties) and has been occupied by humans since the Paleoindian period dating to around 11,500 before present. There are over 2,000 prehistoric and historic archeological sites within the region. The region is characterized by dense woodlands in the east that transition to coastal prairies in the west and extensive bay and estuarine systems along the coast. The region is primarily drained by the Sabine River, the Trinity River, the San Jacinto River, Buffalo Bayou, and the Brazos River. Sediments in the region are generally fluvial sandy and silty clays overlying Pleistocene-aged clay. Prehistoric sites are commonly found within these upper sediments along streams and rivers and along the shorelines of the bays and Gulf coast, close to prime areas for resource exploitation. These sites include campsites, dense shell middens, and cemeteries, which contain projectile points; stone, bone, and shell tools; aquatic and terrestrial faunal remains; hearth features; ceramics; and in some cases, human remains and associated funerary objects. Historic-aged resources in the area consist of farmsteads and ranches, houses, buildings, bridges, tunnels, oil industry structures, cemeteries, lighthouses, shipwrecks, and the ruins of these buildings and structures. Although historic resources can occur anywhere, these sites tend to be concentrated in small towns and urban areas, along roads, and within current and historic navigation paths. Shipwrecks may also occur in numerous locales due to the dynamic nature of the sea floor and bay bottoms and the lack of navigation improvements until the latter part of the nineteenth century. These dynamic conditions can result in shifting shoals and reefs that endanger ships as well as bury their wrecks as shorelines and bars migrate through time.

There are several NHLs, including the San Jacinto Battlefield, the Battleship Texas, the Tall Ship Elissa, and the Spindletop Oil Field, as well as NHL Districts, such as the Galveston Strand Historic District and the Galveston East End Historic District. There are 345 NRHP properties and 418 cemeteries within the region. Many of these historic properties are located in urban areas and are primarily historic houses, commercial and government buildings, and structures represented by the Navy Park Historic District, Houston Heights, Galveston Central Business District, Durazno Plantation, Varner-Hogg Plantation, Fort Travis, Washburn Tunnel, and others. Other NRHP sites and districts located throughout the area include the Apollo Mission Control Center, the Space Environment Simulation Laboratory, the Saturn V Launch Vehicle, the Point Bolivar and Sabine Pass lighthouses, the Beaumont Commercial District, the Jefferson Historic District, the Port Arthur-Orange Bridge, the W.H. Stark House, the Old Wallisville Townsite, Fort Anahuac, and the Chambers and Jefferson County courthouses. The majority of these cultural resources are vulnerable to damage or destruction from hurricane storm surge.

2.5.1.1 Mid to Upper Texas Coast – Matagorda Bay

Human habitation along the north central coast in the vicinity of Matagorda Bay (Matagorda, Jackson, Victoria, and Calhoun counties) has only been identified in the region as early as 7,500 before present. This region is similar to the upper Texas coast with broad coastal estuarine systems and bays and coastal prairies farther inland but lacks the dense woodlands of eastern Texas. The Colorado, Lavaca, San Antonio, and Guadalupe rivers are the major drainages in the region. Sediments in the region consist of fluvial deposits and delta formations overlying Pleistocene-aged clay. There are 577 recorded prehistoric and historic archeological sites in the region, which are similar in nature and location to sites along the upper Texas coast; however, prehistoric sites are primarily located

adjacent to brackish estuarine systems. Shell midden sites are especially common in the region along the shorelines and upland areas adjacent to rivers and bays and on the barrier islands. The mid to upper Texas coast is more rural than the upper Texas coast, and while historic sites are located in small urban centers, farmsteads, ranches, and plantations can occur across the region. Shipwrecks are also common in the region and are subject to the same formation processes as the upper coast.

There are 118 historic properties recorded within the area and these include the South Bridge Street Historic District in Victoria, Texas. The vast majority of the historic properties are also within the city of Victoria including the City of Victoria Pumping Plant, the Old Brownson School, Trinity Lutheran Church, and others. Outside of Victoria, historic properties include the Matagorda Island Lighthouse in Port O'Connor, the Texana Presbyterian Church in Edna, and the Hotel Blessing in Blessing.

2.5.1.2 Mid Texas Coast – Corpus Christi Bay

The mid Texas coast around Corpus Christi and Baffin bays (Refugio, Aransas, San Patricio, Nueces, and Kleberg counties) is very similar environmentally and culturally to the north central coast. There are 950 archeological sites recorded within the region. The primary drainages for this region include the Aransas and Nueces rivers as well as Petronilla and Chiltipin creeks. Prehistoric sites in the region are concentrated on the shorelines of Copano, Corpus Christi, and Baffin bays, as well as along the rivers and streams that drain into these bays. Numerous sites have also been identified on the barrier islands. Both prehistoric and historic archeological sites are similar to those in the upper and mid to upper coast, but, similar to the north central coast, show an increase in the number of shell middens.

There are 21 historic properties listed in the region with many of these located in Corpus Christi and Rockport. Some notable properties include the Ragland Mercantile Company Building, the Nueces and Refugio County courthouses, the Tarpon Inn, Fulton Mansion, and the Henrietta King High School. Historic districts include the Aransas Pass Light Station, the Broadway Bluff Improvement, and the James McGloin Homestead. Two NHLs include the *USS Lexington* in Corpus Christi and the King Ranch. The King Ranch is an NHL District that covers over two-thirds of Kleberg County.

2.5.1.3 Lower Texas Coast – Padre Island

The lower Texas coast (Kenedy, Willacy, and Cameron counties) exhibits some evidence of human habitation as early as 11,500 years before present. This region is primarily drained to the south by the Rio Grande and is characterized by a broad aeolian sand sheet in the north, the Rio Grande delta in the south, and a small portion of coastal prairie dividing the two. There are 390 archeological sites recorded in the region, primarily along the shores of the Laguna Madre and on the barrier islands. Archeological investigations in the region have not been sufficient to clearly identify regional chronology or settlement patterns. However, the archeological record suggests that groups in these areas utilized the inland areas along the Rio Grande and the coastal areas either based on seasonal or territorial constraints. As such, prehistoric sites can be expected within fluvial terraces along streams and rivers and in upland terraces along the shorelines of the bays. Furthermore, the widespread deposition

of aeolian clays has established stable clay dunes or lomas, which have a high probability for archeological sites, but are also at high risk from erosion from wind and water.

There are 22 historic properties listed within the region. Almost all of these properties are located in Brownsville or along the Rio Grande including the Cameron County Courthouse, Southern Pacific Railroad Passenger Depot, the Charles Stillman House, the Immaculate Conception Church, and La Nueva Libertad. Outside of Brownsville, properties include the Point Isabel Lighthouse in Port Isabel, the Brazos Santiago Depot at Boca Chica, and the Old Lyford High School in Lyford. There are six historic districts in the region and five of these are NHLs. These NHLs include Fort Brown, Palo Alto Battlefield, Palmito Ranch Battlefield, and Resaca de la Palma Battlefield, which are associated with the Mexican War and the Civil War. The King Ranch NHL is also located in the region and occupies a large portion of Kenedy and Willacy counties.

2.5.1.4 Cultural Resources Considerations

There are over 5,200 cultural resources recorded within the study area. Many of these resources have national and regional significance and are either listed on or are eligible for inclusion in the NRHP. Additionally, almost all cultural resources within the study area are at risk from hurricane storm damage to varying degrees. Those resources at highest risk are archeological sites along coastal and bay shorelines where storm surge wave action and flooding can cause severe erosion, historic buildings and structures that can be destabilized or destroyed by wave action and flooding, and submerged resources, such as shipwrecks, which can be exposed and dispersed by shifting sea floor and bay bottom during violent storm events. Indirectly, cultural resources whose owners lack sufficient money or resources to rehabilitate damaged properties could be lost entirely.

Structural and nonstructural alternatives for reducing storm risk also pose a threat to cultural resources in the study area as these can involve both direct and indirect impacts. Direct impacts could include damage to surface and subsurface resources from levee or wall construction and associated borrow areas, erosion from redirected storm waters into archeologically or historically sensitive areas, dredging for beach and dune nourishment, and impacts from landscape modification of ER features. Indirect impacts could include visual impacts from obstructions such as levees and walls, increased unregulated construction/renovation in newly protected areas, and noise impacts from increased traffic in protected areas and along evacuation routes.

2.6 SOCIOECONOMIC CONSIDERATIONS

Communities along the Texas coast include the major cities of Houston, Galveston, Corpus Christi, Brownsville, and the major communities of Freeport, Port Arthur, Texas City, League City, Baytown, Matagorda, Palacios, Port O’Connor, Port Lavaca, Rockport, Port Aransas, South Padre, and Port Isabel. All of these areas have historically suffered extensive damage from hurricanes and tropical storms. The impact of preparing for, mitigating, and recovering from these damages has placed a physical and emotional burden on both individuals and communities. Most recently, Hurricanes Rita in 2005 and Ike in 2008 caused significant damage to homes and businesses. In this section, socioeconomic and other social effects data for the Texas coast provide a context from which to evaluate potential effects of the Preferred Alternative.

2.6.1 Population and Housing

Recent population trends in the Coastal Texas Study area are shown in Table 2-31. Since the 1960s, more than one-quarter of Texas's population has lived within the coastal counties (Wilson and Fischetti, 2010). Even with historical hurricane events, the coastal populations in Texas has historically increased. The population of the study area in 2017 was over 6.4 million residents, with over 80 percent of those residents residing along the upper Texas coast (U.S. Census Bureau, 2018a).

Table 2-31
Current Population Trends in the Study Area

Coastal Area	County	Population Trends							
		2010	2011	2012	2013	2014	2015	2016	2017
Upper	Brazoria	314,453	319,274	324,433	330,170	337,782	345,738	353,828	362,457
	Chambers	35,445	35,683	36,489	37,350	38,283	39,059	40,283	41,441
	Galveston	292,470	295,609	301,059	306,662	313,609	321,305	329,306	335,036
	Harris	4,107,854	4,180,816	4,262,689	4,353,517	4,452,695	4,551,362	4,617,041	4,652,980
	Jefferson	252,453	253,397	251,458	253,022	252,708	254,889	255,954	256,299
	Orange	82,013	82,337	82,889	82,816	83,245	83,928	84,508	85,047
	Subtotal	5,084,688	5,167,116	5,259,017	5,363,537	5,478,322	5,596,281	5,680,920	5,733,260
Mid to Upper and Mid	Aransas	23,181	23,228	23,462	23,897	24,581	24,834	25,275	25,572
	Calhoun	21,311	21,356	21,575	21,735	21,805	21,881	21,942	21,744
	Jackson	14,090	14,044	14,267	14,609	14,721	14,792	14,851	14,805
	Kleberg	32,033	32,026	32,092	32,016	31,850	31,398	31,347	31,088
	Matagorda	36,705	36,681	36,543	36,506	36,494	36,762	37,117	36,840
	Nueces	340,261	343,225	347,848	352,781	356,452	360,437	361,529	361,221
	Refugio	7,375	7,319	7,252	7,273	7,354	7,320	7,293	7,224
	San Patricio	64,430	64,455	65,265	66,134	66,638	67,084	67,262	67,215
	Victoria	86,883	87,530	89,067	90,058	90,988	92,082	92,379	92,084
	Subtotal	626,269	629,864	637,371	645,009	650,883	656,590	658,995	657,793
Lower	Cameron	407,590	412,917	415,370	417,095	418,838	419,579	421,766	423,725
	Kenedy	417	436	444	435	431	433	428	417
	Willacy	22,225	22,166	22,198	22,027	21,943	21,882	21,760	21,584
	Subtotal	430,232	435,519	438,012	439,557	441,212	441,894	443,954	445,726
Total		6,141,189	6,232,499	6,334,400	6,448,103	6,570,417	6,694,765	6,783,869	6,836,779

Source: U.S. Census Bureau (2018a).

Housing trends parallel population growth, with most households located in the metropolitan areas of Galveston, Houston, and Corpus Christi (Table 2-32).

Table 2-32
Housing Trends in the Study Area

Coastal Area	County	Housing Unit Trends							
		2010	2011	2012	2013	2014	2015	2016	2017
Upper	Brazoria	118,856	120,703	122,554	124,817	126,875	130,236	133,488	136,364
	Chambers	13,395	13,625	13,853	14,190	14,528	14,932	15,272	15,598
	Galveston	132,782	134,455	136,040	137,724	139,626	142,322	144,478	146,439
	Harris	1,601,877	1,614,336	1,629,134	1,653,440	1,681,500	1,718,277	1,749,027	1,768,827
	Jefferson	104,755	105,628	106,149	106,913	107,057	107,874	108,229	108,582
	Orange	35,387	35,585	35,933	36,110	36,265	36,700	37,005	37,264
	Subtotal	2,007,052	2,024,332	2,043,663	2,073,194	2,105,851	2,150,341	2,187,499	2,213,074
Mid-to Upper and Mid	Aransas	15,381	15,479	15,556	15,654	15,789	15,981	16,175	16,381
	Calhoun	11,422	11,467	11,524	11,590	11,778	11,858	11,934	11,989
	Jackson	6,590	6,594	6,596	6,602	6,614	6,632	6,649	6,666
	Kleberg	12,790	12,787	12,811	12,845	13,246	13,267	13,306	13,301
	Matagorda	18,815	18,858	18,902	18,956	19,053	19,261	19,331	19,400
	Nueces	141,184	141,916	142,616	143,580	145,454	147,615	148,548	149,500
	Refugio	3,726	3,723	3,720	3,725	3,724	3,741	3,741	3,743
	San Patricio	26,552	26,641	26,723	26,861	27,044	27,257	27,971	28,419
	Victoria	35,423	35,445	35,508	35,629	36,073	36,878	36,993	37,042
	Subtotal	271,883	272,910	273,956	275,442	278,775	282,490	284,648	286,441
Lower	Cameron	142,177	143,330	144,413	145,526	146,782	148,200	149,467	151,023
	Kenedy	232	232	232	232	232	233	233	233
	Willacy	7,044	7,049	7,059	7,087	7,125	7,215	7,338	7,367
	Subtotal	149,453	150,611	151,704	152,845	154,139	155,648	157,038	158,623
Total		2,428,388	2,447,853	2,469,323	2,501,481	2,538,765	2,588,479	2,629,185	2,658,138

Source: U.S. Census Bureau (2018a).

According to the Federal Emergency Management Agency (FEMA, 2018) flood claims from storm surge and rainfall damages for the study area paid between 1978 and 2018 totaled $13.5 billion (Table 2-33). (Note: FEMA flood claims occur due to a property experiencing inundation regardless of the source of flooding; however, in the study area, the majority of the flooding experienced derives from a combination of storm surge and heavy rainfall associated with tropical events. The Coastal Texas Study is limited to addressing the risk of damages from flooding derived from hurricane storm surge and does not address flooding associated with rainfall events, even those associated with a hurricane or tropical storm event.)

Table 2-33
FEMA Flood Claims in the Study Area

Coastal Area	County	Number of Claims	Total Nominal Dollar Amount*	Average Dollar Amount per Claim
Upper	Brazoria	17,700	620,738,513	35,070
	Chambers	1,247	68,316,685	54,785
	Galveston	50,857	2,543,551,930	50,014
	Harris	132,858	8,270,089,134	62,248
	Jefferson	14,818	912,029,492	61,549
	Orange	8,880	833,783,137	93,894
Mid	Aransas	4,639	184,452,594	39,761
	Calhoun	481	6,274,860	13,045
	Jackson	164	2,626,922	16,018
	Kleberg	214	1,499,652	7,008
	Matagorda	1,603	23,702,877	14,787
	Nueces	3,155	39,927,580	12,655
	Refugio	62	1,502,342	24,231
	San Patricio	984	10,499,494	10,670
	Victoria	534	10,581,990	19,816
Lower	Cameron	3,408	51,995,534	15,257
	Kenedy	3	51,486	17,162
	Willacy	286	2,417,255	8,452
Total		241,893	13,584,041,477	

Source: FEMA (2018).

* Values reflect price levels at the time the claim was processed.

2.6.2 Coastal Structures

There are numerous coastal communities in the study area at risk from storm surge. A detailed review of the USACE National Structure Inventory database revealed that many of the residential and non-residential developments at risk from storm surge are focused along the upper coast and the lower coast on South Padre Island. The initial evaluation focused on the 1,000-year coastal floodplain for the study area. Approximately

673,346 structures were found within the study area and are shown in figures 2-16 through 2-19, with the 100-year floodplain overlaid.

Along the upper coast, many of the economic resources at risk are focused on the communities of Galveston, Houston, League City, and Baytown (Figure 2-16). The communities of Freeport, Port Arthur, and Texas City are already protected by the existing risk reduction system (e.g., levees/floodwall); however, many of the smaller waterfront communities along the west side of Galveston Bay are at a significant risk from storm surge. Many of these waterfront communities provide employees, employers, and purchasing power that contribute to the economic health of the entire Houston-Galveston region. They are also equally critical to the regional economy that is supported by tourism, water recreation, the science industry (National Aeronautics and Space Administration), and the ports, as well as by industry and offices located in the area. The economies of the communities in this region are heavily intertwined; the health of one community is dependent on the health of all the communities in the area (e.g., the availability of housing in one community helps support businesses in another, etc.).

For example, during Hurricane Ike, the community of Kemah suffered severe damage to the "Boardwalk," a major tourist attraction in the region. The majority of restaurants and other businesses were small, family-owned businesses. Kemah also lost much of its infrastructure that needed to be replaced in order for the city to get back on its feet. There was also the need to maintain an adequate amount of housing for people who work in local industries.

In the mid coast, many of the residential and non-residential developments at risk from storm surge are focused on areas near the barrier islands or bay system; however, many of the structures have already taken actions to mitigate their risk. A large number of structures are elevated, or local communities have taken actions to build structure system (e.g., Corpus Christi seawall, elevated housing) to reduce damages to structures (figures 2-17 and 2-18).

In the lower coast, the main risk is to structures on South Padre Island, mainly due to wave attack during storm events (Figure 2-19).

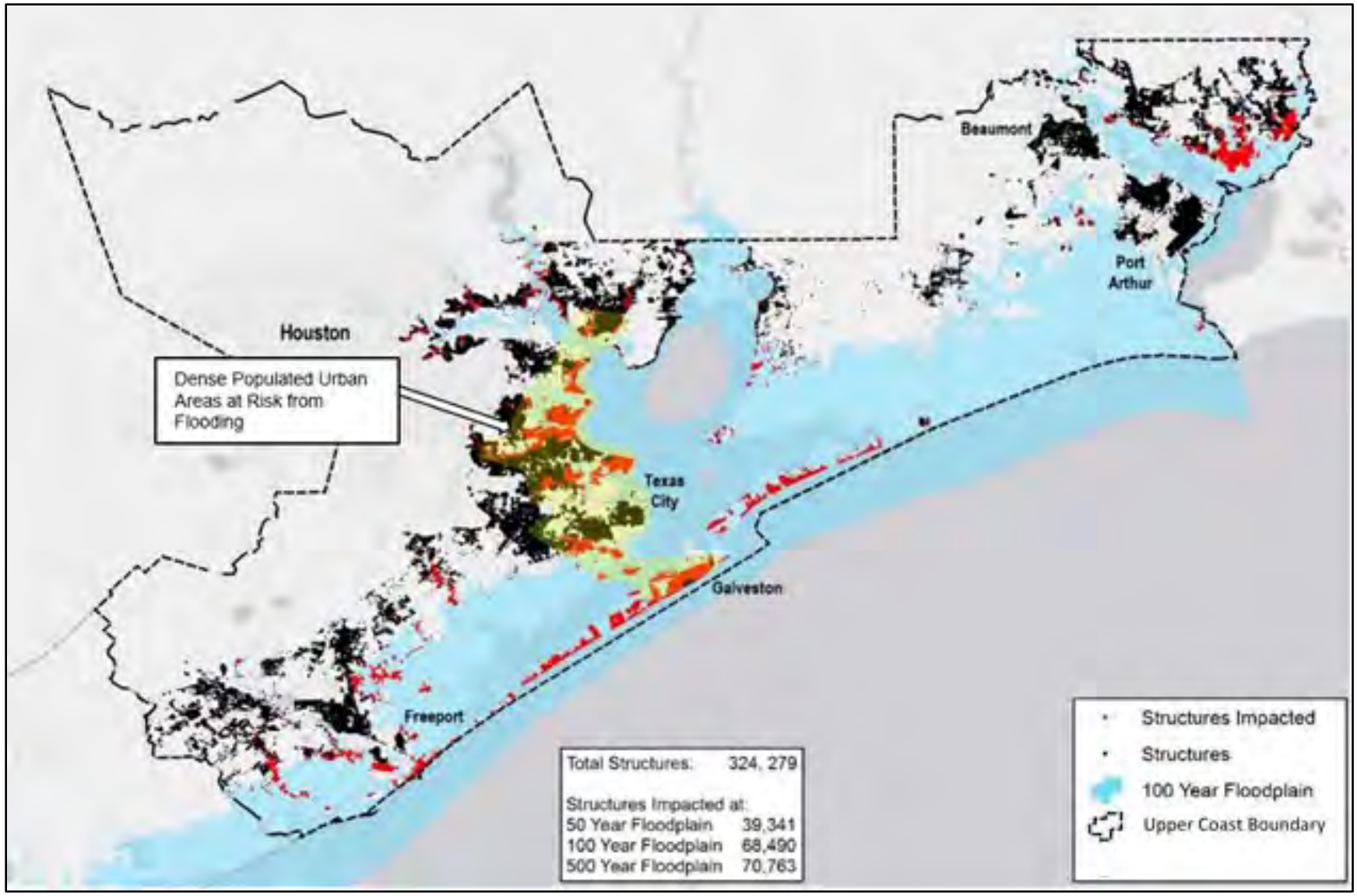


Figure 2-16. Upper Coast Structure Inventory in the 1,000-year Floodplain

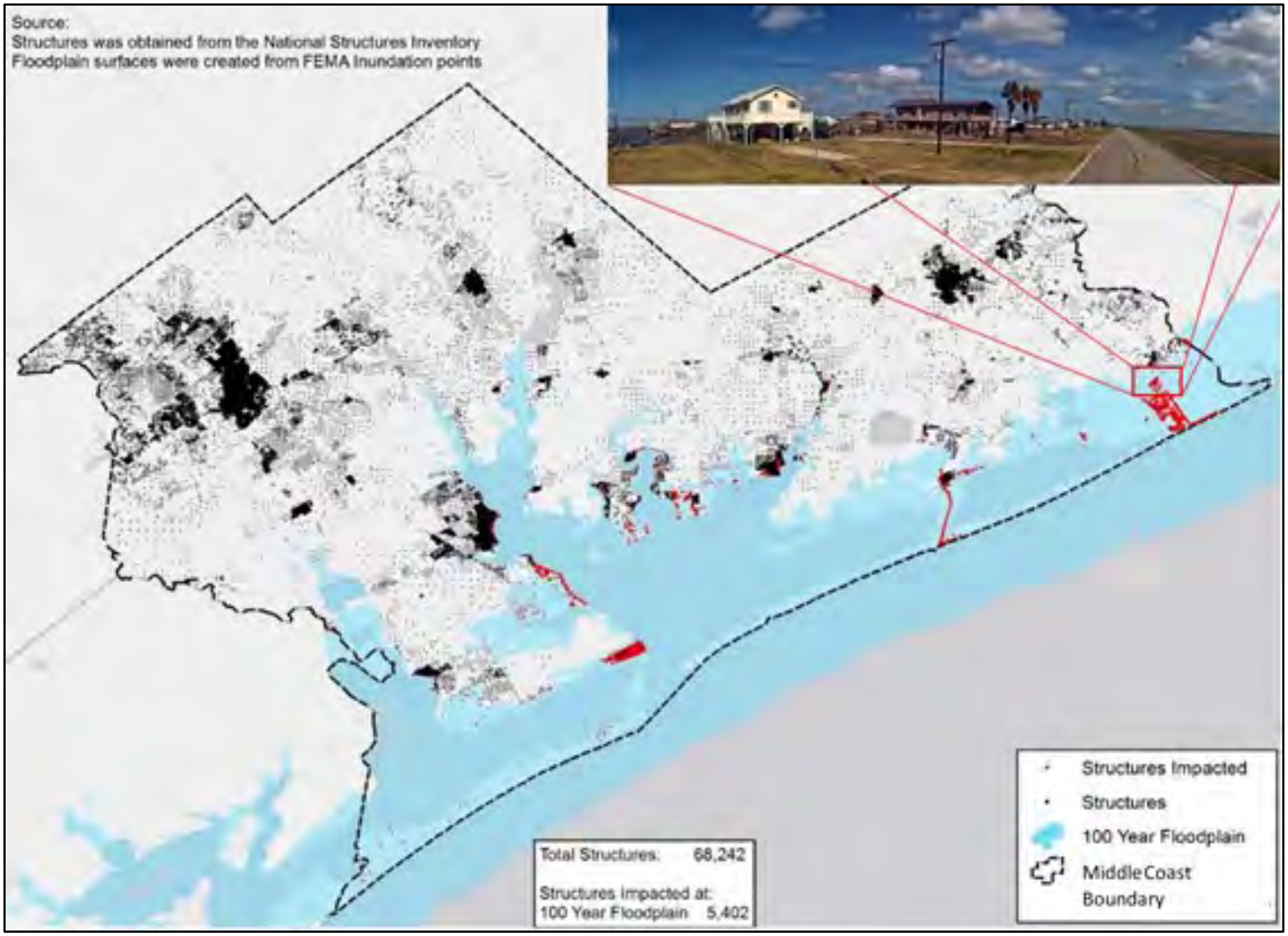


Figure 2-17. Mid Coast Structure Inventory in the 1,000-year Floodplain

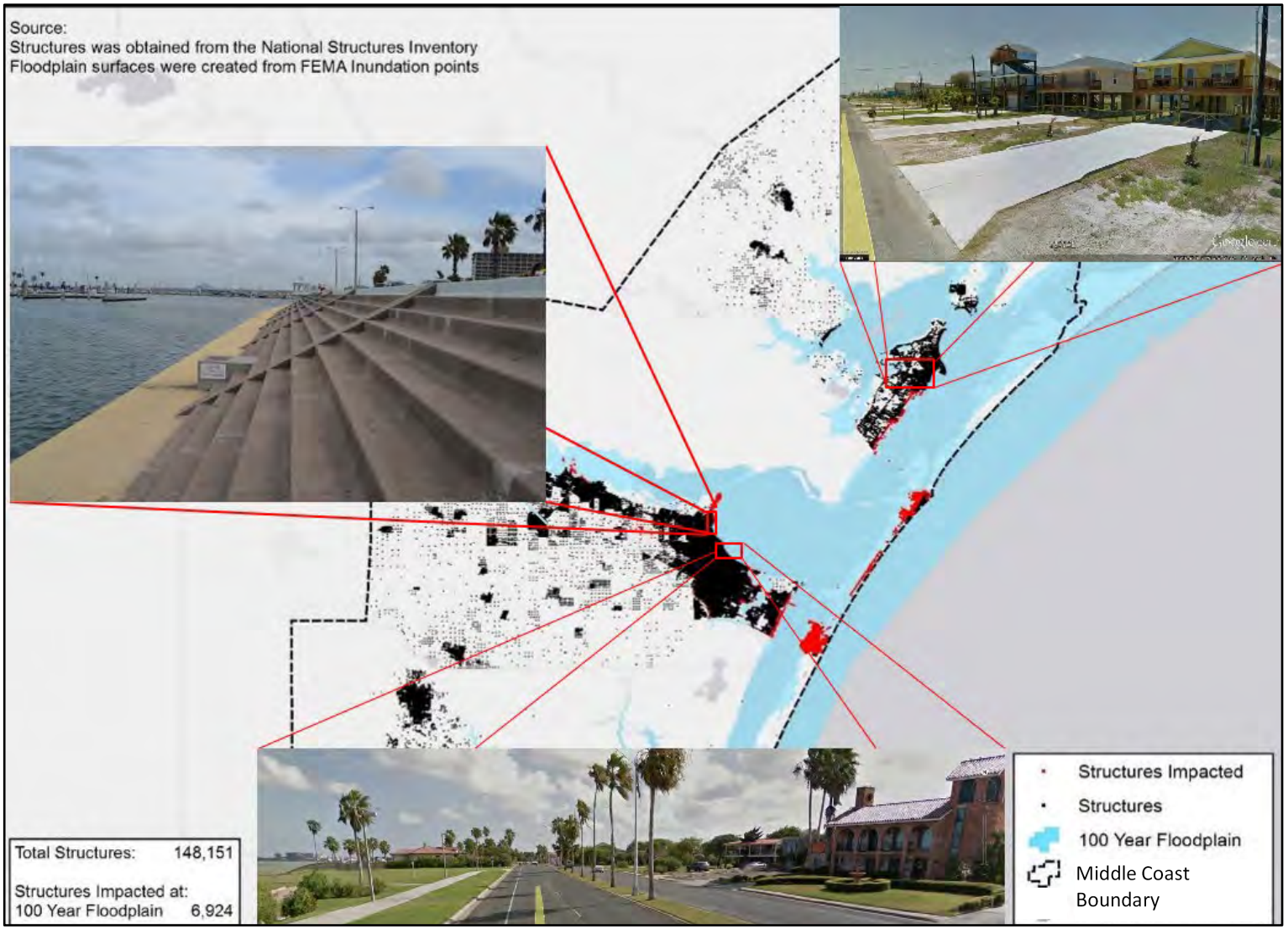


Figure 2-18. Mid Coast Structure Inventory in the 1,000-year Floodplain

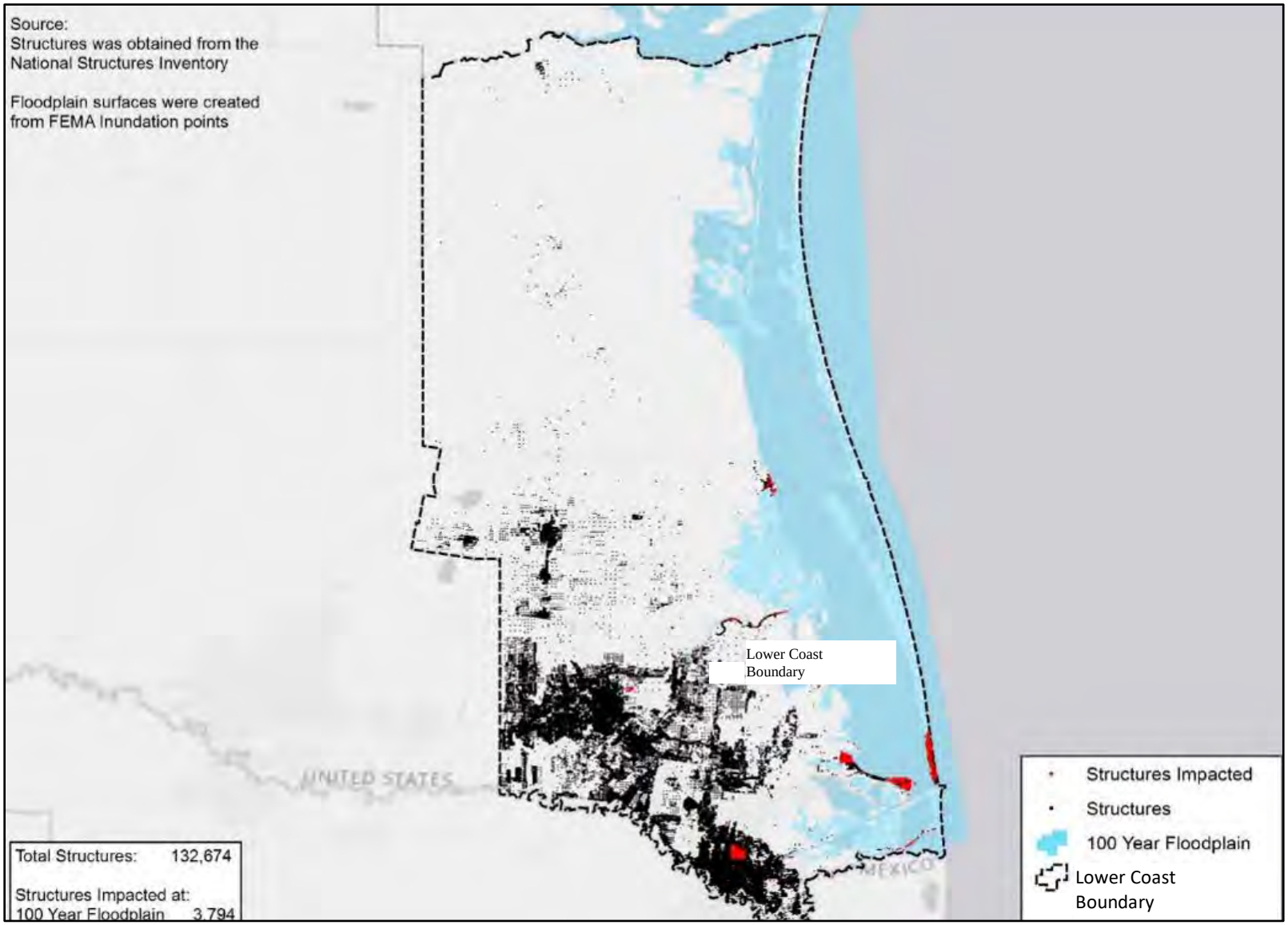


Figure 2-19. Lower Coast Structure Inventory in the 1,000-year Floodplain

2.6.3 Critical Infrastructure at Risk

Critical infrastructure includes assets that are essential for the functioning of a society and an economy, including electricity, gas distribution, water supply, transportation, education, and community services (e.g., police, fire department, etc.). The Coastal Texas Study includes over 3,500 critical infrastructure locations at risk in the study area (Table 2-34). Hospitals, roads, schools, police, and fire facilities play a central role in disaster response and recovery. Understanding which facilities are exposed, and the degree of that exposure, can help reduce or eliminate service interruptions and costly redevelopment. Incorporating this information into development planning helps communities get back on their feet faster. When comparing the FEMA floodplain maps to the critical infrastructure locations, most of the critical infrastructure at risk are focused along the upper coast and the lower coast on South Padre Island (Table 2-34). The Galveston Bay region is at a significant risk. In June 2012, Houston and Galveston were identified as the fifth most vulnerable of U.S. cities to hurricanes because of their low-lying coastal location, large population, and critical economic infrastructure (Freedman, 2012). Over 25 percent of the Galveston County critical infrastructure is within the FEMA floodplain (Table 2-34).

Table 2-34
Critical Infrastructure in the Study Area

Coastal Area	County	Schools	Law Enforcement	Fire/EMS	Hospital/ Medical	Percent in FEMA Floodplain
Upper	Brazoria	116	34	50	3	14
	Chambers	14	10	8	2	--
	Galveston	115	34	48	5	26
	Harris	1,434	132	340	80	9
	Jefferson	109	22	40	12	4
	Orange	29	15	15	2	25
	Subtotal	1,817	247	501	104	
Mid	Aransas	7	3	9	--	--
	Calhoun	11	5	9	1	4
	Jackson	10	7	7	1	12
	Kleberg	26	6	7	1	4
	Matagorda	26	11	15	2	7
	Nueces	153	18	41	13	12
	Refugio	7	7	6	1	--
	San Patricio	37	13	17	2	--
	Victoria	44	4	22	4	3
	Subtotal	321	74	133	25	
Lower	Cameron	182	31	32	11	9
	Kenedy	1	2	--	--	--
	Willacy	16	10	6	--	50
	Subtotal	199	43	38	11	
Total		2,337	364	672	140	

Source: NOAA (2018d).

2.6.4 Community Cohesion

Community cohesion is based on the characteristics that keep the members of the community together long enough to establish meaningful interactions, common institutions, and agreed-upon ways of behavior. These characteristics include race, education, income, ethnicity, religion, language, and mutual economic and social benefits. The study area is composed of communities with a long history and long established public and social institutions including places of worship, schools, and community associations. The economic anchors of the petrochemical, fishing, and shipping industries remain firmly tied to their proximity to the Gulf and its oilfields; however, due to the absence of hurricane storm surge risk reduction measures in sections of the Texas coast, some local populations are forced to evacuate and/or relocate for extended time periods, thereby disrupting community cohesion, temporarily, and in some instances, permanently.

2.6.5 Other Social Effects

The USACE views "social well-being factors as constituents of life that influence personal and group definitions of satisfaction, well-being, and happiness. The distribution of resources; the character and richness of personal and community associations; the social vulnerability and resilience of individuals, groups, and communities; and the ability to participate in systems of governance are all elements that help define well-being and influence to what degree water resources solutions will be judged as complete, effective, acceptable, and fair" (USACE, 2013b). It is the other social effects account that considers these elements and assures that they are properly weighted, balanced, and considered during the planning process under the USACE's Four Accounts Planning Framework.

In accordance with the USACE Institute for Water Resources handbook in Applying Other Social Effects in Alternatives Analysis (2013), seven social factors that describe the social fabric of a community were identified. The social factors identified and described in Table 2-35 are based on conventional psychological Human Needs Theory and Abraham Maslow's Hierarchy of Needs (USACE, 2013b). This section, along with the socioeconomic data presented in the sections above, provides baseline conditions for the social communities in the entire study area.

2.6.5.1 Health and Safety (Stress, Loss-of-Life, Health Care, and Emergency Facilities)

Severe storm surge events threaten the health and safety of residents living within the study area. Loss of life, injury, and post-flood health hazards may occur in the event of catastrophic flooding. For example, the upper coast of the study area was severely impacted by Hurricane Ike in 2008. Hurricane Ike was costly in terms of lives lost and damages incurred, claiming 195 deaths in four countries and ranking as the third costliest storm in U.S. history (National Hurricane Center, 2018). In the Galveston region, there was significant damage to the critical infrastructure. State agencies and local governments needed $89.2 million to repair or replace infrastructure and $1.7 billion for repair/replacement of water and wastewater plants and lines, and other government facilities.

Table 2-35
Social Factors

Social Factor	Description
Health and Safety	Refers to perceptions of personal and group safety and freedom from risks
Economic Vitality	Refers to the personal and group definitions of quality of life, which is influenced by the local economy's ability to provide a good standard of living
Social Connectedness	Refers to a community's social networks within which individuals interact; these networks provide significant meaning and structure to life
Identity	Refers to a community member's sense of self as a member of a group, in that they have a sense of definition and grounding
Social Vulnerability and Resiliency	Refers to the probability of a community being damaged or negatively affected by hazards, and its ability to recover from a traumatic event
Participation	Refers to the ability of community members to interact with others to influence social outcomes
Leisure and Recreation	Refers to the amount of personal leisure time available and whether community members are able to spend it in preferred recreational pursuits

As shown in Table 2-34, there are 140 medical care facilities, 364 police stations/sheriff's offices, and 672 fire stations (parish and volunteer) located within the study area (NOAA, 2018d). When facilities that provide critical care or emergency services are impacted by storm surge events, residents are at an even greater risk for experiencing negative health outcomes. Hurricane Ike reduced the accessibility and availability of health facilities and services and required additional first-responders (fire and police) to respond to emergencies. During Ike, police stations were destroyed by storm surge and/or required to relocate because of flood risk. In addition to the damages of Ike to hospitals, police stations, and fire stations, many employees providing related services lost their homes, reducing the staff that was available to operate health and safety services.

2.6.5.2 Economic Vitality

Growth in employment, business, and industrial activity is expected to follow economic trends in local, regional, and national economies. As stated above, the region's economic anchors of the petrochemical, fishing, and shipping industries remain firmly tied to their proximity to the Gulf and its oilfields; however, without flood risk management alternatives, the stability of employment, business, and industrial activity associated with these economic drivers could be adversely affected over periods of time.

2.6.5.3 Social Connectedness

The degree to which communities are able to instill a shared sense of belonging and purpose among residents is in large part determined by the communities' civic infrastructure. The presence of social institutions, such as libraries, places of worship, and schools, provides residents an opportunity for civic participation and engagement, which allows residents to come together and work toward a common goal.

2.6.5.4 Social Vulnerability/Resiliency

The devastation left behind after Hurricanes Ike brought attention to the salience of the related concepts of social vulnerability and resiliency when evaluating water resources projects (USACE, 2008). Social vulnerability is a characteristic of groups or communities that limits or prevents their ability to withstand adverse impacts from hazards to which they are exposed.

Resiliency, in turn, refers to the ability of groups or communities to cope with and recover from adverse events. The factors that contribute to vulnerability often reduce the ability of groups or communities to recover from a disaster; therefore, more socially vulnerable groups or communities are typically less resilient.

Several factors have been shown to contribute to an area's vulnerability/resiliency, including poverty, racial/ethnic composition, educational attainment, and proportion of the population over the age of 65.

Poverty Rate. High poverty rates negatively impact the social welfare of residents and undermine the community's ability to assist residents in times of need. Within the study area, 14.8 percent of the population fell below the poverty level, with a large percent of the population below the poverty line found in the lower coastal counties (Table 2-36).

Table 2-36
Poverty Level in the Study Area

Coastal Area	County	Percent Below Poverty Level*
Upper	Brazoria	7.9
	Chambers	7.7
	Galveston	10.2
	Harris	14.4
	Jefferson	15.9
	Orange	11.3
	Upper Coast Average	11.2
Mid	Aransas	11.5
	Calhoun	14.4
	Jackson	8.8
	Kleberg	15.3
	Matagorda	18.3
	Nueces	12.8
	Refugio	14.9
	San Patricio	11.8
	Victoria	11.1
	Mid Coast Average	13.2
Lower	Cameron	29.2
	Kenedy	16.1
	Willacy	35.5
	Lower Coast Average	26.9
Study Area Average		14.8

Source: U.S. Census Bureau (2018b).
* Percent of families and people whose income in the past 12 months is below the poverty level.

Racial/Ethnic Composition. Race/ethnicity plays an important role in the everyday lives of Americans. Unequal access to social resources and language barriers may affect preparing for and recovering from storm surge events for certain groups. The majority of the population in the study area is white (83.7 percent) with 45 percent of the total population identifying as Hispanic or Latino (Table 2-37).

Table 2-37
Racial/Ethnic Characteristics in the Study Area

Coastal Area	County	Percent White	Percent Black or African American	Percent American Indian and Alaska Native	Percent Asian	Percent Native Hawaiian and Other Pacific Islander	Percent Some Other Race	Percent Two or Races	Percent Total Population - Hispanic or Latino	Percent Total Population - Not Hispanic or Latino
Upper	Brazoria	74.2	13.0	0.4	6.1	--	4.3	2.0	29.2	70.8
	Chambers	86.7	8.0	0.1	1.4	--	2.4	1.3	21.1	78.9
	Galveston	77.9	13.1	0.4	3.3	--	2.6	2.8	23.6	76.4
	Harris	63.3	18.9	0.4	6.7	0.1	8.4	2.2	41.8	58.2
	Jefferson	58.4	33.9	0.4	3.5	--	1.9	1.8	19.0	81.0
	Orange	87.9	8.1	0.4	1.1	--	0.5	1.9	6.8	93.2
Mid	Aransas	88.2	1.7	0.7	1.0	--	2.9	5.5	26.3	73.7
	Calhoun	86.4	2.8	--	4.7	0.2	1.4	4.5	47.8	52.2
	Jackson	87.1	7.3	0.1	0.2	0.1	2.8	2.4	31.6	68.4
	Kleberg	86.3	3.9	0.5	2.0	--	5.7	1.6	71.9	28.1
	Matagorda	76.8	10.6	0.3	2.1	0.2	6.5	3.4	40.7	59.3
	Nueces	87.4	3.9	0.5	1.9	0.1	4.6	1.7	62.6	37.4
	Refugio	81.2	5.0	0.2	0.1	--	7.3	6.2	49.3	50.7
	San Patricio	92.1	1.9	0.6	1.0	--	2.5	2.0	56.1	43.9
	Victoria	86.7	6.6	0.2	1.3	0.1	2.9	2.2	45.5	54.5
Lower	Cameron	93.0	0.6	0.2	0.6	--	4.7	0.9	89.0	11.0
	Kenedy	97.3	--	--	0.2	--	2.5	--	71.1	28.9
	Willacy	96.2	0.7	0.2	0.1	--	2.3	0.5	87.8	12.2
Average		83.7	7.8	0.3	2.1	0.04	3.7	2.4	45.6	54.4

Source: U.S. Census Bureau (2018a).

Social Vulnerability Index. Every community must prepare for and respond to hazardous events, whether a natural disaster like a hurricane or a disease outbreak, or an anthropogenic event such as a harmful chemical spill. The degree to which a community exhibits certain social conditions, including high poverty, low percentage of vehicle access, or crowded households, may affect that community's ability to prevent human suffering and financial loss in the event of disaster. These factors describe a community's social vulnerability. According to USACE (2013b), the Social Vulnerability Index (SoVI®) is a valuable tool that can be used to identify areas that are socially vulnerable and whose residents may be less able to withstand adverse impacts from hazards.

The Social Vulnerability Index was computed as a comparative measure of social vulnerability for all counties in the United States, with higher scores indicating more social vulnerability than lower scores. Cameron County

(9.10 Social Vulnerability Index 2010–2014, 99.20 national percentile) was ranked to have the top Social Vulnerability Index 2010–2014 score, while compared to Chambers County (–6.28 Social Vulnerability Index 2010–2014, 1.4 national percentile) had the lowest scores in the study area (Table 2-38).

Table 2-38
Social Vulnerability Index 2010–2014 in the Study Area

Coastal Area	County	Social Vulnerability Index	Percentile in the U.S.
Lower	Cameron	9.10	99.20
Lower	Willacy	7.27	98.30
Lower	Kenedy	5.14	96.00
Mid	Refugio	5.04	95.90
Mid	Aransas	3.45	91.30
Mid	Kleberg	3.40	91.10
Mid	Nueces	3.10	90.10
Mid	Matagorda	2.94	89.30
Mid	San Patricio	2.14	82.70
Mid	Victoria	1.53	74.70
Upper	Jefferson	0.87	64.40
Mid	Calhoun	0.73	62.60
Upper	Harris	0.14	52.50
Mid	Jackson	–0.41	43.10
Upper	Galveston	–1.86	22.60
Upper	Orange	–2.26	19.00
Upper	Brazoria	–3.77	7.50
Upper	Chambers	–6.28	1.40

Source: University of South Carolina (2018).

Cameron County is more socially vulnerable than roughly 99 percent of counties in the United States, while Chambers County is less socially vulnerable than roughly 2 percent of counties in the United States. This trend is similar in other Social Vulnerability Indexes such as the Agency for Toxic Substances and Disease Registry for the same coastal counties (Table 2-39); however, a detailed review of some of the census block groups shows that there are pockets of socially vulnerable communities in counties that may have overall low ranking.

Social vulnerability is a key detail that has to be reviewed when addressing surge risk. For example, Galveston County, as a whole, ranks low nationwide; however, some of the census block groups in Galveston County are the highest in the Nation for overall social vulnerability (Figure 2-20). These same census block groups are in some of the highest areas at risk for coastal storm surge, which primarily impacts the areas in the southeastern portion of the county. When reviewing Nueces County, which has a higher overall social vulnerability than Galveston County, the maps show that areas near the Gulf, which are susceptible to storm surges, are in the lower ranking for overall social vulnerability. Areas such as the town of Robstown or areas on the west side of Corpus Christi are for the most part out of the surge zone (Figure 2-21).

Table 2-39
Agency for Toxic Substances and Disease Registry Social Vulnerability Indexes in the Study Area

County	Counties within a State Ranked Against One Another	All U.S. Counties Ranked Against One Another
Willacy	0.9921	0.9952
Kleberg	0.9249	0.9850
Cameron	0.9526	0.9790
Refugio	0.7549	0.8959
Matagorda	0.8063	0.8583
Jefferson	0.6877	0.8555
Calhoun	0.7787	0.8395
Nueces	0.6759	0.8204
San Patricio	0.6838	0.7781
Victoria	0.5336	0.7424
Kenedy	0.7075	0.7221
Harris	0.6285	0.7020
Aransas	0.3953	0.6727
Jackson	0.4308	0.6492
Orange	0.2846	0.5858
Galveston	0.2490	0.5696
Brazoria	0.2213	0.5186
Chambers	0.1146	0.2907

Source: Agency for Toxic Substances and Disease Registry (2018).

2.6.5.5 Leisure and Recreation

Having personal leisure time available and having access to recreational areas contributes to residents' quality of life and is therefore an important aspect of well-being.

The study area is home to over 50 NWRs, WMAs, state parks, preserves, etc. (see Figure 2-14). Recreational fishing and hunting are very important to the area. Game species hunted in the area include waterfowl, deer, rabbit, squirrels, rail, gallinule, and snipe. Recreational fishing is a common year-round pastime along the entire Texas coast. The activity supports bait shops and tackle outfitters up and down the coast. Anglers access fishing spots using boats, kayaks, and by fishing from the shoreline wherever there is access. People commonly fish along the beaches and in the open bay in the spring and summer months and concentrate around Gulf passes during the fall and winter months. Species commonly targeted in these areas include but are not limited to spotted seatrout, red drum, southern flounder, sand seatrout, black drum, sheepshead, gafftopsail catfish, and numerous shark species. There are many fishing tournaments held along the coast and range from amateur to professional level of expertise and sponsorship. Also, many of the fish species will move seasonally to form aggregations that

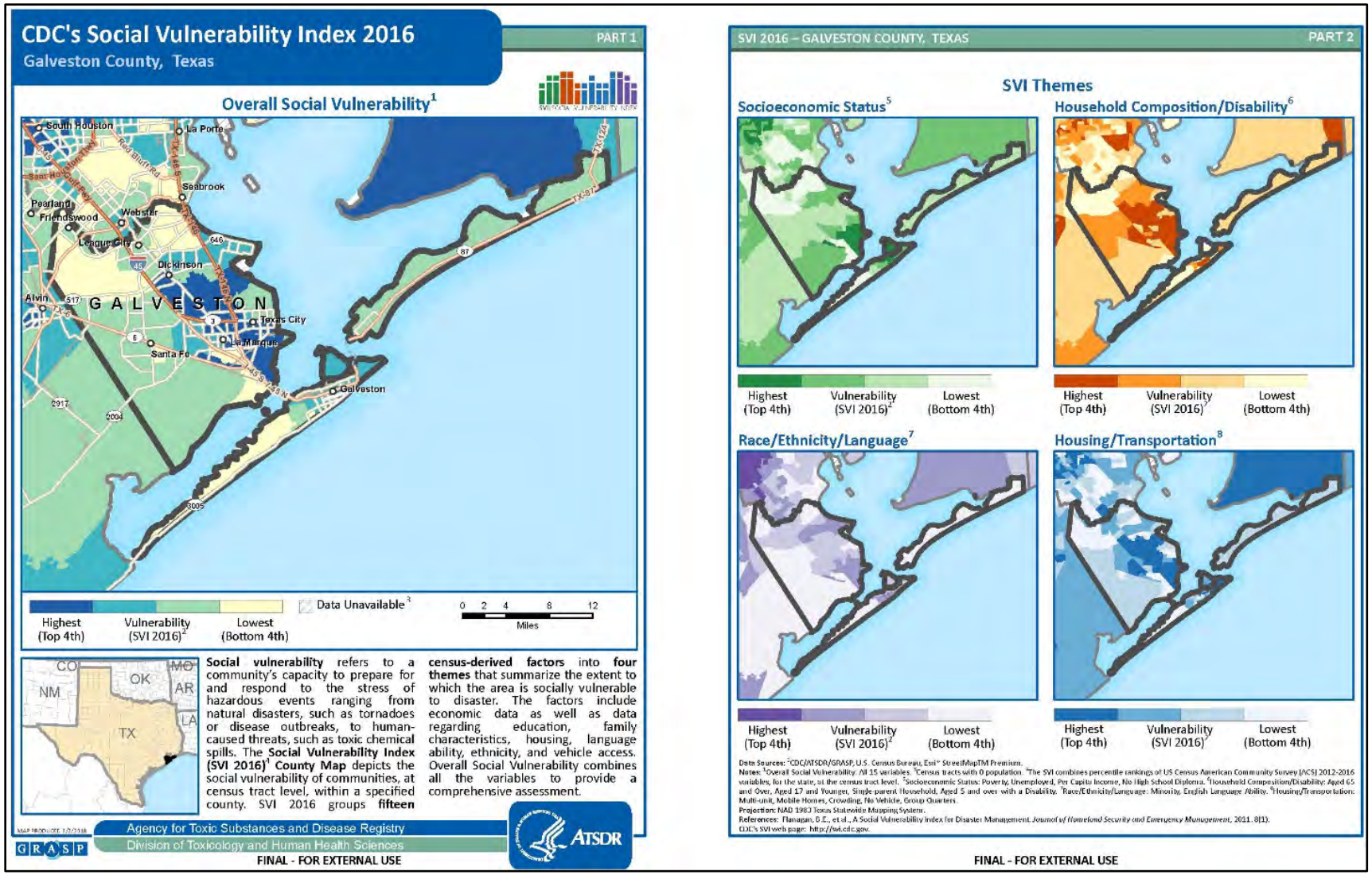


Figure 2-20. Galveston County Social Vulnerability Index
(Source: Agency for Toxic Substances and Disease Registry, 2018)

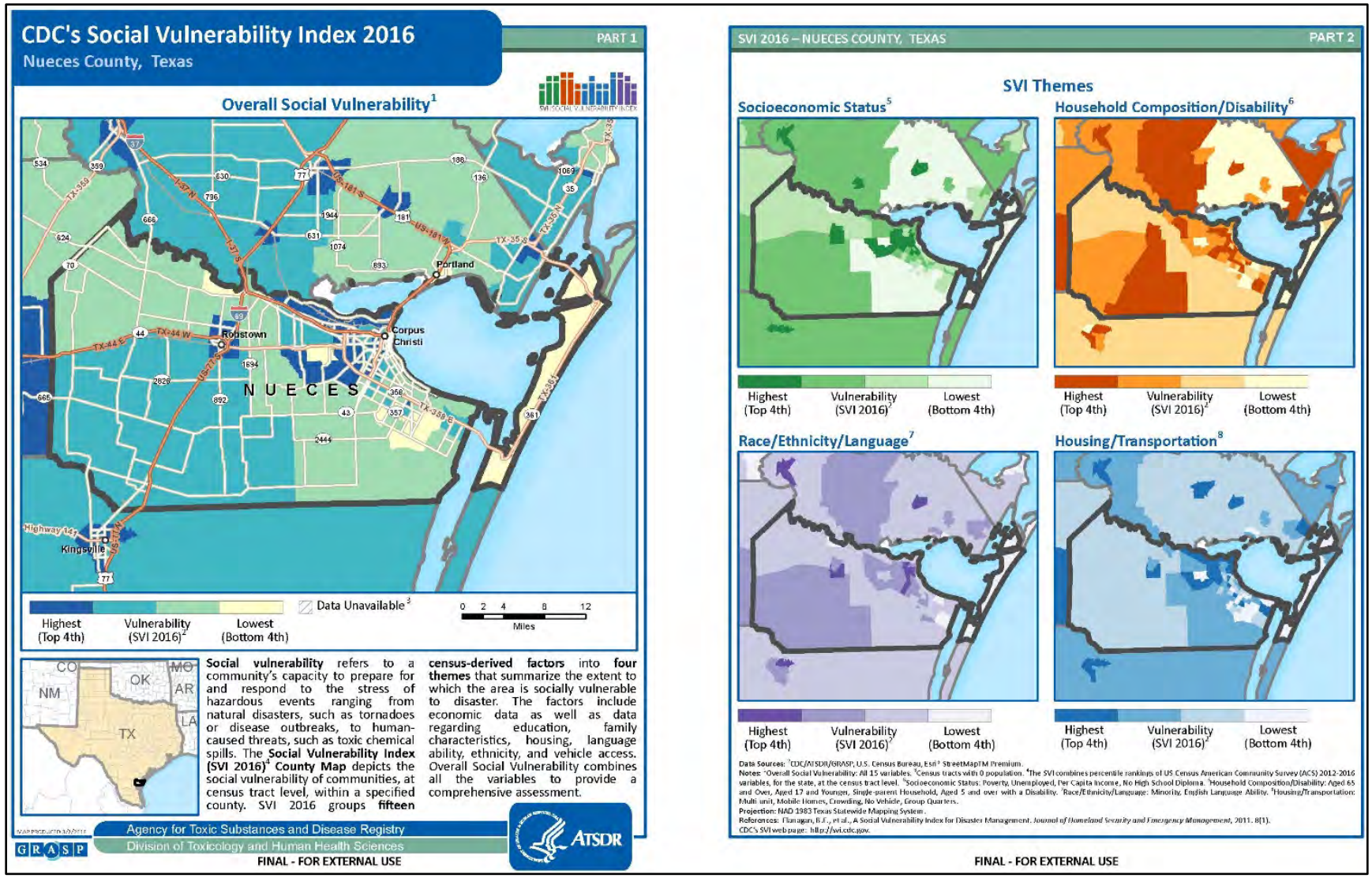


Figure 2-21. Nueces County Social Vulnerability Index
(Source: Agency for Toxic Substances and Disease Registry, 2018)

make them easier to target. Examples of this include the fall southern flounder and red drum "runs" where anglers flock to all of the Gulf passes along the Texas coast to fish for these species from Sabine Pass and the Galveston Ship Channel on the northern part of the Texas coast to Aransas Pass and Port Isabel on the southern part of the Texas coast. Outside of aggregation periods, recreational fisherman generally target the preferred foraging habitats of the above species, which include seagrass, mud bottom, sand bottom, scattered shell, and oyster reefs.

This kind of recreational fishing is common in Sabine Lake, Keith Lake, East Galveston Bay, Bolivar Peninsula, Trinity Bay, West Galveston Bay, Christmas Bay, the San Bernard River, East Matagorda Bay, West Matagorda Bay, Espiritu Santo Bay, San Antonio Bay, Aransas Bay, Copano Bay, Corpus Christi Bay, Baffin Bay, and the Laguna Madre. Anglers flock to the numerous barrier islands (Bolivar Peninsula, Galveston Island, Matagorda Island, Port Aransas, Padre Island, and South Padre Island) for the fishing opportunities.

Specifically, concerning the Galveston Island area, there are two large privately owned public fishing piers (the 61st Street Fishing Pier and the Galveston Fishing Pier 91st Street) and numerous private and neighborhood (e.g., Sea Isle's fishing Pier) fishing piers. The Texas City Dike, a levee that projects southeastward to the mouth of Galveston Bay, has multiple fishing piers and boat ramps. Sea Wolf Park is located on Pelican Island, just south and across the channel from the Texas City Dike and has a well-known and used fishing piers. It's worth noting that there is a flood gate at the mouth of Moses Bayou in Texas City that is a favorite fishing spot for anglers with a boat and those that fish from the shore.

2.6.6 Environmental Justice

Executive Order 12898, *Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations*, directs Federal agencies, "to the greatest extent practicable and permitted by law, to make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories and possessions… ."

To assess for potential disproportionate impacts, low-income and minority populations were identified within the study area using 2010 U.S. Census records (block groups), EPA mapping (EJView), and poverty thresholds as described by the U.S. Department of Health and Human Services. For a full picture of the potential environmental justice-related impacts included in this analysis, see sections 2.6 (Socioeconomic Considerations) and 2.6.5 (Other Social Effects). Table 2-37 shows the racial characteristics of the study area. Overall, minority residents make up 16 percent of the population in the study area. The 2007 to 2011 Census American Community Survey data indicate a large portion of the households in poverty areas or extreme poverty areas (block groups) are focused in Cameron and Willacy counties (Table 2-40). Also, the PDT reviewed the individual block group data in the upper coast and determined that, due to the large-scale CSRM measures evaluated, both alternatives would not disproportionately impact minority populations and low-income populations. Environmental justice concerns at this time are limited to the upper coast related to the structural recommendations, however, as discussed in the DIFR-EIS, the future evaluations of nonstructural measures to address wind-driven surges in the bay should be carefully planned.

Table 2-40
Percent of Households in Poverty in the Study Area

County	Extreme Poverty	Poverty
Aransas	7.94	8.66
Brazoria	4.05	5.58
Calhoun	8.35	8.00
Cameron	13.35	18.22
Chambers	3.66	4.12
Galveston	5.28	6.50
Harris	6.36	9.39
Jackson	4.29	6.63
Jefferson	5.60	9.15
Kenedy	8.00	11.08
Kleberg	7.83	9.20
Matagorda	6.89	12.20
Nueces	8.16	9.81
Orange	5.30	7.26
Refugio	4.22	10.37
San Patricio	6.93	10.72
Victoria	6.69	7.96
Willacy	19.84	18.75

There are also community cohesion and environmental justice concerns in minority populations and low-income populations in some of the communities along the west side of Galveston Bay that will have to be taken into consideration when investigating the details of nonstructural recommendations. A large-scale nonstructural plan could result in challenges since the final detailed evaluations for nonstructural measures must undergo a Benefit-Cost Analysis showing that the estimated cost of addressing flood damage surpasses the cost for applying nonstructural risk reduction measures. Equity concerns have come up around the Benefit-Cost Analysis method when reviewing the Social Vulnerability Index for the communities of La Porte, Santa Fe, and La Marque.

2.6.7 Recreation and Tourism

Tourists visiting the Texas coast in 2014 spent $19.7 billion traveling in this region, over $10.4 million at hotels and motels alone. In the upper coast, cruise business is a major economic driver at the Texas ports. This business generated over $1.3 billion for the Texas economy in 2014. This was a 5.6 percent increase from the previous year. Along with the port calls of 1.06 million passenger and crew visits at the two cruise ports of Houston and Galveston, the cruise industry generates over 20,000 jobs and is estimated to have a total wage impact of $1.42 billion (GLO, 2016).

Outstanding fishing, birding, and waterfowl-hunting opportunities, as well as family outings to the beach, make the coast the second most popular tourist destination in Texas, keeping the economy strong and creating jobs for both coastal residents and inland workers. Ecotourism is also a major sector in coastal Texas. The Texas coast

hosts hundreds of miles of nature tourism opportunities. In the Rio Grande Valley alone in 2011, ecotourism contributed more than 6,613 jobs. An excellent example of nature tourism, or avitourism, is the Great Texas Coastal Birding Trail, the largest nature trail in the Nation, with over 300 birding sites available along the Texas coast (GLO, 2016).

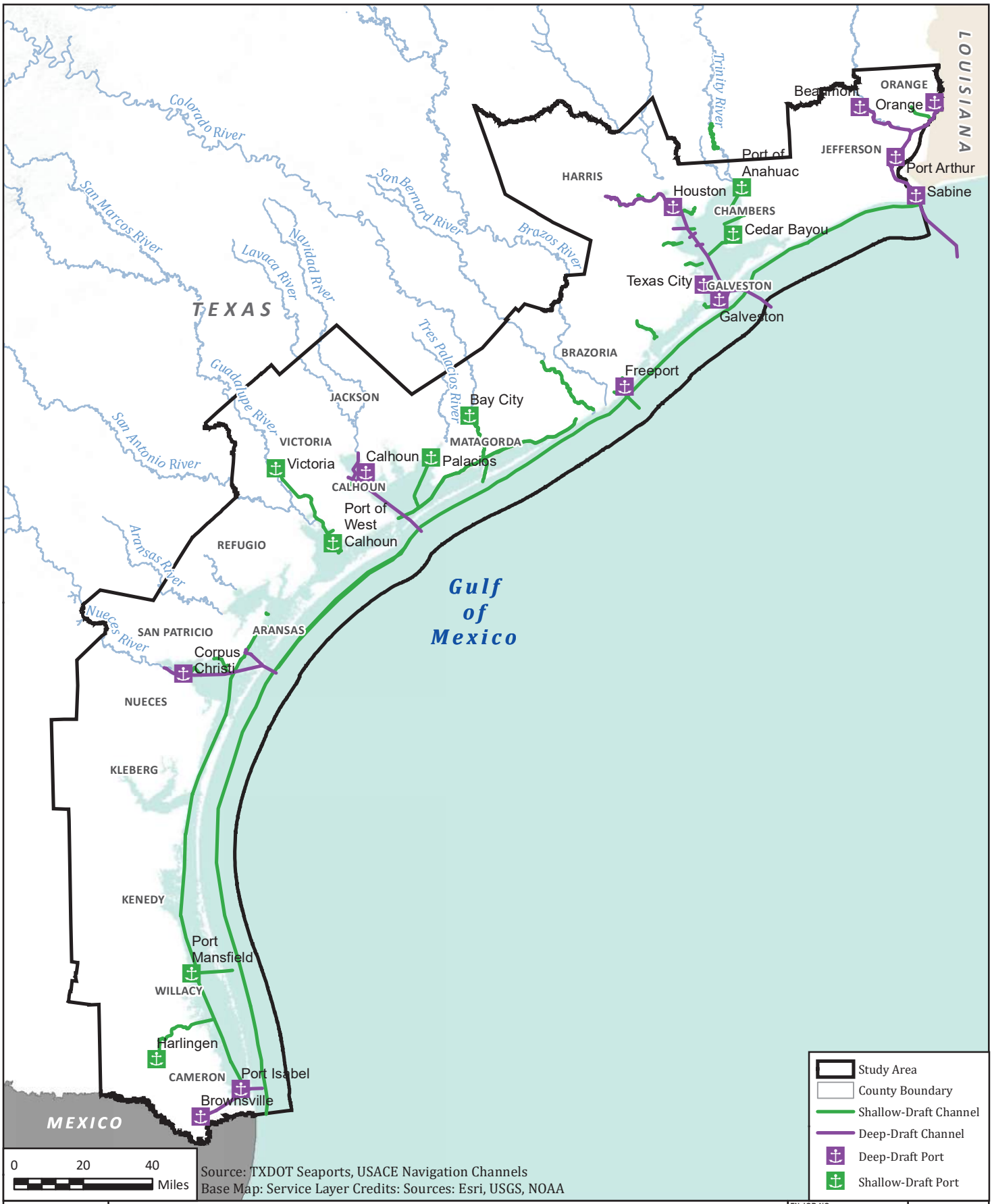
2.7 NAVIGATION

Texas ports and waterways consist of a mix of deep-draft and shallow-draft commercial ports, fishing and recreational ports, and the GIWW, with roughly 270 miles of deep-draft channels (greater than 15 feet deep) and 750 miles of shallow-draft channels (less than 15 feet deep) (Figure 2-22) (Demirbilek and Sargent, 1999; USACE, 2012e). These ports and waterways are major contributors to the economy and security of the State of Texas and the Nation, and additionally serve as key gateways for domestic and international freight movement. With its system of ports and waterways, Texas is ranked first in the Nation in overall tonnage throughput, ranked second in the Nation for waterborne commerce, moving over 500 million tons of cargo annually in recent years, and handles more than one-quarter of the total foreign tonnage throughput in the United States (Texas Ports Association, 2017; TxDOT, 2016b). In total, Texas ports activities contribute over $280 billion in economic value, generates over $6.5 billion in local and State tax revenue, and over $9 billion in Federal import tax revenue annually (TxDOT, 2016b).

Ports are classified by depth (deep-draft and shallow-draft) and the markets they serve. Typically, the ports market is categorized as comprehensive, specialized, and niche. Comprehensive ports handle multiple cargo types to include but not limited to autos, dry bulk, containers, liquid bulk, and military. Specialized ports are equipped to handle large volumes of one cargo type, such as chemicals, petrochemicals, aluminum ore, or agricultural fertilizer. Niche ports provide nontraditional services or handle cargo that is very specific, and typically not serviced by other ports, for example, serving as an asset to the seafood industry. Texas ports accommodate all three categories of the typical ports market place (TxDOT, 2016b).

2.7.1 Commercial Waterborne Commerce

Commercial waterborne commerce in Texas is supported by ports with 11 major deep-draft channels (25 feet or deeper) and six ports with shallow-draft channels, all of which are linked by the GIWW and connected to the Gulf, one of the world's most important oil and gas production and refining regions, to statewide, national, and international markets (tables 2-41 and 2-42) (TxDOT, 2014b). Of the top 10 busiest ports in the Nation in terms of waterborne tonnage, Texas ports account for three of the top 10: Port of Houston, Port of Beaumont, and Port of Corpus Christi (USACE, 2015b). The Port of Houston is the largest port in Texas handling 248 million tons of cargo (USACE, 2016). The Houston Ship Channel region alone accounts for $336 million of daily economic activity, represents 6.2 percent of total U.S. port activity, generates $16.2 billion in annual tax revenue for the Nation, and provides for $285 billion in national economic output. The Port of Beaumont serves as the world's second largest military seaport, along with leading the Nation in the amount of military exports in support on the Global War on Terrorism (USACE, 2012e).



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Texas Ports and Navigation Channels

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FILE NAME	2-10TXPorts_Nav_Chan.mxd
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NAD 1983 Texas Centric Mapping System Albers

Table 2-41
Texas Deep-Draft Port Dimensions, Statistics, and Rankings

Ports	Official Name	Classification	Channel Depth (feet)	Channel Width (feet)	Length (miles)	Port Ranking	Cargo (million tons)
Port of Orange	Orange County Navigation and Port District	Niche	30	200	30	150	0.8
Port of Beaumont	Port of Beaumont Navigation District of Jefferson County	Comprehensive	40	400	40	5	84.5
Port of Port Arthur	Port of Port Arthur Navigation District	Specialized	40	450	19	20	35.2
Port of Houston	Port of Houston Authority	Comprehensive	45	530	61	2	248
Port of Texas City	Texas City Terminal Railway Company	Specialized	40–45	1,200	27	15	41.3
Port of Galveston	Board of Trustees of the Galveston Wharves	Comprehensive	45	1,200	9	52	9.9
Port Freeport	Port Freeport	Comprehensive	45	400	8	33	19.6
Calhoun Port Authority	Calhoun Port Authority	Specialized	36	200	24	76	4.9
Port of Corpus Christi	Port of Corpus Christi Authority of Nueces County, Texas	Comprehensive	45	300	35	6	82
Port Isabel	Port Isabel-San Benito Navigation District	Niche	36	200	21	N/A	N/A
Port of Brownsville	Brownsville Navigation District	Specialized	42	250	21	66	7.3

Source: TxDOT (2016a); USACE (2016).

Table 2-42
Texas Shallow-Draft Port Dimensions, Statistics, and Rankings

Ports	Official Name	Classification	Channel Depth (feet)	Channel Width (feet)	Length (miles)	Port Ranking	Cargo (million tons)
Cedar Bayou	Cedar Bayou Navigation District, Chambers-Liberty Counties Navigation District	Niche	11	N/A	N/A	N/A	N/A
Port of Bay City	Port of Bay City Authority Matagorda County, Texas	Niche	12	200	12+	N/A	N/A
Port of Palacios	Matagorda County Navigation District No. 1	Niche	12	125	4	N/A	N/A
Port of Victoria	Victoria County Navigation District	Specialized	12	125	35+	74	5.1
Port of West Calhoun	West Side Calhoun County Navigation District	Niche	12	N/A	N/A	N/A	N/A
Port of Harlingen	Port of Harlingen Authority	Niche	12	125	25+	N/A	N/A

Source: TxDOT (2016a); USACE (2015b, 2016).

Linking Texas's deep-water commercial ports and shallow-water commercial and recreational ports is the GIWW, a man-made and protected waterway stretching 1,050 miles along the Gulf from Brownsville, Texas, to St. Marks, Florida. It is the Nation's third-busiest inland waterway after the Mississippi and Ohio rivers. Within Texas, the GIWW consist of 406 miles of channel with the main channel extending 379 miles from the Sabine River to Brownsville, handling 63 percent of the entire GIWW's traffic and moving approximately 73 million tons of cargo per year, consisting predominantly of petroleum and chemical-related products (TxDOT, 2016a, 2017). In addition, the GIWW facilitates the transport of over $31 million annually in wholesale seafood products; total coastwide seafood landings in 2012 was estimated to be 90.5 million pounds and valued at more than $213 million (NMFS, 2016e; TxDOT, 2014b).

In June 2016, the Texas segment of the GIWW was designated by the U.S. Maritime Administration as the Marine Highway 69 corridor. The Marine Highway 69 connects commercial navigation channels, ports, and harbors within the State of Texas, and provides relief to landside transportation corridors that are experiencing traffic congestion, excessive air emissions, and other environmental challenges (TxDOT, 2016a).

The USACE, in partnership with its non-Federal sponsors (NFS), is responsible for maintenance of these channels to their authorized dimensions. However, the extent of maintenance dredging activities is dependent upon annual Congressional appropriations, which may be below the USACE's capabilities to perform its annual navigation channel maintenance, resulting in deferred maintenance for a channel or reach, and which may affect the volume of maintenance dredged material available to be used beneficially for ER or CSRM beachfill features (Gulf of Mexico Alliance, 2010). On average, the USACE dredges between 30 and 40 million cubic yards (mcy) of maintenance dredged material on an annual basis. Approximately 4 mcy of maintenance dredged material is beneficially used annually to restore marshes or renourish beaches (USACE, 2012e). Table 2-43 displays the average annual volume of sediments dredged by USACE for the Federally authorized navigation channels it has responsibility for maintaining along the Texas coast.

2.7.2 Recreation

Hunting, fishing, and wildlife viewing provide numerous opportunities for Texas residents and generate significant economic benefits for the state. The Texas coast, along with its waterways and open-water access, is an important destination for Texas residents to participate in these recreational interests. According to Stokes and Lowe (2013), 7.8 million state residents and non-residents participated in some form of fishing, hunting, and wildlife-watching-related recreation, and the combined economic impact of these recreational activities totaled over $5 billion in annual spending and $181 million in State and local annual tax revenue generated. Fishing alone accounted for approximately $1.85 billion in economic activity, and hunting and wildlife viewing across the state accounted for over $43.5 billion in annual economic value.

Table 2-43
USACE Average Annual Maintenance Dredging Volumes in Coastal Texas

Navigation Channel	Total Quantity Sediment Dredged Annually (cubic yards)
Sabine-Neches Waterway Port Arthur Canal, Turning Basin, Junction Area, and Taylors Bayou	3,000,000
Sabine-Neches Waterway Outer Bar and Bank Channel	2,500,000
Texas City Channel Main Channel and Turning Basin	1,500,000
Galveston Harbor Channel	2,000,000
Houston Ship Channel Morgan's Point to Exxon and Barbour's Cut Channel	2,500,000
Houston Ship Channel-Bayport Flare and Redfish Reef to Morgan's Point	3,500,000
Galveston Harbor-Galveston Entrance Channel and Houston Ship Channel – Bolivar Roads to Redfish	2,500,000
Freeport Harbor – Entrance Channel	2,600,000
Matagorda Ship Channel Matagorda Peninsula to Point Comfort	3,000,000
Corpus Christi Ship Channel Entrance Channel	1,000,000
Corpus Christi Ship Channel Inner Basin to Viola Turning Basin/ La Quinta Channel	2,500,000
Brazos Island Harbor Brownsville Jetty Channel	400,000
GIWW, Corpus Christi to Port Isabel	1,500,000
GIWW, Galveston Causeway to Bastrop Bayou	1,000,000
GIWW, Rollover to Causeway	800,000
GIWW, Turnstake to Live Oak	600,000
GIWW, High Island to Rollover and Bolivar Flare	800,000
GIWW, Channel to Victoria Lower and Middle Reach	1,500,000

Source: USACE (2015c).

All Texas bay systems and estuaries provide a range of recreational opportunities. Boating access to these areas is facilitated by shallow-draft ports and the GIWW. Most of the deep-draft ports in Texas do not allow recreational access or boating due to security concerns. However, the deep-draft channels and outlets leading to the Gulf are used extensively by private and charter recreational vessels. Texas ports predominantly used for fishing and recreational purposes and that do not handle commercial cargo are listed in Table 2-44.

Table 2-44
Texas Fishing and Recreational Ports

Ports	Name
Port of Sabine Pass	Sabine Pass Port Authority
Anahuac	Chambers-Liberty Counties Navigation District
Rockport/Fulton/Cove	Aransas County Navigation District No. 1
Port of Port Mansfield	Willacy County Navigation District

Source: TxDOT (2016a).

According to the National Marine Manufacturers Association (2008), the economic significance of recreational boating for the combined Texas Congressional Districts in which the proposed ER and CSRM alternative plans are affected totaled $416 million in 2008 (Table 2-45). Further, the number of participants residing in areas potentially impacted by the proposed ER and CSRM alternative plans exceeded 80,000 in 2008 (Table 2-46). The economic significance of recreational boating and recreational boating by participant within the Texas Congressional Districts of the 112th Congress of the United States (January 2011–2013) and associated counties is outlined in Table 2-45 below.

Table 2-45
Economic Significance of Recreational Boating
Texas Congressional Districts and Counties

Congressional District/Counties	Total Direct Economic Effects (Craft and Trip Spending)			Secondary Effects, Total Impact of Craft and Trip Spending			
	Sales (million $)	Direct Jobs	Labor Income (million $)	Sales (million $)	Jobs	Labor Income (million $)	Value Added (million $)
9th/Fort Bend and Harris	8	89	3	21	183	7	12
14th/Aransas, Brazoria, Calhoun, Chambers, Fort Bend, Galveston, Jackson, Matagorda, Victoria, Wharton	108	1,182	36	284	2,434	92	155
15th/DeWitt, Duval, Goliad, Hidalgo, Jim Wells, Karnes, Live Oak, Refugio, San Patricio	25	272	8	66	563	21	36
22nd/Brazoria, Fort Bend, Harris	65	707	22	170	1,456	55	93
25th/Bastrop, Caldwell, Colorado, Fayette, Gonzales, Hays, Lavaca, Travis	39	426	13	103	880	33	56
27th/Cameron, Kennedy, Kleberg, Nueces, San Patricio, Willacy	45	492	15	119	1,015	39	64

Source: National Marine Manufacturers Association (2008); U.S. Census Bureau (2013).

Table 2-46
Number of Recreational Boating Participants Impacted
Texas Congressional Districts and Counties

Congressional District/Counties	Number of Registered Boats in the District				Number of Boating-related Businesses and Employment	
	Power-boats	Personal Watercraft	Sail-boats	Number Registered Boats	Number Recreational Boating Businesses	Number Persons Employed
9th/Fort Bend and Harris	2,482	550	93	3,125	10	28
14th/Aransas, Brazoria, Calhoun, Chambers, Fort Bend, Galveston, Jackson, Matagorda, Victoria, Wharton	31,278	3,789	1,318	36,385	153	616
15th/Bee, Brooks, Cameron, DeWitt, Duval, Goliad, Hidalgo, Jim Wells, Karnes, Live Oak, Refugio, San Patricio	9,284	1,022	101	10,407	11	82
22nd/Brazoria, Fort Bend, Harris	17,969	3,724	841	22,534	80	675
25th/Bastrop, Caldwell, Colorado, Fayette, Gonzales, Hays, Lavaca, Travis	13,561	2,226	445	16,232	24	149
27th/Cameron, Kennedy, Kleberg, Nueces, San Patricio, Willacy	13,745	1,995	584	16,324	82	412

Source: National Marine Manufacturers Association (2008); U.S. Census Bureau (2013).

2.8 FLOOD RISK REDUCTION

2.8.1 Texas City Hurricane Flood Protection Project

Description. Federally authorized, locally operated, and maintained. The system was authorized and designed to provide risk reduction to 36 square miles for tides, up to and including a hurricane tide, of 15 feet above the National Geodetic Vertical Datum. The system consists of 19.8 miles of earthen embankment having a maximum height of 23 feet, 2.3 miles of concrete floodwall, a tidal control and navigation structure, and two interior pumping stations.

Current Performance. There is concern that a reach of I-Wall could have performance issues during a storm event that could result in catastrophic failure of the I-Wall. Periodic Inspection Report dated October 2012 rated this I-Wall minimally acceptable and recommended that this wall be monitored and reanalyzed. Since 2012, portions of the wall have failed, reducing the level of risk reduction. Mitigation and repair efforts to provide a comprehensive solution are still not completely developed. An interim risk reduction measure has been constructed to address the immediate needs for full level of risk reduction.

2.8.2 Lynchburg Pump Station

Description. Federally authorized, locally operated, and maintained. The Lynchburg Pump Station Hurricane Flood Protection Levee is 0.76-mile-long and provides risk reduction from hurricane storm surge up to an elevation of 22.0 feet for the pump station that provides drinking water for the City of Houston. The levee system consists of earthen embankment with one drainage structure, one moveable gate, and T-Wall and I-Wall segments. The Lynchburg Pump Station is located on the east side of the Houston Ship Channel where the San Jacinto River merges with the ship channel, in the far north end of Galveston Bay. No permanent residences are located inside the levee area; infrastructure is all that is protected by the system.

Current Performance. The Lynchburg Pump Station continues to perform as intended with no issues. The likelihood of failure of the system prior to surge water elevation reaching the top of the levees and floodwalls is low. The primary risk driver in this scenario is seepage of water through the foundation of the levees and floodwalls causing soil to be eroded away until they collapse. After Hurricane Ike there was no evidence of this seepage, thus increasing the certainty of the system to perform well in the next flood event.

2.8.3 Colorado River Flood Protection at Matagorda

Description. Federally authorized, locally operated, and maintained. The Colorado River Flood Protection at Matagorda reduces the risk of flooding to the city of Matagorda for a flood event from the Colorado River occurring concurrently with a minor hurricane from the Gulf. The system provides flood risk reduction to the city of Matagorda with a population of approximately 400 and approximately 1,750 acres of adjacent agricultural lands. The Colorado River Flood Protection at Matagorda consists of 7.3 miles of earthen embankment with an average height of 10 feet. Highway 60 on the north side of the system is the only levee crossing that requires closure before a flood event through the use of sandbags. There are nine gravity drainage structures for interior drainage of the system, and 438 acres for ponding of water when the gravity drainage structures are closed during a flood event. A portion of the levee is used by the USACE for operating a navigation river lock on the GIWW.

Current Performance. The Colorado River Flood Protection at Matagorda continues to perform as intended. There are concerns with maintenance and replacement of the existing drainage systems that are being addressed by the NFS, the Port of Bay City Authority, under their operation and maintenance responsibilities.

3.0 NO-ACTION/FUTURE WITHOUT-PROJECT CONDITIONS (*NEPA REQUIRED)

The USACE is required to consider the future without-project (FWOP) alternative (called the "No-Action" Alternative) during the planning process and assessment of impacts to comply with USACE regulation and guidance for planning as well as National Environmental Policy Act (NEPA). With the FWOP, it is assumed that no project would be implemented by the Federal Government or by local interests to achieve the planning objective. The FWOP forms the basis against which all other alternative plans are measured.

The FWOP condition assumes the continuation of existing conditions for the resources listed above; no improvement of existing hurricane flood protection projects (HFPP); no intervention to reduce the impacts of storm surge on the vulnerable populations and infrastructure of the study area; and no large-scale ER efforts to improve the sustainability of fragile coastal systems and attenuate storm surge. The FWOP condition does consider those projects that have been completed (existing), are under construction, or have been authorized for construction. For the projects that are under construction or authorized for construction, their footprints and actions are included in this analysis as if they existed. Any proposed projects, those not yet authorized for construction, are not considered part of the FWOP conditions for analysis.

3.1 CLIMATE CHANGE

Droughts, heat waves, and floods are climate-related extremes impacting ecosystems and humans (IPCC, 2014). Climate changes occur on time scales longer than the 50-year period of analysis and over broader geographic areas than the study area. These changes would continue to influence coastal climate in Texas. Predicted global climate changes are summarized in IPCC (2014) and described below.

- For the period from 2016 to 2035, there is a medium level of confidence the global average surface temperature would likely rise 0.5 to 1.3°F relative to temperatures from 1986 through 2005 (IPCC, 2014). Climate modeling in Texas indicates temperatures may rise (compared to the 1980 to 1990 average) 4°F by 2040 to 2059 (TWDB, 2012).
- It is "virtually certain" there would be more-frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is very likely that heat waves would occur with a higher frequency and longer duration. Occasional cold winter extremes would continue to occur (IPCC, 2014). The number of days with temperatures exceeding 100°F and the number of warm nights (minimum temperature greater than 80°F) are expected to increase from between 16 to 28 days and 40 to 45 nights between 2041 and 2070 (Shafer et al., 2014).
- Changes in precipitation would not be uniform. In many mid latitude and subtropical dry regions, mean precipitation would likely decrease. Extreme precipitation events over most of the mid latitude land masses and over wet tropical regions would very likely become more intense and more frequent. Recent analysis of the August 2016 severe floods in Louisiana (van der Wiel et al., 2016) support the IPCC (2014) estimates. According to van der Wiel et al. (2016), the probability of an extreme precipitation event like the August 2016 flooding has increased 40 percent and the possible

intensity has increased 10 percent along the middle Gulf coast since 1900. Modeling future precipitation patterns along the coast of Texas does not reveal distinct trends; however, if temperatures increase as predicted, droughts may be more severe and occur more frequently (Shafer et al., 2014; TWDB, 2012).

Texas climate is expected to experience increasing temperature without a predictable trend in precipitation (Nielsen-Gammon, 2016). According to the Southern Climate Impacts Planning Program (2017), higher temperatures, increased droughts, flooding, and more-frequent, intense hurricanes are expected in Texas. Shafer et al. (2014) identified these expected impacts from climate change in Texas and the Great Plains:

- Rising temperatures will increase demand for water and energy,
- Warming winters and changes in magnitude and season of rainfall events will impact agricultural practices,
- Changes in habitat and plant community development resulting from climate change will affect species ability to adapt,
- Vulnerable communities will be increasingly stressed by more-frequent climate extremes, and
- Climate changes will be greater than those experienced from 1900 to 2000 and existing planning is not adequate to respond to anticipated changes.

Climate scientists are "highly confident" eustatic sea levels would continue to rise for centuries. The rate of eustatic sea level rise would very likely exceed 0.07 to 0.09 inch/year and may reach 0.31 to 0.63 inch/year by the end of this century (IPCC, 2014). Parris et al. (2012) identify four possible levels of global eustatic mean sea level (msl) rise by 2100:

- Highest: 6.6 feet
- Intermediate-High: 3.9 feet
- Intermediate-Low: 1.6 feet
- Lowest: 0.7 foot

RSL changes along the Texas coast may be higher or lower than predicted global changes (IPCC, 2014). Rising RSL has likely increased the frequency of extreme water elevations, like those experienced in storm surges since 1970 (IPCC, 2014; Tebaldi et al., 2012). It would potentially amplify the height of storm surges (Arcadis, 2011). Continued RSLR is expected to increase the frequency and duration of coastal floods when normally dry land is flooded with seawater (Table 3-1). The NOAA Sea Level Rise Viewer predicts the number of flooding events and flooding duration per year for tide gauges along the coast, which will occur if RSLR reaches 1.6 and 3.3 feet in the future (NOAA, 2017f). A flooding event is one that exceeds mean high high water (MHHW) by a specified elevation, which varies for each tide gauge and ranges from 1.13 feet above MHHW at the Port Isabel gauge to 2.2 feet above MHHW at the Freeport gauge. Flooding duration is the time in days each year when water levels will exceed the specified elevation above MHHW. The data in Table 3-1 show the predicted increase in the number of times water level will exceed the specified flood elevations and the increased duration of flooding in days each year if RSLR reaches 1.6 or 3.3 feet sometime in the future.

Table 3-1
Predicted Coastal Flood Frequency and Duration Increases in Relation to RSLR at Tide Gauges

Relative Sea Level Rise	Sabine Pass (8770570)	Galveston Pleasure Pier (8771510)	Freeport (8772447)	Rockport (8774770)	Port Isabel (8779770)
1.6 feet:					
Coastal Flooding Events (number)	175	152	86	83	177
Coastal Flooding Duration (days)	50	33	19	94	66
3.3 feet:					
Coastal Flooding Events (number)	218	318	315	No Data	No Data
Coastal Flooding Duration (days)	311	266	266	154	338

Source: NOAA (2017f).

Rising RSL may affect coastal ecosystems in a variety of ways (BEG, n.d.):

- Increase flooding of washover areas on barrier islands during high tides and storms,
- Increase volume of the tidal prism, reducing residence time in bays,
- Submerge habitat due to changes in water depth (seagrass beds, intertidal marshes),
- Inundate greater land area during storms,
- Possible creation of intertidal marsh and other estuarine habitat in areas that are now typically dry, and
- Raise salinity (concentration, duration, and frequency) in the brackish, up-estuary areas of bays and tidal freshwater wetlands, and in shallow groundwater aquifers near the coast.

Sea level rise threatens coastal infrastructure and ecosystems in a variety of ways. Some models suggest scenarios where Texas shorelines would continue to retreat by 13 feet per year. FEMA predicts shoreline retreat resulting from RSL would affect one-fourth of all homes and structures within 500 feet of the coast in 60 years (BEG, n.d.).

Under the No-Action Alternative, barrier islands would likely experience increased erosion, washover areas would likely expand in width and more frequently flood as sea level rises. Islands in bays and marshes would likely be subject to more erosion and saltwater inundation more frequently and to greater depths in the future. Major deltas are retreating, and under the No-Action Alternative, shore erosion and delta marsh inundation rates would likely increase. However, without implementation of the project alternatives proposed under the Coastal Texas Study, some ER actions by organizations outside the Coastal Texas Study would likely occur and provide various levels of risk reduction from rising sea levels.

3.2 PHYSICAL RESOURCES

3.2.1 Physical Oceanography

There would be no direct impacts to physical oceanography under the No-Action Alternative. Changes in physical oceanography are expected to occur in the future. Salinity regimes in estuaries can be expected to change. Rising sea levels are expected to increase tidal exchange through existing passes with the Gulf and may increase the

frequency of washovers and size of washover areas on barrier islands along with erosion of barrier island shorelines (BEG, n.d.). Deepening and widening of ship channels between the Gulf and bays would affect salinity. There is increasing interest in desalinization of seawater as a source of water supply (TWDB, 2012). Discharge of brine from desalinization activities into bays may also increase salinities. Depending on tidal exchange rates, increased tidal exchange may tend to increase salinities in some bays towards Gulf salinities of about 35 ppt. Flooding estuaries with Gulf waters followed by extended periods of low tidal exchange, low rainfall, and evaporation may lead to hypersaline conditions, particularly in the middle coast (Nueces BBEST, 2011). Increased tidal exchange with Gulf waters is presently reducing the areal extent and degree of hypersalinity in the Laguna Madre, a trend expected to continue with sea level rise and channelization (Rio Grande BBEST, 2012).

Increasing tidal exchange with the Gulf from widening and deepening ship channels, combined with breaches in barrier islands, increased frequency, and amount of barrier island washover, and increased bay shore perimeter from RSLR would likely increase tidal range, tidal prisms, storm surge heights, and bay shore erosion (Holleman and Stacey, 2014; Passeri et al., 2015; Passeri et al., 2016). These changes are expected to be nonlinear and influenced by a complex set of factors including shoreline shape, sediment source, shoreline vegetation, and upland development. Modeling of selected northern Gulf bays shows that sea level rise is likely to increase tidal amplitude, tidal velocities, and maximum ebb tide velocities (Passeri et al., 2016). Increased tidal amplitude and velocities can increase shore erosion, and sediment and nutrient transport in bays. The range of effects would vary with shoreline slope, shape, and vegetation. A portion of the coast has exhibited a positive increase in MHHW combined with a decrease in mean low low water (MLLW) (Mawdsley et al., 2015).

Portions of the upper coast in the Galveston Bay and Sabine Lake estuaries would likely experience increased salinities in fresh and brackish marshes that may be moderated with the protection offered by some of the proposed measures and alternatives. Some deltas would likely experience increased shoreline erosion, marsh loss, and higher salinities as salinities increase due to impacts of sea level rise and reduced freshwater inflow to the deltas. Estuarine salinities are likely to increase in the absence of proposed measures and alternatives, particularly those which protect estuaries from increasing tidal prism.

3.2.2 Coastal Processes

There would be no direct impacts to coastal processes by implementing the No-Action Alternative. However, indirect impacts would be experienced. Specifically, barrier islands and coastal wetlands that have historically protected coastal Texas from tropical and hurricane storm surges are prone to future erosion, fragmentation, and loss, resulting from continued coastal development and reduced sediment delivery affecting the natural processes to sustain these features as natural buffers against surges. In addition, rising sea levels and subsidence are a contributing factor affecting important, essential, and vital coastal habitats, as well as the safety of coastal communities and inhabitants. Continued coastal subsidence coupled with increasing sea levels would place residential and commercial properties and supporting infrastructure at risk of damage and destruction by increased levels of future storm surges.

Climate models are predicting increases in sea surface and air temperatures. In addition, they are predicting that a greater wind shear (difference between wind speed and direction over a short time period) would be experienced with climate change over parts of the western tropical Atlantic as air temperatures rise. While greater wind shear could potentially moderate hurricane development and intensification, rising sea surface temperatures would likely support hurricane development and intensification. Regional modeling for the Atlantic forecasts a substantially reduced number of hurricane and tropical storm events, but higher intensity and rainfall rates associated with each event. It showed a substantial decrease (about 25 percent) in the overall number of Atlantic hurricane and tropical storm events in the twenty-first century. However, when multi-model climate projections were introduced, the hurricane model forecasts the lifetime maximum intensity of Atlantic hurricanes would increase by approximately 5 percent, and the frequency of very intense hurricanes (category 4 and 5) would increase by greater than 90 percent (NOAA, 2017g).

Historically in the United States, major hurricanes (category 3 to 5) and very intense hurricanes (category 4 and 5) at landfall account for 86 percent and 48 percent of all damage, respectively, but account for only 24 percent and 6 percent of landfalls. With the effects of climate change to hurricane storm frequency and intensity, it is estimated there would be a 30 percent increase in potential storm damage in the Atlantic by 2100, where the damage potential of the more intense category 4 and 5 hurricanes outweighs the decrease in damage potential from the reduced frequency of weaker storm events. This estimate does not include the influence of future sea level rise or other important factors such as coastal development or changes in building practices (Bender et al., 2010).

Climate change is also impacting storm surge. As a result of sea level rise, storm surges are 8 inches higher today than they were in 1900. It is predicted that by 2100 storm surge will be superimposed on an additional 8 inches to 6.6 feet of sea level rise (NOAA, 2017h). Future sea level rise could magnify the impacts of hurricanes or extra-tropical storms by raising the base water level on which storm surges build, which may flood low-lying areas, damage property, disrupt transportation systems, harm ecosystem habitats, and threaten human health and safety (EPA, 2017e).

As sea level rise accelerates, more-frequent and higher coastal floods would occur globally. For the Texas coast, Strauss et al. (2014) indicates low sea level projections would lead to a greater chance of serious floods exceeding 5 feet above the high tide line by 2050 at most sites across the coast. Mid-range sea level projections for the same time showed that record-breaking floods are likely from Freeport and south of Freeport. High-range sea level projections showed that there is at least a two in three chance of floods above 10 feet by end of century at five of the six locations studied statewide.

3.2.3 Water and Sediment Quality

Water and sediment quality trends are not expected to be substantially affected with the No-Action Alternative and would continue as described in Section 2.3.4. Increased flooding from storms may mobilize nutrients, metals, and synthetic organic hydrocarbons and transport them into estuarine waters and wetlands. Climate change and sea level rise may raise water temperatures and salinities in estuaries. Increased tidal flushing with Gulf waters

may decrease nutrient and plankton concentrations and increase transparency; however, increased human population growth and coastal development may increase nutrient loading, create algal blooms, and decrease transparency in estuaries (Paerl, 2006). Inundation of marshes may kill marsh plants and release sediments into the water column as plants and their root systems die. Estuaries may experience increased transparency in one area from increased seawater intrusion and increased turbidity in other areas due to marsh inundation. Water and sediment quality in the future would be affected by treatment of municipal and industrial wastewater and management of nonpoint source pollution by State and Federal regulations. Availability of funding for wastewater and nonpoint source pollution management will also play a key role in future water and sediment quality changes.

Global climate changes have impacted oceanic chemistry. There is a high degree of confidence that pH of ocean surface water has dropped by 0.1 standard units (a 26 percent increase in acidity) and would continue to decline. By 2100, the expected decrease in ocean surface pH may range from 0.06 to 0.32 standard units (an increase in acidity of 62 percent). Increased acidification of ocean waters may harm organisms that form carbonate structures and shells. Global climate change may also be contributing to reduced oxygen concentrations in coastal waters through increasing temperatures which reduce oxygen solubility (IPCC, 2014). Along the Texas coast the sublethal threshold of ocean acidification of oyster larvae is not predicted to be reached until 2099 (Ekstrom et al., 2015).

3.2.4 Hydrology

Under the No-Action Alternative, there would be no direct impacts to watershed and river basin hydrology. However, indirect impacts would include severe droughts and increased freshwater usage for agriculture; municipal, industrial, and commercial sources would diminish reservoir storage and freshwater inflows to coastal bays and estuaries. Without sufficient freshwater flows and saltwater barriers, salinity levels in estuaries would transition from a brackish to saltwater ecosystem. Rising sea level and saltwater intrusion into bays and upstream into rivers and creeks can cause changes in habitat. Freshwater plants can experience salt burns, and wildlife can have trouble finding potable water. Threatened and endangered species such as the Texas fawnsfoot, southwestern willow flycatcher, and whooping crane rely on freshwater marshes. River flows could be negatively impacted and may relocate to alternative locations. In areas such as Houston, groundwater withdrawal from aquifers that has led to land subsidence and flooding in low-lying areas would continue.

3.2.5 Soils (Prime and Other Important Unique Farmland)

Under the No-Action Alternative, there would be no direct impacts to soil and prime farmlands. Indirect impacts of implementing the No-Action Alternative would be the continued degradation and loss of soil resources as well as prime and unique farmlands. Areas along the Gulf coast would continue to experience increasing RSLR rates that would likely affect the depth, frequency, and severity of storms and hurricanes. Saltwater intrusion throughout the coastal regions along the Gulf coast would continue, further degrading prime and unique farmlands and soils. Repeated inundation could turn non-hydric soils into hydric soils and wetlands into open waterbodies, as edaphic and hydrological change with RSLR. Generally, tidal wetland conversion to open water would be more likely on lands adjacent to East and West Galveston bays, Freeport, and Cow Trap Lakes near the San Bernard River. Prime

farmlands would likely be converted or developed into other uses such as highways, commercial, and residential development. South Texas, which is highly reliant on agriculture and cattle ranching, could potentially face land loss and saltwater intrusion to river, bay systems, and coastal upland areas. The top soil could potentially lose its productivity, and crops could experience salt burns if low-lying areas are inundated by seawater. Existing and likely future ER efforts at the Federal, State, and local levels along the entire Texas coast could likely continue to help mediate and reduce further coastal erosion and land loss.

3.2.6 Energy and Mineral Resources

The No-Action Alternative would result in no substantial direct impacts on energy and mineral resources including oil and gas activities or infrastructure and energy production facilities and platforms. Indirect effects would include continued shoreline recession, land loss, and subsidence. Without the natural buffering provided by features along the shoreline, oil and gas pipelines and infrastructure would be subject to increased exposure along the coast. Wave action from hurricanes or gale force winds have the potential to erode beaches and may expose existing oil and gas pipelines. Reduced protection and continued exposure would increase the susceptibility of the oil and gas infrastructure to rupture or damage. Damage to oil and gas infrastructure may result in releases of petroleum products transported to the environment. In addition, sand and gravel dredging along the coastline is a vital source for mineral resources. Sand and sediment resources are generated from maintenance dredging of the GIWW, ship channels, and bays as well as channel deepening or widening projects. Without dredging activities in the coastal zone, the use of mineral resources to balance land erosion and subsidence would not exist.

3.2.7 Hazardous, Toxic, and Radioactive Waste Concerns

The No-Action Alternative would result in no direct impacts on hazardous materials associated with regulated facilities and shipping traffic. For the Coastal Texas Study, it was assumed that industry had low level protections in place but nothing substantial to protect themselves against higher storm surges. As industrial activity continues to increase to accommodate future anticipated demands for petroleum products, additional indirect impacts would occur. Continued sea level rise and hurricane storm surges would increase degradation of natural and man-made seawalls, levees, and barrier islands leaving industrial facilities more susceptible to damage; increasing the potential for the release of waste materials into the environment. Due to global warming, catastrophic events causing significant damage to industrial facilities would likely increase over time. Due to the high numbers of sites located on the upper Texas coast, this area has the greatest potential to be impacted should no measures be constructed.

3.2.8 Air Quality

Implementing the No-Action Alternative would have no direct impacts on air quality. Indirect impacts would include continued degradation of air quality along coastal areas due primarily to increasing populations, commercialization, industrialization, increased use of motor vehicles, continued oil and gas exploration and refinement operations, and continued loss of vegetation in wetlands and forests which may decrease the removal rate of gaseous pollutants from the atmosphere. For example, the Houston-Galveston area is forecasted to have a

1.8 percent annual population growth, surpassing 7 million people by 2020 and 10 million by 2040 (HGAC, 2016). The increased rate of development has led to quickening conversion of grasslands and wetland draining for residential and commercial purposes. Currently San Patricio and Nueces counties are designated as a special inventory by the TCEQ, which means that O_3 monitoring levels are just below the NAAQS. With population growth, the expansion of the Corpus Christi Ship Channel, and increased industrialization, it is likely that air quality in the area would decrease. This could also lead to a rise in respiratory ailments such as asthma and emphysema in children and sensitive populations. In south Texas, Cameron, Kenedy, and Willacy counties are currently in attainment and have measured well below the threshold for O_3 and other air pollutants. However, like the mid and upper Texas coast, air quality could be negatively affected with increasing population, commercialization, and industrialization.

3.2.9 Noise

Existing noise conditions would continue as described in Section 2.3.11 under the No-Action Alternative. Noise generated by existing noise sources (e.g., waterborne transportation, automobile and train transportation, recreation and commercial enterprises, industrial operations, port activities) would continue into the future. Some periodic, short-duration noise impacts could result from repair or maintenance of existing facilities. Storms and other natural disasters would likely continue to result in infrastructure damage that would require rehabilitation/reconstruction activities that would continue to impact ambient noise at these sites. Numerous authorized for construction and current projects being constructed in the study area (e.g., port expansions, maintenance dredging in shipping channels, maintenance activities of existing coastal infrastructure) would likely continue and result in localized noise impacts. Human population growth would likely continue and result in more commercial/industrial activities within the study area with a likely commensurate growth in ambient noise levels.

3.3 ECOLOGICAL AND BIOLOGICAL RESOURCES

3.3.1 Wetlands

3.3.1.1 Non-tidal Wetlands

Under the No-Action Alternative, there would be no direct impacts to non-tidal wetlands, including riverine forested wetlands, prairie potholes and marshes, or Texas Coastal Sand Sheet wetlands. Indirect impacts under the No-Action Alternative, would be continued loss of wetland, mostly due to development. For example, between 1992 and 2010, Harris County experienced a 30 percent loss of freshwater wetlands, including most of the prairie-pimple mound wetland complexes (Jacob et al., 2014). Populations of Texas are expected to increase 70 percent between 2020 and 2070 (i.e., 29.5 million people in 2020 to 51 million people in 2070; TWDB, 2017c). The increased water demand would have direct and indirect effects to wetlands. Hydrologic alterations of the watershed and floodplains (e.g., new reservoir construction, increases in impervious cover, groundwater pumping, alteration of streams and wetlands, etc.) due to economic and population growth would have a detrimental effect to inland wetlands. Population growth would also increase recreational use of wetlands, such as hunting and fishing. Increased recreational use of wetlands can be negative due to direct impacts; however, increased recreational use may increase awareness and interest in wetland conservation. Continued economic growth within

the coastal zone would affect these wetlands, although it is assumed that some mitigation or protections would take place under regulatory programs and requirements of Section 404 of the CWA, and other regulations that protect wetlands, floodplains, and water resources. However, some research suggests that Federal regulations pertaining to wetland development and loss (and required mitigation; under Section 404 of the CWA) are not adequately complied with by permittees within the Houston-Galveston area, thus leading to an overall wetland loss despite existing Federal laws (Jacob et al., 2015).

It is likely future climate change could affect wetlands. For example, drier future conditions or reduced rainfall could reduce the hydrology associated with these wetlands. Conversely, if increased rainfall is experienced, hydrological inputs to these wetlands would increase. Sea level rise could impact wetlands closer to the coast, resulting in a conversion to a more halophytic plant community. Climate change may also improve the potential for species range shifts, or invasive species colonization, which could lower biodiversity and alter wetland functions (Osland et al., 2013; Rahel and Olden, 2008).

3.3.1.2 Tidal Wetlands

Not implementing coastal restoration projects would have no direct impacts on tidal wetlands. Under the No-Action Alternative, trends of tidal wetland loss would continue. Indirect impacts would include urban and industrial development on the coastline, which would reduce wetland habitat and prevent tidal wetlands from migrating inland (Brody et al., 2008). Hydrologic alterations of the watershed and floodplains (e.g., new reservoir construction, increases in impervious cover, groundwater pumping, alteration of streams and wetlands, etc.) due to development and population growth would have a detrimental effect to tidal wetlands by reducing water quality, or changing the quantity or timing, for example. Similar threats to non-tidal wetlands exist for tidal wetlands, including potential for increased recreational use and pressures and the potential to be developed and improperly mitigated for due to inefficient permittee compliance with Federal laws (i.e., Section 404 of the CWA).

Potential climate change impacts to tidal wetlands could be like those identified for non-tidal wetlands. More or less rainfall (drought or floods), and the timing of those events, could affect wetlands. Decreasing frequency and intensity of freezing weather can also promote the range expansion of mangrove forest that could slowly replace salt marsh habitats as black mangrove has been increasing in extent on the Texas coast (Armitage et al., 2015; Osland et al., 2013). Rising sea level can inundate vegetation more frequently and increase the rate of soil erosion and potential marsh loss. A variety of impacts to coastal wetlands are anticipated by sea level rise and climate change, including changes to hydrology, nutrient inputs, and flood or tide timing and intensity, for example (Scavia et al., 2002).

Tidal wetlands throughout the Texas coast are declining and would likely continue this trend as sea levels continue to rise. Consequently, there is a potential that tidal wetlands would migrate inland in response to rising sea levels, where elevation and topography is more conducive for their continued establishment (Scavia et al., 2002). Marsh migration with sea level rise could result in an increase in the extent of tidal wetlands in some areas; however, according to the NOAA Sea Level Rise Viewer, tidal marsh appears to decrease in Galveston Bay when comparing present day extents of tidal marsh to those under a 3-foot level scenario, for example (NOAA, 2017f).

Feagin and Yeager (2008) found that marsh accretion rates in Galveston Bay were not keeping up with sea level rise, but low marsh accretion rates in Matagorda Bay were. In one study involving the Sea-Level Affecting Marshes Model for the Gulf, regularly flooded salt marshes would increase by 2050 but decline by 2100 (relative to baseline conditions), under several sea level rise scenarios from 3.9- to 6.6-foot increase (Gulf Coast Prairie Landscape Conservation Cooperative, 2016). Sea level rise and potential marsh impacts or responses are complex, and most models may overestimate marsh loss in localized areas (Kirwan et al., 2016). The expected increase in black mangrove may also alter predictability of marsh loss with sea level rise.

3.3.1.3 Seagrass

There would be no direct impacts to seagrass resources by implementing the No-Action Alternative. However, indirect impacts would include the following. Seagrass beds along the Texas coast have been generally expanding in acreage in some areas, except for Galveston Bay, which has been declining overall (however, seagrass persists in Christmas Bay) (Moulton et al., 1997). Much of the increases seen along the Texas coast have been in the lower and mid Texas coasts. Under a No-Action Alternative, it is presumed that these dynamic trends of seagrass, decreases and increases would continue. With predicted climate changes, increasing frequency and strength of coastal storms and hurricanes can damage or bury seagrass meadows with sediments at a higher frequency or intensity. Additionally, it is unclear how sea level rise would affect the distribution or abundance of seagrass. Like tidal marshes, it is possible that seagrass could migrate in response to sea level rise. Much of the seagrass response to sea level rise is likely dependent upon water quantity, quality, and clarity in the future; water quantity and quality would be affected by predicted population growth and development within the watersheds (Saunders et al., 2014; TWDB, 2017c). For example, increased nutrient runoff from agricultural sources can produce algal blooms of higher frequency or intensity in the Gulf, creating a low-light environment and leading to seagrass reduction. With population growth could come increased recreational use of seagrass beds; presently boat prop scars are a primary impact from recreational boaters, and the frequency of prop scars would likely continue (Burfeind and Stunz, 2006).

3.3.2 Aquatic Resources

There would be no direct impacts to aquatic resources by implementing the No-Action Alternative. However, indirect impacts would occur from continued shoreline erosion, subsidence, and land loss, converting marsh to marine and open water. Biological criteria have not been established in Texas for evaluating impacts to aquatic communities, fisheries, and EFH. The assessment of potential impacts is based on scientific literature and best professional judgment of scientific experts. For this evaluation, possible temporary and long-term impacts to aquatic communities, fisheries, and EFH are presented. Temporary impacts would likely occur during project construction, potentially lasting weeks to months following completion of the project, while long-term impacts would last months to years following construction of the proposed project. It should be noted that limited information is available regarding climate change/sea level rise impacts to aquatic communities along the Texas coast (pers. comm. J. Tolan [TPWD], 2017; G. Stunz [Texas A&M University-Corpus Christi], 2017). Where information is not available, best professional judgment was used to assess impacts.

3.3.2.1 Freshwater Habitats and Fauna

There would be no direct impacts to freshwater habitats and fauna resources by implementing the No-Action Alternative. Freshwater habitats would likely experience indirect impacts.

Over the past century, movement of Gulf waters into estuaries has increased as ship channels have been deepened and widened and the GIWW has cut across much of the coastal watershed. Channelization and development for residential and industrial purposes has eliminated some coastal freshwater wetlands and channelized many coastal freshwater streams. Increased coastal development has brought substantial hydrological modifications to many freshwater streams and wetlands with increases in flow from treated wastewater discharges. Rainfall runoff from increased area of impervious and developed surfaces modifies flow regimes allowing floods to pass more quickly with higher peak flows.

For example, Sabine Lake prior to the 1870s, before the development of major navigation projects, was a freshwater system with an oligohaline estuary supporting oysters at its mouth with the Gulf (TPWD, 2003). It now has a 44-foot-deep, 500-foot-wide channel at the mouth of the estuary with plans to deepen the channel to 52 feet and 700 feet wide (Sabine and Neches BBEST, 2009). Tidal waters now extend over 20 river miles upstream into the Neches River from the formerly fresh Sabine Lake. This represents a conversion of over 20 miles of freshwater habitat into tidally influenced brackish waters in a little over a century.

Bessie Heights Marsh at the upper end of Sabine Lake and adjacent to the Neches River was a freshwater marsh complex. Saltwater intrusion, exacerbated by subsidence, converted the freshwater, vegetated complex into a progressively more-saline, open-water system. As a result, freshwater wetland plants have been replaced by euryhaline species like shrimp and red drum feeding where open water meets the vegetated edge.

The extensive loss of freshwater habitat that occurred in the Sabine Lake area may not happen in the same manner farther south along the coast. Coastal streams may retain their mobile freshwater communities like fish, reptiles, and amphibians and switch back and forth between fresh and brackish water communities. Increasing saltwater intrusion and reduced freshwater flows may push mobile freshwater fauna out of these habitats for longer periods of time and more frequently. Communities in these habitats may be more frequently replaced with Gulf menhaden, bay anchovies, blue crabs, and shrimp. Except for the Rio Grande, few streams drain into estuaries south of the Nueces River. Streams in this semiarid region are intermittent or are maintained by treated wastewater discharges, irrigation return flow or storm water runoff from urban, suburban, or agricultural land. Impacts to freshwater ecosystems in the No-Action Alternative case may be more measurable along the coast between the Nueces River and Sabine Lake to the east.

Over the period from 2020 to 2070, Texas's population may increase to 51 million (a 70 percent increase), water demand is expected to rise 17 percent, while existing water supplies may drop 11 percent (TWDB, 2017c). In addition, RSLR has increased saltwater flooding of coastal freshwater marshes and allowed tides to push farther upstream into freshwater tidal streams.

Without actions to protect and/or restore ecosystem structures and functions, this trend of increasing freshwater demand, river and estuarine modifications for navigation, and sea level rise is expected to increase saltwater intrusion into areas that were typically fresh, reducing freshwater and estuarine habitats along the coast. Freshwater habitats may diminish in size and diversity, reducing abundance and diversity of freshwater communities in areas of the coastal zone where alternatives will not be implemented.

3.3.2.2 Estuarine Habitats and Fauna

Under the No-Action Alternative, there would be no direct impacts to estuarine habitats and fauna resources. Aquatic communities would remain as described in Section 2.4.3. Indirect impacts would include the following. Existing conditions and associated changes to aquatic communities would continue into the future.

The significance of the predicted global climate changes is their possible contribution to increasing sea levels, coastal flooding, changing estuarine salinity regimes, and biological communities. Indirect impacts due to climate change stressors (sea level rise, temperature increases, salinity changes, and wind and water circulation changes), storm severity and frequency, and USACE dredging and maintenance dredging operations would continue to have an impact to the aquatic communities. See sections 3.2.1 and 3.2.3 for a more-detailed discussion on how these changes in physical factors are expected to impact the Texas coast in the future.

Trends of tidal wetland loss would continue. Increased development, hydrologic alterations, drought, flooding, and temperature extremes could affect wetlands. Sea level rise and climate change, including changes to hydrology, nutrient inputs, flood or tide timing and intensity could have a variety of impacts on wetlands. See Section 3.3.1.2 for a more-detailed discussion on how these factors are expected to impact Texas coastal wetlands in the future.

Although marshes throughout the Texas coast are declining and would likely continue this trend as sea level rise continues, there is a potential that they would migrate inland in response to rising sea levels in areas where the elevation and topography are conducive for establishment (Borchert et al., 2018; Guannel et al., 2014; Murdock and Brenner, 2016; Scavia et al., 2002). According to the NOAA Sea Level Rise Viewer (2017f) 3-foot scenario model, tidal marsh appears to decrease in Galveston Bay when compared to present day but could result in an increase in other locations along the coast. Feagin and Yeager (2008) found that marsh accretion rates in Galveston Bay are not keeping up with sea level rise, but were in other areas of the coast. Murdock and Brenner (2016) reported that the Coastal Bend area modeling showed an increase in transitional marsh. If wetlands and marshes are unable to keep up with the rate of sea level rise then those habitats may be submerged and converted to subtidal habitat (Borchert et al., 2018). The main barrier to marsh migration in the Galveston Bay area is urban development of low-lying areas preventing this from occurring (Borchert et al., 2018). Similar trends are seen for seagrass (see Section 3.3.1.3) where it has been generally expanding in the mid and lower Texas coast, but declining for Galveston Bay (Moulton et al., 1997). It is unclear how sea level rise would affect seagrass, but like marshes, it is possible that seagrass could migrate in response to sea level rise (Saunders et al., 2014; TWDB, 2017c).

It is anticipated that future sea level rise will force the landward migration of wetlands and marsh and cause major shifts in the amount and distributions of the natural habitats along the coast (Guannel et al., 2014). Recent modeling efforts have been conducted to look at fisheries habitat response to sea level rise. Guannel et al. (2014) modeled fisheries habitat change in Galveston Bay due to sea level rise (assuming a 3.3-foot sea level rise through 2100) on larval and juvenile stages of blue crab, brown shrimp, southern flounder, and red drum. There are currently over 69,000 acres of suitable wetlands, tidal flats, and nearshore estuarine waters for these species and specifically 346 acres of marsh edge for these species to utilize. As sea level rises, the total footprint of these habitats would increase, and wetlands potentially migrate (if not prevented by increasing elevation), marsh edge would shift landward increasing to nearly 593 acres through 2050 and 1,112 acres by 2100. In the Galveston Bay area, the increase would be mainly due to the topography, which is flatter, thus having a greater surface area as sea level rises. Commercial brown shrimp catch may also increase as sea level rises, potentially increasing by 39 percent by 2050 and 100 percent by 2100. As wetlands are lost commercial shrimp catches are also reduced, a 10 percent loss of wetlands equates to a 7 percent loss of shrimp catch and a 20 percent wetland loss to a 17 percent catch reduction. Temperature and salinity variables were not included in this analysis, and these variables may have a greater impact on fisheries than habitat area increases caused by sea level rise (Guannel et al., 2014). Wetlands would only migrate landward if there is undeveloped land at the necessary elevations and slopes with appropriate substrate to support establishment of new wetlands. In developed areas or where environmental variables do not meet species' needs, this migration would not occur (Murdock and Brenner, 2016).

Fulford et al. (2014) modeled projected sea level rise impacts (between 1996 and 2100) to estuarine nursery areas in the Pascagoula River Estuary of Mississippi. Modeling showed that as sea level rises salt marshes first showed a decline transitioning from low level marsh to tidal flat to open water followed by a net increase in quality driven by marsh fragmentation. This mirrors the effect on nursery production which was shown to first be negatively affected by sea level rise, but ultimately may produce positive changes in production due to the increase in marsh-edge habitat that results from fragmentation. These results are consistent with other salt marsh production studies in the Gulf which showed salt marsh fragmentation correlated with a positive effect on fish nursery production, however, there is a threshold of fragmentation where estuarine fisheries production quickly diminishes (Chesney et al., 2000; Minello et al., 2003; Park et al., 1989). Additionally, Roth et al. (2008) conducted similar modeling on brown shrimp and found access to marsh edge habitat was the main driver of increased growth resulting from inundation and marsh fragmentation. This increased estuarine nekton production has been observed by TPWD coastal fisheries in the Sabine Lake area as fresh and brackish water tidal marsh becomes inundated and destroyed. Organic matter and nutrients are generated and utilized by fish and shrimp at the marsh edge, which benefits nekton productivity while the marsh is disintegrating but is harmful in the long run because after the marsh has finished disintegrating there is reduced organic matter productivity and less (or no) nursery habitat (pers. comm. David Buzan, 2017).

Under the No-Action Alternative, it is likely that as sea level rises most fish species (including commercial and recreational fisheries) could benefit from larger areas of available habitats if marshes can migrate. The upper Texas coast exhibits a higher rate of sea level rise than is seen on the lower Texas coast. Based on this information, areas along the Texas coast that are relatively undeveloped would be most likely to support landward migration of wetlands as sea level rises. The upper coast may see the least benefit due to the high proportion of developed

shoreline in that region, while the lower coast, because of the relatively small proportion of developed shoreline, may see the most landward growth of wetlands. According to Jim Tolan of the TPWD, who serves on the Association of Fish and Wildlife Agencies Climate Change Committee, the general consensus is that as long as there is sufficient habitat, the seagrass, fisheries, and oyster reefs can and would adapt and likely show no impacts to RSLR (pers. comm. J. Tolan [TPWD], 2017). In addition, Watson et al. (2017) showed that the vulnerability of spotted seatrout, red drum, and blue crab to sea level rise appears low for these species as these species have the ability to move away from these threats and are able to cope with the projected changes.

Increasing salinities are anticipated with global climate change. Most organisms occupying these environments are ubiquitous along the Texas coast and can tolerate a wide range of salinities (Pattillo et al., 1997). Therefore, no adverse effects on fauna are expected due to changes in salinity that may result from these changes, except loss of habitat due to salinity impacts on marshes. Increases in salinity in wetland habitats may cause small reductions in the health and biological productivity and may cause additional stress on some marsh vegetation, which could cause some impacts to associated fish and shellfish species.

Increasing water temperatures is another effect of global climate change. Tolan and Fisher (2009) describe population increases of gray snapper (*Lutjanus griseus*) in Texas estuaries attributed to increased winter surface water temperatures. Whitney et al. (2016) provide a comprehensive review of possible ways climate change may affect fish communities. These impacts may range from cardiorespiratory responses to changes in reproductive behavior triggered by temperature changes. They also review documented effects of climate change on North American inland fish populations. These effects included changes in community composition, shifts in distribution, and changes in migration timing.

Under the No-Action Alternative, oyster reefs would continue their current decline as described in Section 2.4.3. Hurricanes and other storms may catastrophically impact oyster reefs, affecting commercial harvest and ecological services provided by oysters as was seen in 2008 when Hurricane Ike struck Galveston Bay burying 8,000 acres of oyster reef under sediment (Freese and Nichols, Inc., 2015). Although it is known that oysters can tolerate relatively high salinities, temperatures, and increased water depths, it is also known that some oyster predators (stone crabs [*Menippe mercenaria*] and oyster drills) and diseases (Dermo) may occur more frequently or in higher concentrations with higher temperatures and salinities (Cake, 1983; Murdock and Brenner, 2016; Soniat and Kortright, 1998). Rybovich et al. (2016) found that changes in climate, sea level, and land use would cause decreases in the extent and/or ecosystem function, negatively affecting oyster reefs. Altered weather patterns resulting in salinity changes, increases/decreases in precipitation, and increases in sea surface temperatures also affected oyster growth and survival. Increased mortality of oysters was largely a result of the coupled effects of high temperatures and low salinities (Rybovich et al., 2016). Oyster reefs may be able to shift their distribution in response to these changes assuming conditions are favorable (Watson et al., 2017). Watson et al. (2017) found oysters to be highly vulnerable in Texas; altered hydrology and inability to move away from threats was considered the greatest threat. Oysters' ability to keep up with changing sea level rise is dependent upon recruitment and oyster growth (minus harvesting) exceeding sea level rise rates. If the oyster fishery is managed sustainably, it is assumed that oyster reefs would be able to keep up with moderate sea level rise (Soniat et al., 2012; Watson et al., 2017). Increased acidification would make it more difficult for oysters to thrive;

however, the sublethal threshold for oyster larvae is not predicted to be reached until 2099 (Ekstrom et al., 2015; Murdock and Brenner, 2016).

Numerous oyster reef restoration efforts are taking place in Sabine Lake, Galveston Bay, East Bay, Matagorda Bay, and Copano Bay. Some oyster reef restoration is intended to support the commercial oyster fishery with the expectation that newly created reefs may not persist more than 2 or 3 years. In other cases, hard substrate reefs with vertical relief are being constructed to enhance long-term oyster colonization while providing many of the ecological structures and functions supported by oyster reefs. Reef construction is focused in areas where reefs historically occurred. These activities may not be able to accommodate or survive the current declining trend in oyster reef area.

Currently there are many other restoration efforts being undertaken by the GLO, TPWD, TCEQ (through its National Estuary Program offices), USFWS, local governments, and non-governmental organizations including TNC, Audubon, Ducks Unlimited, and Galveston Bay Foundation along the entire Texas coast that would benefit aquatic communities. However, these activities may not maintain estuarine productivity within the current trends in habitat loss and RSLR.

Maintenance dredging activities and activities associated with authorized deepening and widening projects would continue to increase water column turbidity (i.e., suspended material in the water column) during and for a short time after dredging activities. Benthic organisms would continue to be buried by open-bay disposal of dredged material. Many proposed ER activities would also increase turbidity during construction. Increased turbidity in estuarine and coastal waters is generally cited as having a complex set of impacts on a wide array of organisms (Hirsch et al., 1978; Stern and Stickle, 1978; Wright, 1978; Wilber et al., 2005). Increased turbidity can interfere with light penetration thus reducing photosynthetic activity by phytoplankton, algae, and seagrass. This reduced productivity may be offset by an increase in nutrients released into the water column during dredging activities that can increase productivity (Newell et al., 1998; Wilber and Clarke, 2001). Increased sedimentation can temporarily impact juvenile and adult finfish by disrupting foraging patterns, reducing feeding rates and effectiveness, burying habitat for feeding and reproduction, and coating gills of fish resulting in asphyxiation (Clarke and Wilber, 2000; Newcombe and Jensen, 1996; Wilber and Clarke, 2001). Finfish and shellfish are motile enough to avoid highly turbid areas and under most conditions, finfish and other motile organisms are only exposed to localized suspended-sediment plumes for short durations (minutes to hours) (Clarke and Wilber, 2000; Newcombe and Jensen, 1996; Wilber and Clarke, 2001). Temporary impacts to oysters include reduced filtering rates, and clogging of filtering mechanisms interfering with ingestion, respiration, and abrasion (Newcombe and Jensen, 1996; Stern and Stickle, 1978; Wilber and Clarke, 2001). Shrimp and crabs are less impacted by elevated suspended sediments since these organisms reside on or near the bottom where sedimentation naturally occurs (Wilber and Clark, 2001; Wilber et al., 2005). Turbidities can be expected to return to near ambient conditions within a few months after dredging ceases in a given area; thus, no long-term effects are anticipated.

3.3.3 Wildlife Resources

There would be no direct impacts to wildlife resources by implementing the No-Action Alternative. However, indirect impacts would include the continued human development and encroachment into wildlife habitat could decrease species diversity and abundance. RSLR would likely inundate low-lying marshes, beaches, and islands that provide valuable stopover habitats for nesting and migrating avian species. With the loss of suitable habitat, wildlife could be forced to relocate to alternative areas causing loss of biodiversity, tourism, and recreational income for the Texas coast. Without invasive species control, the affected area can experience increased prevalence of nuisance animal and plant species such as nutria, hydrilla, water hyacinth, and feral pig. These invasive species can decrease diversity and damage natural resources. Project continued economic growth, particularly around the Houston metroplex and Rio Grande Valley, is likely to result in losses or degradation to portions of the Texan and Tamaulipan biotic province, respectively.

3.3.4 Protected Resources

3.3.4.1 Protected Lands

There would be no direct impacts to protected lands by implementing the No-Action Alternative. State and Federal lands would continue to be managed for conservation and recreational purposes. Coastal refuges and protected lands may continue to lose upland and tidal wetlands if shoreline stabilization or nourishment projects do not occur. Low-lying areas such as Anahuac NWR, Brazoria NWR, San Bernard NWR, Mad Island WMA, Big Boggy NWR, and Powderhorn Ranch State Park could experience tidal wetland conversion to open water. Without beach nourishment and shoreline protection, protected areas such as the Padre Island National Seashore and Laguna Atascosa NWR would continue to experience land loss and shoreline erosion. Wildlife species associated with these parks could face increased pressure from lack of suitable habitat and human encroachment and be forced to relocate. Wildlife species diversity would decrease if resources at the parks and refuges are diminished. Historical buildings and ships would require regular routine maintenance and restoration, or risk being condemned. Park facilities such as docks and boat ramps close to the coastline could experience property damage and loss due to rising sea level and strong storm surges.

3.3.4.2 Threatened and Endangered Species

There would be no direct impacts to threatened and endangered species by implementing the No-Action Alternative. Rising sea level and shoreline erosion would likely reduce sea turtle, piping plover, and rufa red knot habitat along Galveston Bay and Bolivar Peninsula. Without additional shoreline protection and beach nourishment projects, more open water from shoreline erosion may provide more favorable conditions for the largetooth sawfish and West Indian manatee. Stronger storm surges and increased inundation of uplands could increase soil salinity and potentially degrade habitat for the Texas prairie dawn-flower.

The continued loss of native coastal prairie to development and habitat conversation to pasture would reduce potential habitat for the Attwater's prairie chicken (although they only exist at the Attwater Prairie Chicken NWR west of Houston). Loss of coastal barrier islands of Matagorda Bay and its surrounding wetlands from RSLR and

shoreline erosion could potentially reduce foraging, nesting, or wintering habitat for the interior least tern, aplomado falcon, rufa red knot, piping plover, whooping crane, and sea turtles.

Without continual shoreline restoration and erosion control, the wetlands and brackish marsh at the Aransas NWR would continue to be converted into open water. This would impact the wintering population of endangered whooping cranes commonly found around the refuge that rely on the wetlands to forage and roost. RSLR would also inundate shoreline foraging habitat for piping plovers, and rufa red knots, and nesting habitat for sea turtles.

Without shoreline protection measures and continual beach nourishment, Padre Island could potentially lose important nesting sites for Kemp's ridley and loggerhead sea turtles. Avian species like the aplomado falcon, rufa red knot, and piping plover that forage, nest or roost on the barrier island could be forced to relocate. In the Lower Rio Grande Valley, continuing human development and encroachment, particularly with the construction of barriers, habitat loss and vehicle strikes, can also negatively affect ocelots and jaguarundis that migrate between the Texas-Mexico border.

3.3.4.3 Essential Fish Habitat

Under the No-Action Alternative there would be no direct impacts to EFH resources. Existing conditions of EFH (including estuarine water column, estuarine mud and sand bottoms [unvegetated estuarine benthic habitats], estuarine shell substrate [oyster reefs and shell substrate], estuarine emergent wetlands, seagrasses, mangroves, marine water column, unconsolidated marine water bottoms, and natural structural features) would continue as described in Section 2.4.5 and be available to Federally managed species for which EFH has been designated (managed species) through the 50-year period of analysis. These areas would be available for use by EFH managed species.

Impacts to EFH under the No-Action Alternative would be the same as those described in Section 3.3.2.2, Estuarine Habitats and Fauna.

3.3.4.4 Migratory Birds

With the No-Action Alternative, migratory birds will continue to be protected under the MBTA of 1918 which extends Federal protection to and prohibits the "take" of migratory birds.

The Houston-Galveston area is estimated to have a 1.8 percent annual population growth, surpassing 7 million people by 2020 and 10 million by 2040 (HGAC, 2016). As human population increases, development along the Texas Gulf coast will continue to encroach on wetlands and marshes that provide habitat and resources for migratory birds as they overwinter or stopover along their migration routes. Shorebird and migratory bird habitat will continue to be vulnerable to human development along beachfronts and coastal properties.

The USACE (2018) has predicted that the Texas coast would experience a RSLR of 1.4 to 2.0 feet by the year 2065. Rising sea levels can inundate and erode tidal flats, beaches, and low-lying islands used by shorebirds to forage and nest. Continual beach nourishment and shoreline restoration measures are needed to provide a buffer

for migratory bird habitat along the coast experiencing shoreline erosion and land loss. Climate scientists predict that future storms may become more intense and produce more hurricanes (Earth Observatory, 2018). Without the coastal risk reduction measures, protected lands, such as bird sanctuaries and coastal NWRs, like Anahuac or Aransas, can experience damages from storm surges, saltwater intrusion, and powerful winds. Because of climate change, bird distribution would shift farther north, which could affect their potential occurrence in Texas with mild winters and warmer springs, migration season for birds may also shift earlier in the year, which could affect migratory bird access to food and habitat along the Texas Central Flyway (Wormworth and Mallon, 2006).

3.3.4.5 Marine Mammals

Under the No-Action Alternative, coastal and BSE bottlenose dolphin stocks would likely continue to be exposed to the current (2018) environmental conditions, habitat, resources, and stressors as modified by increased human populations, urbanization, and different climatic conditions (EPA, 2016m; Pörtner et al., 2014; Runkle et al., 2017; Walsh et al., 2014; Wong et al., 2014). The major additional factors that may influence dolphin stocks are projected water demand that would reduce freshwater inflows and planned projects outside the scope of this project.

As described in Section 2.4.5.5, Texas marine mammals are subject to many stressors, and with outdated population assessments, Texas BSE stocks are considered “strategic” with the Galveston Bay and West Bay stocks receiving a “high priority” ranking (Waring et al., 2016). Based on current stock assessment data, future risks and stock status as described in Section 2.4.5.5 would likely remain under the No-Action Alternative.

The projected amount of sea level rise will likely influence various physicochemical and ecological processes within Galveston Bay and adjacent coastal areas. The increase in open water area should provide some additional open-water habitat for bottlenose dolphins assuming other life history requirements are met including sufficient prey and suitable velocity, depth, and salinity regimes. Due to current and likely future urbanization and continuing construction of flood-prevention infrastructure, these can produce barriers that will likely impede the migration of intertidal and subtidal vegetated wetlands in the Galveston Bay system (Enwright et al., 2016). How this may ultimately affect Galveston Bay food webs and ultimately upper-level predators such as bottlenose dolphins is difficult to estimate.

The occurrence and duration of low salinity can be examined at varying magnitudes utilizing tentative recommended thresholds of: <11 ppt (high), 8 ppt (medium), and 2 ppt (low) during May through October and November through April seasons, for extended periods of time (>5 days) to provide a qualitative assessment of potential health risks (e.g., skin disease) to Galveston Bay BSE dolphin stocks caused by exposure to low salinity.

Under future sea level rise scenarios and a Hurricane Ike-type storm making landfall southeast of Galveston Island, the maximum surge in Galveston Bay could reach 21 feet (Arcadis, 2011). Hurricane Rita displaced seven dolphins under a 15-foot surge (Rosel and Watts, 2007). Under the No-Action Alternative, it is likely that storm surges capable of stranding dolphins and washing dolphins out of their normal habitat will occur.

Warmer temperatures and an increase in frost-free days have already begun to alter the overall species composition of terrestrial and aquatic ecosystems (Canning-Clode et al., 2011; Scheffel et al., 2018). Changes in the composition of wetland and nekton communities may alter the abundance and composition of available prey for dolphins as the ecosystem adjusts to higher temperatures.

Würsig et al. (2001) speculated that bottlenose dolphin are exceptionally unspecialized and adaptable as a species and presumably among the more resilient species, which may benefit in some cases from potential changes in climate. The most likely climate change related stressors that can impact BSE and western coastal stocks include changes in sea level, rainfall, freshwater inflow, salinity, storm frequency, wave conditions, loss of habitat, and changes in food chain composition (Evans and Bjorge, 2013; Learmonth et al., 2006).

3.4 CULTURAL RESOURCES

There are an estimated 247 cultural resources located within CSRM measures and 97 cultural resources within the 9 ER measures. The formation processes that currently affect these sites would continue with the No-Action Alternative. Submerged cultural resources could be at risk from future dredging activities, shifting bars, and wave damage for shallow sites. Submerged resources are also at risk from high energy storms that can dislodge wrecks from the seafloor or impact wrecks on beaches or in shallow water. Upland historic and prehistoric sites would continue to be at risk from shoreline erosion and commercial, industrial, and residential development. Shoreline sites are also at risk from sea level rise and storm surge. These formation processes may result in partial or total loss of historic properties.

3.5 SOCIOECONOMIC CONDITIONS

3.5.1 Population and Housing

Changes in population, households, and housing are expected to follow the growth in employment within the study area (Table 3-2). Generally, the overall population is projected to increase coastwide; however, in the upper coast the population is expected to increase under the No-Action Alternative. This is due to the upper coast having one of the most robust economies in the Nation with major economic assets in the energy, international ports, agriculture, and medical industries.

Growth in employment, business, and industrial activity is expected to follow national economic trends to the extent that economic growth is dependent upon macroeconomic variables such as inflation, interest rates, and the business cycle. However, employment in this region is also partially dependent on the petroleum exploration, production, and refining industries, which do not necessarily correlate with national economic trends. It is expected that even with the risk of hurricane storm surge, the area would still see growth between storm events. For example, the HGAC (2018) regional growth forecast shows intensified household and job growth in the counties of Brazoria, Chambers, Galveston, and Harris (tables 3-3 and 3-4). This trend is expected in other areas of the Texas coast where petroleum exploration, production, and refining industries are the main economic driver.

Table 3-2
Coastal Texas Population Projections

Coastal Area	County	2017	2020	2025	2030	2035	2040	2045	2050	Est. Percent Change
Upper	Brazoria	378,766	410,571	470,735	540,453	620,528	711,049	812,134	924,456	144
	Chambers	43,513	47,621	55,343	64,504	75,373	88,058	102,677	119,555	175
	Galveston	321,627	335,006	358,588	382,798	406,941	431,323	456,709	484,451	51
	Harris	4,633,511	4,885,616	5,326,919	5,777,639	6,223,358	6,660,246	7,092,182	7,527,827	62
	Jefferson	262,687	268,231	278,939	291,737	306,179	322,226	340,645	362,564	38
	Orange	86,261	88,026	91,033	94,084	97,027	99,829	102,606	105,721	23
Mid	Aransas	25,311	26,041	26,993	27,558	27,617	27,296	26,793	26,276	4
	Calhoun	24,071	25,263	27,366	29,570	31,734	33,816	35,873	37,899	57
	Jackson	14,277	14,356	14,431	14,398	14,266	14,011	13,704	13,366	–6
	Kleberg	34,388	35,499	36,928	38,202	39,284	40,018	40,409	40,555	18
	Matagorda	38,879	39,696	40,954	41,864	42,375	42,445	42,226	41,834	8
	Nueces	365,275	376,623	396,093	413,594	427,578	438,565	447,701	455,730	25
	Refugio	7,488	7,514	7,556	7,525	7,386	7,221	7,061	6,880	–8
	San Patricio	67,385	68,331	69,643	70,310	70,379	69,911	68,978	67,771	1
	Victoria	91,033	92,845	95,370	97,790	99,721	101,124	102,304	103,519	14
Lower	Cameron	466,790	493,571	539,676	584,883	627,835	668,322	706,203	741,902	59
	Kenedy	450	462	483	494	489	484	467	438	–3
	Willacy	25,386	26,817	29,227	31,526	33,649	35,787	37,790	39,693	56

Source: Texas Demographic Center (2018).

Table 3-3
Existing Condition and Projected Households by County (1,000s)

County	2010	2015	2020	2035	2045
Brazoria	106,589	124,719	144,996	197,229	279,708
Chambers	12,967	13,234	14,580	25,008	44,515
Galveston	115,685	119,789	129,130	163,765	196,953
Harris	1,536,259	1,593,148	1,726,726	2,216,515	2,485,984
Total	1,771,500	1,850,890	2,015,432	2,602,517	3,007,160

Source: HGAC (2018).

Table 3-4
Existing Condition and Projected Employment by County (1,000s)

County	2010	2015	2020	2035	2045
Brazoria	92,057	113,315	120,961	172,436	286,849
Chambers	10,268	16,433	21,672	31,270	36,882
Galveston	100,892	130,215	134,347	144,987	148,175
Harris	2,107,125	2,482,334	2,665,583	3,257,098	3,597,670
Total	2,310,342	2,742,297	2,942,563	3,605,791	4,069,576

Source: HGAC (2018).
Note: 2010 employment based on wage and salary employment

3.5.2 Coastal Structures

Many of the existing structures identified in Section 2.6.2 would continue to be impacted by coastal storm surges. The No-Action Alternative would include an increased potential for flood damage to structures due to RSLR. As a consequence of this increased flood risk, property owners and the National Flood Insurance Program (if insured) over time would together incur increased costs to repair flood-damaged property. Additional costs to implement appropriate risk reduction measures to address potential increased flood risk from sea level rise would also be incurred. Such actions could include the migration (or displacement) of affected populations from areas exposed to high flood risk to areas with relatively lower flood risk. Migration out of the area could also result from the temporary or permanent relocation of businesses and employment opportunities.

3.5.3 Critical Infrastructure at Risk

The No-Action Alternative would include a greater potential for permanent displacement of public facilities and community services due to hurricane storm surge events. Public facilities and community services are expected to grow with the needs of the population and would follow population growth trends; however, there would be a greater potential for permanent displacement of critical public facilities and community services due to increased storm surge elevations.

One of the key areas of impacts would be surge risk to the critical transportation infrastructure. A study of the U.S. central Gulf coast between Galveston, Texas, and Mobile, Alabama, indicated that RSLR will make much of the existing infrastructure more prone to frequent or permanent inundation; 27 percent of the major roads, 9 percent of the rail lines, and 72 percent of the ports are built on land at or below 4 feet in elevation. Increased storm intensity may also lead to increased service disruption and infrastructure damage. One factor that complicates impacts to the transportation network is the effects of both storm surge and RSLR on the condition of the Texas coast barrier islands. Wave heights in coastal bays will tend to increase due to the combined erosional effects of sea level rise and storms on coastal barrier islands and wetlands. As the barrier islands erode, their role in shielding Texas coastal waterways and infrastructure from the effects of waves would diminish, which means their ability to protect coastal infrastructure from waves at current sea levels and future sea levels, as well as from storm surge, would likely diminish (Climate Change Science Program, 2008).

3.5.4 Community Cohesion

The area would become more susceptible to damage caused by hurricane storm surge events that are projected to increase over the period of analysis. The increased risk of damage from hurricane storm surge to residential and non-residential structures and the resulting temporary and/or permanent relocation of populations would negatively affect the community cohesion in many communities. Additionally, there would be a greater potential for reducing community cohesion if the civic infrastructure continues to be damaged as a result of hurricane storm surge events. Community cohesion may also be reduced if residents and businesses relocate to lower-risk areas.

3.5.5 Other Social Effects

The area's social vulnerability is expected to increase over time as subsidence and sea level rise continues to increase, which in turn would increase the area of influence of storm surges. Increasing population trends would further increase the study area's social vulnerability. The absolute number of socially vulnerable people (e.g., low-income, minority, less-educated, and over the age of 65) at risk for damage from hurricane storm surge events would increase. This, in turn, may lead to an increased burden placed on local, State, and Federal agencies to ensure that the most socially vulnerable populations have access to resources before, during, and after hurricane storm surge events.

3.6 NAVIGATION

Under the No-Action Alternative, it is anticipated the economy of the State and Nation would continue to grow in the future, placing greater demands on port infrastructure and efficiency of transport (TxDOT, 2016a). Along Texas's inland waterway system, wave action from barge traffic within the GIWW has and would continue to induce shoreline erosion and wetland loss. Additionally, an increasing population in Texas would increase shoreline development along navigable waterways, including marinas, residential developments, docks, piers, and other shoreline modifications, resulting in further safety concerns. These anthropogenic waterborne activities, coupled with RSLR and future storm events, threaten the stability and integrity of existing coastal wetlands and marshes that serve as a natural barrier to protect GIWW's barge traffic from storm-induced winds and waves and from excessive channel shoaling. Continued degradation of these natural coastal resources features will increase the risk to navigation safety and increase the frequency and expense of maintenance dredging (GLO, 2016).

A major catalyst in the potential port infrastructure improvements demand is the expansion of the Panama Canal system, which increases the maximum size of ships and overall volume of freight to be transported through the canal's new third set of locks complex and improved navigation channels. Expansion of the Panama Canal system would allow for container ships with nearly triple the current capacity, and the new generation of LNG and bulk carriers to transit through the Canal. The expanded Panama Canal complex can accommodate vessels up to 180 feet wide, 1,400 feet long, which draft up to 60 feet, and is able to handle the transit of the new post-Panamax "Neopanamax" container ship, with its 13,000 to 14,000 Twenty Foot Equivalent Unit capacity and is also able to accommodate the transit of approximately 88 percent of the existing LNG vessels (TxDOT, 2016b).

Until recently, the oil and gas market was a driving factor on port exports. Although the slumping prices of petroleum have caused a slowdown in this market, the development of oil and gas reserves in Texas would continue to play an important role to the export industry in Texas. It is anticipated a key driver in future freight movements through Texas ports would be the natural gas industry. With two LNG export facilities under construction at Freeport and Corpus Christi, and eight other facilities awaiting approval for construction, LNG may in the future be exported from Texas through the expanded Panama Canal, facilitating this export growth (TxDOT, 2016b).

Increases in throughput of containers via the expanded Panama Canal by way of the larger Neopanamax container ships may benefit Texas ports. However, the maritime transportation infrastructure and system within Texas

would need to be improved considerably to allow for capitalizing on benefits of the expanded Panama Canal. For Texas, only the Port of Freeport, Port of Corpus Christi, and Port of Brownsville to date have obtained Congressional authorization to have its navigation channels deepened to depths greater than 50 feet. The Port of Houston has recently deepened its navigation channels at Bayport and Barbours Cut container terminals to 45 feet. But, even with the deepened Bayport/Barbours Cut channels, the Port of Houston would be limited to accommodate post-Panamax container ships with a maximum capacity of 10,000 TEUs instead of the larger 50-foot draft, 14,000 Twenty Foot Equivalent Unit containerships (TxDOT, 2016b).

As assessed by TxDOT's Panama Canal Stakeholders Group, it is forecasted that the expanded Panama Canal complex would induce an increase in cargo throughput at some Texas ports, although the throughput volumes would most likely not be dramatic, and that future trade patterns for Texas ports would be governed more by population increases and economic growth (TxDOT, 2016b).

Considering the growth drivers in Texas, improvements to many of the deep-draft navigation channels have been planned or are under consideration, as well as continued maintenance of existing and authorized deep-draft and shallow-draft navigation channel geometries, to include the GIWW. The Water Resources Reform and Development Act of 2014 authorized investment in port infrastructure and navigation channel modifications to improve or facilitate waterborne shipping. Of notable importance to navigation were channel improvement projects for the Ports of Freeport and the Sabine-Neches Waterway, and the reauthorization of the deepening of the Corpus Christi Ship Channel (Port Authority Advisory Committee, 2014; Water Resources Reform and Development, 2014). Table 3-5 presents an overview of navigation channel improvement projects planned and authorized under Water Resources Reform and Development Act and Department of Army Individual Permits.

Table 3-5
Texas Ports Navigation Channels Planned Improvements

Navigation Improvement Project	Port Sponsor	Planned Channel Improvements (depth)
Brazos Island Harbor	Brownsville Navigation District	Increase Depth to 52 feet
Sabine-Neches Waterway	Sabine Neches Navigation District	Increase Depth to 48 feet
Freeport Harbor	Port Freeport	Increase Depth to 55 feet
Corpus Christi Ship Channel	Port of Corpus Christi Authority	Increase Depth to 52 feet
Matagorda Ship Channel	Calhoun Port Authority	Increase Depth to 44 feet

Source: Water Infrastructure Improvements for the Nation Act (2016); Water Resources Reform and Development Act (2014); USACE (2010).

The planned improvements for the Matagorda Ship Channel were approved by the USACE with the intent for the Calhoun Port Authority to serve as the implementing entity for the improvements. Subsequent to the 2010 approval, the Calhoun Port Authority has opted to defer implementation to allow for reviewing the benefits of an improved navigation channel through a cost-shared feasibility study with USACE (2010). Additional navigation improvements are being considered for the Houston Ship Channel (Houston Ship Channel 45-Foot Expansion Channel Improvement Project) through a cost-shared feasibility study between the USACE and the Port of Houston (USACE, 2017a).

Dredged material generated for navigation channel maintenance and improvements would afford an opportunity to beneficially use the material for marsh restoration and beach renourishment purposes. However, in cases where beneficial use of dredged material is not an option, dredged sediments would be required to be placed in upland or offshore dredged material placement areas. Upland placement areas are increasingly being stressed for capacity. Loss of placement area capacity may affect the ability of navigation channels to be maintained to authorized depths or constructed to improved depths. As a result, future dredging activities may be deferred in some instances, which may affect the efficiency of the navigation channels to carry waterborne cargo.

3.7 FLOOD RISK REDUCTION

3.7.1 Texas City Hurricane Flood Protection Project

Future Performance. The system's primary risk driver is the I-Wall section that would allow storm surge flooding at the design storm (1 percent event). The system reduces flood risks to approximately 45,000 people, $4 billion worth of commercial, residential, and public property in the Texas City and La Marque area.

Operations, Maintenance, Repair, Replacement and Rehabilitation (OMRR&R). Galveston County, the NFS, is currently providing resources to address identified deficiencies and replacement items as scheduled. Projects are ongoing under the Flood Control and Coastal Emergency Act (Public Law 84-99) to address the I-Wall failure, erosion protection replacement, and repair of the embankment erosion.

Reliability of performance of the Texas City Hurricane Flood Protection Project (HFPP) is shown in Table 3-6.

Table 3-6
Reliability of Performance of the Texas City Hurricane Flood Protection Project

What is driving the risk?	What is being done about it?
Failure of the floodwalls due to storm surges prior to reaching the top of the structure	The public sponsor and USACE are currently monitoring the floodwall sections for signs of distress. The public sponsor has placed Hesco baskets behind this floodwall as an interim risk reduction measure.
Failure of the floodwalls or levee due to overtopping of the structures by storm surge	The USACE will coordinate with the public sponsor on corrective actions.
Failure of the floodwalls due to seepage beneath the structure	The USACE will coordinate with the public sponsor on corrective actions.

3.7.2 Lynchburg Pump Station

Future Performance. The risk associated with this levee system is considered low. For the Lynchburg Pump Station, the record surge loading is 75 percent of the levee height, which occurred in 2008 during Hurricane Ike. Likelihood of failure of the system when surge water elevation is greater than the heights of the levees and floodwalls is high. This overtopping of the structure by water can quickly erode the backsides of the earthen levees

and the foundations soil of floodwalls until they collapse. If the system were to fail, the flood depths could be over 22 feet for some areas.

OMRR&R. Coastal Waster Authority, the NFS, is currently providing resources to address identified deficiencies and replacement items as scheduled. No current activities are ongoing with the Lynchburg Pump Station system.

Reliability of performance of the Lynchburg Pump Station is shown in Table 3-7.

Table 3-7
Reliability of Performance of the Lynchburg Pump Station

What is driving the risk?	What is being done about it?
Failure of the levees and floodwalls due to overtopping of the structures by surge water that is greater in height than the structure. This would cause erosion of the levee backside and foundation of the floodwalls until they collapsed.	Due to low probability of occurrence, nothing is being done to address this risk driver.
Failure of the levees and floodwalls due to seepage of water through the foundation of the structures. The soils beneath these structures would be eroded away until they collapsed.	Due to low probability of occurrence, nothing is being done to address this risk driver.

3.7.3 Colorado River Flood Protection at Matagorda

Future Performance. The risk associated with this system is considered moderate. Seepage of water through the levee is the greatest concern for the system. The foundation soils of the levee contain porous materials such as sand and oyster shells that are susceptible to erosion from passing water. A portion of the levee was built on top of an oyster shell dump site, creating uncertainty on how it will perform. If the levee system were to fail during a flood event, flood depths in Matagorda could be over 14 feet for some areas.

OMRR&R. The Port of Bay City Authority, the NFS, is currently providing resources to address identified deficiencies and replacement items as scheduled.

Reliability of performance of the Colorado River Flood Protection at Matagorda is shown in Table 3-8.

Table 3-8
Reliability of Performance of the Colorado River Flood Protection at Matagorda

What is driving the risk?	What is being done about it?
Failure of the levee due to seepage of water through the foundation soils causing erosion of these foundation soils.	The NFS is working to address these concerns under their OMRR&R responsibilities.
Failure of the levee due to seepage of water around the pipes of the gravity drainage structures causing internal erosion of the levee.	The NFS is working to address these concerns under their OMRR&R responsibilities.

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5.0 ENVIRONMENTAL CONSEQUENCES (*NEPA REQUIRED)

5.1 INTRODUCTION

Two action alternatives and the No-Action Alternative were carried forward for further analysis. The two action alternatives are made up of a combination of CSRM and ER measures for reducing coastal storm risk through structural measures, including levees, floodwalls, surge barrier gates (which includes both navigable and environmental control gates), and breakwaters, and nonstructural measures, including habitat restoration and shoreline erosion control structures that take advantage of natural features like barrier islands and storm surge storage in wetlands. Under the No-Action Alternative, no coastal storm risk reduction would occur in the upper Texas coast in the vicinity of Galveston or in the lower Texas coast along the South Padre Island shoreline.

- **Coastal Barrier Alternative**. Includes the Coastal Barrier CSRM System (Coastal Barrier), the South Padre Island CSRM measure, and the nine ER measures.
- **Bay Rim Alternative**. Includes the Bay Rim CSRM System (Bay Rim), the South Padre Island CSRM measure, and the nine ER measures.

The following section describes the environmental consequences associated with the Coastal Barrier and Bay Rim alternatives. There are nine ER measures associated with both action alternatives that are made up of a combination of the following features: revetment/breakwater, island restoration, marsh restoration, oyster reef creation, dune/beach restoration, and out-year marsh nourishment in 2065. Table 5-1 lists these ER measures with the number of acres associated with each feature. Environmental consequences are discussed for the features included in the ER measures. Where applicable, specific ER measure impacts are discussed.

The Coastal Barrier and Bay Rim alternatives include storm surge gates that differ from the No-Action Alternative. The range of impacts presented in this section is based upon this design. Future iterations will refine the gate design to reduce potential impacts, improve performance, and confirm cost effectiveness.

The direct cover types for CSRM and ER measures that would be affected during initial construction are presented below (tables 5-2 and 5-3).

In areas that would convert to open water or unconsolidated shoreline over the period of analysis due to RSLR, additional footprints are proposed for marsh restoration, referred to as out-year marsh nourishments. The location of the additional marsh restoration footprints were identified using the NOAA Marsh Migration RSLR layer of 2.5 feet for year 2065 (pers. com. N. Herold [NOAA], 2017). Table 5-4 presents the total acres of out-year nourishment proposed for the four ER measures and the direct habitat cover type acres. The timing of the additional marsh restoration has been proposed for 2065 to allow time for the marsh to mature in anticipation of RSLR, although implementation is subject to change in response to actual sea level change and the adaptive management plan.

Additionally, 112,666.4 acres of the Lower Laguna Madre would be hydrologically restored to help protect SAV with ER measure W-3, and 295.8 acres at CA-5 and 3,257.9 acres at SP-1 of SAV would be protected/enhanced.

Table 5-1
ER Measures and Features

ER Measure	ER Measure Features/Acres					
	Revetment/ Breakwater	Island Restoration	Marsh Restoration	Oyster Reef Creation	Dune/ Beach Restoration	Out-year Nourishment 2065
G-5 Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration	–	–	–	–	5,057.1	–
G-28 Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection	326.0	326.0	664.0	18.0	–	6,891.0
B-2 Follets Island Gulf Beach and Dune Restoration	–	–	–	–	1,113.8	–
B-12 West Bay and Brazoria GIWW Shoreline Protection	257.0	–	551.0	2.1	–	19,794
M-8 East Matagorda Bay Shoreline Protection	52.3	92.7	239.0	14.6	–	6,034.0
CA-5 Keller Bay Restoration	22.8	–	–	7.1	–	623.0
CA-6 Powderhorn Shoreline Protection and Wetland Restoration	30.3		531.0	–	–	–
SP-1 Redfish Bay Protection and Enhancement	44.5	391.4	–	2.0	–	–
W-3 Port Mansfield Channel, Island Rookery, and Hydrologic Restoration	3.9	27.8	–	–	1,404.9	–

Table 5-2
CSRM Measures Direct Habitat Cover Type Acres

CSRM Measure	Developed/ Upland[1]	Palustrine Emergent Wetland[2]	Estuarine Emergent Wetland[3]	Oyster Reef	Open Water	Dune[4]	Supra-tidal[5]	Inter-tidal[6]	Total Acres
Coastal Barrier	1,520.9	512.5	338.0	–	2,154.0	–	–	–	4,525.3
Bay Rim	1,371.2	227.1	172.0	0.03	564.0	–	–	–	2,334.3
South Padre Island	4.6	–	–	–	358.5	0.5	2.1	0.1	365.8

Source: NOAA (2017i, 2017j).

[1] Includes bare land, cultivated crops, deciduous forest, developed (low, medium, high, open space), evergreen forest, grassland/herbaceous, mixed forest, pasture/hay, and shrub/scrub

[2] Includes freshwater wetland and marsh

[3] Includes saline and brackish wetland and marsh

[4] Subaerial habitat ≥5 feet North American Vertical Datum of 1988 (NAVD 88) and encompasses foredune, dune, and reardune

[5] Occurs from 2.0 to 4.9 feet NAVD 88. This habitat type primarily encompasses swale and may include low-elevation dune and beach habitat.

[6] Occurs from 0 to 1.9 feet NAVD 88. This habitat type encompasses intertidal marsh, mudflats, beach, and any other habitats within that elevation range on the Gulfside and bayside of the barrier island.

Table 5-3
ER Measures Direct Habitat Cover Type Acres

ER Measure	Developed/ Upland[1]	Islands/ Bird Rookeries	Estuarine Emergent Wetland[2]	SAV	Oyster Reef	Open Water	Dune[3]	Supra-tidal[4]	Inter-tidal[5]	Total Acres
G-5	579.3	–	–	–	–	3,362.3	572.0	504.2	39.1	5,056.7
G-28	105.7	23.5	513.7	–	–	735.9	–	–	–	1,378.8
B-2	79.6	–	–	–	–	624.3	220.7	168.3	20.9	1,113.8
B-12	41.1	–	427.0	1.0	0.7	405.6	–	–	–	875.4
M-8	240.4	2.6	29.3	15.2	–	112.3	–	–	–	399.8
CA-5	–	–	–	295.4	2.5	27.8	–	–	–	325.7
CA-6	6.8	–	244.4	4.0	21.2	283.8	–	–	–	560.2
SP-1	90.5	117.8	–	3,088.8	5.2	434.6	–	–	–	3,736.8
W-3	4.6	3.8	–	1.8	–	1,109.4	257.6	53.3	1.0	1,431.5

Source: NOAA (2017i, 2017j).

[1] Includes bare land, cultivated crops, deciduous forest, developed (low, medium, high, open space), evergreen forest, grassland/herbaceous, mixed forest, pasture/hay, and shrub/scrub

[2] Includes saline and brackish wetland and marsh

[3] Subaerial habitat ≥5 feet NAVD 88 and encompasses foredune, dune, and reardune

[4] Occurs from 2.0 to 4.9 feet NAVD 88. This habitat type primarily encompasses swale and may include low-elevation dune and beach habitat.

[5] Occurs from 0 to 1.9 feet NAVD 88. This habitat type encompasses intertidal marsh, mudflats, beach, and any other habitats within that elevation range on the Gulf side and bayside of the barrier island.

Table 5-4
Out-Year Marsh Nourishment for 2065 Direct Habitat Cover Type Acres

ER Measure	Developed/ Upland[1]	Estuarine Emergent Wetland[2]	SAV	Open Water	Total Acres
G-28	543.7	5,664.0	3.5	678.4	6,889.7
B-12	751.0	10,056.4	225.6	3,514.3	14,547.3
M-8	632.2	4,513.4	92.6	794.8	6,033.0
CA-5	48.8	530.0	--	43.9	622.7

Source: Pers. com. N. Herold, NOAA (2017).

[1] Includes bare land, cultivated crops, deciduous forest, developed (low, medium, high, open space), evergreen forest, grassland/herbaceous, mixed forest, pasture/hay, and shrub/scrub

[2] Includes saline and brackish wetland and marsh

Sediment volumes required to construct the CSRM measures have been estimated. Material excavated during construction of the surge barrier gates for CSRM would be placed beneficially for construction of the proposed ER measure if the quality of material is appropriate.

Borrow source locations for construction of CSRM and ER measures have been identified by the USACE. Upland commercial sources are anticipated for the CSRM features in the upper Texas coast and a combination of routine dredging, offshore sources, and excavation from coastal barrier construction are reflected in the cost

estimate and construction phasing. Commercial borrow sources were assumed for levee construction and potential sources are identified in the Engineering Appendix (Appendix D of the DIFR-EIS). Sources were identified throughout Galveston, Harris, Brazoria, and Chambers counties. It is anticipated the material would be hauled to the site features via major highways. The commercial sites identified as sources with suitable material for levee construction are currently active and may no longer be available at the start of construction. A detailed inventory and analyses of borrow source materials is currently under way. Study results will be available during the next phase of the study. The suitability of the material for levee construction could require structural or chemical measures to assure stability of the levee.

Measures to manage coastal storm risk are not proposed in the Coastal Texas Study for Sabine Lake, the Brazos River estuary, Brazos-Colorado Coastal Basin, Matagorda/Lavaca Bay complex, San Antonio/Aransas Bay complex, Nueces/Corpus Christi Bay complex, Laguna Madre, or the Rio Grande estuary.

5.2 ESTUARINE MODELING SUMMARY

The USACE Engineer Research and Development Center conducted quantitative analyses using a 3D Adaptive Hydraulics (AdH) model for the Coastal Texas Study's Coastal Barrier CSRM Measure, which includes a levee/ floodwall along Bolivar Peninsula and Galveston Island, improvements to the Galveston seawall, a ring levee around the city of Galveston, and several flow control structures across the Houston Ship Channel at Bolivar Roads, High Island, Offatts Bayou, Dickinson Bayou, and Clear Creek. The structures at Clear Creek, Dickinson Bayou, and Offatts Bayou consist of a single opening 112 feet wide with varying sill elevations: Clear Creek sill elevation –10 feet, Dickinson Bayou sill elevation –9 feet, and Offatts Bayou sill elevation –15 feet. The structure for the Houston Ship Channel at Bolivar Roads includes a single 1,200-foot-wide, –60-foot sill elevation surge barrier gate at the ship channel with thirty-nine 100-foot environmental gates (22 having a –30-foot sill elevation and 17 having a –15-foot sill elevation). All elevations are referenced to MLLW.

The AdH model was developed and validated to simulate water level, velocity, and salinity. For all simulations the model was set up to run for 2 years, the first year being a spin up period to obtain an accurate initial salinity field as well as an accurate sediment bed and the second year was used for all analyses. Documentation of the model includes the geometric modifications to the system, defined as "project," as well as the input conditions for the "present" project year zero (2035) and "future" project year 50 (2085). Additional details on the modeling can be can be found in Appendix D (Engineering Design, Cost Estimates, and Cost Risk Analysis) (McAlpin et al., 2018). Present without-project (PWOP), present with-project (PWP), FWOP, and future with-project (FWP) were simulated using 3D AdH model. Present is year 2035, and future is year 2085 assuming a 50-year project lifespan. The results include changes in salinity, velocity, and water level throughout the model domain. Given the variability in several input parameters for the present and future conditions, care should be taken when reviewing the model results. Changes from present to future must be understood with no project in place in order to understand the project impacts. In other words, comparison of with- and without-project should be done on the present conditions and the future conditions separately.

Modeling was used to determine the general behavior of the bay system while comparing with- and without-project scenarios. The AdH modeling was conducted to understand potential environmental impacts and confirm whether the potential impacts made the alternative infeasible. This modeling characterizes the changes to the Galveston Bay system with the storm surge gates across Bolivar Roads in the open condition (which represents the non-storm condition or "everyday" operations of the gate structures). All modeling was conducted using a tentative gate configuration across Bolivar Roads that would reduce the flow conveyance roughly by 27.5 percent.

Environmental modeling was completed using a 27.5 percent constriction at Bolivar Roads to represent the proposed surge barrier gates. Changes to the system geometry can impact the tidal exchange into a bay environment such as the Galveston Bay system. The Coastal Barrier impacts the cross-sectional area of the entrance into the bay system, which as modeled, would cause changes in the volume of flow being exchanged through the inlets. The tidal prism is a calculation of the volume of water that enters and leaves through the inlets with each tide cycle. The tidal amplitude is the change in the water level from low tide to high tide and vice versa. The tidal prism gives an overall impact on the water exchange whereas the tidal amplitude may vary at locations depending on where the system modifications are made and changes in the flow patterns within the system. The average tidal prism and average tidal amplitudes vary between with- and without-project over the simulation year. The change in tidal prism with the project in place is a 13.5 and 16.5 percent reduction for the present and future conditions, respectively. The tidal amplitudes were also reduced at all bay side locations by between 9 and 22 percent. The percentage change in amplitude is generally greater for the future comparison than for the present and the comparisons within the bay vary by location but all show a decrease in the tidal amplitude for the project condition as compared to the without-project condition.

The velocity magnitudes vary little between with and without-project conditions for locations away from the structure. The mean surface and bottom velocity magnitude generally drops when the project is in place, but this change is less than 0.33 foot per second at all analysis points and for most locations it is 0.16 foot per second or less. The change from the without-project condition is greatest in areas at and immediately around where the structures are located. Eddies are also expected on the backside of the gate structures, which has not yet been fully resolved. There are changes to the magnitude of the velocity extending into the bay, but they are much smaller than the effects at the locations of the modifications. The models suggest that in certain situations the velocity differences between the with- and without-project condition could be as high as 6.6 feet per second. For example, a scenario that presented a combination of a high tide and strong winds could lead to such an increase in velocity. Future project refinements may minimize differences currently seen between with- and without-project velocities (McAlpin et al., 2018).

5.3 PHYSICAL RESOURCES

5.3.1 Geomorphology and Coastal Processes

5.3.1.1 Sediment Transport

To analyze overall sediment transport impacts, the individual factors that act upon coastal sediment transport along the Texas Gulf shorelines causing deposition or erosion needs to be addressed. While regional fluvial

sediment supply and the Gulfwide sediment distribution patterns will not change due to the Preferred Alternative, localized impacts are expected.

As previously stated, the fluvial sediment supply that nourishes the Gulf has been highly altered due to extensive reservoir construction, changes in land use, and instream sand and gravel mining (Dunn and Raines, 2001). The reduction in sediment supply to bay shorelines has resulted in regional sediment sinks, and this loss has resulted in or caused the disintegration of marsh systems, deltas, inlets, bird island habitat, oyster reefs, and other eco-geomorphologic systems (Moya et al., 2012). However, the existing reduction of fluvial sediment supply, while negatively impacting the stability and health of both Gulf and bay shorelines, will not be altered by the Preferred Alternative.

The regional trend that sediments, which migrate to the Gulf, will be carried in a southwesterly direction along the coast from Port Arthur to south of Corpus Christi via longshore drift, and an opposing current, which transports sediments in a northerly direction from the Mexico coastline toward Corpus Christi, will continue with or without the Preferred Alternative (Freese and Nichols, Inc., 2016).

However, even though passes and channels will remain open most of the time, and sediments will be exchanged with the tidal flows, the exchange volume will be constricted by the proposed structures (i.e., surge barrier gates, flood walls, levees), specifically for Galveston Bay.

Neither of the alternative project plans would change the status of the Texas coast as a sediment-starved system. The construction of either alternative would not diminish the future need to identify dedicated in-situ sediment borrow sources and capture more opportunities to use dredged material beneficially.

For the Coastal Barrier system for Galveston Bay, estuarine modeling was conducted by the USACE with the conclusion that the construction of the surge barrier gates will reduce the cross-section area of flow by 27.5 percent, which would have the following impacts that directly correlate to sediment transport responses and changes (McAlpin et al., 2018):

- Reduced flow into and out of the bay
- Increase of velocities, primarily in areas at and immediately adjacent to structures (i.e., gates)
- Eddy formation on the backside of gate structures
- Reduction in the average tidal prism at Bolivar Roads of 16.5 percent
- Increase of water retention times in the bay
- Changes in tidal prism will have impacts on the water exchange throughout the bay, with greatest impacts closest to the Coastal Barrier structures
- Tidal amplitude reduction up to 0.23 foot in areas of the bay
- Channel velocity differences between the with- and without-project

5.3.1.1.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier would result in a permanent reduction in tidal connectivity and associated sediment transport, even with the gate structures open during non-storm conditions (i.e., everyday condition is open, only closed for storm surge). As modeled by the USACE, Bolivar Roads surge barrier gates alone would reduce the cross-section area of flow by 27.5 percent, which will affect the volume of water exchanged through the inlet. This reduced cross section would cause a reduction in tidal prism (13.5 percent present, 16.5 percent future). Furthermore, the reduction in flow exchange through the inlets would cause a reduction in the tidal amplitude (9 to 22 percent), at the protected side of the proposed coastal barrier system (McAlpin et al., 2018). Sediment transport and patterns are linked to and affected by flow exchange and velocities, and hence, to tidal amplitude.

With the Coastal Barrier in place, overwash and other storm-related sediment deposition in Galveston Bay would be reduced. Based on McAlpin et al. (2018), a reduction in the shoaling along the Houston Ship Channel can be observed, when compared to the without-project results for the present condition. The largest changes were observed in the areas upstream of Red Fish Reef and near the Bayport Channel and flare. This reduction is directly linked to the modified conditions caused by implementing the Coastal Barrier, which reduces the velocity that is pushing sediment into those areas upstream of the Bolivar Roads surge barrier gates.

During storm events, the reduction in sloshing of storm surge within the bay and impacts due to increased surge and wave heights would be reduced due to the Coastal Barrier, since the closed surge barrier gates at Bolivar Roads would block storm surge from entering the bay, which would ultimately reduce storm-induced bay-shoreline erosion. Under natural conditions, without a barrier system in place, storms provide a large influx of sediments into bay systems, which settle in the bay regions and adjacent marshes as storm surge dissipates. Losing this storm-induced sediment infusion to the closure of the barrier system would negatively impact the post-storm sediment budget. Overwash and storm-induced sediment influx could be reduced with the coastal barrier in place. This could decrease the available sediment inside the bay system post-storm events, which would especially negatively impact the marsh sustainability on Bolivar Peninsula along the GIWW on the protected side of the Coastal Barrier, since during overwash events, marshes serve as features that capture sediments transported from the Gulfside of barrier islands (Rosati, 2009).

During storm surges, an increase in water levels Gulfward of the coastal barrier resulting from surge build-up, will result in increased flow velocities in inlets without surge barrier gates. Erosion in these unprotected inlets, such as San Luis Pass, is anticipated to initially increase due to the increase in average velocities, but over time return to without-project erosion rates as the inlets equilibrate (McAlpin et al., 2018). During non-storm conditions, the increase in velocity within and near Bolivar Roads (McAlpin et al., 2018) would cause additional localized scouring.

In addition, storm surges piling against the barrier would negatively impact erosion on Galveston Island. The beaches fronting the seawall currently experience a lack of natural sand nourishment during non-storm conditions,

especially near the Bolivar Roads jetties, but would be exposed to greater surge and wave impacts during storms with the Coastal Barrier in place.

During non-storm conditions, the reduction in tidal amplitude inside Galveston Bay and the reduction in flow exchange between the Gulf and the bay due to the imposed constriction of the Coastal Barrier would result in a decrease of everyday shoreline erosion impacts within the bay (McAlpin et al., 2018). Although aeolian sediment distribution may not occur on the same scale as it did previous to the anthropogenic changes to the area, such as roads and placement areas, any of these processes that still occur would also be negatively impacted by the proposed barriers. The changes to these natural processes would impact the health of adjacent natural features such as marsh and wetland complexes. As a result, existing marshes and wetlands may deteriorate or convert to open water at an accelerated rate.

In addition, levee and floodwall features artificially act as permanent barriers for natural exchange of hydraulic and sediment flow occurring throughout Galveston Bay's ecosystem. The interchanges of tidal hydraulics, hydraulically driven sediment transport, and other natural ecosystem exchanges will be negatively impacted by these CSRM features,

Summary. When compared with the No-Action Alternative, the Coastal Barrier could result in an overall reduction in sediment exchange within Galveston Bay. Specifically, marsh and wetland complexes adjacent to the GIWW on the bay-side of Bolivar Peninsula would be negatively impacted by a reduction of natural nourishment from storm-induced sediment overwash. The constricted tidal flows exchange results in a smaller tidal prism, which in return should reduce shoreline erosion in the Galveston Bay area, especially during storm events. Contrarily, on the Gulfside of the Coastal Barrier, the rate of sediment erosion is anticipated to increase due to local scouring during storm events generated by surge build-up, coupled with the greater availability of sediments and Gulf-facing shoreline area associated with the proposed beach/dune ER measures within a sediment-starved environment.

South Padre Island CSRM Measure

The proposed beach and dune features at South Padre Island would predominantly serve as a CSRM measure but should also provide ecological benefits not quantified by this study. Due to the interference and impoundment of naturally supplied sediments at the Brazos Island Harbor south jetty, beach sediments within the boundaries of the city of South Padre Island provide the primary source for the south to north littoral drift of the entire beach system from the city of South Padre Island to Port Mansfield (McGrail et al., 1985). Sediments placed to construct the South Padre Island beach and dune features would be transported northward by the littoral drift and eventually be impounded at the Port Mansfield south jetty. The transported sediments would contribute to the further accretion of sediment at Port Mansfield immediately south of the jetty, resulting in an increase of sediment bypassing to the entrance of the Port Mansfield Channel. These additional sediments will add to the shoaling within the entrance channel (Kieslich, 1977).

The beachfill component of the South Padre Island CSRM measure would provide a source of sediments that would be transported by aeolian processes to beneficially nourish existing and newly constructed dune cells by

supplying sand for foredune accretion. In addition, sediments supplied for the beach and dune features will be washed over during storm events, which would be beneficially redistributed throughout the South Padre barrier island system undergoing sea level rise (Del Angel, 2012).

ER Measures

Revetment/Breakwater. The construction of revetment/breakwater features would stabilize shorelines and reduce navigation and wind-induced wave energy to adjacent wetlands, resulting in overall reduced shoreline erosion along the banks of the GIWW. This reduction in erosion would decrease the rate of sedimentation into the bays and waterways. The construction of breakwaters or revetments would replace some habitat with hardened structures, and the structures would reduce or restore habitat lost to erosion.

Island Restoration. Fill for the island restoration would be contained and protected by rock structures and stabilized with vegetation; therefore, it is expected that sediment losses from the restored islands would be minimal. During construction, temporary impacts of increased sediment suspension and dispersion within the water columns adjacent to the constructed islands should be expected.

Marsh Restoration/Out-year Marsh Nourishment 2065. Because material would be predominantly obtained from maintenance and/or new construction dredging of the GIWW, there is no net increase of sediment in the system, since it is only moved from the waterway to designated restoration areas. Marsh restoration areas would be protected by rock structures and enhanced with vegetative plantings, which would contribute to trapping sediments from migrating or eroding into the waterway. Sediments placed for out-year marsh nourishment in 2065 are expected to be retained by the aquatic vegetation within the complexes, thus trapping the sediments from migrating or eroding into the waterway.

Oyster Reef Creation. Creation of oyster reefs is expected to provide additional protection to restored islands and prevent breaching of islands and shorelines. It is anticipated that oyster reef creation would enhance sediment deposition and provide shoreline protection within the vicinity of oyster reef areas by dampening wave energy.

Dune/Beach Restoration. Temporary impacts due to construction are an increase in suspended sediment near the restoration feature. As a result of beach and dune restoration, additional sediment would be available in the natural system and allow natural processes such as reworking, erosion, and deposition to take place and enhance sediment availability for longshore transport. Increase in shoaling through longshore transport can be expected at tidal inlets downdrift of ER beach and dune features. Locations of anticipated shoaling increases due to proposed ER beach and dune restoration features include Bolivar Roads and San Luis Pass. The shoreline at the Surfside Village beach may temporarily benefit from the downdrift transport of sediments from the Follets Island Gulf Beach and Dune Restoration (B-2) feature. However, wave amplification at Port Freeport's north jetty would mobilize the sediments transported to Surfside Beach carrying the sediments along the jetty and into Port Freeport's navigation entrance channel (Watson, 2007). An anticipated impact from the Follets Island Gulf Beach and Dune Restoration (B-2) feature is an increase in shoaling within the entrance channel at Port Freeport.

Hydrologic Restoration. The hydrologic restoration of the Lower Laguna Madre includes the dredging of Port Mansfield Channel to improve the tidal circulation between Laguna Madre and the Gulf. Sediments dredged from the Port Mansfield Channel would be beneficially used for bird island restoration within the Laguna Madre and for the nourishment of approximately 10 miles of shoreline along the Padre Island National Seashore starting immediately north of Port Mansfield's north jetty. Dredged sediments placed along the National Seashore's shoreline would migrate northward with the littoral drift to the longshore current convergence zone located along North Padre Island at Big Shell Beach near Baffin Bay (HDR Engineering, Inc., 2014).

Summary. The temporary impacts due to the ER implementation, such as increases to suspended sediment in the water column near the construction sites, do not cause long-term sediment transport changes. When compared with the No-Action Alternative, the implementation of the ER measures has a net positive impact on the overall sediment budget, since it is adding sediment to the system in the form of marsh and sand/dune restoration, while the addition of revetments and breakwaters along navigational routes reduces wave impacts and overall shoreline erosion. Increase in shoaling at Bolivar Roads, San Luis Pass, and the Port Freeport Entrance Channel should be anticipated.

5.3.1.1.2 Bay Rim Alternative

Bay Rim CSRM System

The Bay Rim consists of surge barrier gates at Fred Hartman Bridge, Clear Lake, Dickinson Bayou, the bay rim levee/floodwall, and the Texas City Hurricane Flood Protection Improvements. These Bay Rim features disrupt natural exchange of flow and sediment across land features and through channels and passes. It can be expected that regular hydraulic flow conditions within the passes and channels would be reduced by the surge barrier gates. During non-storm periods, the reduction in tidal flows would impact the sediment and tidal exchanges between the Galveston Bay, Clear Lake, Dickinson Bayou, and Tabbs Bay watersheds.

The Bay Rim Alternative, when compared to the Coastal Barrier Alternative, does not have a barrier on the Gulf-facing shore of Galveston Island and Bolivar Peninsula and therefore still allows for natural sediment processes to interact between the Gulf and Galveston Bay. However, when compared to the No-Action Alternative, the watershed protected by the Bay Rim would experience a reduction in intertidal connectively to Galveston Bay due to the construction of the alternative. The Bay Rim features, while located in a more urbanized part of the watershed, alter the natural processes within the watershed protected by the Bay Rim when compared to the No-Action Alternative.

During storm events, Galveston Bay would receive the same storm surge magnitude and associated sediment overwash into the bay as the No-Action Alternative; however, when coupled with the ER measure for Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration (G-5), additional volume of sediments would be available for overwash, which would beneficially nourish bay marshes and redistribute sediments on Bolivar Peninsula and Galveston Island. Conversely, the overwash sediments would also be deposited within the GIWW, increasing shoals within the waterway that would increase maintenance dredging needs.

In addition, an increase in scouring along the bay rim should be expected from storm surges and waves. When compared to the No-Action Alternative, the erosion on the non-protected rim shorelines is expected to increase from the surge build-up against the barrier and the sloshing of the water mass within the bay, causing larger impacts to the shoreline erosion and associated sediment transport. Because of the fetch lengths within the bay, shoreline erosion will continue to be experienced under typical and normal wave and current conditions.

Additionally, levee and floodwall features artificially act as permanent barriers for natural exchange of hydraulic and sediment flow occurring throughout Galveston Bay's ecosystem, which would negatively impact watershed sediment transport patterns.

Summary. When compared with the No-Action Alternative, the Bay Rim could result in an overall reduction in sediment exchange between Galveston Bay and the bay's watersheds. Overwash would be the same as the No-Action Alterative; however, when coupled with the ER measure for Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration (G-5), additional volume of sediments would be available for overwash to nourish bay marshes and for redistribution on Bolivar Peninsula and Galveston Island. An increase in shoaling within the GIWW would be expected from overwash events. In addition, an increase in storm-induced shoreline erosion at the eastern, non-protected bay rim of Galveston Bay, is to be expected.

South Padre Island CSRM Measure

Impacts to the sediment transport associated with the proposed South Padre Island CSRM measure features would be the same as those described for the Coastal Barrier Alternative.

ER Measures

Impacts to the sediment transport associated with the proposed ER measure would be the same as those described for the Coastal Barrier Alternative, with one exception. When the Bay Rim measure is coupled with the ER measure for Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration (G-5), additional volume of sediments would be available for overwash to nourish bay marshes and for redistribution on Bolivar Peninsula and Galveston Island. An increase in shoaling within the GIWW from these expected overwash events would induce an increase in maintenance dredging requirements of the waterway.

5.3.1.2 Shoreline Change

Changes to both Gulf and bay shorelines would be induced by the Coastal Barrier and Bay Rim alternatives CSRM and ER measures, through stabilization, nourishment, and restoration activities, and by alterations to tidal amplitudes.

5.3.1.2.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

With the Coastal Barrier, increases to Gulfside erosion rates are expected, especially in years of high storm frequency and intensity, since the beach/dune and marsh habitat fronting the barrier would experience increased impacts from storms and subsequent erosion. Because the barrier itself is a hard structure, it would eventually become the shoreface, if no additional countermeasures are taken. Erosion rates within the Galveston Bay area are anticipated to be reduced and should be reflected in their respective shoreline retreat rates.

When compared with the No-Action Alternative, the Coastal Barrier could result in an increase in Gulfside shoreline retreat in areas fronting the barrier, especially along Bolivar Peninsula. At Galveston Island the shoreface is currently partially protected by a seawall, the shoreline erosion rates would increase but be stopped by the hard structure. In addition, due to the reduced exchange of flow and sediments through the tidal channels, the sediment contributed from the bay to the longshore transport along the Gulf shoreface would be reduced.

South Padre Island CSRM Measure

The South Padre Island CSRM measure, which consists of a beach, berm, and dune complex, would impact the configuration of approximately 4 to 8 miles of shoreline by extending the beach width by 100 feet at a berm height of 4 feet NAVD 88, coupled with constructing a dune with a width of 20 feet and a height of 12.5 feet NAVD 88. The beach and dune complex would be renourished four times at a frequency of once every 10 years. Sediments to construct the South Padre Island CSRM measure would eventually be transported northward by the littoral drift and be impounded by Port Mansfield south jetty. Impoundment and accumulation of these sediments would result in widening of the Port Mansfield immediately south of the jetty and would contribute to the ongoing sediment bypassing into the entrance of the Port Mansfield Channel. The beachfill extent may be as little as 4 miles, but may extend to 8 miles following further evaluation of the recreation benefit stream in future planning and design phases of the study.

ER Measures

Revetment/Breakwater. The construction of a total of approximately 100 miles of revetment/breakwater features would protect and stabilize existing and restored island shorelines and marsh fringes against navigation and wind-induced wave energy.

Island Restoration. In-bay island restoration features are components of four ER measures, resulting in a total of approximately 32 miles of island shoreline restored or created. Shorelines created or restored as part of the island restoration work is a positive impact in counteracting shoreline loss. Loss over time from natural processes is anticipated.

Marsh Restoration/Out-year Marsh Nourishment 2065. Marsh restoration features would occur behind each of the constructed revetment/breakwater features. Over 64 miles of marsh fringe directly interfacing with bay waters

and/or the GIWW would be created or restored. Marsh restoration areas would be protected by rock structures and enhanced with vegetative plantings, which would contribute to stabilizing the fringes. For out-year marsh nourishment, sediments would be placed to nourish these ER measures marsh complexes to preserve over 50 miles of marsh fringe that have immediate adjacency to bay waters and/or the GIWW.

Oyster Reef Creation. Creation of oyster reefs is expected to provide additional protection to restored islands and prevent breaching of islands and shorelines. It is anticipated that oyster reef creation would enhance sediment deposition and provide over 12 miles of shoreline protection within the vicinity of oyster reef areas by dampening wave energy.

Dune/Beach Restoration. As a result of beach and dune restoration, additional sediment would be available in the natural system and allow natural processes such as reworking, erosion, and deposition to take place and enhance sediment availability for longshore transport, possibly resulting in enhancing downdrift shorelines. Specifically, the shoreline at the Surfside Village beach may temporarily benefit from the downdrift transport of sediments from the Follets Island Gulf Beach and Dune Restoration (B-2) measure. Harvesting of nearshore sediment sources adjacent to the Port Mansfield south jetty for nourishing Padre Island National Seashore's shoreline may result in temporary retreat of the shoreline south of the south jetty. However, the long-term effects of longshore transport of sediments immediately south of the jetty should result in recovery of the south jetty shoreline.

Hydrologic Restoration. The hydrologic restoration of the Lower Laguna Madre includes the dredging of the Port Mansfield Channel to improve the tidal circulation between the Laguna Madre and the Gulf. Sediments dredged from the Port Mansfield Channel would be beneficially used for island restoration of Mansfield Island and for the nourishment of approximately 10 miles of shoreline along the Padre Island National Seashore starting immediately north of Port Mansfield's north jetty.

Summary. The ER measures would protect, create, and/or restore Gulf and bay island shorelines and marsh fringes. Placement of sediments to restore marshes, beach and dune, and island habitats may temporarily increase suspended sediments in the water column near the construction sites. Long-term effects of sediment placement on Gulf shorelines may include increase in shoaling at Bolivar Roads, San Luis Pass, and the Port Freeport Entrance Channel. Implementation of the ER measures has an overall net positive impact by protecting, creating, and restoring shorelines and marsh fringes. Breakwater construction to support the sediment placement will replace a soft shoreline but will interrupt erosion and land loss. When compared with the No-Action Alternative, the implementation of the ER measures has a net positive impact by protecting, creating, and restoring shorelines and marsh fringes.

5.3.1.2.2 Bay Rim Alternative

Bay Rim CSRM System

With the Bay Rim, the surge barrier gates at Fred Hartman Bridge, Clear Lake, Dickinson Bayou, the bay rim levee/floodwall, and the Texas City Hurricane Flood Protection Improvements would result in reduced watershed-

based sediments to be transported into Galveston Bay. During storm events, the expected scouring in front of the Bay Rim would temporarily increase suspended sediment within Galveston Bay.

Erosional patterns at the shorelines of Bolivar Peninsular would only slightly increase during storm events, when compared to the No-Action Alternative, since the surge build-up within Galveston Bay is anticipated to increase due to the Bay Rim, which would also increase surge impacts to marsh, beach, and dune habitat on the peninsula. This expected surge increase in Galveston Bay would also result in an increase in shoreline erosion rates at non-protected shorelines of the Galveston Bay rim due to an increase in impacts from flow and wave energy. At Galveston Island, the shoreface is already partially protected by a seawall; therefore, the shoreline erosion rates would increase due to beach erosion but be restricted by the hard structure as a point of no change.

When compared with the No-Action Alternative, the Bay Rim could result in an increase in shoreline retreat within the non-protected bay rim areas as well as a slight increase in storm-induced shoreline retreat at Bolivar Peninsula and Galveston Island.

South Padre Island CSRM Measure and ER Measures

Impacts to the shoreline change associated with the proposed South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.3.2 Physical Oceanography

5.3.2.1 Tides and Currents

5.3.2.1.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier would maintain the existing geomorphic features with levee/floodwall systems at Bolivar Peninsula and the west end of Galveston Island. It is further enhanced with improvements to the Galveston seawall and closure gates at Bolivar Roads to prevent storm surge from entering into Galveston Bay. Additional flow control structures of the Coastal Barrier are proposed for Offatts Bayou, Dickinson Bayou, and Clear Creek.

The Bolivar Roads closure gates consist of a series of surge barrier gates to be closed during storm surge events but remain open all other times. The proposed environmental gates consist of thirty-nine 100-foot-wide gates with sill elevations ranging from –30 to –15 feet MLLW, and the surge barrier gates are proposed to be 1,200 feet wide (total) with a sill elevation of –60 feet MLLW.

The flow control structures at Clear Creek, Dickinson Bayou, and Offatts Bayou are proposed to each consist of a single opening with a width of 112 feet. Sill elevations are –10 feet MLLW at Clear Creek, –9 feet MLLW at Dickinson Bayou, and –15 feet MLLW at Offatts Bayou.

The AdH modeling was applied to the Coastal Barrier to simulate hydrodynamics, salinity, and sediment transport (McAlpin et al., 2018). The AdH model mesh was adjusted to account for intermediate sea level rise projections, since sea level rise will induce more wetted areas around the perimeter of Trinity Bay, West Galveston Bay, and East Galveston Bay. Approximately 172 square miles of wetted area was added to account for 2085 projected sea level rise. Model simulations included freshwater inflows from the Trinity River, the San Jacinto River, and seven ungagged flow locations (McAlpin et al., 2018; see Appendix D).

Tides. The Coastal Barrier's proposed surge barrier gates system at Bolivar Roads reduces the cross-sectional area of Bolivar Roads by 27.5 percent for water flow and exchange through the inlet. Resulting changes in tidal amplitude vary in different locations of the bay. Generally, the tidal amplitude change at locations throughout Galveston Bay will vary between 0 and 0.23 feet, with most locations experiencing a 0.16-foot tidal amplitude reduction (McAlpin et al., 2018).

Currents. The velocity magnitudes vary little between with and without-project conditions for locations away from the gate structure. The mean surface and bottom velocity magnitude generally drops when the project is in place, but this change is less than 0.33 feet per second at all analysis points and for most locations it is 0.16 feet per second or less. The change from the without-project condition is greatest in areas at and immediately around where the structures are located. The models suggest that in certain situations the velocity differences between the with-project condition and the without-project condition could be as high as 6.6 feet per second. For example, a scenario that presented a combination of a high tide and strong winds could lead to such an increase in velocity. Future project refinements may minimize differences currently seen between with- and without-project velocities (McAlpin et al., 2018).

South Padre Island CSRM Measure

The South Padre Island measure is not expected to have an appreciable impact on tides, currents, or circulation. Sediments placed for the dune/beachfill features are expected to migrate northward with the littoral drift, to be impounded by the Port Mansfield Channel immediately south of the jetty. Ultimately, the sediment buildup immediately south of the jetty would migrate into the entrance of the Port Mansfield Channel and add to the shoaling of the channel. This additional accumulation of sediments within the channel may nominally contribute to reduced tidal circulation between the Lower Laguna Madre and the Gulf. However, this impact would be somewhat offset by construction of ER measure W-3.

ER Measures

Revetment/breakwaters, island restoration, marsh restoration, oyster reef creation, dune/beach restoration, and out-year marsh nourishment ER features would protect and stabilize existing and restored island shorelines and marsh fringes. Appreciable impacts to tides, currents, and circulation are not expected, although localized current and circulation changes at the ER features may be experienced. The hydrologic restoration of the Lower Laguna Madre includes the dredging of the Port Mansfield Channel, which improve the tidal circulation between Laguna Madre and the Gulf. Sediments dredged from the Port Mansfield Channel would be beneficially used for bird island restoration within Laguna Madre and for the nourishment and widening of approximately 10 miles of

shoreline along the Padre Island National Seashore starting immediately north of Port Mansfield's north jetty. Measurable beneficial impacts to tides, currents, and circulation with Lower Laguna Madre are expected to be induced by the dredging of the Port Mansfield channel.

5.3.2.1.2 Bay Rim Alternative

Bay Rim CSRM System

The Bay Rim would maintain the existing geomorphic features with levee/floodwall systems at Bolivar Peninsula and the west end of Galveston Island. The Bay Rim is further enhanced with improvements to the Galveston seawall and closure gates at Tabbs Bay to prevent storm surge from entering into the upper reaches of the Houston Ship Channel. Additional flow control structures of the Bay Rim are proposed for Offatts Bayou, Dickinson Bayou, and Clear Creek with geometries similar to the Coastal Barrier.

The closure structures system for Tabbs Bay crosses Tabbs Bay to Hog Island then to the Spillman Island Placement Area, a distance of 9,870 feet. The Tabbs Bay crossing consists of combi-wall and a series of 100-foot environmental gates that would connect to the north bank of the bay with Hog Island. A 3,070-foot crossing at the Houston Ship Channel would consist of a combi-wall and a sector gate to accommodate the existing channel width of 530 feet.

Tides. Modifications to Bolivar Roads are not proposed for the Bay Rim; therefore, for the most part, tidal prism and tidal amplitude are expected to remain relatively unchanged between without- and with-project conditions. The exception may be in the vicinity of Tabbs Bay near the Fred Hartman Bridge where a system of surge barrier gates is proposed for the Houston Ship Channel where tidal prism and amplitude would be nominally impacted. The water bodies feeding into Galveston Bay at the Fred Hartman Bridge contribute influential amounts of freshwater to the bay during normal conditions. The tidal amplitude impacts are considerably less than those at Bolivar Roads since the area is farther from the Gulf.

Currents. McAlpin et al. (2018) reported mean surface and bottom current velocities increased minimally from without- to with-project conditions at locations farther upstream within Galveston Bay for the Coastal Barrier. Although not modeled, it is anticipated, based on the Coastal Barrier hydrodynamic analysis findings, that there may be slight increases in current velocities induced by the Bay Rim by partially constricting tidal flows adjacent to Tabbs Bay, Clear Creek, and Dickinson Bay with the closure structures system. Throughout the rest of Galveston Bay, velocity magnitude changes are expected to be negligible.

Additional information can be found in the Engineering Appendix (Appendix D).

South Padre Island CSRM Measure and ER Measures

Impacts to the tides and currents resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.3.2.2 Salinity

5.3.2.2.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

Salinity and currents of Galveston Bay were modeled in 2018 for the Coastal Barrier at Bolivar Roads by the USACE using the AdH model (McAlpin et al., 2018). The model predicted effects of the Coastal Barrier on salinity for most of the Galveston Bay system. Table 5-5 presents average salinities over the model period for the PWP (Year 2035), PWOP (Year 2035), FWP (Year 2085), and FWOP (Year 2085) conditions.

Table 5-5
Galveston Bay Modeled Mean Salinity with the Coastal Barrier*

Model Period	Galveston Bay at Bolivar Roads	Lower Galveston Bay	Upper Galveston Bay	Trinity Bay	East Bay	West Bay
PWP (surface)	21 (0–33)	17 (6–30)	13 (0–26)	8 (0–24)	6 (0–15)	20 (8–31)
PWP (bottom)	27 (8–35)	26 (7–34)	14 (0–26)	9 (0–25)	6 (0–15)	20 (8–31)
PWOP (surface)	23 (0–34)	18 (5–31)	14 (0–28)	9 (0–25)	7 (0–15)	22 (8–31)
PWOP (bottom)	28 (11–35)	27 (7–35)	15 (0–28)	10 (0–25)	7 (0–15)	22 (8–31)
FWP (surface)	24 (1–33)	20 (7–31)	15 (1–24)	9 (0–18)	12 (4–15)	22 (12–31)
FWP (bottom)	28 (13–35)	28 (13–34)	17 (3–26)	11 (0–19)	12 (5–15)	23 (12–31)
FWOP (surface)	25 (0–34)	21 (7–32)	15 (1–26)	9 (0–19)	13 (5–16)	24 (12–32)
FWOP (bottom)	29 (16–35)	28 (13–35)	18 (3–27)	12 (0–20)	13 (6–16)	24 (12–32)

Source: McAlpin et al. (2018)
* Values in parentheses represent modeled minimum and maximum salinities.

The model assumed the Coastal Barrier would reduce the volume of water entering and leaving the bay with each tide (tidal prism) between 13.5 and 16.5 percent. If the final, constructed Coastal Barrier blocks a smaller portion of the cross section at Bolivar Roads than used for this modeling, salinity impacts would be expected to be lower. Likewise, if the Coastal Barrier blocks more of the tidal prism, greater impacts on salinity than those listed in Table 5-5 would be expected.

The AdH model predicts tidal circulation would be reduced when the tidal prism is reduced by an average of 16.5 percent. The reduced circulation would increase residence time in the bay upstream of the Coastal Barrier and allow greater dilution by freshwater inflows. During periods of normal to relatively high freshwater inflow ("wet" periods), the model predicts salinity from surface to bottom would be lower and remain lower for a longer time.

During periods of severe drought, with low freshwater inflow and high evaporation, or when storms push saline water into the bay upstream of the barrier, saline water remains in the bay above the barrier for longer periods of time, and salinities would be higher than without the barrier in place. The storm surge or drought condition was not modeled. Modeled mean salinity in surface and bottom water when the Coastal Barrier is in place (PWP and FWP) was lower than bay salinities without the barrier in place (PWOP and FWOP). The Coastal Barrier is

predicted to reduce surface and bottom water salinities throughout the entire Galveston Bay system during typical freshwater inflow conditions. Predicted differences in mean surface salinity at Bolivar Roads (from 25 ppt in 2085 without the Coastal Barrier down to 24 ppt in 2085 with the Coastal Barrier) and in lower Galveston Bay (down from 21 to 20 ppt) reflect decreased volume of inflow from the Gulf in the lower portion of the bay complex (see Table 5-5). Predicted differences in Trinity Bay and East Bay mean salinities between the FWP and FWOP conditions were less than 1 ppt. The greatest change in mean bottom water salinities is predicted to be a 1 ppt decrease in West Bay from the FWOP to the FWP condition.

Reduction in tidal prism at Clear Creek, Dickinson Bayou, and Offatts Bayou is predicted to range from 16 percent (Clear Creek in the future with the TSP) to 16.2 percent (Dickinson Bayou in the future with the TSP). Most of the reduction is a direct result of the reduced tidal prism through Bolivar Roads (McAlpin et al., 2018). Mean modeled salinities at the mouths of Clear Creek, Dickinson Bay, and Offatts Bayou are predicted to be 1 ppt lower than without the Coastal Barrier in place for both the PWP and FWP condition. Although salinities were not modeled upstream of the barriers into these systems, the reduced tidal prism is expected to result in increased periods and extent of lower salinities than the condition without the barriers. The proposed barrier at Offatts Bayou is predicted to reduce the tidal prism about 16 percent. Since there is limited freshwater inflow into Offatts Bayou, salinities may be slightly higher at times upstream of the barrier than if the barrier were not in place.

South Padre Island CSRM Measure

The South Padre Island CSRM measure would not affect salinities, because it would be constructed along the Gulf beach.

ER Measures

The hydrologic restoration portion of the W-3 ER measure, which would involve dredging and maintaining Port Mansfield Channel open, should affect salinity in the Lower Laguna Madre. Salinity in the Gulf near the Port Mansfield Channel is about 35 ppt, while salinities in the Lower Laguna Madre at the Port Mansfield Channel have ranged up to 40 to 50 ppt in the past (King et al., 2016). Measured salinities near Port Mansfield from 1995 through 2009 ranged from 7 to 45 ppt and averaged 31 ppt (Schoenbaechler and Guthrie, 2011f). Cited literature indicates salinity in the Lower Laguna Madre has averaged 32 ppt over the period from 1995 to 2002 (Rio Grande BBEST, 2012).

The ability of this ER measure to influence salinity in the Lower Laguna Madre is affected by flow patterns in the estuary. It is long, narrow, and oriented along a south-southeast to north-northwest axis. This shape and orientation, combined with prevailing winds from the southeast and a microtidal environment, result in flow at Port Mansfield Channel flowing out of the estuary into the Gulf much of the time (King et al., 2016). Prevailing winds from the southeast for most of the year force water northward in the lower Laguna Madre and tend to push it out the Mansfield Cut. This wind-driven hydrodynamic forcing commonly overwhelms the tidal prism on incoming tides in this microtidal environment. This flow out of the Port Mansfield Channel functions more like a river mouth with outgoing currents occurring most of the time rather than a tidally influenced estuary opening. Maintaining Port Mansfield Channel open with dredging is likely to help reduce the frequency and magnitude of

high salinity conditions in the Lower Laguna Madre. Effects of this ER measure on salinity have not been modeled for the Coastal Texas Study.

There may be localized and temporary changes in salinity associated with the following ER measures: Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection (G-28), West Bay and Brazoria GIWW Shoreline Protection (B-12), East Matagorda Bay Shoreline Protection (M-8), Keller Bay Restoration (CA-5), Powderhorn Shoreline Protection and Wetland Restoration (CA-6), and Redfish Bay Protection and Enhancement (SP-1). These measures involve construction of structures, which would modify local current patterns and may require enclosing areas temporarily for marsh construction. Effects of these ER measures on salinity have not been modeled. Salinity effects of these measures, if they occur, are expected to be temporary and relatively small in magnitude.

The Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration (G-5) and Follets Island Gulf Beach and Dune Restoration (B-2) ER measures are not expected to impact salinities, because they would be primarily constructed out of the water.

5.3.2.2.2 Bay Rim Alternative

Bay Rim CSRM System

Salinities were not modeled in portions of the system upstream from the Bay Rim, including the upper Houston Ship Channel, Buffalo Bayou and its tributaries, and the San Jacinto River tidal. Mean salinities are not expected to differ by more than 0.4 ppt in the bay system with this CSRM measure in place based on screening level analysis conducted by the USACE (pers. com H. Das [USACE], 2018). Its position in the extreme upstream end of the bay would minimize any impact on the tidal prism. This CSRM measure, upstream of most of the bay system, is expected to have the least impact on bay salinities.

As with the Coastal Barrier Alternative, surge barrier gates are proposed for Clear Creek, Dickinson Bayou, and Offatts Bayou. Impacts on these systems are expected to be like those in the Coastal Barrier Alternative.

South Padre Island CSRM Measure and ER Measures

Impacts to salinity associated with the proposed South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.3.3 Coastal Processes

5.3.3.1 Storm Surge Effects

Massey et al. (2018) performed coastal storm model simulations of waves and water levels, reporting on storm surge modeling scenarios, and comparing without-project versus with-project alternative CSRM project plans. Storm surge simulations were performed using the Coastal Storm Modeling System (CSTORM-MS), with inclusion of the deepwater Wave Model to produce offshore wave boundary conditions for use with the nearshore

Steady-state Wave (STWAVE) model. The STWAVE model was used to provide the nearshore wave conditions including local wind-generated waves. The ADvanced CIRCUlation (ADCIRC) model was used to simulate two-dimensional depth-integrated surge and circulation responses to the storm conditions. CSTORM was coupled with the ADCIRC and STWAVE models in order to allow for dynamic interactions between the simulated surge/circulation and wave results.

The ADCIRC mesh topography/bathymetry values being used for the Coastal Texas Study's study area are relative to NAVD 88 datum, 2004.65 epoch with an applied geoid offset of +1.0 foot, which was applied to 660 synthetic generated tropical storms. Three sets of starting water levels were used for the synthetic storms to include the present-day water level, sea level change value of +2.5 feet, and sea level change value of +4.9 feet. The latter two sea level change values correspond to the intermediate and high sea level rise scenarios in year 2085.

Under the without-project conditions, the 660 synthetic tropical storms along with the 3 starting water levels were used to compute storm surge and nearshore wave conditions using the CSTORM-MS. Nearly 2,000 model simulations were performed for without-project conditions. Model grids were modified to incorporate the Coastal Barrier CSRM measure. For each of these measures, the ADCIRC mesh was altered to include surge protection features in the form of levees, which are also captured as depth features in STWAVE. Storms were modeled from basin scale down to local scale, where the probabilities of storm responses were computed. Storm responses included storm surge, astronomical tide, waves, wave effects on water levels, storm duration, wind, currents, and the effect of sea level change.

An initial screening level comparison of the with-project CSRM measures was modeled using 20 representative synthetic storms selected from the full suite of 660 storms. These representative storms were selected since they mimic water level responses that correlate with the return period analysis curves in the Galveston Bay area. The effectiveness of each alternative CSRM measure was evaluated based on individual storms that produced the maximum storm surge results from the CSTORM coupled ADCIRC+STWAVE simulations.

5.3.3.1.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

Individual Storm Surge Reduction. Two individual storms provided maximum storm surge results from the CSTORM coupled ADCIRC+STWAVE simulations. Surge or water surface elevation comparisons between without- and with-project conditions for Storm 154 (Category 3) and Storm 356 (Category 4) are displayed on figures 5-1 and 5-2, respectively. For Storm 154 (Category 3), the Coastal Barrier provides storm surge reductions along the northern and eastern sides of Galveston Bay, with slight increases in surges along the southwestern edge of Galveston Bay (Figure 5-1). For Storm 356 (Category 4), the Coastal Barrier reduces storm surge in the entire Galveston Bay system by between 0.5 and 10 feet (Figure 5-2). For both storms 154 and 356, the proposed Galveston Island ring levee does not appear to be overtopped by the surge.

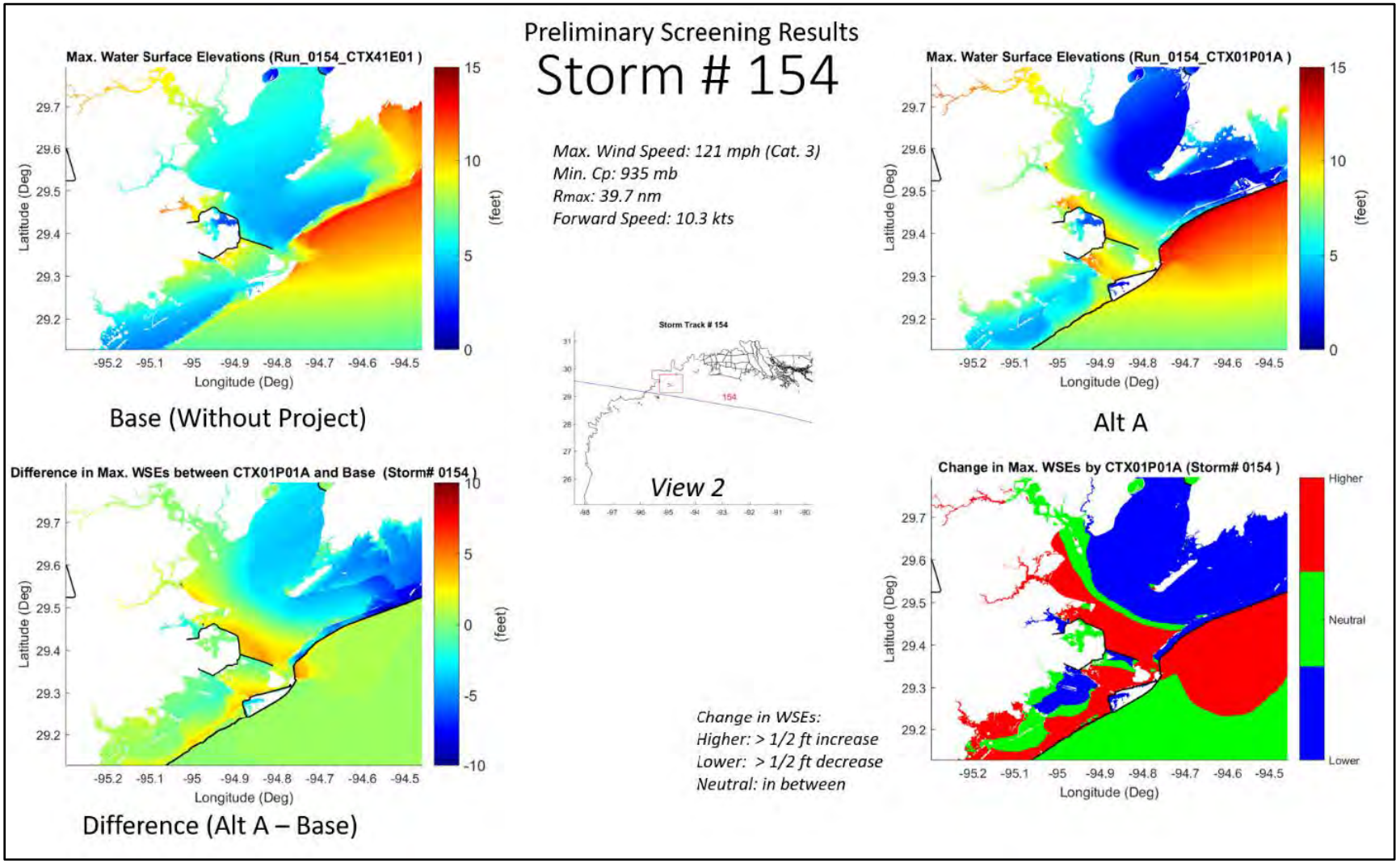


Figure 5-1. Storm Surge Results for Storm 154, Category 3 – Coastal Barrier
(Massey et al., 2018)

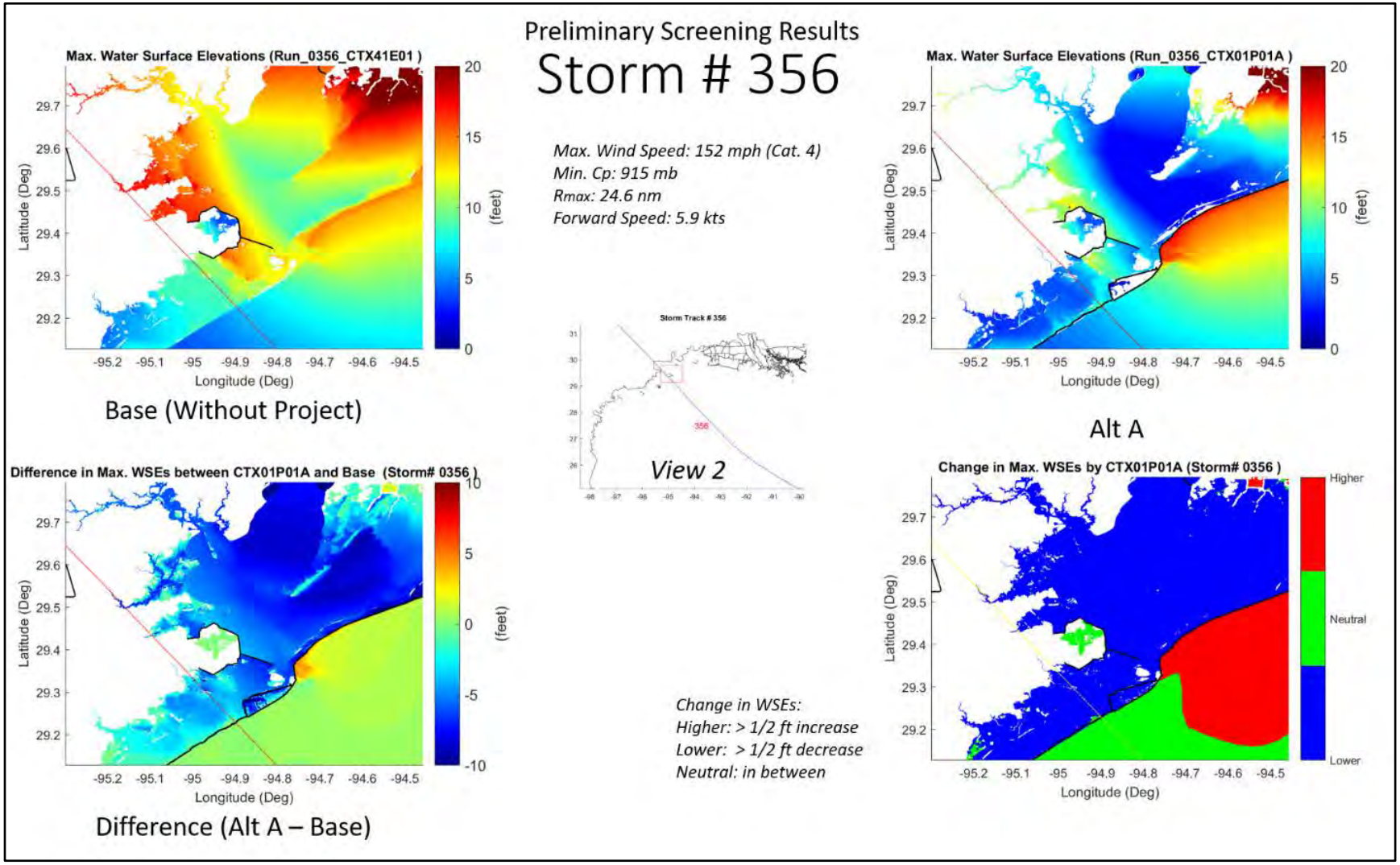


Figure 5-2. Storm Surge Results for Storm 356, Category 4 – Coastal Barrier
(Massey et al., 2018)

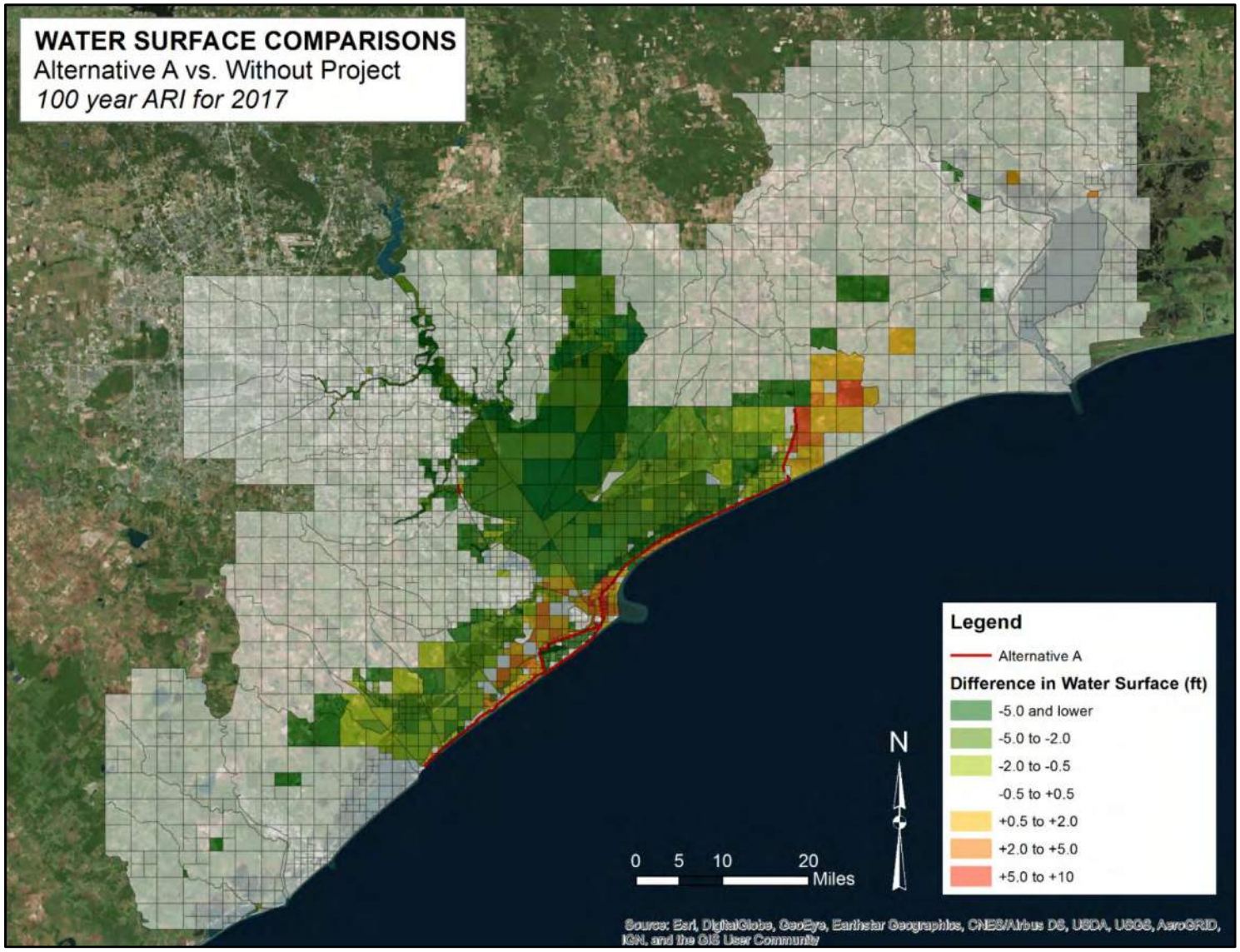


Figure 5-3. Storm Surge Elevation Changes Between the Coastal Barrier and FWOP
(Massey et al., 2018)

Storm Surge Reduction. For the maximum simulated storm surges, the Coastal Barrier reduces storm surge within the entire Galveston Bay system by between 0.5 and 10 feet. Figure 5-3 displays the water surface elevation changes between the proposed Coastal Barrier system and without-project condition. When storm surge is evaluated by individual storms and maximum simulated storm surges, reduction in storm surge elevation throughout Galveston Bay is observed with the proposed Coastal Barrier.

South Padre Island CSRM Measure

The South Padre Island CSRM measure entails constructing a beach template with a dune height of 12.5 feet, a dune width of 20 feet, and a beach width of 100 feet. The beach/dune fill feature is proposed for 11,600 feet of shoreline at South Padre Island Reach 3 (R3) and Reach 4 (R4) (Figure 5-4) with a 10-year nourishment cycle.

This beach template was derived by employing the integrated engineering-economic Beach-fx model, which simulates the condition of a beach profile as it evolves due to storms and background erosion. Sea level change was incorporated into the Beach-fx model runs based on the intermediate scenario and the trend at Port Isabel, Texas, which is +0.01289 foot per year (Sanderson and Mays, 2018; Appendix E-2).

This beach/dune feature of the beach template would act as a natural barrier to absorb the impact of storm surges and wave attack by reducing wave energy and elevation; however, the beach/dune features would still be overtopped by storm surge and result in residual flooding and damages to inland structures and infrastructure. Overall, the South Padre Island CSRM measure consisting of beach/dune features would provide structures risk reduction against storm surges, but with residual damages.

ER Measures

Revetment/breakwaters, island restoration, marsh restoration (including out-year marsh nourishment in 2065), oyster reef creation, and dune/beach restoration ER features would protect and stabilize existing and restored island shorelines and marsh fringes and would contribute to absorbing storm surges from tropical cyclone storm events. The hydrologic restoration of the Lower Laguna Madre includes the dredging of Port Mansfield Channel to improve the tidal circulation between Laguna Madre and the Gulf. Sediments dredged from the Port Mansfield channel would be used beneficially for bird island restoration within Laguna Madre and for the nourishment and widening of approximately 10 miles of shoreline along the Padre Island National Seashore starting immediately north of Port Mansfield's north jetty. The island restoration and Padre Island National Seashore nourishment features would contribute to absorbing storm surges from tropical cyclone storm events.

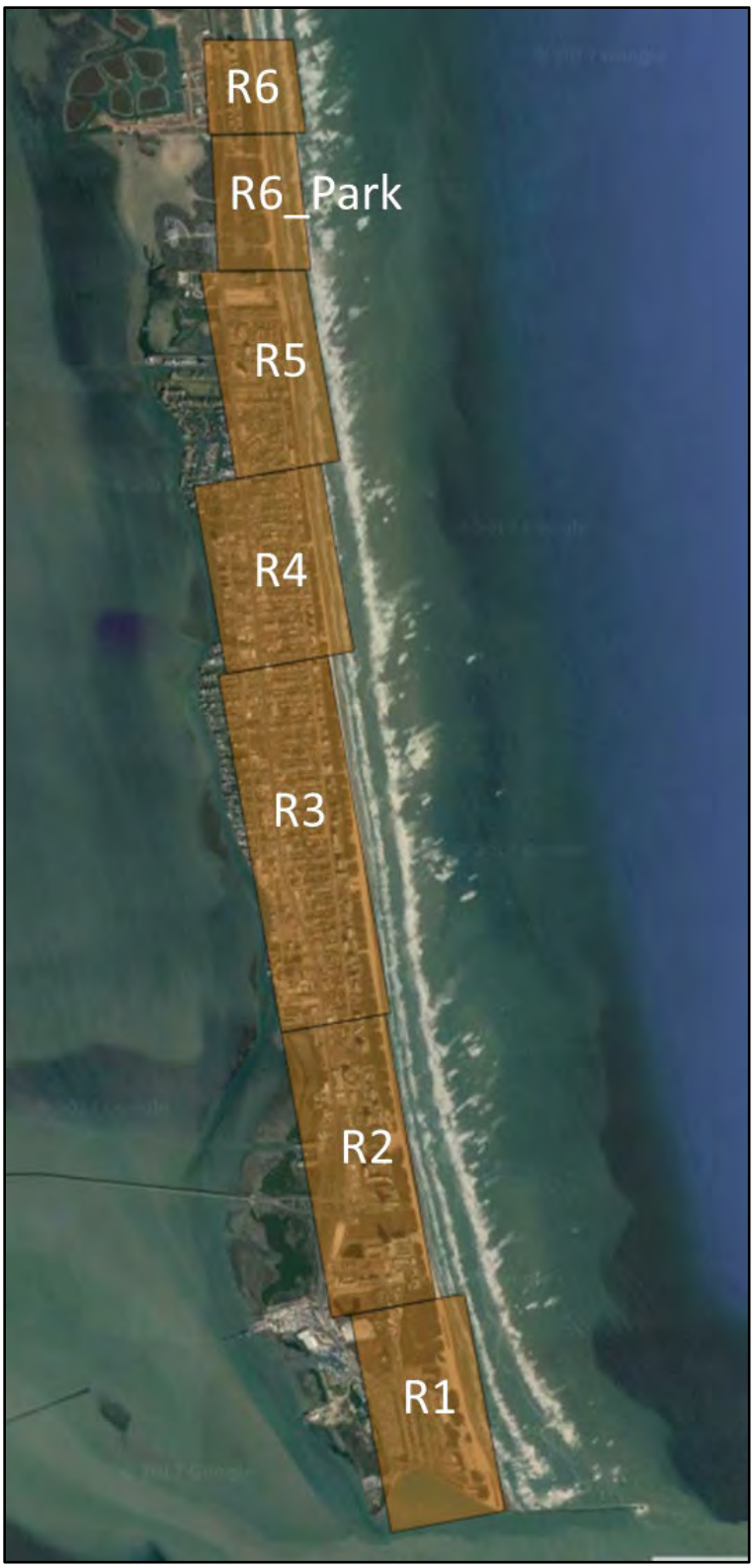


Figure 5-4. South Padre Island Beach-fx Reaches
(Sanderson and Mays, 2018; Appendix E-2)

5.3.3.1.2 Bay Rim Alternative

Bay Rim CSRM System

Individual Storm Surge Reduction. Two individual storms provided maximum storm surge results from the CSTORM coupled ADCIRC+STWAVE simulations. Surge or water surface elevation comparisons between without- and with-project conditions for Storm 154 (Category 3) and Storm 356 (Category 4) are displayed on figures 5-5 and 5-6, respectively. For Storm 154 (Category 3), the Bay Rim provides no major differences in maximum storm surge over the without-project condition for almost the entirety of Galveston Bay, with reduced surge values occurring only north and west of the structures (Figure 5-5). For Storm 356 (Category 4), the Bay Rim provides storm surge reductions landward on the southwestern portions of the bay, which are areas on the protected side of the levees (Figure 5-6). For both storms 154 and 356, the proposed Galveston Island ring levee does not appear to be overtopped by the surge.

Storm Surge Reduction. For the simulated maximum storm surges, the Bay Rim provides storm surge reductions landward on the southwestern portions of the bay, which are areas on the protected side of the levees. Figure 5-7 displays the water surface elevation changes between the proposed Bay Rim measure and without-project condition. When storm surge is evaluated by individual storms and simulated maximum storm surges, reduction in storm surge elevation landward on the southwestern portions of Galveston Bay throughout Galveston Bay is observed with the proposed Bay Rim CSRM measure.

South Padre Island CSRM Measure and ER Measures

Impacts to the storm surges associated with the proposed South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.3.4 Water and Sediment Quality

5.3.4.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier is expected to impact water and sediment quality throughout the Galveston Bay system, because it would reduce flushing and mixing of point and nonpoint source pollutants entering the bay. Gulf water contains fewer pollutants than the bay and tidal exchange dilutes pollutants entering the bay (Brock et al., 1996). Eighty percent of the tidal flow into and out of Galveston Bay occurs at Bolivar Roads, and the barrier is estimated to reduce the volume of tidal flow between 13.5 and 16.5 percent (McAlpin et al., 2018; Ruijs, 2011).

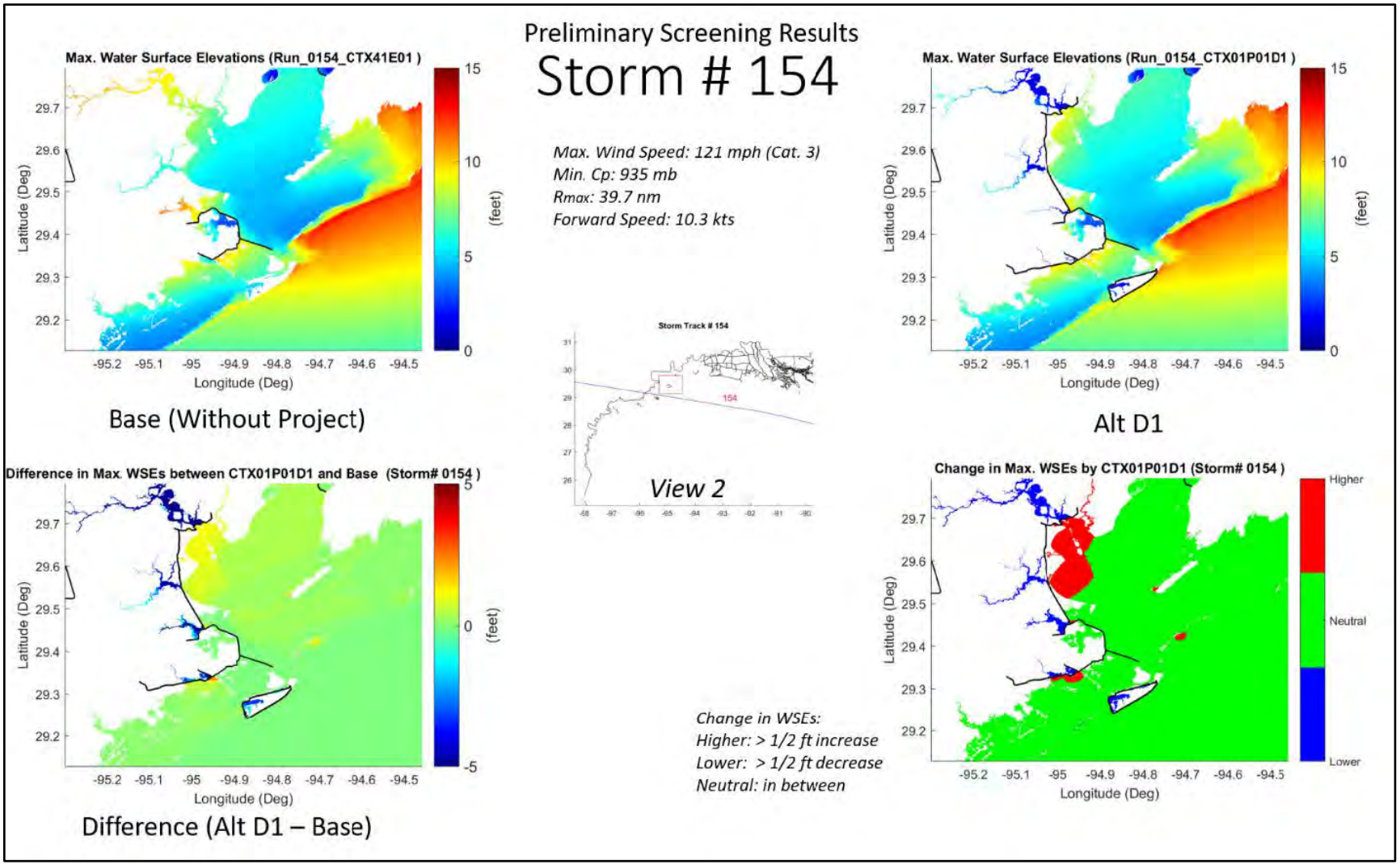


Figure 5-5. Storm Surge Results for Storm 154, Category 3 – Bay Rim
(Massey et al., 2018)

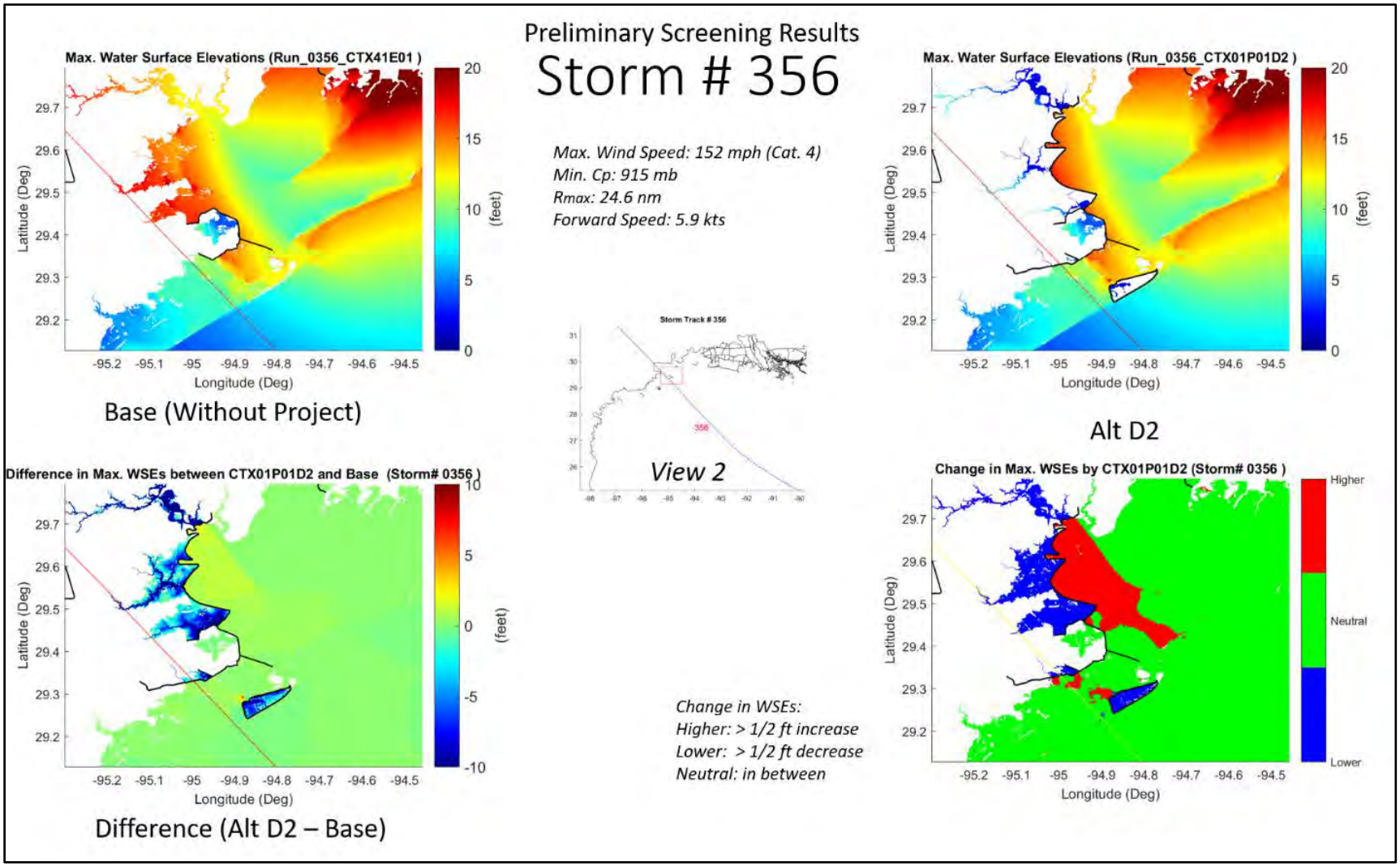


Figure 5-6. Storm Surge Results for Storm 356, Category 4 – Bay Rim
(Massey et al., 2018)

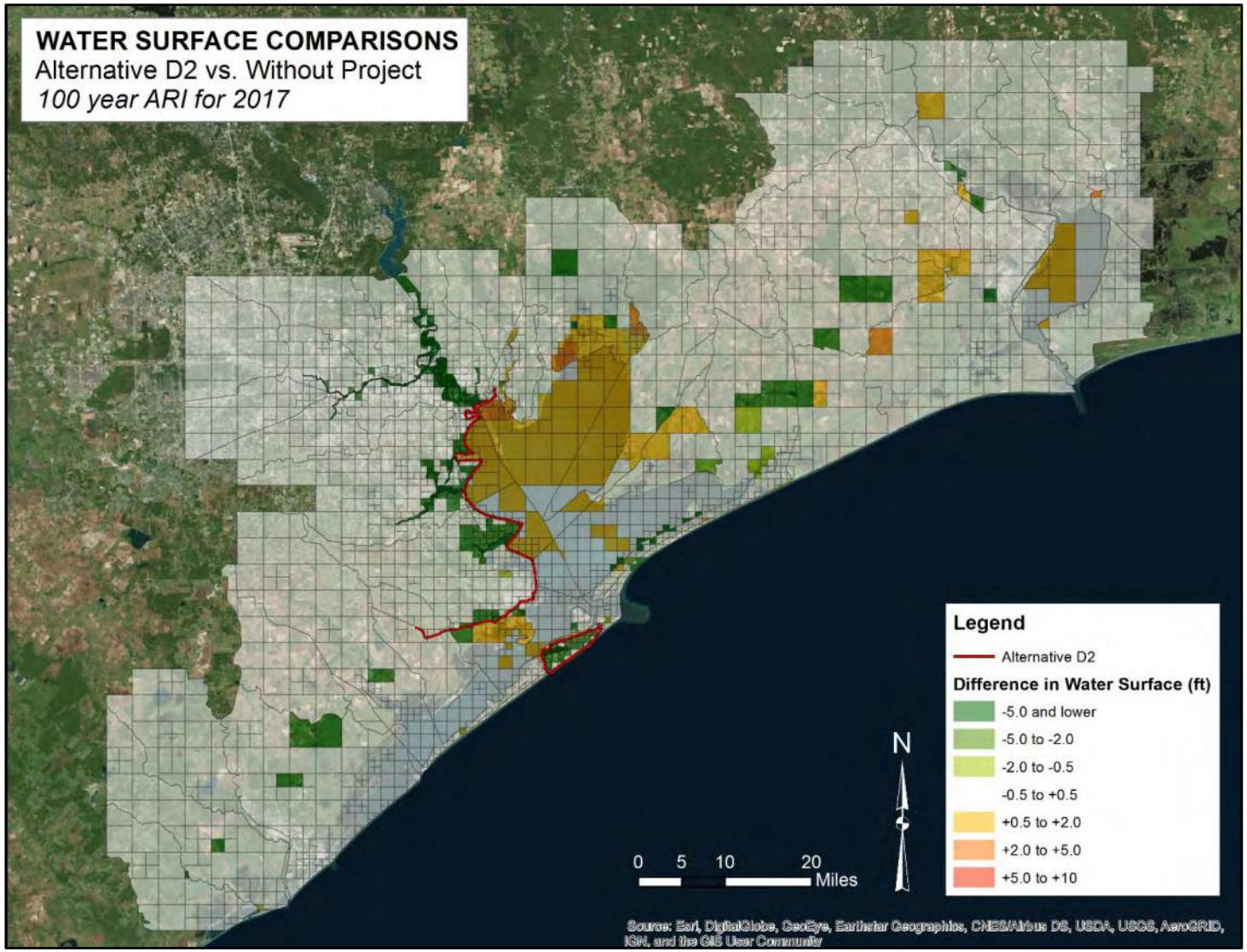


Figure 5-7. Storm Surge Elevation Changes Between the Bay Rim and FWOP
(Massey et al., 2018)

In addition to tidal exchange with the Gulf, water retention time in Galveston Bay is affected by freshwater inflow. Main sources of freshwater are the Trinity River, San Jacinto River, and Buffalo Bayou and its tributaries (Lester and Gonzalez, 2011). Retention time in Galveston Bay may be as low as 20 days during high inflows and up to 8 months during periods with low inflow (Arcadis, 2017; Joye and An, 1999; Rayson et al., 2016). Hydraulic modeling indicates the Coastal Barrier along with barriers at Clear Lake, Dickinson Bay, and Offatts Bayou would increase retention time upstream of each barrier. Salinity upstream of the barriers at Clear Lake, Dickinson Bay, and Offatts Bayou may be lower on average than in the past because of this increased retention time. Increased retention may increase sediment deposition and development of low dissolved oxygen conditions upstream of the barriers.

Reduced mixing and water exchange combined with pollution and episodic storms are considered major contributors to low dissolved oxygen levels in estuaries (Howarth et al., 2011; Paerl, 2006). These conditions have occurred in Dickinson Bay and Dickinson Bayou in Galveston Bay (Quigg et al., 2009). Most fish die-offs in the Galveston Bay system have been attributed to low oxygen (Lowe et al., 1991; Thronson and Quigg, 2008). Galveston Bay has been considered a hot spot for fish kills with more fish reported killed in Galveston Bay than any other estuary in Texas from 1970 to 2006 (Thronson and Quigg, 2008). Many of those fish kills occurred in residential boat canals with limited water exchange. Thronson and Quigg (2008) identified reduced mixing and algal blooms as contributing to a substantial number of coastal fish kills in Texas.

Estuaries are typically nitrogen-limited for all or much of the year (Howarth et al., 2011). Phosphorus is not usually a limiting nutrient, because it is continually transported from Gulf waters (where phosphorus is usually present) into estuaries by tides. Nitrogen was found to be primarily removed from the bay system through outflow to the Gulf (Brock et al., 1996). Reducing tidal flushing by construction of barriers may alter nutrient balance by reducing phosphorus input into the bay and nitrogen transport out of the bay. Changes in ratios of nitrogen and phosphorus may change plankton communities in the bay, particularly in areas where oysters rely on plankton as their primary food source.

Parts of the bay that are farther from development and point sources of pollutants have lower nutrient concentrations and algal biomass than parts of the bay closer to urban and industrial development. Nitrogen, phosphorus, and chlorophyll α levels were considered good in West and East bays where concentrations from 2000 to 2009 were less than TCEQ screening criteria in more than 85 percent of samples. Concentrations of these substances in Upper and Lower Galveston Bay exceeded TCEQ screening criteria in 16 to 30 percent of samples collected over the same period. Although the largest impacts in tidal exchange will occur closest to the Coastal Barrier structures, the increase in retention time may allow effects of high algal productivity, low oxygen, and potentially harmful algal blooms to be expressed more widely and frequently in these areas of the bay (Lester and Gonzalez, 2011).

South Padre Island CSRM Measure

There would be localized increases in turbidity at the Gulf associated with dredging and placement for this CSRM measure. These effects would occur over a 40- to 60-day period (estimated time to dredge and place the sediments)

approximately once every 10 years. There may also be release of low oxygen water, high ammonia, and nutrients at the borrow source location as sediments are dredged (Riemann and Hoffman, 1991). These conditions, like elevated turbidity, would be expected to be temporary and localized, ending when dredging was completed.

ER Measures

Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration (G-5) and Follets Island Gulf Beach and Dune Restoration (B-2) ER measures would experience localized increases in turbidity at the sediment borrow and beach placement locations. There may also be releases of low oxygen water and nutrients at the borrow source location as sediments are dredged. These conditions, like elevated turbidity, would be expected to be temporary and localized, ending when dredging was completed. The extent and frequency of these impacts depends on the renourishment approach used. If a standard 50-year beach renourishment plan is followed, these impacts may be experienced every 5 to 10 years. If a one-time sand motor approach is used, the period of increased turbidity and possible low oxygen and elevated nutrient release from the borrow source would only occur once but would extend substantially longer than borrowing sediment every 5 to 10 years.

Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection (G-28), West Bay and Brazoria GIWW Shoreline Protection (B-12), East Matagorda Bay Shoreline Protection (M-8), Keller Bay Restoration (CA-5), Powderhorn Shoreline Protection and Wetland Restoration (CA-6), Redfish Bay Protection and Enhancement (SP-1), and the Port Mansfield island enhancement (W-3) would experience localized and temporary increases in turbidity associated with placement of materials for breakwaters, marsh nourishment, marsh restoration, island restoration, or oyster reef creation. Localized and temporary increases in turbidity associated with dredging material for marsh nourishment, marsh restoration, and island restoration would occur; however, if the dredging is associated with dredge maintenance or virgin material from navigation channels, like the GIWW, these impacts would occur even if the ER measures were not implemented. Areas receiving marsh nourishment or restoration (G-5, B-12, M-8, CA-5, CA-6) may experience more impacts from additional periods of elevated turbidity and depressed oxygen levels associated with extended periods of construction and dredged material placement.

Water and sediment quality impacts resulting from the ER measures are expected to be temporary and associated with actual periods of construction.

5.3.4.2 Bay Rim Alternative

Bay Rim CSRM System

The intensity, frequency, and severity of possible impacts may be greater with the Bay Rim than with the Coastal Barrier since most of the waste load enters the bay upstream of the proposed barriers across the Houston Ship Channel and Tabbs Bay. The area for mixing and the volume for dilution would be reduced, which could have harmful effects since this area upstream of the proposed barriers already experiences the poorest water quality in the system. Most nutrients and potential pollutants enter the upper end of the bay, particularly the Houston Ship Channel and Upper Galveston Bay. The portion of the Bay Rim alternative that is upstream of the proposed barriers across the Houston Ship Channel and Tabbs Bay creates the smallest areas where flushing would be

reduced combined with the highest nutrient and pollutant loading. This combination of reduced flushing and pollutant loading may create more detrimental effects like hypoxic zones and harmful algal blooms than the Coastal Barrier.

Nearly three-fourths of permitted wastewater treatment plants in the five counties around Galveston Bay discharge treated wastewater into Harris County. Prior to 2009, there were 753 treated wastewater discharges in Harris County. It has the greatest land area, 1.1 million acres, of the five counties surrounding the bay, and of those counties, it has the highest percentage (43 percent) of developed land, indicating its high potential contributions to nonpoint source pollution (Lester and Gonzalez, 2011). Lester and Gonzalez (2011) also identified the western, urbanized portion of the bay's watershed as the area with most of the water quality problems.

Sediment concentrations of nine heavy metals and chlorinated organic compounds were reviewed and concentrations above TCEQ screening criteria were identified only in the Houston Ship Channel (Lester and Gonzalez, 2011). Mixing with Gulf waters, which might otherwise transport some of these materials out of the bay and allow some dilution of these potentially hazardous materials, would be reduced. This reduction in mixing and dilution may increase sediment loading in areas where hazardous materials are above screening criteria. Increased concentrations of these materials in sediment may contribute to bioaccumulation and biomagnification of potential pathogens, heavy metals, and synthetic organic compounds in fish and shellfish in the area.

The TDSHS sampled fish tissues from Galveston Bay for metals, PCBs, dioxins, and pesticides (TDSHS, 2013c). Sampling from 1997 to 2000 showed "…little evidence of contamination…." with substances that could pose a risk to human health in East, West, and Lower Galveston, and Trinity bays. The same sampling indicated potentially hazardous concentrations of PCBs and dioxins in upper portions of Upper Galveston Bay, the upper Houston Ship Channel, and the lower San Jacinto River. As a result, Fish and Shellfish Consumption Advisory, ADV-55, for the Houston Ship Channel and the San Jacinto River from upstream of the Fred Hartman Bridge to the Lake Houston Dam for the San Jacinto River was issued, limiting consumption of fish and blue crabs from those areas (TDSHS, 2015). Fish and Shellfish Consumption Advisory, ADV-50, was also issued restricting consumption of catfish, spotted seatrout, and blue crab in Upper Galveston Bay and catfish throughout Galveston Bay (TDSHS, 2013a). Sampling for PCBs in the Houston Ship Channel, its tributaries, and the San Jacinto River tidal revealed concentrations in water and fish tissue high enough to pose a concern to human health (Rifai et al., 2005).

The Bay Rim would be upstream of Trinity Bay, Upper Galveston Bay, Lower Galveston Bay, West Bay, and East Bay. Fewer nutrients, pollutants, and potential pathogens may be transported past this barrier than in the past, and Upper Galveston Bay, Trinity Bay, Lower Galveston Bay, Bolivar Roads, West Bay, and East Bay may experience improved water and sediment quality since they would be downstream of the barrier. If low oxygen conditions or harmful algal blooms develop upstream of the barrier, they would be expected to impact some portion of the bay downstream as they move through the barrier. Water and sediment quality impacts may be minimal and possibly improve relative to recent conditions.

South Padre Island CSRM Measure and ER Measures

Impacts to water and sediment quality resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.3.5 Hydrology

As discussed in Section 2.3.6, the study area can be divided into three regions: the Upper Coast River and Coastal Basins, the Middle Coastal River Basins, and the Lower Coast Basins, each encompassing several individual water basins (see Figure 2-8). The following subsections identify possible impacts resulting from implementation of CSRM and ER measures.

5.3.5.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier may impact the following watersheds in the Upper Coast River and Coastal Basins which are connected to the Galveston Bay system (see Figure 2-8):

- (7) Neches-Trinity Coastal Basin
- (8) Trinity River Basin
- (9) Trinity-San Jacinto River Basin
- (10) San Jacinto River Basin
- (11) San Jacinto-Brazos River Basin

Galveston Bay. The barrier at Bolivar Roads is not expected to affect watershed hydrology except for very localized impacts where the barrier connects to the shore. The structures and support systems for the barrier that are constructed on or adjacent to land may influence the direction and rate of rainfall runoff from the land, and it may influence bay or Gulf water levels where the barrier meets the land. The barriers at Offatts Bayou, Dickinson Bayou, Clear Lake, and the GIWW near High Island may increase localized flooding upstream and downstream of the barriers during extreme rainfall runoff events or water level fluctuations in the bay (extreme high tides or storm-generated waves). This flooding may occur if the barriers reduce the existing cross-sectional area of the channels where the barriers are proposed for construction. Water might rise higher than it would without the constriction in place, flooding adjacent land that does not flood now under those conditions. The extent of flooding would depend on the severity of rainfall runoff or rise in water elevation, which is anticipated to be managed and offset by the optimized sizing of the planned pump stations associated with each gate. However, residual flooding and damages may occur within the protected areas. Based on the estuarine modeling conducted by the USACE, the tidal amplitude in the bay would be reduced, meaning the shoreline around the bay would be less frequently exposed to higher tides (McAlpin et al., 2018).

Galveston Island. The proposed ring levee around urbanized areas of Galveston would block some rainfall runoff from drainage channels and sheet flow from the watershed into the bay. Stormwater would be routed to pump stations and drainage gates, requiring hydrologic modification of watershed drainage.

Gulf Coast Aquifer. No impacts to the Gulf Coast Aquifer are anticipated from this alternative.

South Padre Island CSRM Measure

The South Padre Island CSRM measure, which includes a dune system and the nourishment of the South Padre Island Gulf shoreline, is not expected to impact regional hydrology. The placement of sediments on the beach may have very localized effects on where rainfall runoff flows but would not block or interfere with any existing stream channels or other permanent inland waterbodies. No long-term or spatially extensive impacts to watershed hydrology are anticipated resulting from the South Padre Island CSRM measure.

ER Measures

Revetment/Breakwater. Breakwaters constructed in the water would not affect watershed hydrology. Revetments constructed on restored and created island shorelines may have minor, localized effects on the direction of flow of rainfall runoff into the bay adjacent to the revetment. Breakwaters that block water exchange with tidal channels could cause flooding of land on the upstream side of the structure. Maintaining water exchange between the bay and marsh and tidal streams is considered important for maintaining ecological health, and structures are expected to be designed to not interfere with that water exchange.

Island Restoration. Placement of material to preserve existing island features may affect rainfall runoff and its flow on the island, but any effects are expected to be temporary and localized. Impacts would not extend beyond the islands. Island creation would not impact any permanent bodies of inland waters like freshwater streams or ponds and therefore not negatively impact watershed hydrology.

Marsh Restoration/Out-year Marsh Nourishment 2065. The placement of material to restore or create marsh habitat may locally change hydrology if containment levees are built on uplands. Containment levees built on uplands would probably change patterns of sheet flow from rainfall runoff towards the bay. Although these impacts, if they occur, are expected to be localized, they could continue for up to 10 years during the marsh restoration process. Marsh restoration is not expected to impact any permanent bodies of inland waters like freshwater streams or ponds. A one-time out-year marsh nourishment would occur in 2065 for four of the ER measures in areas that would convert to open water or unconsolidated shoreline over the period of analysis due to RSLR. Impacts to the local watershed hydrology are not anticipated because sediments would be placed in intertidal marsh only.

Oyster Reef Creation. Oyster reefs do not induce hydrologic changes. Therefore, impacts to watershed hydrology are not anticipated to result from creation of these features.

Dune/Beach Restoration. The placement of sediments on the beach may have very localized effects on the direction in which rainfall runoff flows but would not block or interfere with any existing stream channels or other permanent inland waterbodies. No long-term impacts to watershed hydrology are anticipated to result from these ER features.

Hydrologic Restoration. ER Measure W-3 (Port Mansfield Channel, Island Rookery and Hydrologic Restoration) is in the Nueces-Rio Grande Basin and the only ER measure specifically designated to achieve hydrologic improvements in the Lower Laguna Madre. Port Mansfield Channel is a navigable waterway authorized to be maintained by the USACE. Deferred maintenance dredging has resulted in loss of navigable channel cross section and subsequent loss of Gulf flow into the Lower Laguna Madre. Dredging the channel would enhance flow and tidal exchange between the Gulf and the Lower Laguna Madre. Sediment dredged from the channel that will be placed in an offshore berm would not impact watershed hydrology in the area.

Summary. The ER measures are designed to provide an overall positive benefit to the ecosystem in a variety of ways. These benefits work together to contribute to the multiple lines of defense strategy that was developed by the Coastal Texas Study. When comparing the ER measures to the No-Action Alternative, the benefits resulting from the ER measures far outweigh the localized impacts that would be expected, especially when incorporating hydrologic connectivity as a design criterion.

5.3.5.2 Bay Rim Alternative

Bay Rim CSRM System

The Bay Rim would impact the following water basins in the Upper Coast River Basins (see Figure 2-8):

- (9) Trinity-San Jacinto River Basin
- (10) San Jacinto River Basin
- (11) San Jacinto-Brazos River Basin

Galveston Bay. The surge barrier gates may increase localized flooding upstream and downstream of the barriers during extreme rainfall runoff events or water level fluctuations in the bay (extreme high tides or storm-generated waves). The extent of flooding would be affected by the extent the barriers reduce the existing cross-sectional area of the channels where the barriers are proposed for construction.

Because of the extensive nature of the levees and surge barrier gates proposed for this alternative, rainfall runoff in drainage channels and as sheet flow is expected to be intercepted by the levees and forced into areas not typically inundated or into different channels for additional stormwater runoff. Channel designs would need to ensure drainage features to pumps have adequate capacity to transport flood flows. Pump stations would be installed upstream of the levees, and hydrologic modifications would be required to direct flood flows to the pump stations.

Galveston Island and Gulf Coast Aquifer. Impacts would be the same as those described for the Coastal Barrier Alternative.

South Padre Island CSRM Measure and ER Measures

Impacts to the hydrology resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.3.6 Soils (Prime and Other Important Unique Farmland)

Prime and unique farmlands were mapped using the NRCS Web Soil Survey website (NRCS, 2018). The NRCS database was used to calculate prime farmland impacts associated with construction right-of-way.

5.3.6.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier would convert 2.3 acres of prime farmlands, as defined by the NRCS Web Soil Survey (NRCS, 2018), into a levee barrier. The impacted prime farmland is located north of High Island on Farm to Market Road 124. Most of the area along Farm to Market Road 124 (excluding Anahuac NWR) has previously been converted from grasslands and wetlands to farmlands and cattle pastures (NRCS, 2018). The Coastal Barrier would have the least impact to prime farmlands compared to the Bay Rim.

The levee barrier footprint would result in permanent impacts to prime and unique farmlands from construction activities such as grubbing and clearing, levelling, borrow, and piling fill material for the storm surge barrier. Construction access roads and staging areas may temporarily impact additional land. Indirect effects of the levee barriers may include fragmentation, soil compaction, and development.

No prime or otherwise important farmlands were identified on Galveston Island or Bolivar Roads (NRCS, 2018). Upon completion, the Coastal Barrier is expected to benefit prime farmlands by providing a buffer and protective barrier against rising sea level and erosive wind/wave action that could potentially wash out prime farmland soils. No long-term substantial impacts are expected resulting from the Coastal Barrier. Prior to construction, the NRCS would be consulted to minimize or avoid impacts to prime farmlands.

South Padre Island CSRM Measure

The South Padre Island CSRM measure proposes filling the beach with fill material and restoring the dune system along South Padre Island beach. There are no prime farmlands on South Padre Island and therefore this measure is not expected to impact any prime farmlands on the island. The CSRM measure is expected to provide a benefit to soils and prime farmlands in the future by providing a storm buffer and protecting soils from erosive wave and wind action. No long-term impacts to prime farmlands are anticipated resulting from the South Padre Island CSRM measure.

ER Measures

Revetment/Breakwaters. The construction of revetment and breakwater structure will directly impact 1.6 acres of prime farmlands located adjacent to the GIWW. Riprap breakwaters will be placed over prime farmlands. Most of the ER features will be limited to open water and bay bottoms and away from land and would not affect prime farmlands. Soils and other prime farmlands would overall benefit from the ER measure from the shoreline protection and stabilization provided by the revetment and breakwater structures.

Island Restoration. There are four proposed island restoration ER measures that would increase the size, stability, and composition of islands along the GIWW. The restoration of these islands is not expected to affect any prime farmlands. All fill material for the islands would be harvested from the GIWW. Placement areas for fill material would be away from prime soils in containment levees. There are no anticipated short- or long-term effects on prime farmland soils from the ER measures.

Marsh Restoration/Out-year Marsh Nourishment 2065. Approximately 0.9 acre of prime farmland in Brazoria County would be directly affected by marsh and wetland restoration. Impacts associated with the measure are from the construction of temporary containment levees and placement of fill material. The prime farmlands around the ER measure could be affected by sedimentation or buried with fill material. Completion of the marsh restoration ER measures are expected to indirectly benefit prime farmlands by providing a buffer area for rising sea level and storm surges and prevent washing out of soils. With the exception of the 0.9 acre in Brazoria County, there are no anticipated negative short- or long-term effects on prime farmlands from the ER measures.

Marsh nourishment would require the construction of temporary containment levees, placement of fill material, and plantings. Approximately 20.4 acres of prime farmlands in Brazoria County and East Matagorda Bay would be affected by out-year marsh nourishment. The construction of containment levee and placement of fill would impact prime farmland. The new marsh features would benefit prime farmlands by providing a buffer and protecting farmland soils from rising sea levels and storm surges. Except for the area listed above, no long-term impacts to prime farmlands are anticipated resulting from out-year marsh nourishment.

Oyster Reef Creation. Oyster cultch for the reefs would be placed in the water. There will be no anticipated impacts to prime farmlands from the placement of oyster cultch and construction of oyster reefs. Oyster reef creation is expected to only affect open water habitat. Prime farmlands are expected to benefit from the shoreline protection measures from future rising sea level.

Dune/Beach Restoration. There are no proposed dune or beach improvements on designated prime farmlands. Prime farmlands are expected to benefit from the ER measures due to the characteristics of dunes and beaches at blocking erosive coastal winds and wave action from washing out prime soils located farther inland.

Summary. A total of 2.3 acres for the Coastal Barrier and 22.9 acres for ER measures of prime farmlands would be impacted. The ER measures proposed will have very little impact to prime farmlands. Steps would be taken to avoid, minimize, and reduce any potential impacts to the best extent practicable. Overall the effects of the ER measures will benefit productive soils. The lines of defense from revetment/breakwater, oyster reef,

dunes/beaches, and marsh nourishment will provide a buffer from erosive wave and wind action. Comparing the ER measures to the No-Action Alternative, the benefits outweigh the limited impacts to prime farmlands.

5.3.6.2 Bay Rim Alternative

Bay Rim CSRM System

Potential impacts from the Bay Rim would be similar to those described for the Coastal Barrier, with the exception of the differences in the acres of impact to prime farmlands. The Bay Rim would impact approximately 332 acres of prime and unique farmlands. The majority of impacts to prime farmlands are located on the west extension of the Texas City Hurricane Flood Protection System and along the western edge of Galveston Bay. This CSRM measure would have the most impact to prime and unique farmlands. Impacted prime farmlands are currently used for residential, commercial, and agricultural practices.

Upon completion, the Bay Rim is expected to benefit prime farmlands by providing a buffer and protective barrier against rising sea level and erosive wind and wave action that could potentially wash out prime farmland soils. No long-term impacts are anticipated to prime farmlands resulting from the Bay Rim.

South Padre Island CSRM Measure and ER Measures

Impacts to the soils (prime and other important unique farmlands) resulting from the construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.3.7 Energy and Mineral Resources

The Gulf Coast Basin is an oilfield along the Texas Gulf coast. The counties of Chambers, Harris, Galveston, Brazoria, Matagorda, Calhoun, Nueces, Kenedy, Willacy, and Cameron are located within this oil field and depict a high concentration of oil and gas activities (Texas Oil and Gas, 2015).

Harris, Galveston, Chambers, Brazoria, and Matagorda counties are in an area that is home to one of the world's largest hubs for petroleum refining and drilling that is ranked first in the United States in foreign waterborne tonnage, imports, and export tonnage (Port of Houston, 2018a). Additionally, Houston, the energy capital of the world, is the leading domestic and international center for every segment of the energy industry. Approximately 4,800 energy-related firms are located within the Houston metro area, which include 700 exploration and production firms, 800 oilfield services companies, and 80 pipeline transportation firms (Greater Houston Partnership, 2017). These companies and their products are serviced by the Houston Ship Channel to the north of Galveston Island.

Furthermore, Calhoun, San Patricio, and Nueces counties contain a high concentration of oil and gas activities (Railroad Commission of Texas [RRC], 2018). High regional concentrations of petroleum industry are located in San Patricio and Nueces counties (Petroleum Product Manufacturing, 2015). Oil and gas activities are present within Kenedy, Willacy, and Cameron counties; however, the concentration of the activity is not as dense (RRC, 2018).

All in all, the Texas coast is home to an enormous system of oil and gas pipeline and well network that stretches from the Texas-Louisiana border to Mexico. This analysis is being conducted to provide a broad overview of the potential impacts and proximity of energy and mineral resources within 1 mile of each CSRM and ER measure limit along the Texas Gulf coast.

5.3.7.1 Data Used and Method of Analysis

ArcMap 10.4.1 was utilized to conduct a search of oil and gas pipelines and well locations within a 1-mile radius of each CSRM and ER measure limit. The oil and gas pipeline and well shapefile data were purchased from the RRC in 2018 and utilized for the Coastal Texas Study. For each measure limit, a 1-mile radius was created using the "buffer" geoprocessing tool. For each RRC shapefile, the "clip" geoprocessing tool was used to identify the sites within a 1-mile buffer of each measure limit. Following this process, an additional step was taken to identify the sites that intersect each measure limit.

Numerous oil and gas pipelines and wells are depicted along each measure. Locations and number of wells were identified during each analysis of the measure limits. Different types of oil and gas pipelines were identified within the attribute data. The following sections provide more-detailed information on these findings.

5.3.7.2 Coastal Barrier Alternative

Coastal Barrier CSRM System

Table 5-6 breaks down the number of oil and gas wells and pipelines within 1 mile of and that intersect the Coastal Barrier. These sites are also shown in Attachment 1, figures A–C.

The highest concentration of oil and gas wells is along the Galveston and Chambers county line and within Galveston, Brazoria, and Matagorda counties. A total of 1,267 oil and gas wells are located within 1 mile of the Coastal Barrier, with 57 oil and gas wells intersecting the Coastal Barrier footprint.

Pipeline intersections of the Coastal Barrier appear to be dispersed along the entirety of the measure. An increase in concentration of pipelines is visible within the 1-mile radius of the gates at the mouth of Clear Lake and Dickinson Bayou. A total of 49 pipelines are located within 1 mile of the Coastal Barrier, with 36 pipelines intersecting the Coastal Barrier footprint.

Table 5-6
Coastal Barrier – Analysis of Oil and Gas Pipelines and Wells

Feature Type	1-mile Radius	Intersect
Butane Pipeline	1	1
Carbon Dioxide Pipeline	1	0
Chemical Grade Propylene Pipeline	1	0
Crude Oil Pipeline	6	3
Diesel Fuel Pipeline	1	1
Ethylene Pipeline	2	2
Ethylene Gas Pipeline	1	1
Hydrogen Gas Pipeline	2	1
Isobutane Pipeline	1	1
Liquified Petroleum Gas Pipeline	3	3
Natural Gas Pipeline	17	11
Natural Gas Liquids Pipeline	1	1
Nitrogen Pipeline	2	1
Propane Pipeline	1	1
Propylene Pipeline	4	4
Propylene Chemical Pipeline	1	1
Propylene Dilute Pipeline	1	1
Refined Products Pipeline	3	3
Total Pipelines	49	36
Total Oil and Gas Wells	1,267	57

South Padre Island CSRM Measure (South Padre Island)

An analysis of oil and gas wells and pipelines was performed for South Padre Island. However, no oil and gas wells and pipelines were observed during the analysis. The limits of South Padre Island are depicted in Attachment 1, Figure H.

ER Measures

Table 5-7 breaks down the number of oil and gas wells and pipelines within 1 mile of and that intersect the ER measures. These sites are also shown in Attachment 1, figures A and C–G.

The highest concentration of wells is along the Galveston and Chambers county line and within Galveston, Brazoria, and Matagorda counties. A total of 2,826 oil and gas wells are located within 1 mile of the ER measures, with 1,223 oil and gas wells intersecting the ER measure footprints.

Pipeline intersections of the ER measures are dispersed along the entirety of the ER measure limits. A total of 164 pipelines are located within 1 mile of the ER measures with 65 oil and gas pipelines intersecting the ER measure footprints.

Table 5-7
ER Measures – Analysis of Oil and Gas Pipelines and Wells

Feature Type	1-mile Radius	Intersect
Directional Well Pipeline	256	100
Ammonia Pipeline	1	0
Anhydrous Ammonia Pipeline	2	0
Anhydrous Hydrochloric Acid Pipeline	2	0
Benzene Pipeline	1	1
Butadiene Pipeline	2	0
Butene Pipeline	1	0
Carbon Monoxide Pipeline	1	0
Chemical Grade Propylene Pipeline	1	0
Chlorine Gas Pipeline	1	0
Crude Oil Pipeline	20	9
Crude Oil FWS Pipeline	1	0
Cumene Pipeline	1	0
Cyclohexane Pipeline	1	1
Distillate Pipeline	1	1
EP Mix Pipeline	2	1
Ethane Pipeline	4	1
Ethane/Propane Pipeline	3	0
Ethane/Propane/Butane/Y-Grade	1	0
Ethylene Pipeline	6	1
Ethylene Gas Pipeline	1	0
Fuel Oil Pipeline	1	0
Hexene Pipeline	1	0
Hydrogen Gas Pipeline	5	2
Isobutane Pipeline	1	0
Liquified Petroleum Gas Pipeline	3	0
Methane Pipeline	1	1
Naphtha Pipeline	1	0
Natural Gas Pipeline	71	36
Natural Gas FWS Pipeline	7	3
Natural Gas Liquids Pipeline	3	3
Nitrogen Pipeline	2	0
Octene Pipeline	1	0
Polymer Grade Propylene Pipeline	1	0
Propane Pipeline	2	1
Propylene Pipeline	8	2
Propylene Chemical Pipeline	1	0
Pyrolysis Gasoline Pipeline	1	0
Styrene Pipeline	1	0
Syngas Pipeline	1	1
Xylene Pipeline	1	1
Y-Grade Products Pipeline	1	0
Total Pipelines	164	65
Total Oil and Gas Wells	2,826	1,223

5.3.7.3 Bay Rim Alternative

Bay Rim CSRM System

Table 5-8 breaks down the number of oil and gas wells and pipelines within 1 mile of and that intersect the Bay Rim. These sites are also shown in Attachment 1, figures I and J.

The highest concentration of wells is along the Galveston and Chambers county line and within Galveston, Brazoria, and Matagorda counties. A total of 3,813 oil and gas wells are located within 1 mile of the Bay Rim, with 89 oil and gas wells intersecting the Bay Rim footprint.

Pipeline intersections of the Bay Rim appear to be dispersed along the entirety of the Bay Rim footprint, with a higher concentration concentrated in western Galveston County, near the Port of Texas City, and in Harris County, near La Porte, Texas. A total of 206 pipelines are located within 1 mile of the Bay Rim, with 103 pipelines intersecting the Bay Rim footprint.

South Padre Island CSRM Measure and ER Measures

Impacts to the energy and mineral resources resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative. These sites are also shown in Attachment 1, figures C–J.

5.3.7.4 Conclusions

This Energy and Mineral Resource analysis is preliminary. A historical use and regulatory records search review was not used to formulate these preliminary conclusions. Digital data from the RRC were used to determine the location and density of oil and gas activities; however, these conclusions are very broad. Therefore, pointed conclusions should not be gathered from this information. This analysis is to be utilized to inform and guide decision-making. However, some general conclusions can be made (Table 5-9):

- Oil and gas activities are generally concentrated within Galveston, Matagorda, and Nueces bays.
- The Coastal Barrier Alternative has the least oil and gas wells and pipelines within the project footprint and 1-mile radius and the Bay Rim Alternative the most.
- Approximately 5 percent of the oil and gas wells and 74 percent of the oil and gas pipelines occur within the Coastal Barrier footprint and 1-mile radius.
- Approximately 2 percent of oil and gas wells and 50 percent of the oil and gas pipelines are located within the Bay Rim footprint and 1-mile radius.
- More oil and gas activities and infrastructure are found within ER measure footprints than the Coastal Barrier, but less oil and gas activities and infrastructure than the Bay Rim. A total of 1,223 oil and gas wells intersect the ER measures. This is the largest number of oil and gas wells to intersect any of the measures.

Table 5-8
Bay Rim – Analysis of Oil and Gas Pipelines and Wells

Feature Type	1-Mile Radius	Intersect
Acetic Acid Pipeline	2	2
Acrylic Acid Pipeline	1	1
Ammonia Pipeline	1	0
Anhydrous Ammonia Pipeline	2	1
Anhydrous HCL Pipeline	1	1
Benzene Pipeline	4	2
Butane Pipeline	2	1
Butane/Isobutane Pipeline	1	0
Butane/Isobutane/Isobutylene Pipeline	1	1
Butane/Isobutane/Natural Gas Pipeline	2	0
Butanol Pipeline	3	3
Butene Pipeline	1	1
Butyl Acrylate Pipeline	2	2
Butylene Pipeline	1	0
Carbon Dioxide Pipeline	1	1
Carbon Monoxide Pipeline	1	1
Chemical Grade Propylene Pipeline	1	1
Condensate Pipeline	1	0
Crude Oil Pipeline	19	8
Crude Oil FWS Pipeline	2	2
Cumene Pipeline	1	0
Cyclohexane Pipeline	1	1
Diesel Fuel Pipeline	1	1
Dripoline Pipeline	1	1
Empty Pipeline	4	2
EP Mix Pipeline	2	1
Ethane Pipeline	2	1
Ethane/Propane Pipeline	1	1
Ethane/Propane/Butane/Y-Grade Pipeline	1	0
Ethyl Acrylate Pipeline	1	1
Ethylene Pipeline	10	5
Ethylene Gas Pipeline	1	0
Ethylene Glycol Pipeline	3	3
Fuel Oil Pipeline	2	0
Gas/Diesel/Fuel Oil/Kerosene Pipeline	3	1
Gas/Jet Fuel/Diesel Pipeline	1	0
Hexene Pipeline	1	0
Hydrogen Gas Pipeline	10	5
Isobutane Pipeline	2	1
Isobutane/Natural Gas Pipeline	1	0
Isobutylene Pipeline	1	1
Kerosene Pipeline	2	0
Liquid Petroleum Gas Pipeline	4	1
Methanol Pipeline	2	1

Feature Type	1-Mile Radius	Intersect
Methyl Acetate Pipeline	1	0
Naphtha Pipeline	2	0
Natural Gas Pipeline	45	22
Natural Gas FWS Pipeline	3	2
Natural Gas Liquids Pipeline	4	2
Nitrogen Pipeline	6	2
Octene Pipeline	1	0
Petroleum Pipeline	3	0
Polymer Grade Propylene Pipeline	1	1
Propane Pipeline	7	3
Propane/Propylene Pipeline	1	1
Propylene Pipeline	14	8
Propylene Chemical Pipeline	1	0
Propylene Dilute Pipeline	1	0
Propylene Oxide Pipeline	2	1
Pyrolysis Gasoline Pipeline	1	1
Raffinate Pipeline	1	0
Refined Products Pipeline	5	1
Styrene Pipeline	1	1
Tertiary Butyl Alcohol Pipeline	1	1
Toluene Pipeline	1	0
Toluene Ethyl Benzene Pipeline	1	1
Vinyl Acetate Pipeline	2	1
Xylene Pipeline	1	0
Y Grade Products Pipeline	1	1
Total Pipelines	206	103
Total Oil and Gas Wells	3,813	89

Table 5-9
Summary of Energy and Mineral Resource Sites

Measure	Pipelines Within 1 mile	Pipeline Intersections	Oil/Gas Wells Within 1 mile	Oil/Gas Well Intersections
Coastal Barrier CSRM	49	36	1,267	57
Bay Rim CSRM	206	103	3,813	89
ER Measures	164	65	2,826	1,223
South Padre Island CSRM	0	0	0	0

- Approximately 43 percent of the oil and gas wells and 40 percent of the oil and gas pipelines are located within the footprints of the ER measures and 1-mile radius.
- No oil and gas activities occur within a 1-mile radius of the South Padre Island CSRM.

Steps would be taken to avoid, minimize, and reduce any potential impacts to oil and gas activity to the best extent practicable. A more-detailed oil and gas activity record is included in the Draft HTRW Assessment (Appendix C-7).

5.3.8 Hazardous, Toxic, and Radioactive Waste

Harris, Galveston, Chambers, Brazoria, and Matagorda counties are in an area that is home to one of the world's largest hubs for petroleum refining and drilling and is ranked first in the United States in foreign waterborne tonnage, imports, and export tonnage (Port of Houston, 2018b). Additionally, in 2016, a total of 6,367 manufacturing establishments called the greater Houston area home (Greater Houston Partnership, 2017). The city of Houston alone accounts for 42 percent of the Nation's base petrochemical capacity and is home to approximately 5,000 energy-related firms (Petroleum Refining and Chemical Products, 2015). One of the most densely concentrated areas of industrial, manufacturing, petroleum refining, and commercial facilities in the greater Houston area appears along the western shoreline of Galveston Bay (EIA, 2018; EPA, 2018a; TCEQ, 2018b). These industrial, manufacturing, petroleum refining, and commercial facilities are serviced by the Houston Ship Channel to the north of Galveston Island.

Furthermore, the Calhoun County coastline, adjacent to Lavaca and Matagorda bays, is home to Port Lavaca, Port O'Connor, Formosa Plastics Corporation Texas, and Alcoa World Alumina LLC. Industrial and commercial activities are present in the vicinity of Aransas Pass, Ingleside, Corpus Christi, and South Padre Island (EIA, 2018; EPA, 2018a; TCEQ, 2018b). This area contains a high concentration of basic chemical manufacturing; for example, petrochemicals, chlorine, and industrial gases are all produced in this area of the Texas Gulf coast (Basic Chemicals Manufacturing, 2015).

This analysis is being conducted to provide a broad overview of the potential impacts and proximity of HTRW within 1 mile of each measure along the Texas Gulf coast.

5.3.8.1 Data Used and Method of Analysis

The following GIS geospatial data was used:

- EIA (2018): Power Plant Sites
- EPA (2018a) Facility Registry Service (FRS) – Major/Special interest:
  - AFS Majors – Sources of Toxic Air Pollutants
  - ACRES – Brownfield Program Sites
  - NPDES Majors – Major National Pollutant Discharge Elimination System (NPDES) outfalls
  - RCRA Info – Resource Conservation and Recovery Act (RCRA) hazardous waste handlers

  - TSDs and LQGs – Treatment, Storage, and Disposal (TSD) and Large Quantity Generators (LQG) of RCRA hazardous waste
  - RMP – Facilities that require a Risk Management Plan (RMP) under Sec. 112(r) of the CAA, due to the presence of a certain amount of regulated substances at the facility
  - SEMS NPL – CECLA Superfund Enterprise Management System (SEMS) National Priorities List (NPL) Sites
  - SSTS – Section Seven Tracking System (SSTS) of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) Section 7
  - TRI – Toxic Release Inventory (TRI) Program Sites
- TCEQ GIS data (2018a):
  - Municipal Solid Waste (MSW) Sites/Landfills
  - Superfund Sites
  - Radioactive Waste Sites
  - Petroleum Storage Tank Sites
  - Active Air Monitoring Sites

ArcMap 10.4.1 was used to analyze these data and the proximity to each CSRM and ER measure. Each of the above data sources has a shapefile associated with it. For each CSRM and ER measure, a 1-mile radius was created using the "buffer" geoprocessing tool. For each shapefile, the "clip" geoprocessing tool was used to identify the sites within 1-mile buffer of each measure limits. Following this process, an additional step was taken to identify the sites that intersect the limits of each measure. The following sections provide more-detailed information on these findings.

5.3.8.2 Coastal Barrier Alternative

Coastal Barrier CSRM System

Table 5-10 breaks down the number of HTRW sites within 1 mile of and the number of HTRW site intersections of the Coastal Barrier. These sites are also shown in Attachment 2, figures A–C.

The highest concentration of HTRW sites are located in and around Galveston. A total of 112 HTRW sites were identified within 1 mile of the Coastal Barrier, with 13 HTRW sites intersecting the Coastal Barrier footprint. Approximately half of the HTRW sites identified within 1 mile of the Coastal Barrier are TCEQ Petroleum Storage Tank (PST) sites.

Table 5-10
Coastal Barrier – Number of HTRW Sites

Feature Type	1-mile Radius	Intersect
EPA National FRS Major Sites	49	5
TCEQ Petroleum Storage Tank Sites	57	6
TCEQ Active Air Monitoring Sites	2	0
TCEQ Superfund Site	0	0
TCEQ Radioactive Site	0	0
TCEQ MSW Sites	4	2
Total	112	13

South Padre Island CSRM Measure

Table 5-11 summarizes the number of HTRW sites within 1 mile of and the number of HTRW sites intersecting the South Padre Island limits. These sites are included in Attachment 2, Figure H.

Table 5-11
South Padre Island – Number of HTRW Sites

Feature Type	1-mile Radius	Intersect
EPA National FRS Major Sites	1	0
TCEQ Petroleum Storage Tank Sites	7	0
TCEQ Active Air Monitoring Sites	0	0
TCEQ Superfund Sites	0	0
TCEQ Radioactive Sites	0	0
TCEQ MSW Sites	0	0
Total	8	0

The highest concentration of HTRW sites is located to the west of the South Padre Island limits. A total of eight HTRW sites are located within 1 mile of the South Padre Island footprint; however, no HTRW were found within the South Padre Island limits. The majority of HTRW sites identified within 1 mile are TCEQ PST sites.

ER Measures

Table 5-12 summarizes the number of HTRW sites within 1 mile of and the number of HTRW sites intersecting the ER measures. These sites are included in Attachment 2, figures A and C–G.

The highest concentration of HTRW sites is located on Galveston Island and southwestward toward Matagorda County. A total of 61 HTRW sites are located within 1 mile of the ER measures, with 1 HTRW site intersecting the ER measure footprints. The majority of HTRW sites identified within 1 mile are EPA FRS sites and TCEQ PST sites.

Table 5-12
ER Measures – Number of HTRW Sites

Feature Type	1-mile Radius	Intersect
EPA National FRS Major Sites	24	1
TCEQ Petroleum Storage Tank Sites	30	0
TCEQ Active Air Monitoring Sites	2	0
TCEQ Superfund Sites	2	0
TCEQ Radioactive Sites	1	0
TCEQ MSW Sites	2	0
Total	61	1

5.3.8.3 Bay Rim Alternative

Bay Rim CSRM System

Table 5-13 breaks down the number of HTRW sites within 1 mile of and the number of HTRW sites intersecting the Bay Rim. These sites are also shown in Attachment 2, figures I and J.

Table 5-13
Bay Rim – Number of HTRW Sites

Feature Type	1-mile Radius	Intersect
EPA National FRS Major Sites	44	5
TCEQ Petroleum Storage Tank Sites	83	1
TCEQ Active Air Monitoring Sites	7	1
TCEQ Superfund Sites	2	0
TCEQ Radioactive Sites	1	0
TCEQ MSW Sites	7	1
Power Plants	3	0
Total	147	8

The highest concentration of HTRW sites is located in Galveston, La Marque, Texas City, and in between Seabrook and Deer Park. A total of 147 HTRW sites were identified within 1 mile of the Bay Rim, with 8 HTRW sites intersecting the Bay Rim footprint. The majority of HTRW sites identified within 1 mile of the Bay Rim are EPA FRS and TCEQ PST sites.

South Padre Island CSRM Measure and ER Measures

Impacts to the HTRW resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative. These sites are also shown in Attachment 2, figures C–J.

5.3.8.4 Conclusions

This HTRW site analysis is preliminary. A historical use and regulatory records search review were not used to formulate these preliminary conclusions. Therefore, pointed conclusions should not be gathered from this information. This analysis is to be utilized to inform and guide decision-making. However, some general conclusions can be made (Table 5-14):

- The largest number of HTRW sites are within a 1-mile radius of the Bay Rim.
- Most HTRW site intersections are within the Coastal Barrier footprint.
- The fewest HTRW sites are within a 1-mile radius of the South Padre Island CSRM.
- The EPA FRS sites and TCEQ PST sites make up 92 percent of the HTRW sites within a 1-mile radius of the Coastal Barrier Alternative (Coastal Barrier, ER Measures, and South Padre Island).
- The EPA FRS sites and TCEQ PST sites make up 88 percent of the HTRW sites within a 1-mile radius of the Bay Rim Alternative (Bay Rim, ER Measures, and South Padre Island).

Table 5-14
Summary of HTRW Sites

Measure	1-mile Radius	Intersect
Coastal Barrier CSRM	112	13
Bay Rim CSRM	147	8
ER Measures	61	1
South Padre Island CSRM	8	0

Potential HTRW concerns have been identified for the TSP. A desktop HTRW Assessment was conducted to identify the existence of, and potential for, HTRW contamination, which could impact or be impacted by the TSP. The assessment follows guidance provided by Engineer Regulation 1165-2-132 and consists of a review of recent and historic aerial photographs and a review of Federal, State, and local regulatory agency database information. Steps would be taken to avoid, minimize, and reduce any potential impacts to HTRW concerns to the best extent practicable. The draft HTRW Assessment is included as Appendix C-7.

5.3.9 Air Quality

Air emissions during construction of the Coastal Texas Study alternatives would consist primarily of tailpipe emissions (due to fossil fuel combustion from dredging equipment and land-side vehicles) and fugitive dust (ground surface disturbance). Air quality impacts would include an increase in PM with particle diameters of PM_{10}, $PM_{2.5}$, SO_2, CO, NO_2, VOC, and CO_2. Construction of the selected action is anticipated to occur from 2025 through 2034 and would be considered a one-time activity, i.e., the construction activities would not continue past the projected date of completion. Therefore, potential air emissions would be temporary and may vary in intensity and composition over the 10-year period of construction.

Estimates of air contaminant emission rates for the Coastal Texas Study alternatives require more-detailed construction schedule and phasing details that are developed at the time of this report. Therefore, the following is a qualitative description of the methods that will be used to estimate air emissions and a preliminary discussion of potential impacts to air quality in the study area. It is anticipated that additional construction-related information will be developed for the alternatives as the project analysis progresses through future planning and design phases.

5.3.9.1 Coastal Barrier Alternative

Construction Emissions

Temporary increases in air pollution would result from the equipment associated with the construction of the Coastal Barrier Alternative. These air contaminant emissions would result from the use of marine vessel and land-based mobile sources that would be used during construction activities, including:

- Dredge and Support Equipment – dredging vessels and supporting vessels such as tugboats, crew boats, works boats;
- Non-Road Construction Equipment – land-based equipment such as bulldozers and graders;
- On-Road and Employee Vehicles – land-based equipment such as cars and trucks;
- Maintenance Dredging – dredging vessels and support vessels; and
- Landside Maintenance – land-based equipment such as bulldozers and graders.

The marine vessel emission sources would be primarily diesel-powered engines. The off-road and on-road equipment may be assumed to be a mix of gasoline- and diesel-powered vehicles.

Once construction details are developed for the alternative, air contaminant emissions due to construction activities associated with this alternative will be compared to an emissions inventory for the affected counties within the study area. It is anticipated that air contaminant emissions from the construction activities associated with this alternative would result in a relative increase in emissions above those from the existing inventory of emissions sources in the affected counties. As a result, the estimated increase in emissions may also result in corresponding impact on air quality in the immediate vicinity of the project area.

The rate of emissions from the project construction equipment is directly related to the horsepower rating of each engine, load factor, duration of use, and the projected amount of dredged material and surface area disturbed. The rate of emissions from employee commuter vehicles is directly related to the type of vehicle and total miles traveled for each vehicle. The combustion of diesel fuel in internal combustion engines during the construction operations would result in air emissions of particulate matter (PM_{10} and $PM_{2.5}$), SO_2, CO, NO_2, VOC, and CO_2. Air contaminant emissions will be estimated using emission factors currently approved or recommended by the EPA and TCEQ. These emission factors, in combination with the equipment lists, engine load rate levels, and

scheduling information as prepared by the USACE in support of the Coastal Texas Study, will serve as the basis for calculating annual and total emissions for the project.

Non-Road Construction Equipment

Air contaminant emissions from non-road construction equipment used for onshore excavation and construction will be estimated based on the anticipated type of equipment, activity, horsepower, and anticipated hours of operation. Onshore construction equipment would include cranes, trucks, dozers, front-end loaders, backhoes, compactors, graders, dump trucks, etc. The operation of construction vehicles would generate air emissions typical of vehicles powered by diesel-fueled internal combustion engines. The estimate of emissions for this equipment will be based on emission factors derived from EPA's Motor Vehicle Emissions Simulator model, version 2014a (hereafter, MOVES2014a), using the NONROAD modeling function. This computer model may be used to calculate emissions for many non-road equipment types, categorizing them by horsepower rating and fuel type available for specific years, for a specific geographic area, state, or county.

Marine Vessels and Support Equipment

Marine vessel emissions would include those that would be expected to result from the use of dredging vessels, tug boats, and miscellaneous support vessels used in support of dredging activities. Air emissions directly related with the dredging equipment will be calculated on an annual basis based on the anticipated type of engine, activity, horsepower, and anticipated hours of operation. Air contaminant emissions from marine vessels will be estimated using emission factors from the EPA published study, *Current Methodologies for Preparing Mobile Source Port-Related Emission Inventories* (EPA, 2009).

Tugboat Assisted Barge Equipment

Tugboat assisted barges may also be used to transport construction materials and equipment to the construction sites. For example, if the surge barrier gates are fabricated in Louisiana, they may be shipped by barge via the GIWW to the construction site. If appropriate, tugboat assisted barge equipment emissions will be estimated to account for barge travel within the Coastal Texas Study area. For purposes of General Conformity, the emissions may also be broken out by area, e.g., those that would occur in the Houston-Galveston-Brazoria (HGB) Nonattainment Area, the Beaumont-Port Arthur Maintenance Area, and the Baton Rouge, Louisiana Nonattainment Area traversed by the tug-assisted barges enroute to the construction delivery docks.

On-Road Mobile Sources

Mobile source emissions associated with the project construction would be generated from on-road construction vehicles, employee commuter vehicles, buses, and supply vehicles. Commuter vehicles may also be used to transport the crew and staff from the shore to land-side locations and back to the shore. Mobile on-road emissions associated with employee vehicles will be calculated using EPA's MOVES2014a.

Operating Emissions

Under the Coastal Barrier Alternative, operating emissions are anticipated to be minor. It is anticipated the proposed surge barrier gates across Bolivar Roads and other surge barrier gates would be electrically powered, therefore there would be no direct emissions from routine gate operation. These gates would be operated periodically for maintenance and testing for operational readiness. However, other than for maintenance and storm events, they would remain in their static open position except during storm events.

It is anticipated that diesel-fueled generators would also be installed to provide power during an emergency event, such as a hurricane, which would require operation of the gate. In case of an emergency event that would result in an electrical power failure, the generator would activate to provide power for movement of the gate. It is anticipated this event would normally last until the emergency event is gone and power is restored. Each generator would require testing on a monthly basis, but usually no more than 100 hours per year of routine operation for purposes of maintenance and testing for operation readiness. A summary of the estimated emissions in tons per year resulting from the operation of the emergency generator engine(s) for purposes of maintenance and testing in support of gate operation for the Coastal Barrier Alternative will be provided in future planning and design phases of the study.

Maintenance Activities

Annual maintenance activities for the Coastal Barrier Alternative will result in higher air contaminant emissions in the localized area of activity compared to the No-Action Alternative. Air emissions would result from the combustion of fuel used in dredging and support equipment and for land-side equipment necessary to support maintenance operations.

Summary

Air emissions associated with construction of the Coastal Barrier Alternative would impact the air quality of the study area compared to the No-Action Alternative. It is expected that air contaminant emissions from construction activities would result in temporary and localized impacts on air quality in the immediate vicinity of the project site as they are considered one-time activities (i.e., the construction activities would not continue past the date of completion).

After construction, temporary impacts to air quality would continue due to maintenance and renourishment activities, e.g., routine dredging would be required to maintain the ER activities. It is anticipated these maintenance activities would be intermittent and of relatively short-term duration for each segment being maintained.

VOC and NO_X emissions from these activities can combine under the right conditions to form O_3, possibly increasing the concentration of O_3 in the region. However, these reactions take place over a period of several hours, with maximum concentrations of O_3 often far downwind of the precursor sources.

It is anticipated that air contaminant emissions from the operation of the surge barrier gates under the Coastal Barrier Alternative would result in a relatively minor increase in air contaminant emissions above those for existing emissions sources in Galveston County. Essentially, these operating emissions would be from products of combustion of diesel fuel in the proposed emergency generators, which would be operated periodically for maintenance and testing, and during an emergency event.

5.3.9.2 Bay Rim Alternative

Impacts to air quality from the construction of the Bay Rim Alternative are anticipated to be similar to those described for the Coastal Barrier Alternative.

Construction Emissions

Construction emissions would be the same as those described for the Coastal Barrier Alternative.

Air contaminant emissions associated with the construction activities would be primarily combustion products from fuel burned in equipment used for project dredging, support vessels, and dredged material placement equipment. Equipment such as excavators, backhoes, and front-end loaders would also be required. The marine vessel emission sources would be primarily diesel-powered engines. The off-road and on-road equipment may be assumed to be a mix of gasoline and diesel-powered vehicles.

Air contaminant emissions will be estimated in tons per year for each vehicle or piece of equipment based on the equipment horsepower, fuel type, and expected operating hours during the year of construction activity. These construction activities would be considered one-time activities, i.e., the construction activities would not continue past the date of completion.

Operating Emissions

Under the Bay Rim Alternative, operating emissions are anticipated to be minor. It is anticipated that the proposed surge barrier gate across the Kemah-Seabrook Channel would be electrically powered; therefore, there would be no direct emissions from routine gate operation. These gates would be operated periodically for maintenance and testing for operational readiness. However, other than for maintenance and storm events, they would remain in their static open position.

It is anticipated diesel-fueled emergency generators would also be installed to provide emergency power during an emergency event, such as during a hurricane, which would require operation of the surge barrier gate. In case of an emergency event that would result in an electrical power failure, the emergency generator would activate to provide emergency power for movement of the gate. It is anticipated this event would normally last until the emergency event is gone and power is restored. The emergency generators would require testing on a monthly basis, but usually no more than 100 hours per year of operation for purposes of maintenance and testing for operation readiness.

Maintenance Activities

Annual maintenance activities for the Bay Rim Alternative would result in higher air contaminant emissions compared to the maintenance activities required under the No-Action Alternative. Air emissions would result from the combustion of fuel used in dredging and support equipment and for land-side equipment such as bull dozers.

Summary

It is anticipated that air contaminant emissions from the construction activities associated with this alternative would also result in an increase in emissions above those from the existing inventory of emissions sources in the affected counties. As a result, the estimated increase in emissions may also result in corresponding impacts on air quality in the immediate vicinity of the project area. Due to the limited duration of these activities, emissions from these construction activities are not expected to adversely impact the long-term air quality in the area after construction has ceased. It is anticipated the impact to air quality in the study area resulting from this alternative would be less than those resulting from the construction of the Coastal Barrier Alternative due to the need for construction of a larger surge barrier gate and the larger area affected by construction activities under the Coastal Barrier Alternative compared to the smaller surge barrier gates and affected area proposed for the Bay Rim Alternative.

As discussed for the Coastal Barrier Alternative, temporary impacts to air quality would continue after construction due to maintenance and renourishment activities, e.g., routine dredging would be required to maintain the ER activities. It is anticipated these maintenance activities would be intermittent and of relatively short-term duration for each segment being maintained.

It is anticipated that air contaminant emissions from the operation of the Kemah-Seabrook Channel under the Bay Rim Alternative would result in a relatively minor increase in air contaminant emissions above those for existing emissions sources in Galveston County. Essentially, these operating emissions would be from products of combustion of diesel fuel in the proposed emergency generator, which would be operated periodically for maintenance and testing and during an emergency event.

5.3.9.3 Conformity of General Federal Actions – General Conformity Determination

The Coastal Texas Study, as a Federal action, is subject to the General Conformity Rule promulgated by the EPA pursuant to the CAA, Section 176(c)(1). The rule mandates that the Federal Government not engage in, support, or provide financial assistance for licensing or permitting, or approving any activity not conforming to an approved SIP. In Texas, the applicable plan is the SIP, an EPA-approved plan for the regulation and enforcement of the NAAQS in each air quality region within the state.

General Conformity is applicable only to nonattainment or maintenance areas and refers to the process of evaluating plans, programs, and projects to determine and demonstrate they meet the requirements of the CAA

and the SIP. The General Conformity Rule establishes conformity in coordination with and as part of the NEPA process.

The purpose of this General Conformity requirement is to ensure Federal agencies consult with State and local air quality districts, so they become aware of the project and its expected air emissions and would consider these expected emissions in their SIP. The General Conformity Rule is codified at Title 40 CFR Part 93, "Determining Conformity of Federal Actions to State or Federal Implementation Plans."

The CAA defines conformity to an implementation plan as the upholding of "an implementation plan's purpose of eliminating or reducing the severity and number of violations of the NAAQS and achieving expeditious attainment of such standards" (40 USC, Title 42, §7506). Conforming activities or actions should not, through additional air pollutant emissions, result in the following:

- Cause or contribute to new violation of any NAAQS in any area
- Increase the frequency or severity of any existing violation of any NAAQS in any area
- Delay timely attainment of any NAAQS or interim emission reductions or other milestones in any area

The Coastal Barrier and Bay Rim alternatives include components located within Chambers, Galveston, Harris, and Brazoria counties. These counties are part of the eight-county HGB O_3 nonattainment area that is currently classified as "marginal" in terms of its degree of compliance with the current 8-hour O_3 standard (TCEQ, 2007b). Therefore, the General Conformity Rules would apply to facilities in the project area that generate O_3 precursors (NO_X and VOC). A General Conformity Determination will be required if project emissions are greater than 100 tons per year of either NO_X or VOC; the *de minimis* thresholds set by the General Conformity Rules for a moderate nonattainment area such as the HGB O_3 nonattainment area. Only those air emissions of NO_X and VOC related to the project that are within a nonattainment area should be considered in this General Conformity Determination. General Conformity is not applicable to activities at locations in attainment areas or operating emissions covered by an air quality permit.

A recent court decision has provided the possibility that the HGB may be reverted to a "serious" O_3 nonattainment area under the 1997 8-hour O_3 standard. If this is the case, the applicability thresholds requiring a General Conformity analysis will be lowered to 25 tpy of either NO_X or of VOC (South Coast Air Quality Management District v. EPA, No. 15-1115 [D.C. Cir. 2018]).

The General Conformity rules specifically exclude from applicability maintenance dredging where no new depths are required, applicable permits are secured, and disposal will be at an approved disposal site. In addition, routine maintenance and repair activities, including repair and maintenance of administrative sites, roads, trails, and facilities are also exempt under the General Conformity Rule. Therefore, a General Conformity Determination for this project would not include emissions from the anticipated maintenance activities of this type that are exempted under this rule.

If it is determined during future planning and design phases of the study that air contaminant emissions resulting from the project construction activities would be more than 100 tpy of VOC and NO_X for each year during the anticipated duration of the construction period, then it will be necessary to prepare a General Conformity Determination for estimated emissions of NO_X and VOC emissions for these activities under the current attainment status for the HGB.

To demonstrate conformity with the SIP, General Conformity may be demonstrated as follows:

- Offsetting the emissions of NO_X and VOC from construction and operation with the purchase and retirement of Emission Reduction Credits from the HGB nonattainment area;
- Obtaining a specific commitment from the TCEQ to account for emissions of NO_X and VOC in the next revision of the SIP; or
- Otherwise making a demonstration that the project would conform with the HGB SIP based on the criterion provided in 40 CFR Part 93.158(a)(5)(i)(A), whereby the TCEQ determines that the total of direct and indirect emissions from the action will result in a level of emissions which, together with all other emissions in the nonattainment (or maintenance) area, would not exceed the emissions budgets specified in the applicable SIP.

For the General Conformity Determination, an inventory of annual NO_X and VOC emissions will be prepared for each year of project-related activities within the HGB nonattainment area based on the schedule and other assumptions as developed by the USACE. Air emissions estimates will be calculated using techniques appropriate for a specific emissions-generating activity or source.

SIP Emissions Budgets

Section §93.158(a)(5)(i)(A) of the General Conformity Rule applies to an O_3 nonattainment area, where the EPA has approved a revision to an area's attainment demonstration after 1990, and the state makes a determination that "the total of direct and indirect emissions from the action, or portion thereof, is determined and documented by the State agency primarily responsible for the applicable SIP to result in a level of emissions which, together with all other emissions in the nonattainment (or maintenance) area, would not exceed the emissions budgets specified in the SIP."

The words "emissions budget" for General Conformity purposes is used in terms of the category of projected emission inventories used in the SIP to demonstrate compliance with the air emissions standard for which the area is in nonattainment; e.g., ozone. Essentially, the emissions budget is the amount of emissions allowed in the SIP from certain categories of air emissions sources such as construction equipment, industrial sources including chemical plants or cement plants, area sources such as gasoline stations, mobile emissions, etc. The air emissions budgets are based on data gathered for a base year with a known air emissions inventory that are projected to a future attainment year. The SIP emissions budget is designed to allow for existing air emissions sources, growth in the area, and future projects with consideration of measures that will be required to reduce emissions from existing and new sources where possible.

Since the state air quality agencies may not be aware of future Federal actions at the time of the SIP development, few Federal actions requiring conformity have their emissions specifically identified and accounted for in the SIP. In the cases where the emissions caused by the action are not specifically identified in the SIP but are included in an emission budget category, the Federal agency may demonstrate conformity by having the State air quality agency provide a written statement documenting that the emissions caused by the action along with all other emissions in the area will not exceed the budget for those emissions in the SIP. For example, the TCEQ could document that when the emissions from the construction phase of the action are combined with the emissions from all other construction activities in the area, the total will not exceed the SIP budget for construction emissions (EPA, 2018b).

For the HGB nonattainment area, the most recently approved SIP revision that provides applicable emissions budgets is the HGB 1997 8-Hour Ozone Attainment Demonstration, adopted by the TCEQ on March 10, 2010, and approved by the EPA on January 2, 2014. In this SIP, the emissions budgets for NO_X and VOC are based on emissions inventories for the year 2006 baseline projected to the year 2018 (TCEQ, 2010).

However, a more recent SIP revision is pending review by the EPA, which will likely be approved in the near future that provides applicable emissions budgets, the HGB Reasonable Further Progress SIP Revision for the 2008 8-Hour Ozone Standard Nonattainment Area, adopted by the TCEQ on December 15, 2016, and pending EPA approval. In this SIP, the emissions budgets for NO_X and VOC are based on emissions inventories for the year 2011 baseline projected to the year 2017 attainment year.

Reasonable Further Progress SIP Non-Road Mobile Emissions Source Emissions Budget

The non-road mobile emissions budget in the SIP is a very broad category that generally includes engines mounted on construction equipment and includes emissions from commercial marine equipment. The non-road mobile emissions budget includes emissions from equipment associated with agricultural, aircraft, commercial, ground support (airport), industrial, lawn and garden, railroad maintenance, logging, locomotives, oil and gas exploration, recreational, and recreational marine equipment. The non-road mobile emissions weekday budget in the Reasonable Further Progress SIP is 86.97 tons per day (tpd) of NO_X and 33.58 tpd of VOC.

Reasonable Further Progress SIP On-Road Mobile Emissions Budget

The on-road mobile emissions budget in the SIP consists of automobiles, trucks, motorcycles, and other motor vehicles traveling on public roadways. The on-road mobile emissions weekday budget in the Reasonable Further Progress SIP is 95.56 tpd of NO_X and 54.40 tpd of VOC.

5.3.9.4 Potential Air Quality Mitigation Measures

Measures that could be used to reduce emissions for the project would consider the equipment used for the project over the expected life of the project and the feasibility and practicality of such measures. Alternatives considered for their ability to reduce or mitigate emissions are those that may provide for enhanced energy efficiency, lower NO_X-emitting technology, repowering, etc., as appropriate, for the construction and operating equipment and

vehicles to be used. Efforts to reduce emissions from the construction and operation of the project could include the following.

Dredging Mitigation Options

- Contracting with dredging companies that have energy-efficient equipment
- Design of the dredging operation and schedule to reduce overall fuel use and hours of operation
- Repowering/refitting with cleaner diesel engines; i.e., those that would emit less air contaminant emissions
- Selection of newer dredges with more-efficient engines, if possible
- Selection of dredges equipped with emissions control equipment; e.g., selective catalytic reduction, etc., if available
- Provision of electric power to dredging equipment

Land-side Mitigation Options

- Use of vehicles fueled by compressed natural gas or liquefied petroleum gas – compressed natural gas could provide about a 24 percent reduction in CO_2 emissions compared to gasoline, and liquefied petroleum gas could provide about a 12 percent reduction (40 CFR Part 98, Table C-1)
- Repowering/refitting with cleaner, more-fuel-efficient, diesel engines
- Use of newer vehicles with more-fuel-efficient engines, if possible
- Use of non-road ultra-low sulfur diesel fuel

PM contaminants may be reduced by dust reduction techniques such as enforcing speed limits of construction vehicles within work zones, watering or misting work areas, and applying mulch or vegetation to disturbed areas (Wisconsin Department of Natural Resources, 2018).

5.3.9.5 Agency Coordination

The USACE and GLO participated in an initial meeting with the TCEQ and EPA on April 16, 2018. The purpose of this meeting was to introduce these agencies to the project, provide a brief overview, and to discuss potential General Conformity issues relating to the project. This was an introductory meeting with the intent of participating in future meetings as the project progresses.

On July 11, 2018, the USACE and GLO participated in a follow-on meeting with the staff of the TCEQ and EPA to discuss potential methods for demonstration of conformity for the project emissions. During this discussion, the USACE presented a brief overview of the project, including the breadth of new construction, environmental restoration and mitigation features, and anticipated schedule for document preparation, approvals, design, engineering, and construction. Based on this presentation, the following issues were discussed:

- Because of the project scale and duration, it is anticipated by the TCEQ that emissions of NO_X and VOC may exceed the level of emissions anticipated and allotted for growth in the most recently approved SIP emissions inventory for construction emissions. Therefore, making a demonstration that the project emissions would conform with the HGB SIP based on the criterion provided in 40 CFR Part 93.158(a)(5)(i)(A) may be difficult.
- It is unclear what the impacts of the recent court case will have on the attainment status for the HGB nonattainment area and the *de minimus* thresholds, which would trigger a general conformity determination. For example, if the HGB is redesignated to a "serious" nonattainment area, a SIP revision with more-current emissions budgets would be required for approval by the EPA.
- Because of the project scale and duration, inclusion of the project emissions in a future SIP revision may be the more appropriate method for demonstration of conformity. This method has not been used by the TCEQ for previous conformity determinations, but appears to be a method available under the General Conformity rules. The process would require coordination with the USACE, TCEQ, and EPA in the development of a detailed emissions inventory for NO_X and VOC emissions from the project, identification of mitigation measures to reduce NO_X and VOC emissions, and the development and approval of a SIP revision that would include a future inventory and attainment date that would be representative of the anticipated schedule for construction (years 2025–2034) for the project.

The TCEQ has suggested that follow-on coordination with the USACE and GLO would be appropriate so that the project emissions may be properly documented in a future SIP revision.

5.3.9.6 Greenhouse Gas Impacts

Climate change impacts are, by nature, cumulative and long term. Therefore, consideration of a proposed action's impact to climate change is essentially an analysis of a project's contribution to a cumulatively global impact through its emission of GHGs. In addition, GHG emissions persist in the atmosphere for decades or longer, impacting the climate over the long term.

Because the GHG emissions from the construction phase of the project alternatives are relatively short term in nature, the associated adverse impacts on global climate change would be anticipated to be minor. The long-term effects of the proposed alternatives would be a consequence of their operational GHG emissions, which assuming the use of electric-powered barrier gates, would also be anticipated to be minor.

5.3.10 Noise

The following sections describe noise impacts during construction, maintenance, and operation activities. Underwater noise is addressed in Section 5.4.4.5 (Marine Mammals).

5.3.10.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

Direct noise impacts to noise-sensitive receivers such as residential, recreational, and worship areas are expected during initial construction of the levee/floodwall and during periodic maintenance activities along the levees/floodwall. Construction and maintenance activities would be temporary, and therefore, noise generated by those activities would be temporary. Except for isolated areas and under rare circumstances, the levee/floodwalls have no noise-generating components. Typical construction-related noise sources would be construction machinery (e.g., excavators, front end loaders) and movement of heavy trucks hauling construction spoils and materials within the construction right-of-way. Noise levels related to construction would be based upon the actual number and type of equipment operating in one location at a specific time. Typical temporary noise levels that could be associated with construction include 73 dBA for large front-end loaders from a distance of 100 feet and 86 dBA for off-road haul trucks at 50 feet (Epsilon Associates, Inc., 2006). Due to the existing high volume of traffic within the region, the potential increase in heavy trucks traveling throughout the region to transport materials related to the proposed project would be inconsequential. General areas near the proposed levee/floodwall with noise-sensitive receivers would be primarily limited to the residential areas on Galveston Island and Bolivar Peninsula. Noise impacts associated with construction would be temporary and would typically take place during normal working hours (daytime) and therefore are considered minor. In addition, many of these homes are likely weekend homes that may not be continuously occupied during peak times of construction (weekdays) or during winter months.

Construction of the surge barrier gates within Bolivar Roads and gates at the GIWW are not expected to result in noise impacts to noise-sensitive receivers, like residential and recreational areas, due to the distance from the proposed gates to these areas. Similarly, the operation of the gates in these two areas is not expected to result in noise impacts. Initial construction, long-term maintenance, and intermittent operation of proposed gates at Clear Lake, Dickinson Bayou, and Offatts Bayou would likely result in temporary and/or short-term noise impacts to a small number of residences near these proposed facilities. These areas have a low concentration of potential noise-sensitive receivers, and as such, noise impacts related to the construction and operation of the surge barrier gates for the Coastal Barrier are expected to be minor.

Initial construction of proposed pump stations along the Coastal Barrier to drain the protected systems during storms would likely result in temporary noise impacts to a small number of residential areas during the operation of heavy construction equipment. Long-term maintenance and operation of the pump stations would likely not result in noise impacts, because the proposed pump stations would be enclosed, and thereby would not generate loud off-site noise during operation. Noise impacts related to the construction and operation of the pump stations along the Coastal Barrier are expected to be minor.

A long-term beneficial effect on noise (i.e., a reduction in noise near noise-sensitive receivers) is expected in residential areas protected from storm surges. The long-term reduction in noise would be from the expected decrease in infrastructure damage and subsequent construction/rehabilitation activities near receivers following

storm surges. This would be an indirect noise effect, and due to the infrequency of potentially damaging storm surges, the benefit is considered minor.

South Padre Island CSRM Measure

Similar to the Coastal Barrier, direct noise impacts to noise-sensitive receivers, such as residential, recreational, and worship areas are expected during initial construction of the levee/floodwall and during periodic maintenance activities along the levees/floodwall. General areas near the proposed levee/floodwall with noise-sensitive receivers would be primarily limited to the beach-front recreational, residential, and commercial areas along South Padre Island. This area is more heavily utilized during the summer months and weekends. As such, potential noise impacts would likely be less during peak times of construction (weekdays) and during winter months. Potential noise impacts related to the construction and periodic maintenance of the South Padre Island CSRM measure are expected to be temporary and minor. Noise-sensitive areas protected from storm surges by the South Padre Island CSRM measure are expected to benefit from a minor long-term reduction in construction noise due to the reduction of storm damage.

ER Measures

Revetment/breakwaters, island restoration, marsh restoration, out-year marsh nourishment, and oyster reef creation are proposed for undeveloped areas that are not near permanent noise-sensitive receivers like residences. Intermittent recreational activities like recreational fishing may take place near the proposed locations, and noise generated by the operation of barges and other heavy equipment could result in temporary noise impacts to recreational fishermen or boaters. However, active construction areas could be restricted from recreational access during construction, which would limit the potential for noise impacts. Construction activities related to the operation of heavy equipment during construction of temporary levees and drainage structures during the one-time out-year marsh nourishment could result in temporary noise impacts at recreational areas. Potential impacts from these ER restoration activities are expected to be temporary and minor.

Construction activities related to the operation of heavy equipment during dune and beach restoration could result in temporary noise impacts at beach-front recreational areas and residences. During construction, access for recreational uses may be limited at the areas of construction, which would reduce the potential of noise impacts. In addition, many of the beach-front residences are likely weekend homes that may not be continuously occupied during peak times of construction (weekdays) or during winter months. Potential noise impacts from dune and beach restoration are expected to be temporary and minor.

Summary. The ER measures could result in potential temporary noise impacts during construction and maintenance activities within the areas immediately adjacent to the proposed ER areas. Most of the ER areas are within undeveloped areas without nearby noise-sensitive receivers, and as such, potential noise impacts are expected to be minor.

5.3.10.2 Bay Rim Alternative

Bay Rim CSRM System

As described for the Coastal Barrier Alternative, temporary and minor noise impacts related to construction noise along the proposed levee/floodway are expected. Typical construction-related noise sources would be heavy construction machinery (e.g., excavators, front end loaders) and movement of heavy trucks hauling construction spoils and materials within the construction right-of-way. Due to the existing high volume of traffic within the region, the potential increase in heavy trucks traveling throughout the region to transport materials related to the proposed project would be inconsequential. The expected temporary noise impacts from the Bay Rim would be in the developed, urban areas with high concentrations of residences in the cities of Galveston, Hitchcock, Texas City, San Leon, Bacliff, Kemah, Seabrook, and La Porte. This CSRM measure is expected to have greater noise impacts from construction of the levee/floodway than the Coastal Barrier due to the greater lengths of proposed levee/floodway in proximity to residential areas.

Construction of the surge barrier gates within Tabbs Bay is not expected to result in noise impacts to noise-sensitive receivers, like residential and recreational areas, due to the distance from the proposed gate to these areas. Similarly, the operation of the gates is not expected to result in noise impacts. Construction, long-term maintenance, and intermittent operation of proposed surge barrier gates at Clear Lake, Dickinson Bay, the bay rim levee/floodwall, and the Texas City Hurricane Flood Protection Improvements would likely result in temporary and/or short-term noise impacts to a small number of residences near these proposed facilities. These areas have a low concentration of potential noise-sensitive receivers, and as such, noise impacts related to the construction and operation of surge barrier gates for the Bay Rim are expected to be minor.

Construction of proposed pump stations along the Bay Rim to drain the protected systems during storms would likely result in temporary noise impacts to noise sensitive receivers during construction. Long-term maintenance and operation of the pump stations would likely not result in noise impacts, because the proposed pump stations would typically be enclosed, and thereby would not generate offsite noise during operation. Noise impacts related to the construction and operation of the pump stations along the Bay Rim are expected to be minor.

Noise-sensitive areas protected from storm surges by the Bay Rim are expected to benefit from a minor long-term reduction in construction noise due to the reduction in rebuilding after storm events.

South Padre Island CSRM Measure and ER Measures

Potential noise impacts resulting from the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.4 ECOLOGICAL AND BIOLOGICAL RESOURCES

5.4.1 Wetlands

Coastal wetland and marsh habitats are important features in the landscape that have environmental and economic importance and provide numerous beneficial services for people and for fish and wildlife. These ecosystem services include protection of upland areas from flooding caused by RSLR and storm surge, coastline stabilization due to their ability to absorb energy from ocean currents and vessel wakes, and habitat for many Federally threatened and endangered species and State species of concern (Carter, 1997; Costanza et al., 2008; EPA, 2018c; USFWS, 2018h).

The Texas coast contains thousands of acres of coastal wetlands and marshes that are situated between the open Gulf and the coastal plains (NOAA, 2018e). Galveston Bay is one of the largest estuaries on the Gulf coast, and the CSRM measures considered for the upper Texas coast are expected to have direct and indirect impacts on those habitats. Likewise, estuarine habitats of the Lower Laguna Madre, which is bordered by South Padre Island, are expected to be indirectly affected by the CSRM measure proposed for the lower Texas coast.

Strategic planning initiatives were inaugurated during the development of the CSRM measures to minimize the amount of wetland loss and to mitigate impacts associated with the structures. Preliminary studies have shown that levees and surge barrier gate structures, both of which are proposed as features of the CSRM measures, may affect wetland functions by constricting tidal exchange and altering hydrosalinity gradients (McAlpin et al., 2018). Conversely, material dredged from the construction of the CSRM measures in open water may be used beneficially to restore degraded marsh habitats or to provide beach nourishment in the Galveston Bay region.

5.4.1.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The proposed Coastal Barrier, including the levee, floodwall, seawall, surge barrier gates, are expected to have direct and indirect impacts to wetland and marsh habitats in the Galveston Bay region. Approximately 512.5 acres of non-tidal and 338.0 acres of tidal wetlands are expected to be altered or damaged due to the construction of this measure. Construction of the measure components on Bolivar Peninsula and Galveston Island would require clearing, grubbing, levelling, and filling of wetland and marsh habitats. The potential for erosion and increased sedimentation during construction could affect the water quality and bury or damage adjacent vegetation in marshes. Hydrological barriers, such as levees, can lead to a loss of sheet flow, degradation of the wetland and marsh vegetation, and fragmentation of the coastal ecosystem (Harvey et al., 2011). Specifically, the wetland and marsh habitats located south of the proposed footprint could potentially be exposed to higher salinity from the Gulf for longer periods of times during storm events. Proper best management practices, including implementation of a Storm Water Pollution Prevention Plan and general avoidance and minimization measures can contain and prevent sediments from entering wetlands. Silt fencing, silt curtains, rock berms, and mulch socks may be used to prevent sediment and contaminant transport to wetlands.

The proposed levee would likely provide some level of protection to wetland habitats located north of the footprint by serving as a barrier from saltwater intrusion during storm events. To reduce impacts during construction, best management practices, including implementation of a Storm Water Pollution Prevention Plan and general avoidance and minimization measures, can be utilized to contain and prevent sediments from entering wetlands during construction. Silt fencing, silt curtains, rock berms, and mulch socks may be used to prevent sediment and contaminant transport to wetlands.

Diurnal tides account for 50 percent of the water level variance in Galveston Bay; the remainder of the variability is due to wind-driven coastal setup along the Texas-Louisiana shelf (Rayson et al., 2015). The hydrology of wetland and marsh habitats, and more specifically, the duration and seasonality of flooding, has a strong influence on the number, type, and distribution of plants and plant communities within these ecosystems (Carter, 1997). This affects resources that are critical to the survival of Gulf coast fisheries, which are almost entirely dependent on wetland and marsh habitats (Barbier, 2013; Texas A&M Agrilife Extension, 2018). The surge barrier gates associated with the Coastal Barrier would likely alter the hydrology of Galveston Bay, which could affect the ecology of the estuary altering available habitat conditions for various fish and shellfish species (Minello et al., 2012, 2015) (see Section 5.3.2 for more details). This in turn would impact birds and wildlife species, which depend on the resources provided by the marshes (see sections 5.4.3 and 5.4.4.2 for more information).

Following completion of the surge barrier gate structures across Bolivar Roads, the cross-sectional entrance into Galveston Bay would be constricted by 27.5 percent causing a reduction in tidal amplitude. This reduction would likely lead to lower high tides and higher low tides and less marsh habitat regularly or seasonally flooded. The constriction is also predicted to minimally affect bay salinities and water and sediment exchange between the Gulf and the bay. The modeling shows that most locations would experience a reduction in tidal amplitude of 0.16 foot (McAlpin et al., 2018). As a result of changes in tidal amplitude and tidal prism, potential changes to the characteristics and abundance of wetland and marsh vegetation could occur. Less tidal inundation could potentially convert wetland areas to ephemeral wetlands or uplands. Section 5.3.3 discusses how the constriction would likely increase residence time in the bay upstream of the Coastal Barrier and allow greater dilution by freshwater inflows. This could potentially result in a conversion of plant communities and an expansion of freshwater wetlands on the bayside of the structure.

To estimate the potential area of affected wetland and marsh habitats within Galveston Bay resulting from the reduction in tidal amplitude due to the surge barrier gate structures across Bolivar Roads, an analysis was conducted using the NOAA C-CAP 2010 landcover dataset for estuarine wetlands. Approximately 3,375 acres of wetlands along the interior of the bay are expected to be indirectly impacted resulting from altered hydrology primarily leading to eventual deterioration of those habitats. A total of 7,295 acres of mitigation will be required for these impacts. Refer to the Mitigation Plan (Appendix C-9) for a more-detailed discussion of mitigation for indirect wetland impacts.

Summary. Compared to the No-Action Alternative, the Coastal Barrier would most likely result in substantial impacts to the wetland and marsh habitats within the Galveston Bay region. Construction activities associated

with the levee/floodwall features on Bolivar Peninsula and Galveston Island and the reduced flow and reduced tidal amplitude resulting from the surge barrier gates would have long-term effects on the estuarine habitats.

Once construction is complete, the levee may benefit tidal and freshwater wetlands north of SH 87 on Bolivar Peninsula and Farm to Market Road 3005 on Galveston Island by providing a physical barrier against erosion during storm surges. Compared to the No-Action Alternative, the freshwater wetlands near Moody NWR and Anahuac NWR north of Bolivar Peninsula would be less likely to be inundated with seawater from the Gulf for long periods of time during storm events, which could result in a conversion of plant communities and an expansion of freshwater tidal on the bayside of the structure.

South Padre Island CSRM Measure

The beach and dune restoration feature proposed for South Padre Island is not likely to have direct impacts on adjacent wetland and marsh habitats resulting from the sediment placement. Once construction is complete, the restored beach and dune complex would likely help preserve existing wetland and marsh habitats on the bayside of the measure by providing increased risk reduction from storm surges and RSLR.

ER Measures

Revetment/Breakwater. Revetment and breakwaters along bay and Gulf shorelines act as protective barriers that prevent saltwater tides and wave energy from damaging wetland and marsh habitats. Erosion from barge traffic along the GIWW and other shipping channels that bisect the marshes has reduced the stability of these shorelines and increased saltwater intrusion in upstream habitats. Increased salinity in these areas can result in salt-damaged vegetation, exposure of sediments to wave action, and conversion of tidal marsh habitat to open water. Revetment/breakwater features can prevent further loss of marsh from erosion and improve SAV growth (TPWD, 2018a).

Rock revetments and breakwaters are intended to protect intertidal and freshwater marsh complexes from erosion caused by RSLR and increased wave energy from vessel traffic and storms. Specifically, shoreline protection structures are proposed along areas of unprotected segments of the GIWW and would result in a loss of wetland and marsh habitat in the upper and mid Texas coast due to construction, dredging, and placement activities associated with the feature. Construction of rock breakwaters would protect SAV along the shoreline of Keller and Redfish bays. Wetland impacts are expected to be temporary. Breakwaters and living shorelines will protect coastlines, accumulate sediments, and provide stable habitat for marsh expansion.

Island Restoration. Island restoration is intended to protect intertidal and freshwater marsh complexes from erosion caused by RSLR and wave energy from vessel traffic and storms. Source material would be deposited within the island restoration footprints from dedicated dredging of the GIWW or another adjacent navigation channel. The island would be designed so the material would form a natural slope and would create elevations suitable for marsh growth, wading birds, and SAV colonization. Marsh vegetation would be planted in the intertidal range on the backslope of the island. Nesting habitat on the crest of the islands would be improved with nesting platforms and native shrub planting, which would cover approximately half of the island.

Impacts to existing wetlands and SAV, such as sedimentation from placement of fill material, increased turbidity that can affect opacity and disrupt photosynthesis in SAV, installation of containment levees, or disturbances due to channel maintenance operations, would be temporary and localized. Turbidity from the project is expected to decrease after completion of construction. Sediments on seagrasses are expected to be flushed by tides and wave action (Newell and Koch, 2004). No long-term impacts are anticipated from construction, dredging, or placement activities associated with the island restoration features.

Marsh Restoration/Out-year Marsh Nourishment 2065. Coastal wetlands are deteriorating due in part to sediment depletion, subsidence, and RSLR. The NOAA Sea Level Rise Viewer was used to identify wetland and marsh areas that would be degraded to unconsolidated shorelines or open water by 2035 (NOAA, 2017f). These areas are planned to be raised up to 2.0 feet NAVD 88 using material from shoaled or virgin sediments in adjacent navigation channels or from excavation associated with construction of the revetment/breakwaters. Construction activities include temporary containment levees and draining structures to contain the dredged material, followed by planting and marsh establishment, which would take 10 years to complete. Thin layer placement of material may also be used to add sediment to the existing degraded marsh areas.

Supplying sediments to subsiding marshes is a method that has demonstrated success in potentially slowing wetland loss (Ray, 2007). The methods of supplying sediments have the potential to help restore damaged marshes as well as provide a beneficial use of dredged material opportunity. Projects that have been implemented by Federal and State agencies that have demonstrated success include Goose Island Marsh Restoration Project in Aransas Bay led by TPWD and GLO (Jenkins, 2008), San Jacinto Marsh Restoration led by TPWD and private contractors (Atkins, 2017), and North Deer Island Shoreline Restoration Project led by TPWD (Galveston Bay Estuary Program, 2018), among many others. These projects were successful in restoring wetland and marsh habitat using dredged material in areas that have seen degradation due to coastal erosion and subsidence. The newly restored vegetation has provided increased habitat for birds, wildlife, and marine species and shoreline stabilization and resiliency.

Disposal of dredged material can adversely affect wetland and marsh habitats and water quality if the restoration sites are not properly managed. USACE guidelines will be followed to minimize adverse impacts, which include: using suitable, uncontaminated dredged material; using containment levees and stabilizing sites with vegetation to reduce erosion; managing dredge pipes to avoid habitat damage; and additional considerations should be accounted for when temporary impacts are unavoidable, so the site can be restored to pre-project conditions (USACE, 2015d). Dredging and placement of sediment material can create turbidity and suspend sediments, which may increase opacity and inhibit photosynthesis in SAV. Impacts to SAV are expected to be temporary and localized. Sediments from dredging on seagrass leaves and within the water column would eventually be flushed by tides and wave action (Newell and Koch, 2004).

The overall benefits to the marsh restoration features as part of the ER measures are expected to outweigh short-term construction impacts. Wetlands and marshes provide numerous benefits, including improvement of water quality, flood attenuation, aesthetics, and recreational opportunities, as well as mitigating for RSLR and impacts to coastal infrastructure and ecosystems from storm events (USFWS, 2018i).

Restoring marsh elevations with sediment dredged from nearby navigation channels is an established approach for creating, restoring, and maintaining coastal marshes and has demonstrated success in slowing or reversing losses of wetlands due to coastal development and RSLR (USACE, 2015d; Virginia Institute of Marine Science, 2014). One-time, out-year marsh nourishments are proposed for four of the ER measures and represent areas that are expected to degrade to unconsolidated shoreline or open water by 2065 due to RSLR (NOAA, 2017i). These areas are planned to receive source material from shoaled or virgin sediments in adjacent navigation channels to increase marsh elevations up to 2.0 feet NAVD 88. Combined, these areas total 28,000 acres of proposed marsh restoration in Galveston, Brazoria, Matagorda, and Calhoun counties.

The benefits from the out-year marsh nourishments are expected to outweigh short-term construction impacts. Wetlands and marshes provide numerous benefits, including improvement of water quality, flood attenuation, aesthetics, recreation opportunities, and mitigating for RSLR and impacts to coastal infrastructure and ecosystems from storm events (USFWS, 2018i).

Oyster Reef Creation. Oyster reefs are effective for shoreline stabilization and provide many positive ecological benefits in open water and intertidal marsh complexes. Oyster reef creation would involve placement of oyster cultch or reef balls in shallow, nearshore water. Direct impacts resulting from construction activities would likely not affect the wetland and marsh habitats, because the reefs would be in nearshore waters, away from the marshes. The features would protect valuable wetland and marsh habitats from erosion and improve resiliency against coastal storms. The creation of new oyster reefs can improve water clarity and in effect increase available habitat for SAV (Newell and Koch, 2004).

Dune/Beach Restoration. Direct impacts resulting from construction activities would likely not affect the wetland and marsh habitats where dune and beach restoration features are proposed. The features would protect valuable wetland and marsh habitats from further erosion and would provide resiliency against coastal storms and RSLR.

Similar considerations and design criteria discussed above in *Marsh Restoration/Out-year Marsh Nourishment 2065* should be applied to this section. The biodiversity, water quality, and natural hydrologic flow regimes of a regional landscape are often affected by the area and position of the wetlands within it (National Research Council, 1995). It is likely that the out-year nourishments would result in hydrologic or energy regime changes due to the large scale of the area to be nourished. Although hydrology or energy regime changes may be likely, best management practices would be utilized to ensure the maintenance of natural hydrologic flow regimes within these areas.

Summary. The ER features are designed to provide a variety of services that are expected to have positive ecosystem benefits at the local, regional, and landscape levels across the Texas coast. The benefits gained resulting from the implementation of these features are expected to outweigh the short-term construction impacts. Additionally, the features would enhance the resiliency of coastal communities and ecosystems throughout the Texas coast by conserving, protecting, and enhancing fisheries, wildlife, and their habitats.

5.4.1.2 Bay Rim Alternative

Bay Rim CSRM System

The proposed Bay Rim, including the surge barrier gates at the Fred Hartman Bridge, Clear Lake, and Dickinson Bayou, the bay rim levee/floodwall, and the Texas City Hurricane Flood Protection improvements are expected to have direct and indirect wetland and marsh impacts in the Galveston Bay region. The level of impact would partially depend on the location of the wetlands and marsh, whereas some areas are expected to benefit from construction of the Bay Rim.

Construction of the Bay Rim could directly impact approximately 227.1 acres of non-tidal and 172.0 acres of tidal wetland and marsh habitat. The majority of these impacts would occur on private land. Construction of the levee/ floodwall features along the bay rim are proposed to start near the intersection of SH 99 and 146B in Baytown, Texas, and end northwest of the intersection of Farm to Market Road 2004 and SH 646 south of Santa Fe, Texas. Construction activities would include clearing, grubbing, levelling, and filling of wetland and marsh habitats. The potential for erosion and increased sedimentation during construction could affect the water quality, bury, and damage adjacent vegetation in marshes. However, proper best management practices, including implementation of a Storm Water Pollution Prevention Plan, and general avoidance and minimization measures can contain and prevent sediments from entering wetlands. Silt fencing, silt curtains, rock berms, and mulch socks may be used to prevent sediment and contaminant transport to wetlands.

Direct and indirect impacts associated with constructing the surge barrier gates would be similar to those described for the Coastal Barrier (Section 5.4.1.1). Freshwater and tidal wetland and marsh habitats in Tabbs Bay and the Upper San Jacinto Bay would likely be impacted from construction of the crossing south of the Fred Hartman Bridge due to decreased tidal exchange. Once construction is complete, the Bay Rim would likely benefit freshwater wetlands situated inland of the structure, such as wetlands within Clear Creek Lake, Dickinson Bay, Dickinson Bayou, and Moses Bayou, by providing a physical barrier against erosion during storm surges and high winds.

However, tidal wetlands along the Bay Rim could be negatively impacted by the construction of the levee/ floodwall by disconnecting the tidal exchange on the portion of those wetlands on the interior of the system. The wetlands outside of the system may also be negatively impacted by the changes in hydrology and sediment exchange that could occur as a result of construction.

South Padre Island CSRM Measure and ER Measures

Impacts to wetland and marsh habitats resulting from construction of the South Padre Island CSRM and ER measure would be the same as those described for the Coastal Barrier Alternative.

5.4.2 Aquatic Communities

5.4.2.1 Freshwater Habitats and Fauna

Fluctuations between prolonged low-salinity/freshwater-dominated conditions and higher salinity/drought-dominated conditions depend on rainfall patterns, reservoir releases, and discharges of treated municipal wastewater. As these changes occur, suitable conditions in the bay for freshwater organisms would expand and contract. Freshwater fish, macroinvertebrates, and plants are more likely to be present when salinities are below 5 to 10 ppt. Concentrations of freshwater organisms may be higher near the mouths of tidal streams receiving freshwater inflow where salinities may be more favorable. When near the mouths of tidal streams or shorelines, fish may be closer to instream cover (large woody debris, undercut banks, submerged/emergent vegetation, etc.) like that in freshwater habitats, which they rely on for protection. These habitat characteristics are less likely to occur in the open bay.

When salinities remain sufficiently low through a growing season, freshwater plants may colonize parts of the bay that experience higher, unfavorable, salinities in other years. Wild celery (*Vallisneria americana*) is a submerged aquatic plant that can grow in the Trinity River Delta in Trinity Bay when salinities are below 10 ppt (Adair et al., 1994). It was not observed in this area in 2011 during drought and high salinity (above 12 ppt) for over a year but was found during multiple surveys in 2016 when salinity in the area was below 3 ppt (Guillen et al., 2016; Quigg et al., 2013).

Tolan (2008) found salinity influenced nekton community structure in bag seine samples from Texas tidal streams. Tolan and Nelson (n.d.) found salinity to be the main factor affecting biological community structure in the tidal reaches of the Mission and Aransas rivers. Zimmerman et al. (1990) found white crappie (*Pomoxis annularis*) and channel catfish (*Ictalurus punctatus*) in the Trinity River Delta marsh where salinities were below 5 ppt. Gelwick et al. (2001) found sunfish (*Lepomis* sp.), white crappie, and gizzard shad (*Dorosoma cepedianum*) in the channelized zones in estuarine marsh in Matagorda Bay where salinity was below 5 ppt.

Nordlie (2003) identified freshwater fish known to utilize estuarine marsh in Texas, including alligator gar (*Atractosteus spatula*), gizzard shad, threadfin shad (*D. petenense*), and inland silverside (*Menidia beryllina*). Freshwater fish with identified salinity tolerances, which could utilize expanded and prolonged areas of lower salinity, might include the following species. Indicated salinities are those that the species can tolerate for extended periods of time:

- Largemouth bass (*Micropterus salmoides*): 8 ppt (Meador and Kelso, 1990);
- Channel catfish: 12 ppt (Allen and Avault, 1971);
- Blue catfish (*Ictalurus furcatus*): 8 ppt (Graham, 1999);
- Gizzard shad: 41 ppt (Nordlie, 2003);
- Flathead catfish (*Pylodictis olivaris*): 8-11 ppt (Bringolf et al., 2005); and
- Threadfin shad: 32 ppt (Froese and Pauly, 2017).

In addition to salinity changes affecting freshwater communities, movement and distribution of some freshwater species may be impeded by the physical barriers. Three species that may have their movements impacted are the American eel (*Anguilla rostrata*), alligator gar, and freshwater prawn (*Macrobrachium ohione*).

Adult American eel migrate out of streams and estuaries to the Atlantic Ocean to spawn. Larval and juvenile eel move from the ocean to estuaries and rivers where they live up to 30 years before returning to the sea to reproduce. American eel have been reported from tributaries to Galveston Bay including Spindletop Ditch (Nueces-Trinity Coastal Basin), Dickinson Bayou, Halls Bayou and White Rock Creek (Trinity River tributary). Although American eel have been found in tributaries to Galveston Bay, literature review did not find any studies of American eel movement through Galveston Bay or other estuaries along the Gulf coast (Hendrickson and Cohen, 2015). It is not known if their migratory movements would be impacted by water movement around the barriers or if the structures would be placed in portions of the bay where they may block eel migration. The species is recognized in Texas as a "Species of Greatest Conservation Need" by TPWD (2011).

Alligator gar is also recognized as a "Species of Greatest Conservation Need" by TPWD (2011). It spawns over shallow flooded plants when freshwater streams flow over their banks (Buckmeier, 2008; Hendrickson and Cohen, 2015). Successful spawning may occur where salinities are below 7 ppt and the optimal salinity range for juveniles is up to 8 ppt (Suchy, 2009). Alligator gar have been collected in Texas bays at salinities up to 40 ppt. Over the period from 1975 to 2012, 2,597 alligator gar were collected in gillnets in Galveston Bay. This is considered a conservative number since large specimens typically break free and are not retained by gillnets. In general, this species was collected more frequently after freshwater inflow had increased and when salinities were lower (Daugherty et al., 2017). Alligator gar can move long distances and have been tracked moving over 62 miles in the lower Trinity River (Buckmeier et al., 2013). It is not known if alligator gar movement around the proposed structures for each measure would be affected.

The freshwater prawn migrates from freshwater streams to estuaries to spawn. Freshwater prawn preparing to spawn were collected around the mouths of Dickinson Bayou in Upper Galveston Bay and Cedar Bayou in Trinity Bay (Reimer et al., 1974). This species spawns in estuaries or enters estuaries as drifting larvae while juveniles migrate upstream into streams where they mature into adults (Benson, 2017). Information was not readily available describing the estuarine habitat occupied by larval and juvenile prawns before they begin migrating upstream. They may concentrate in marsh, which provides protection from predators and ready access to detrital food sources. Rozas and Minello (2006) reported collecting Ohio shrimp (*Macrobrachium ohione*) in wild celery beds in Barataria Bay, Louisiana, with highest concentrations in the interior of the plant bed rather than along its edge.

5.4.2.1.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

Although hypersaline (high salinity) and hyposaline (low salinity) events occur within Galveston Bay, depending on amounts of freshwater inflow, drought conditions result in hypersaline conditions, large amounts of rainfall lead to fresher conditions; the impacts of these events could have greater effects with the Coastal Barrier in place.

Salinity modeling (McAlpin, et al., 2018) indicates portions of Galveston Bay upstream of the barrier would have lower salinities for longer periods when freshwater inflows are normal to high. Conversely, these areas would maintain higher salinities for longer periods when freshwater inflows are below normal for extended periods and evaporation is high or when a storm from the Gulf pushes large volumes of more-saline water upstream of the barrier. Areas upstream of the barrier, which are fresher for longer periods, may allow temporary expansion of freshwater fish, invertebrate, and plant communities into some of those areas. These areas with salinities most favorable to freshwater organisms are expected to be near freshwater inflows entering the bay.

The exact design and positioning of the Coastal Barrier and surge barrier gates at Dickinson Bayou, Clear Lake, and Offatts Bayou would be optimized during future planning and design phases. Preliminary design includes gates placed near shore in shallow water at Bolivar Roads to facilitate ingress and egress of aquatic organisms moving along the shore. These barriers may be designed and operated in ways that avoid or minimize impacts on movements of freshwater organisms. The Coastal Barrier might have the greatest impact on American eel, because it may reduce access to the bay system at its confluence with the Gulf and its tributaries, which provide habitat for maturing eel. The Coastal Barrier may have less impact on alligator gar, because the barrier is at the mouth of the bay and would not appear to inhibit movement of the fish between spawning tributaries and the bay. Since alligator gar occur in the bay, they may occasionally move into the Gulf through Bolivar Roads; however, this movement is not necessary for completion of their life cycle and not believed to be frequent. Since other freshwater organisms are not known to move between the bay and Gulf under ordinary conditions, the Coastal Barrier is not expected to impact movement of other freshwater organisms through the gate systems (Hendrickson and Cohen, 2015).

When low salinities occur in the bay, the barriers at Dickinson Bayou, Clear Lake, and Offatts Bayou may inhibit movement of freshwater fish and shellfish past the barriers.

South Padre Island CSRM Measure

The South Padre Island CSRM measure is not expected to impact freshwater organisms. American eel migrate through the Gulf and it may be possible they migrate near the sediment source area in the Gulf. Monitoring data suggest the probability of American eels occurring near the sediment source area is very low when dredging is occurring. If American eels do move past the sediment source area, they may be mobile enough to avoid entrainment by the dredge.

ER Measures

All ER measures involve construction of breakwaters, some of which are proposed to be miles long. These breakwaters may create barriers to movement of American eels and alligator gar but are not expected to impair their movement through the estuaries, because breakwaters will also be designed to facilitate movement of organisms back and forth through the breakwaters. The Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection (G-28), West Bay and Brazoria GIWW Shoreline Protection (B-12), East Matagorda Bay Shoreline Protection (M-8), Keller Bay Restoration (CA-5), and Powderhorn Shoreline Protection and Wetland Restoration (CA-6) include combinations of marsh restoration and nourishment that could impact freshwater

organisms. The degree of impact would be determined by the salinity when restoration and/or nourishment is occurring. If salinities are below 8 to 10 ppt, some species of freshwater organisms could be in the marsh and would be impacted by increased turbidity, possible increased temperatures, increased ammonia, and lowered oxygen in the marsh enclosed by the marsh restoration levees. ER measures like Redfish Bay Protection and Enhancement (SP-1) and Port Mansfield Island Rookery (W-3), which include breakwaters and island restoration, are not expected to impact freshwater organisms.

Since the Bolivar Peninsula/Galveston Island (G-5) and Follets Island (B-2) Gulf Beach and Dune Restoration ER measures would be constructed on the beach, sediment placement is not expected to affect freshwater organisms. American eel migrate through the Gulf, and it may be possible they migrate near the sediment source areas in the Gulf. Monitoring data suggest there is a relatively low probability of American eel occurring near the sediment source area. If American eel do move near the sediment source area, they may be mobile enough to avoid entrainment by the dredge.

5.4.2.1.2 Bay Rim Alternative

Bay Rim CSRM System

The CSRM measure with the least impact on American eel is most likely the Bay Rim Alternative, because the alternative would reduce access only to the upper Houston Ship Channel, San Jacinto River tidal, Buffalo Bayou, Dickinson Bayou, and Clear Creek watersheds, and it is unlikely that those watersheds are utilized by American eel. The Bay Rim is also the only CSRM measure that would allow unobstructed eel access to the Trinity River and its watershed below Lake Livingston. The Trinity River watershed below Lake Livingston is a fourth of the potential habitat for eel in the Galveston Bay system downstream of Lake Livingston.

About 3 percent of the area of Galveston Bay occurs upstream of the Bay Rim. This relatively small area of the bay receives about 38 percent of the average combined freshwater inflow to the estuary (TWDB, 2018). Having a large portion of the bay's freshwater inflow into only 3 percent of the bay would be expected to reduce salinities and create longer periods with low salinity upstream of the barrier. These lower salinity conditions should benefit freshwater organisms.

Effects of the barriers at Dickinson Bay, Clear Lake, and Offatts Bayou on freshwater organisms would be similar to the effects in the Coastal Barrier Alternative.

South Padre Island CSRM Measure and ER Measures

Impacts to freshwater organisms resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.4.2.2 Estuarine Habitats and Fauna

The AdH modeling was conducted for the Coastal Barrier CSRM system to understand potential environmental impacts. As no detailed data are available on the storm surge barrier or the environmental gates, modeling was

limited only to understand the general behavior of the bay system while comparing with- and without-project scenarios. All modeling was conducted using a tentative gate configuration across Bolivar Roads that would reduce the flow conveyance roughly by 27.5 percent. All gates were kept in open condition during simulations (McAlpin et al., 2018).

Modeling results suggest that the average tidal prism and average tidal amplitudes at various locations did vary between with- and without-project over the simulation year. The tidal prism change with the Preferred Alternative in place is a 13.5 and 16.5 percent reduction for the present and future conditions, respectively. The tidal amplitudes are also reduced at all bayside locations, between 9 and 22 percent. These indicate that the proposed structures have the potential to restrict the flow and limit the volume of water moving in and out of the bay at Bolivar Roads. The velocity magnitudes vary little between with- and without-project conditions. The mean surface and bottom velocity magnitude generally drops when the project is in place, but this change is 0.16 foot per second or less. The change from the without-project condition is greatest in areas at and immediately around where the structures are located. Eddies are also expected on the backside of the gate structures. There are changes to the magnitude of the velocity extending into the bay, but they are much smaller than the effects at the locations of the modifications. The models suggest that in certain situations the velocity differences between the with- and without-project condition could be as high as 2.0 feet per second. For example, a scenario that presented a combination of a high tide and strong winds could lead to such an increase in velocity. Future project refinements may minimize differences currently seen between with- and without-project velocities (McAlpin et al., 2018).

5.4.2.2.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

With the Coastal Barrier, the surge barrier gates at Bolivar Roads, GIWW, Clear Lake, Dickinson Bayou, and Offatts Bayou (Galveston ring levee/floodwall) would result in a permanent loss of 2,154 acres of open water and bay bottom habitat (see Table 5-2). Of that loss, the majority would occur at Bolivar Roads, which would be covered by the support structures and gates for the surge barrier gates. Water depth at the floating sector gate would be 60 feet and 15 to 30 feet through the environmental gates.

Construction of the surge barrier gates at Bolivar Roads includes construction of a bypass channel. The bypass channel would be dredged to accommodate vessel traffic from the Houston Ship Channel. Dredged material would be placed beneficially for construction of the ER measures, mitigation features, and/or other CSRM structures.

Open Bay and Bay Bottom. During construction of the Coastal Barrier, temporary disturbances and impacts to benthic organisms, plankton, and nekton assemblages would occur.

Turbidity in estuarine and coastal waters is generally cited as having a complex set of impacts on a wide array of organisms (Hirsch et al., 1978; Stern and Stickle, 1978; Wilber et al., 2005; Wright, 1978). During construction of the Coastal Barrier, water column turbidity is expected to increase. The release of sediment during dredging

increases turbidity in the water column, which creates a sediment plume, the extent of which is determined by the direction and strength of the currents and the sizes of particles (Wilber and Clarke, 2001).

Turbidity from total suspended solids tends to reduce light penetration and thus reduce photosynthetic activity by phytoplankton, algae, and seagrass (Wilber and Clarke, 2001). Such reductions in primary productivity would be localized around the immediate area of the dredging and placement operations. This reduced productivity may be offset by an increase in nutrients released into the water column during dredging activities that can increase productivity in the area surrounding the dredging activities (Newell et al., 1998; Wilber and Clarke, 2001). In past studies of impacts of dredged material placement from turbidity and nutrient release, the effects are both localized and temporary (May, 1973). Due to the capacity and natural variation in phytoplankton and algal populations, the impacts to phytoplankton and algae from project construction, dredging within the project area, and dredged material placement of material would be temporary.

Increased concentrations of suspended sediment can temporarily impact benthic macroinvertebrates and juvenile and adult finfish and shellfish by disrupting foraging patterns, reducing feeding rates and effectiveness, burying habitat for feeding and reproduction, and reducing respiration rates by coating gills with sediment (Clarke and Wilber, 2000; Newcombe and Jensen, 1996; Wilber and Clarke, 2001). Finfish and shellfish can avoid highly turbid areas and under most conditions are only exposed to localized suspended-sediment plumes for short durations (minutes to hours) (Clarke and Wilber, 2000; Newcombe and Jensen, 1996; Wilber and Clarke, 2001). Shrimp and crabs are less impacted by elevated suspended sediments since these organisms reside on or near the bottom where sedimentation naturally occurs (Wilber and Clark, 2001; Wilber et al., 2005). Furthermore, turbid waters may actually provide a refuge for these species from predation (Wilber and Clarke, 2001). Research has shown that more-sensitive species and life stages (i.e., eggs, larvae, and fry) are more negatively impacted by longer exposure to suspended sediments than less sensitive species and older life stages (Germano and Cary, 2005; Newcombe and Jensen, 1996; Wilber and Clark, 2001; Wilber et al., 2005).

Effects of elevated suspended solids on the adult stages of various filter-feeding organisms such as oysters, copepods, zooplankton, and other species include reduced filtering rates and clogging of filtering mechanisms interfering with ingestion, respiration, and abrasion (Armstrong et al., 1987; Newcombe and Jensen, 1996; Stern and Stickle, 1978; Wilber and Clarke, 2001). These effects tend to be more pronounced when total suspended solids concentrations are greater than 100 milligrams per liter but are apparently reversible once turbidities return to ambient levels (Newcombe and Jensen, 1996). These impacts would be localized around the immediate area of dredging and placement operations.

Turbidities can be expected to return to near ambient conditions within a few months after dredging ceases in a given area; thus, no long-term effects are anticipated. Modeling of dredged material discharge in the Laguna Madre, Texas, determined that turbidity caused by dredging was short lived, and therefore, impacts to the estuarine and offshore water column would be minimal (Teeter et al., 2003). No long-term impacts of elevated turbidities to finfish or shellfish populations are anticipated from construction, dredging, and placement activities associated with construction of the Coastal Barrier compared with the No-Action Alternative. Additionally, best

management practices would be used such as silt curtains, etc. to help alleviate some of the temporary construction impacts.

Although the bay bottom at Bolivar Roads is considered a permanent loss, the area of the Houston Ship Channel between the surge barrier gate would be left as natural bay bottom and regularly maintenance dredged by the USACE. There would be direct impacts during construction of the Coastal Barrier due to the removal of material from the seabed that removes benthic organisms living on and in the sediment. Dredging can result in a reduction of species diversity by 30 to 70 percent, the number of individuals by 40 to 95 percent, and a similar reduction in the biomass of benthic fauna existing within the boundaries of dredged areas (Newell et al., 1998). Recolonization of areas impacted by dredging occurs through immigration of postlarval organisms from the surrounding area, larval recruitment from the water column, and/or sediments slumping from the side of the dredged area (Bolam and Rees, 2003; Newell et al., 1998). The response and recovery of the benthic community from dredged material placement are affected by many factors, including environmental (e.g., water quality, water stratification), sediment type and frequency, and timing of disposal. Communities in these dynamic ecosystems are dominated by opportunistic species tolerant of a wide range of conditions (Bolam and Rees; 2003, Bolam et al., 2010; Newell et al., 2004; Newell et al., 1998). Although changes in community structure, composition, and function may occur, these impacts would be temporary in some dredging areas (Bolam and Rees, 2003).

Repeated dredging during maintenance dredging operations may prevent benthic communities from fully developing. Benthic diversity, biomass, and species diversity is reduced in areas of repeated disturbance (Rehitha et al., 2017). New recruits tend to be small, opportunistic, surface-dwelling organisms with high growth rates. Large, deep-dwelling organisms that grow slower and live longer are lost to the areas of repeated excavation. In this way, excavation associated with maintenance dredging may not cause a decrease in production, but rather a shift in community structure (Montagna et al., 1998; Rehitha et al., 2017). Sheridan (1999) found that benthic communities can take anywhere from 18 months to over 3 years to recover, and Ray and Clarke (1999) found that at least 1 year is required for benthic communities to return to pre-placement conditions. Depending on the maintenance dredging schedule, the reestablishment of a stable benthic community in the area might not be possible (Rehitha et al., 2017).

Dredged material from construction of the Coastal Barrier features would be used beneficially for construction of ER measures, mitigation features, and/or other CSRM structures.

Salinity. Construction of the Coastal Barrier could slightly decrease bay salinities on average of 2 ppt based on the estuarine modeling conducted by the USACE (McAlpin et al., 2018). During normal flow conditions, average salinities range from less than 10 ppt in upper Trinity Bay to 30 ppt at Bolivar Roads (Lester and Gonzalez, 2011). Most organisms occupying these environments are ubiquitous along the Texas coast and can tolerate a wide range of salinities (Pattillo et al., 1997). Therefore, no adverse effects on fauna are expected due to changes in salinity that may result from the construction of the Coastal Barrier.

Fisheries. The predicted reduced flow and increased velocities through Bolivar Roads could impede the migrations and movements of various life stages of fish into and out of the Galveston Bay system. Eggs and larval

stages of aquatic organisms are transported by currents, moving into the bay on the incoming tides. Larval forms of some species drop near the bottom on outgoing tides, particularly in the shallow areas nearshore to reduce transport out of the bay. An environmental gate along the shore of Bolivar Roads is expected to help alleviate some of the potential impacts to aquatic organisms that utilize shallow edge habitats. The important commercial/recreational and forage fish target species that are most vulnerable to flow constriction and velocity increases were identified by Rusty Swafford at NMFS (Table 5-15) (pers. com. R. Swafford [NMFS], 2017). Table 5-15 describes the life stage relative abundance of these species in Galveston Bay and their migrations and movements.

Table 5-15
Key Species Most Vulnerable to Flow Constriction

Species	Life Stage*	Galveston Bay Abundance	Migrations and Movements
Commercial/Recreationally Targeted Species:			
Brown shrimp	E, A	Not present	Adults move offshore to spawn from May through August, eggs offshore
	L, J	Abundant	Larvae move into estuaries from February to April with incoming tides and migrate to shallow, vegetated areas
			Juveniles move into open bays
White shrimp	E	Not present	Adults spawn offshore from spring through fall
	L, J	Abundant	Larvae move into estuaries from May to November
	A	Common	Juveniles migrate farther up the estuary into less-saline water
			As they grow and mature they leave the marsh for deeper, higher salinity areas of the estuary
			Juveniles and subadults move from estuaries to offshore in late August and September
Blue crab	L, J, A	Abundant	Eggs hatch near the mouths of estuaries and zoeal larvae are carried offshore to grow for up to one month
			Re-entry to estuarine waters occurs during the megalopal stage
Gray snapper	E, L	Not present	Pre-juveniles move into estuarine habitats, juveniles occupy inshore grassy areas
	J, A	Rare	Adults migrate offshore in summer to spawn
Red drum	E	Not present	Adults spawn offshore
	L, J, A	Common	Larvae and early juveniles are carried by tides and currents in the late fall into estuaries and bays and move to quieter back bay areas to grow
			Young move into primary bays
			Older fish move into the Gulf in the fall and winter
Spotted seatrout	E, L, J, A	Common	Estuarine dependent, completing entire life cycle in inshore waters
			Eggs associated with grass beds at or near barrier islands, larvae in deep channels
			Juveniles and adults found in seagrass, deep basins, tidal river mouths, channels and canals
			Adults can be found in nearshore Gulf waters (surf zones) during the fall and winter
Sand seatrout (*Cynoscion arenarius*)	E, L	Not present	Spawning occurs offshore
	J	Abundant	Larvae migrate to estuaries in April to early fall, preferring small bayous, shallow marshes, channels

Species	Life Stage*	Galveston Bay Abundance	Migrations and Movements
	A	Common	Migration from bay to offshore occurs late fall or winter, after spawning adults move back into higher salinity areas of the bay
Southern flounder	E, L	Not present	Adults move from estuaries during the fall and winter to spawn offshore
	J	Common	Post-larvae and juveniles immigrate into bays and estuaries from later winter to spring
	A	Abundant	Adults migrate back into the estuary during spring and summer
Atlantic croaker	E, L	Not present	Seasonal inshore and offshore migrations
	J	Abundant	Adults move into bays and estuaries in the spring and offshore in the fall
	A	Common	Larvae are carried by tides into the estuaries October to May
			Juveniles move into headwater areas where they remain 6 to 8 months and begin migrating offshore in March-April
Black drum	E, L, J, A	Common	Larvae and small young move into upper estuary and tidal creeks to low-salinity nursery areas during flood tides
			Juveniles move into bays, passes, and nearshore Gulf
			Spawn near passes, bays, channels, and nearshore Gulf
			Adults occupy bays and nearshore Gulf
Sheepshead	E, L	Not present	Adults move offshore in the spring to spawn, returning to bays after spawning
	J, A	Common	Larvae move from offshore into estuaries
			Adults occur in nearshore waters during warm seasons and move out of the estuaries during periods of low temperatures
Gafftopsail catfish	E L, J, A	Present	Spawn in bays
			Adults migrate offshore in winter and return inshore in the spring
Gulf whiting	E	Not present	Adults spawn offshore
	L, J, A	Present	Eggs are offshore, larvae move to estuarine nursery areas
			Adults generally inhabit offshore waters and near barrier islands
			Juveniles are found mainly offshore, less common in estuaries
Forage Fish of Importance:			
Striped mullet	E, L	Not present	Adults move offshore in the fall and winter to spawn, adults return to estuary after spawning
	J	Abundant	Pre-juveniles migrate to estuary in the spring, migrating to nursery areas (secondary and tertiary bays)
	A	Common	
Gulf menhaden	E, L	Not present	Adults migrate from estuaries to the Gulf late summer to winter to spawn
	J, A	Abundant	Larvae migrate to estuaries October to May
			During flood tides larva can be dense in tidal passes
Bay anchovy	E, L, J, A	Abundant	Bays, estuaries, and shallow waters of the Gulf
			Spawning occurs near barrier islands, bays, estuaries, tidal passes, harbors, and in the Gulf

Source: Pattillo et al. (1997).

*E = eggs; L = larva; J = juvenile; A = adult

Fisheries productivity is dependent upon environmental conditions and habitats that are present in marshes. Generally, spawning occurs offshore in coastal waters and larvae move into the estuaries, which serve as nursery habitat, protection from predators, and provide food for growth. Subadults migrate back to th7e Gulf to mature following a certain growth period (Minello et al., 2017). Marshes form a transition between aquatic and terrestrial ecosystems consisting of vegetation interspersed with shallow open water (Minello et al., 2008). The vegetation/ edge of the marsh is important in providing access to the marsh surface, which is used by aquatic organisms when it is flooded. The less the marsh surface is flooded, the less surface area is available for these species to utilize as nursery habitat (Minello et al., 2012, 2015). Tidal inundation is very important in determining marsh value and use. Studies have shown high densities of fish, crabs, and penaeid shrimp utilize about the first 10 feet of vegetation adjacent to open water. In Texas, juvenile red drum, spotted seatrout, penaeid shrimp, and blue crab densities are high in marsh edge habitat; these high densities could be associated with high flooding durations of these marshes (Minello et al., 2012).

Estuarine modeling is predicting a reduction in tidal amplitude, and lower high tides and higher low tides (McAlpin et al., 2018). Lower water levels mean less of the marsh would be flooded, resulting in a loss of marsh surface area available for aquatic organisms to use as nursery habitat. Reduced marsh area due to the tidal amplitude change was estimated for impacts due to the Coastal Barrier (Appendix C-9). A tidal amplitude reduction predicted by the AdH model was used to calculate this area of reduced marsh. This could result in a reduction of fish and shellfish densities, thus reducing the overall populations in the bay. This, coupled with reduced immigration of eggs and larvae from the Gulf into the bay because of the flow constriction, could exacerbate the impacts further. It's worth noting that numerous anthropogenic modifications have occurred in the Galveston Bay system (e.g., Causeway Bridge, Texas City Dike, Galveston Jetties, and the establishment of numerous dredge material placement areas), and while those modifications may have had adverse effects on fisheries, the ecosystem in Galveston Bay has proved resilient.

Oyster reef. Information from the GLO GIS Maps and database for oyster reefs were used to determine impacts to oysters. No mapped oyster reefs occur in the direct footprint of the Coastal Barrier; therefore, no direct impacts are anticipated. The interagency team has noted that oysters do occur in locations that are not included in the GLO dataset, specifically where the proposed Galveston ring levee/floodwall would cross Offatts Bayou. A more-detailed impact assessment, including additional oyster information from the interagency team, will be conducted on the TSP in future planning and design phases.

Water column turbidity would increase during project construction that could affect survival or growth of oysters nearby. Temporary impacts to oysters include reduced filtering rates and clogging of filtering mechanisms causing abrasion and interfering with ingestion and respiration (Newcombe and Jensen, 1996; Stern and Stickle, 1978; Wilber and Clarke, 2001). Adult oysters are more capable of withstanding such conditions than spat, and during periods of high turbidity can close up tightly for a week or more until normal conditions return (Cake, 1983). Turbidity increases from construction of the Coastal Barrier should be temporary and local.

Indirect effects to oyster reef habitat may result from a lower salinity regime due to the reduced flow of water into and out of the bay and the longer retention times. An overall decrease in salinity of about 2 ppt could be expected

based on the estuarine modeling conducted by the USACE (McAlpin et al., 2018). A benefit of a slight decrease in salinity is a potential reduction in exposure to oyster predators and pathogens, drills, and Dermo, which may occur more frequently with higher salinities (Cake, 1983; Soniat and Kortright, 1998). It is not anticipated that this potential salinity decrease would cause any long-term impacts to oyster reefs in the Galveston Bay system.

Increased nutrients could cause algal blooms that could impact oysters. Freshwater inflow during rain events would bring additional nutrients into the system and could cause algal blooms. The freshwater on top of the saltwater could stratify the water and reduce oxygen causing anoxic conditions in bottom waters, thus impacting oysters.

Summary. When compared with the No-Action Alternative, the Coastal Barrier could result in a reduction in overall estuarine fauna productivity. Dredging and construction activities associated with construction of the Coastal Barrier would cause temporary and localized impacts resulting from increased turbidity, suspended sediments, and bottom impacts. In-bay construction durations are not known at this time; however, construction lasting for extended time periods could take estuarine habitats and fauna in those areas longer to recover to pre-construction conditions. Reduced flow, reduced tidal amplitude, and periodic high velocities around the gates could have long-term effects on estuarine habitats and fauna in Galveston Bay. Potential long-term direct impacts to fish and shellfish with larval and juvenile life stages that depend largely on passive transport could result from the cumulative impacts of the Coastal Barrier. Losses could result from 1) reduced numbers entering the bay proportional to the reduced volume flowing into the bay; 2) loss of individuals trapped in eddies that could form on the backside of the gate structures; 3) increased exposure to predation while migrating across the open bay to the marshes due to reduced velocities and increased transport times; and 4) reduced area of accessible marsh caused by reduced tidal amplitude. Species that rely on passive transport in early life stages are important forage for fish, birds, and dolphins. This could result in indirect impacts resulting from reduced access to forage.

South Padre Island CSRM Measure

Impacts to the estuarine habitats and fauna could occur in the Gulf portions of the South Padre Island CSRM measure due to increased water column turbidity and sediment placement that can be expected during construction activities. A total of 358.5 acres of open water would be impacted. Turbidity impacts would be the same as those described above for the Coastal Barrier and would be expected to return to normal once construction is completed. Renourishment of the measure every 10 years throughout the period of operation would cause short-term water column turbidity and impacts to benthos during placement activities. No long-term impacts to the aquatic community are anticipated to result from the South Padre Island CSRM measure.

ER Measures

Revetment/Breakwater. As a result of constructing the revetment/breakwater features, a total of 802 acres of bay bottom habitat and open bay habitat would be permanently lost. Impacts associated with bay bottom habitat loss and temporary disturbances to water column turbidity on estuarine habitat and fauna would be the same as those described above for the Coastal Barrier open bay and bay bottom and would be expected to return to normal once construction is completed. No long-term impacts to finfish or shellfish populations are anticipated from

construction, dredging, and placement activities associated with construction of revetment/breakwater features of ER measures.

When revetment/breakwaters are placed in areas where the environments are predominantly soft sediments, it creates suitable habitat for marine organisms, which can settle and colonize on the new hard substrate. The ecological value of the created habitat is low when compared to natural rocky shores, colonized mainly by species with opportunistic traits (Dugan et al., 2011; Fowler and Booth, 2013). Fish and invertebrate communities tend to be less diverse on created habitat when compared to the natural shoreline (Dugan et al., 2011). However, Scyphers et al. (2015) showed that fish populations (including commercial and recreationally important species), smaller fishes, and crustaceans were greater near breakwaters than mudflat areas. It is reasonable to assume that constructed revetment/breakwaters would attract marine organisms and provide a greater ecological service than without the structure in place. If water quality is adequate, revetments/breakwaters provide habitat for oyster colonization and the biological communities associated with oysters. Although there is a permanent loss of bay bottom habitat and open bay habitat, there is a gain of rocky habitat that attracts fish and invertebrate communities. These structures would also protect valuable marsh, SAV, and oyster reef habitat from eroding, in turn protecting valuable nursery grounds for the many fish and shellfish species that live within these estuaries.

Island Restoration. As a result of island restoration features, bay bottom habitat and open bay habitat would be permanently lost. Impacts associated with bay bottom habitat loss and temporary disturbances to water column turbidity on estuarine habitat and fauna would be the same as those described above for the Coastal Barrier open bay and bay bottom and would be expected to return to normal once construction is completed. Care would be taken to avoid existing SAV and oyster reef to the greatest extent practicable, and silt curtains would be deployed during construction to prevent movements of sediments into nearby SAV beds and oyster reef habitats. Notwithstanding the potential harm to some individual organisms, no long-term impacts to finfish or shellfish populations are anticipated from construction, dredging, and placement activities associated with construction of island restoration features of ER measures.

Marsh Restoration. Marsh restoration would occur behind each of the constructed revetment/breakwater features. The area of bay bottom habitat and open bay habitat under the revetment/breakwater features would be permanently lost. Impacts associated with bay bottom habitat loss and temporary disturbances to water column turbidity on estuarine habitat and fauna would be the same as those described above for the Coastal Barrier open bay and bay bottom and would be expected to return to normal once construction is completed. A total of 10 years would be required for construction, planting, and marsh establishment and may require construction of temporary containment levees and drainage structures to contain the material. Thin layer placement may also be considered. Material would be obtained from excavation associated with construction of the revetment/breakwaters and shoaled or virgin sediments from nearby sources. During construction of containment levees and drainage structures, water column turbidity impacts would be the same as those described above for the Coastal Barrier and would be expected to return to normal once construction is completed. Placement of material could also increase water column turbidity temporarily.

Although bay bottom and open bay habitat would be lost for marsh restoration, once the marsh is functioning, the overall benefits outweigh the initial impacts. Wetlands and marshes provide numerous ecosystem services including providing nursery and feeding habitat for juvenile and adult fish and shellfish species, which in turn provide economic value to the community (Schuster and Doerr, 2015). They provide important habitat and food for both recreational and commercial fish, and shellfish spawning and growth. Additionally, they play an important role in estuarine chemical cycles (Minello, 1999; Schuster and Doerr, 2015; Yoskowitz et al., 2012). More fish and invertebrate species utilize vegetated marsh habitat as nursery areas compared to unvegetated habitat, and more adult fish used these areas compared to adjacent estuarine open water habitats (Yoskowitz et al., 2012). Sinuous circulation channels would be created or maintained in the marsh. Minello et al. (1994) showed that creating marshes with these types of sinuous circulation channels was important in determining nekton use. Shrimp showed a strong affinity for marsh-edge habitat, which increased their densities on the inner marsh surface. Marsh bottom habitat would be gained supporting benthic organism growth, which would provide food for fish and shellfish species. Nekton densities and species richness in created marshes in Galveston Bay were similar or in some instances greater than natural marshes about 2 years following marsh planting (Minello, 2000; Rozas et al., 2005). It is expected that the marsh restoration features would improve the fish and shellfish habitat in the areas compared to the No-Action Alternative.

Out-year Marsh Nourishment 2065. A total of 28,092.7 acres are proposed for out-year marsh nourishment. It is assumed that due to RSLR, some of those areas would have converted to open water by the year 2065, and therefore, some amount of open bay and bay bottom habitat would be lost resulting from this feature. Construction details are currently not available and will be refined during future planning and design phases of the study.

A total of 10 years would be required for construction, planting, and marsh establishment and would require construction of temporary containment levees and drainage structures to contain the material. Material from borrow source locations or maintenance material from other sources would be used to construct these features. Assuming these areas would have converted to open water by the year 2065, open bay and bay bottom habitat would be lost resulting from this feature. During construction of containment levees and drainage structures, water column turbidity impacts would be the same as those described above for the Coastal Barrier and would be expected to return to normal once construction is completed. Placement of material could also increase water column turbidity temporarily. Although similar types of water quality impacts to those of the Coastal Barrier may occur, the severity of the impacts may be greater because of proximity of sediment placement to marsh, which is extensively used by juvenile fish and shellfish. Juvenile forms of some of the species that utilize the marsh are more susceptible to effects from sediment placement activities than adults, which may not occur as frequently or in as high numbers as juveniles in these habitats.

While it has been shown that created marshes are not functionally equivalent to natural marshes for nekton and other estuarine organisms, they do provide a highly productive habitat for these species to thrive (Minello and Caldwell, 2006; Minello and Webb, 1997). The key characteristic for support of fishery populations is access to marsh surface, which can provide food for growth and structure to help increase survival (Minello et al., 2003). The plan is to create sinuous circulation channels and ponds in the created marsh, which would increase the marsh edge/vegetation habitat that is important in providing access to the marsh surface and is used by aquatic organisms

when it is flooded (Minello et al., 2012, 2015). Once construction of the out-year marsh nourishment features is complete, the created marsh would increase commercial and recreational fish and shellfish productivity and serve as a nursery area, providing more-productive habitat than the open water and bay bottom habitat it replaced.

Oyster Reef Creation. Oyster cultch would be placed as part of four ER measures, while CA-5 would be a reef constructed by placing reef balls in shallow water. Creation of oyster reefs is expected to protect restored islands, prevent breaching of islands and shorelines, protect SAV, and increase oyster populations. Impacts during construction of the oyster reefs include water column turbidity and bay bottom habitat loss and would be the same as those described above for the Coastal Barrier. Water column turbidity would be expected to return to normal once construction is completed.

Oyster reef creation is a type of living shoreline, which is an improvement over traditional armoring techniques (Schuster and Doerr, 2015). Oyster reefs have a positive benefit to the estuaries by providing ecosystem services such as water filtration and nutrient removal, fisheries habitat, benthic invertebrate habitat, and stabilization of adjacent habitats and shorelines (Baggett et al., 2014; LaPeyre et al., 2014; Schuster and Doerr, 2015). Scyphers et al. (2011) found that oyster reef creation using cultch material provided substrate for oyster recruitment and protected a diverse fish and invertebrate community. Oyster reefs also protect adjacent vegetated habitats from wave action, currents, and tides. Reduced wave action can help stabilize the shoreline by allowing sediments to accumulate landward of the reef. Sediment accumulation and shoreline stabilization work hand-in-hand protecting nearby marsh habitat from erosion, while allowing expansion of marsh through accretion. Water quality improvement and sediment stabilization provided by the oyster habitat may also allow for SAV recruitment or protection (Baggett et al., 2014).

The overall benefits from oyster reef creation as part of an ER measure outweigh any short-term construction impacts. These benefits, coupled with the benefits from the other ER features, work together in the multiple lines of defense strategy to help protect the Texas coast.

Dune/Beach Restoration. Impacts to the aquatic community could occur in the Gulf portions of the project area due to increased water column turbidity that can be expected during construction of the dune/beach restoration feature. Impacts associated with temporary disturbances to water column turbidity on estuarine habitat and fauna would be the same as those described above for the Coastal Barrier open bay and bay bottom and would be expected to return to normal once construction is completed. Renourishment of the feature would occur through standard renourishing every 5 to 10 years or continuously through a sand motor. Renourishment of the measure throughout the period of operation would cause short-term water column turbidity during placement. If a sand motor is used, large amounts of sand would be deposited at one location along the shoreline near the feature. Placement of the sand would cause benthic organisms to be smothered and water column turbidity impacts as described above for the Coastal Barrier. However, no long-term impacts to the aquatic community are anticipated resulting from dune/beach restoration features.

Summary. The ER measures are designed to provide an overall positive benefit to the ecosystem in a variety of ways. These benefits work together to contribute to the multiple lines of defense strategy that was developed by

the Coastal Texas Study that relates to protection of coastal ecosystems and human infrastructure from storm damage caused by hurricanes and tropical storms coming ashore from the Gulf. The multiple lines of defense provided first by the barrier islands, then by living shorelines, and finally coastal marshes, can reduce the physical impacts of storm surges and winds that enter the bays. This combination of multiple lines of defense and ER is intended to provide redundant and resilient levels of protection and restoration for both humans and Texas coastal ecosystems. When comparing the ER measures to the No-Action Alternative, the benefits resulting from the multiple lines of defense strategy far outweigh the short-term construction impacts that would be expected.

5.4.2.2.2 Bay Rim Alternative

Bay Rim CSRM System

With the Bay Rim, the surge barrier gates at Fred Hartman Bridge, Clear Lake, Dickinson Bayou, the bay rim levee/floodwall, and the Texas City Hurricane Flood Protection Improvements would result in a permanent loss of 564.0 acres of open water and bay bottom habitat (see Table 5-2). About half of that loss would occur at Fred Hartman Bridge, which would also permanently convert to deeper-water habitat resulting from the underwater footprint needed to construct the surge barrier gates.

Direct impacts associated with constructing the Bay Rim would be similar to those described for the Coastal Barrier (Section 5.4.2.1), with the exception of the smaller open water impacts. The Bay Rim has much less open water impacts compared to the Coastal Barrier. Minimal indirect impacts are anticipated with this alternative.

Open bay and bay bottom habitat would be disturbed during construction of the Bay Rim. The same types of temporary disturbances to water column turbidity and construction impacts would occur as those described for the Coastal Barrier (Section 5.4.2.1). Turbidity and bottom conditions would be expected to return to normal once construction is completed. Effects on salinity and velocity have not been modeled for the Bay Rim. Similar effects to those caused by the Coastal Barrier may be expected with reduced flow through the barrier, reduced tidal amplitude upstream of the barrier, and periodically measurably higher velocities around the surge barrier gates. Aquatic organism exchange between upper Galveston Bay and Tabbs/Upper San Jacinto/Burnet bays and Buffalo Bayou could be impeded with construction of Bay Rim. However, due to this measure being located in the upper portions of Galveston Bay, impacts would not be as great as those seen with the Coastal Barrier, which reduces flow to the entire bay complex. Gates at Clear Lake, Dickinson Bay, and Offatts Bayou could also impede aquatic organism exchange with lower Galveston Bay.

Oyster Reef. A total of 0.03 acre of oyster reef falls in the direct footprint of the Bay Rim and would be lost resulting from this measure. Impacts to nearby oysters during project construction would be the same as those described in Section 5.4.2.1. The interagency team has noted that oysters do occur in locations that are not included in the GLO dataset, specifically where the proposed Galveston ring levee/floodwall would cross Offatts Bayou. A more-detailed impact assessment, including additional oyster information from the interagency team, will be conducted on the TSP in future planning and design phases. Due to the small amount of impact, mitigation for oysters would be determined during future planning and design phases to include this and any additional impacts.

Summary. The Bay Rim would result in less impacts to estuarine fauna productivity when compared to the Coastal Barrier. Although no hydrologic modeling was conducted for the Bay Rim, it is expected that the effects of flow constriction and reduced tidal amplitude would impact less of Galveston Bay than the Coastal Barrier would. A greater proportion of the area above the Bay Rim has less marsh and is more developed/ industrialized than Galveston Bay as a whole and there may be less impacts to recreational and commercial fisheries associated with this measure when compared to the Coastal Barrier.

South Padre Island CSRM Measure and ER Measures

Impacts to the estuarine habitats and fauna resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.4.3 Wildlife Resources

Compared to the thousands of undeveloped wetlands, a small fraction of uplands and other wildlife habitats would be directly or indirectly impacted by the CSRM measures. Direct impacts to wildlife habitats would be temporary. During construction, wildlife would be able to move out of construction corridors and staging areas into adjacent habitats to avoid disturbance and harm. Species competition in the remaining undisturbed habitat may temporarily lower reproductive rates. Clearing and grubbing associated with construction would be conducted during the fall or winter, when practicable, to minimize impacts to nesting migratory birds. Wildlife are also at risk of possible oil, chemical, or other hazardous material spills during the construction phase of the project. These risks would be reduced with adequate best management practices and spill response actions outlined by the USFWS (2003). Construction activities near the water may disturb feeding behaviors of wading birds inhabiting the project area due to increased noise and turbidity; however, suitable feeding and loafing areas can be found in the project vicinity (Greene, 2002). Wetlands, forested areas, and shorelines would be surveyed prior to construction to avoid or minimize sensitive wildlife such as bald eagles. Impacts to bald eagle nests would be avoided in accordance with the National Bald Eagle Management Guidelines (USFWS, 2007b) and impacts to migratory bird nests should be avoided in accordance with the MBTA (USFWS, 2017b). Construction of the levee barrier might interfere with existing wildlife corridors due to increased difficulty crossing over the levees or roadways.

After construction is completed, terrestrial wildlife would be able to traverse, burrow, and access earthen levees to adjacent habitats (Bayoumi and Meguid, 2011). If the CSRM barrier utilizes levee borrow pits, the pits could provide year-round water containment for wildlife, such as waterfowl, amphibians, and mammals. The surge barrier gates may influence the movements of local fisheries in Galveston Bay which, in turn, could change foraging areas for shorebirds and other wildlife. Changes in hydrology, nutrients, and organic matter from the presence of the surge barrier gate may also have an indirect impact to wildlife in the bay by altering or changing fish distribution, movement, or production (see Section 5.4.2).

5.4.3.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

Most of the levee barrier would be placed adjacent to roadways and developed areas. The proposed levee would be located parallel to SH 87 and TX-124. Construction of the levee barrier would further limit and fragment the wildlife corridors between adjacent habitats from the Gulf-bay side of Bolivar Peninsula and east-west through wetlands and pastures near Anahuac NWR (Beier et al., 2008). Due to the proximity of construction along the Gulf coast, it is expected that shorebirds and coastal wildlife would be most impacted by the Coastal Barrier. Construction activity and noise can potentially disrupt and disturb wildlife behavior and their ability to hear (Dufour, 1980). Clearing and grubbing vegetation would remove potential habitat for wildlife species. Wildlife can avoid the area and potentially relocate away from the project area to adjacent habitat.

Once construction of the levee barrier and surge barrier gate are completed, terrestrial wildlife displaced from construction activity would be able to recolonize the earthen levee and access corridors to adjacent habitat. It would be assumed that the levee barrier would be routinely maintained, regularly mowed, and vegetation prevented from growing on the structure (Bayoumi and Meguid, 2011). Levees on Bolivar Peninsula would maintain the existing coastal dune habitat characteristics. The marshes and wetlands impacted by the levee barrier are in previously impacted areas, parallel to the highway or along grazed cattle pastures. Wildlife resources along Galveston Bay would benefit in the long-term risk reduction from coastal storms. No long-term impacts to wildlife resources are anticipated from the construction of the Coastal Barrier.

South Padre Island CSRM Measure

Impacts to wildlife from the South Padre Island CSRM measure would be limited. The placement area is located on beachfront residential and commercial property and does not provide pristine habitat for wildlife. South Padre Island beach is fragmented and used heavily for human recreation. Urban wildlife such as raccoons, rodents, and coyotes found within the area are highly adaptable and familiar with living near humans and would be able to occupy new habitats (Adams et al., 2005). For the coastal wildlife found within the project area, temporary construction activity and noise can disturb and disrupt foraging, nesting, and roosting behavior (Dufour, 1980). Construction and fill placement can temporarily increase turbidity and bury productive foraging habitat within the surrounding area. Turbidity can potentially inhibit bird foraging. Beach bulldozing can cause sand compaction and impact populations of sand and ghost crabs (Greene, 2002). Wildlife could avoid the construction area or potentially relocate to adjacent habitat. Future renourishment of the measure every 10 years would continue to temporarily affect wildlife within the project area.

Once dredging and beach nourishment is complete wildlife would benefit from additional habitat and stabilized shoreline for foraging, nesting, and roosting. Excluding temporary disturbance from beach nourishment every 10 years, no long-term impacts are anticipated from the South Padre Island CSRM measure.

ER Measures

Revetment/Breakwater. Temporary disturbance of wildlife is expected during the construction and placement phase of the revetment and riprap breakwater. Localized turbidity is also expected around the riprap placement area, which might impact water quality and foraging efficiency for wildlife in the area (Greene, 2002). Hard shoreline structures, such as revetments and breakwaters, may fragment the wetland-open water interface and provide an obstacle for amphibious wildlife species such as frogs and toads. Once completed, breakwater and revetment structures can provide hard surface areas for oyster colonization and habitat for small fish, crustaceans, and mollusks which provide food for wildlife such as raccoons, skunks, reptiles, and small mammals (see Section 5.4.2). Revetment and breakwater structures would also slow the rate of shoreline erosion of marshes, SAV, wetlands, and tidal flats that are used by wildlife for foraging, nesting, and roosting (Swann, 2008). Overall benefits from revetment and breakwater structures as part of the ER measures likely outweigh short-term construction impacts. There are no long-term impacts to wildlife resources associated with revetment and breakwater structures.

Island Restoration. Island restoration would increase the size, stability, and composition of islands along the Texas Gulf coast. Short-term disturbance of island wildlife is possible during the construction, dredging, and placement phase of the project. Sediment placement would be away from oyster reefs and SAV and would not impact foraging wildlife. Concrete blocks placed on the GIWW side of the island, used for erosion control, can impair nesting and foraging habitat. Island restoration is expected to increase vegetation coverage and increase available nesting habitats. Wildlife is expected to recolonize the island as soon as construction is completed with migratory birds, insects, rodents, and reptiles. Native and nesting platforms would provide additional habitat for bird species such as brown pelicans, double-crested cormorants, and great egrets (Schreiber and Schreiber, 1978). As the island matures, habitat for greater species diversity is expected to increase. Trees, shrubs, and groundcover would increase cover for nesting and roosting habitats and attract different species of wildlife (Michel et al., 2013; Schreiber and Schreiber, 1978). Long-term negative impacts are not expected with island restoration.

Marsh Restoration/Out-year Marsh Nourishment 2065. Wildlife utilize wetlands and marsh areas for shelter, nesting, foraging, and raising young. Short-term impacts to wildlife from marsh restoration can include disturbance from construction activities and turbidity in the water column from dredging and sediment placement (Greene, 2002; Michel et al., 2013). Impacts to water quality from turbidity are expected to be localized and temporary (Greene, 2002). Wildlife may relocate during the construction phase of the ER measures but would be expected to return to the area once the wetlands are restored. Wildlife are expected to benefit from marsh restoration measures (Swann, 2008). Substantial impacts to wildlife resources from the ER measures are not anticipated.

Out-year marsh nourishment is designed to nourish existing marshes with additional fill material, followed by planting of smooth cordgrass and other native marsh plants to expedite marsh stabilization. Material from borrow sites along the GIWW would be used as fill for these features. A total of 10 years would be required for the construction and marsh establishment. During the period of construction, wildlife would continue to access and utilize the marsh nourishment sites. Construction activity and noise would disturb sensitive wildlife and cause

temporary turbidity in the vicinity of the feature (Dufour, 1980; Greene, 2002). Once construction is completed, the restored wetlands would be colonized by wildlife such as invertebrates, herpetofauna, and birds (Greene, 2002; Rewa, 2007). The improved marsh habitat would include circulation channels and tidal access for marine life, and provide shelter, forage, roost, and nursery habitat for wildlife. Substantial impacts to wildlife resources are not anticipated from out-year marsh nourishment.

Oyster Reef Creation. Oyster reefs are expected to be constructed away from the shoreline and would not affect terrestrial habitats. The creation of oyster reefs can have an indirect effect on wildlife. Construction of the oyster reefs can potentially cause turbidity in the water column, which can affect foraging by shorebirds and coastal wildlife. Once the reefs are completed, a functioning oyster reef can support an abundance of fish, crustaceans, and macroinvertebrates, which are food resources for wildlife such as raccoons, water snakes, and herons (see Section 5.4.2). In addition, oyster reefs and living shorelines would reduce wave action and protect vulnerable wildlife habitat close to the shoreline (Swann, 2008). There are no anticipated long-term impacts to wildlife resources from oyster reef creation.

Dune/Beach Restoration. A wide range of wildlife utilize coastal Texas dunes and beaches, including pocket gophers, raccoons, aplomado falcons, and sea turtles (TPWD, 2018b). During the period of construction, noise from machinery may disturb some wildlife and cause turbidity, potentially reducing bird foraging efficiency (Greene, 2002; Notice Nature, 2007). Disturbances to wildlife are expected to be short term, and wildlife will recolonize beaches and dunes once construction is completed. Studies have documented that invertebrate fauna and prey species such as amphipods, polychaetes, and coquina clams recovered to pre-construction abundance following beach disturbance (Greene, 2002). Upon completion, the restored beaches and dunes are expected to enhance wildlife habitat. Sand dunes and beaches would provide a natural barrier to erosive wind and wave action (United Nations Environment Programme, 2018). Substantial impacts to wildlife resources are not anticipated from dune/beach restoration.

Summary. The ER measures are expected to have a net positive effect on wildlife resources. In addition to improved coastal stability, the measures are expected to improve available wildlife habitats and increase productivity. Relative to the No-Action Alternative, the benefits of a barrier against RSLR and improved habitat are expected to outweigh short-term construction impacts.

5.4.3.2 Bay Rim Alternative

Bay Rim CSRM System

A majority of the levee associated with the Bay Rim would be placed on developed property and along the western rim of the Galveston Bay shoreline. Since most of the CSRM measure would be in developed areas, species affected would include urban wildlife, such as raccoons, rodents, and coyotes. Most of affected wildlife would be habitat generalists that traverse between urban areas to Galveston or West Bay uplands and marsh habitats. Urban wildlife are usually more adaptive to changes in the environment (Adams et al., 2005). The Bay Rim would have less of an impact on wetland and upland habitats than the Coastal Barrier. Segments of the Bay Rim would be constructed along previously constructed breakwater, levees, and floodwalls. Construction along the Texas City

West Levee Extension would be located close to roadways, railroads, and existing levee structures. These areas have been previously disturbed and fragmented. Nevertheless, construction activity and noise around the project area could potentially interfere with wildlife behavior and their use of corridors (Dufour, 1980). Grubbing and removal of vegetation along the levee footprint would decrease available woodland wildlife habitat. The levee barrier can potentially fragment the north-south migration corridor of wildlife from West Bay to developed areas north near Hitchcock and Farm to Market Road 2004.

After construction, the earthen levee system would continue to allow wildlife to traverse and move through to adjacent habitat. The levee barrier would be routinely maintained, regularly mowed, and trees prevented from growing on the structure. It is not known whether the levee barrier would be fenced or gated. Fences or gates would inhibit wildlife from using the earthen levee as a corridor between habitats. No long-term impacts to wildlife resources are anticipated from the Bay Rim.

South Padre Island CSRM Measure and ER Measures

Impacts to wildlife resources resulting from the construction of the South Padre Island CSRM and ER measures would be the same as those described the Coastal Barrier Alternative.

5.4.4 Protected Resources

5.4.4.1 Protected Lands

Protected areas are locations that receive legal protection because of their recognized natural, ecological, or cultural values. The International Union for Conservation of Nature (2018) has provided a definition of protected areas that has been widely accepted across regional and global frameworks: “A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.”

The Texas coast contains many important natural, historical, and cultural resources that are managed by Federal, State, and local governments or are privately owned. These protected resources hold ecological, cultural, and economic value for individuals and communities throughout the state. The CSRM and ER measures considered for the upper, mid, and lower Texas coast would have direct and indirect impacts on managed or protected lands.

5.4.4.1.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The proposed Coastal Barrier levee system is expected to impact State-owned and Federally owned protected lands directly and indirectly. The impacts discussed below describe the sections of Anahuac NWR and Galveston Island State Park that are anticipated to be adversely affected, in addition to areas that are expected to benefit from construction of the Coastal Barrier.

Anahuac NWR is located on the upper Texas coast in Chambers County and borders the north shore of East Galveston Bay, within the Chenier Plain region of southwestern Louisiana and southeast Texas. The southern boundary consists of nearly 7 miles of bay shoreline and comprises over 37,000 acres of brackish and saline marshes, coastal prairie, and coastal woodlands (USFWS, 2018i). The refuge is part of the NWR System and the USFWS protects and manages the area for waterfowl, shorebirds, and water birds. Approximately 300 acres within the Anahuac NWR are expected to be directly impacted by construction operations from the Coastal Barrier, including potential grubbing and clearing, levelling, and piling of fill material. The impacts would be limited to a section of the proposed levee system that would parallel the east side of SH 124 adjacent to the refuge north and west of High Island. Direct impacts from the proposed levee system are expected to result in permanent loss of approximately 100 acres of potential wetlands and marshes along the eastern and southern border of the refuge within the structure footprint and temporary impacts to wetlands and marshes due to construction of access roads and staging sites. The indirect impacts to the refuge are expected to result in changes to wildlife migration patterns and natural topography and drainage patterns of the area.

Galveston Island State Park is located on the west end of Galveston Island in Galveston County and covers about 2,000 acres of beach, bay, and freshwater habitats. The park protects both natural and cultural resources within the area, and provides recreational opportunities for anglers, boaters, and bird watchers. Approximately 70 acres within the park are expected to be directly impacted by construction operations from the Coastal Barrier, including potential grubbing and clearing, levelling, and piling of fill material. The impacts would be limited to a section of the proposed levee system on Galveston Island that would parallel the north side of Farm to Market Road 3005 adjacent to the park. The park is already bisected by FM 3005; direct impacts from the levee system would continue to fragment the coastal ecosystem of the barrier island and decreased accessibility between the two halves of the park.

Collectively, the Coastal Barrier is expected to directly impact approximately 370 acres of protected lands from construction operations within the Galveston Bay region. Conversely, upon completion of the Coastal Barrier, several Federal, State, and privately owned protected lands within the Galveston Bay region would indirectly benefit from the coastal levee protection measures by gaining risk reduction from storm surges and RSLR. These areas include the Atkinson Island WMA owned by TPWD, Candy Abshire WMA owned by TPWD, Moody NWR owned by USFWS, North Deer Island owned by the Audubon Society, and Scenic Galveston Preserve owned by Scenic Galveston.

South Padre Island CSRM Measure

The beach and dune restoration feature footprint proposed for South Padre Island does not overlap with any Federal, State, local, or privately owned protected lands. Therefore, no direct impacts are expected in conjunction with the measure. Other protected lands outside of the measure footprint, including the Lower Rio Grande Valley NWR and Laguna Atascosa NWR owned by USFWS, would most likely receive some level of risk reduction from storm surges and RSLR provided by the restored beach and dune complex on South Padre Island.

ER Measures

Revetment/Breakwater. Revetments/breakwaters are proposed as shoreline protection for unprotected segments of the GIWW, areas of degrading and eroding marsh, or to serve as additional protection to bird rookery islands and are an assumed component of the initial construction features to be constructed in 2035. Constructing the revetments/breakwaters would result in a permanent loss of approximately 240 acres of bay bottom habitat in the upper and mid Texas coast. Specifically, approximately 35 acres of the Anahuac NWR, 113 acres of the Brazoria NWR, 13 acres of the Justin Hurst WMA, 68 acres of the San Bernard NWR, and 9 acres of the Big Boggy NWR would be converted from bay bottom habitat to rock revetments/breakwaters that would act as shoreline stabilization features.

No long-term impacts are anticipated from construction, dredging, or placement activities associated with the construction of the revetment/breakwater features. Although there is a permanent loss of bay bottom habitat within the structural footprints, the measures would protect valuable wetland and marsh habitats from eroding and would provide resiliency against coastal storms and RSLR.

Island Restoration. Island restoration is intended to protect intertidal and freshwater marsh complexes from erosion caused by RSLR and increased wave energy from vessel traffic and storms. These measures involve the restoration of islands adjacent to the GIWW in West Bay and East Matagorda Bay, along the bay side of the Redfish Bay complex east of Corpus Christi Bay, and restoration of the Port Mansfield bird rookery island in the Lower Laguna Madre. The feature footprints do not overlap with any Federal, State, local, or privately owned protected lands. Therefore, no direct impacts are expected in conjunction with the island restoration features. Other protected lands outside of the measure would most likely experience indirect effects and benefit from the increased protection provided by the islands.

Marsh Restoration. Marsh restoration features are planned behind each of the constructed rock revetment/breakwater features. These would require construction of temporary containment levees and draining structures to contain the material followed by planting and marsh establishment, which would take 10 years to complete. Approximately 500 acres of protected lands are expected to be restored by the marsh restoration features and would be subject to temporary impacts during construction. Specifically, approximately 31 acres of the Anahuac NWR, 2 acres of the Muddy Marsh Bird Sanctuary owned by TNC, 320 acres of the Brazoria NWR, 15 acres of the Justin Hurst WMA, 130 acres of the San Bernard NWR, and 5 acres of the Big Boggy NWR would be temporarily impacted during construction but would ultimately benefit as restored marsh.

The overall benefits from the marsh restoration features as part of the ER measures are expected to outweigh short-term construction impacts. Wetlands and marshes provide numerous benefits, including improvement of water quality, flood attenuation, esthetics, and recreational opportunities, as well as mitigating for RSLR and impacts to coastal infrastructure and ecosystems from storm events (USFWS, 2018i).

Out-year Marsh Nourishment 2065. The out-year marsh nourishments represent areas that were identified by the NOAA sea level rise viewer as degrading to unconsolidated shoreline or open water over the period of analysis due to RSLR. A total of 10 years would be required for construction, planting, and marsh establishment, and

would involve construction of temporary containment levees and draining structures to contain the material. Approximately 18,500 acres of Federal, State, or privately owned lands are expected to be restored by the out-year marsh nourishment features and would be subject to temporary impacts during construction. This includes approximately 2,500 acres of the Anahuac NWR, 30 acres of the McFarlane Marsh owned by TNC, 6,250 acres of the Brazoria NWR, 2,000 acres of the Justin Hurst WMA, 6,000 acres of the San Bernard NWR, and 1,700 acres of the Big Boggy NWR would be impacted during construction but would ultimately benefit as restored marsh.

The benefits from the out-year marsh nourishment features as part of the ER measures are expected to outweigh short-term construction impacts. Wetlands and marshes provide numerous benefits, including improvement of water quality, flood attenuation, aesthetics, recreational opportunities, and mitigating RSLR impacts to coastal infrastructure and ecosystems from storm events (USFWS, 2018i). The out-year marsh nourishment features would provide a long-term approach to enhance resiliency of coastal communities and improve our capabilities to prepare for, resist, recover, and adapt to coastal hazards.

Oyster Reef Creation. Four ER measures would involve placement of oyster cultch and one ER measure would include construction of a reef by installing reef balls in shallow water. Oyster reefs are a type of shoreline stabilization and provide many positive benefits to open water habitats and intertidal and freshwater marsh complexes by providing protection from wave action, currents, and tides. The oyster reef creation features are intended to protect restored islands, prevent breaching of islands and shorelines, and protect SAV. Approximately 2 acres of bay bottom habitat within the Brazoria NWR would be directly impacted resulting from oyster reef creation along the eastern shorelines of Oyster Lake in West Bay. However, the overall benefits of oyster reef creation are expected to outweigh short-term construction impacts to the refuge. Oyster reef creation would protect valuable wetland and marsh habitats from eroding, act as a shoreline stabilization alternative, and provide resiliency against coastal storms and RSLR (Schuster and Doerr, 2015). No other direct or indirect impacts to Federal, State, or privately owned lands are expected resulting from these features.

Dune/Beach Restoration. Dune and beach restoration features involve 5- to 10-year renourishment cycles or continuous renourishment through a sand motor. The features are intended to protect dune and beach complexes along Gulf shorelines from breaches and erosion caused by storm surge and RSLR. Approximately 1,950 acres of protected lands are expected to be impacted by the dune and beach features and would be subject to temporary impacts during construction, including pumping and spreading of material on the shoreline, planting of dune vegetation, and installment of sand fencing for erosion control. Specifically, approximately 70 acres of McFaddin NWR, 330 acres of Anahuac NWR, 20 acres of Bolivar Flats Shorebird Sanctuary, 130 acres of Galveston Island State Park, and 1,400 acres of the Padre Island National Seashore would be temporarily impacted during construction but would ultimately benefit from the restored beach and dune profile.

Summary. The ER features are designed to provide a variety of services that are expected to have positive ecosystem benefits at the local, regional, and landscape levels across the Texas coast. The benefits gained resulting from the implementation of these features would outweigh the short-term construction impacts. Additionally, the features support the missions of the parks, preserves, and refuges by conserving, protecting, and enhancing

fisheries, wildlife, plants, and their habitats and further enhancing the resiliency of coastal communities and ecosystems throughout the Texas coast.

5.4.4.1.2 Bay Rim Alternative

Bay Rim CSRM System

The proposed levee system and surge barrier gate structures of the Bay Rim are expected to indirectly impact State and Federally owned lands. No protected lands are within the footprint of the measure, and therefore, no direct impacts are expected. Other protected lands outside of the Bay Rim would most likely not be affected by the proposed levee system or surge barrier gate structures.

Upon completion of the Bay Rim, water velocities could potentially increase near the structures and decrease exchange into and out of Galveston Bay. Atkinson Island WMA, which is located in the very northern tip of Galveston Bay on the edge of Harris and Chambers counties, could be indirectly impacted resulting from the erosional effects from increased velocity against the northern portion of the island.

Protected lands upstream of the proposed levee system and gate structure, such as the San Jacinto Battleground and Battleship Texas State Historic site, may experience inundation and drainage issues when the gates are closed during storm surge events.

South Padre Island CSRM Measure and ER Measures

Impacts to protected lands resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described the Coastal Barrier Alternative.

5.4.4.2 Threatened and Endangered Species

There are 23 Federally listed threatened or endangered species with potential to occur within the proposed alternatives project areas (Table 5-16). Federally listed species that potentially occur within these project areas include the endangered prairie dawn-flower, interior least tern, northern aplomado falcon, whooping crane, Kemp's ridley sea turtle, and hawksbill sea turtle. Federally listed threatened species include West Indian manatee, piping plover, red knot, green sea turtle, and loggerhead sea turtle. Candidate species include red-crowned parrot,

Table 5-16
Endangered, Threatened, or Candidate for Listing Species of Potential County[1] Occurrence in the CSRM and ER Project Areas

Common Name	Scientific Name	Federal Status	Potential of Occurrence within the Project Areas
PLANTS			
Slender rush-pea	*Hoffmannseggia tenella*	E	No
South Texas ambrosia	*Ambrosia cheiranthifolia*	E	No
Texas ayenia	*Ayenia limitaris*	E	No
Texas prairie dawn-flower	*Hymenoxys texana*	E	Yes
BIRDS			
Attwater's prairie chicken	*Tympanuchus cupido attwateri*	E	No
Interior least tern	*Sterna altillarum*	E	Yes
Northern aplomado falcon	*Falco femoralis septentrionalis*	E	Yes
Piping plover	*Charadrius melodus*	T	Yes
Red knot	*Calidris canutus rufa*	T	Yes
Red-crowned parrot	*Amazona virdigenalis*	C	No
Whooping crane	*Grus americana*	E	Yes
MAMMALS			
Gulf coast jaguarundi	*Herpailurus yagouaroundi cacomitli*	E	No
Ocelot	*Leopardus pardalis*	E	No
Blue whale	*Balaenoptera musculus*	E	No
Fin whale	*Balaenoptera physalus*	E	No
Humpback whale	*Megaptera novaeangliae*	T	No
Sei whale	*Balaenoptera borealis*	E	No
Sperm whale	*Physeter macrocephalus*	E	No
West Indian manatee	*Trichechus manatus*	E	Yes
REPTILES			
Hawksbill sea turtle	*Eretmochelys imbricata*	E	Yes
Kemp's ridley sea turtle	*Lepidochelys kempii*	E	Yes
Leatherback sea turtle	*Dermochelys coriacea*	E	No
Green sea turtle	*Chelonia mydas*	T	Yes
Loggerhead sea turtle	*Caretta caretta*	T	Yes
MOLLUSKS			
Golden orb	*Quadrula aurea*	C	No
Smooth pimpleback	*Quadrula houstensis*	C	No
Texas fawnsfoot	*Truncilla macrodon*	C	No
Texas pimpleback	*Quadrula petrina*	C	No

Source: NMFS (2016b); USFWS (2017a, 2018g).

E – Endangered; T – Threatened; C – Candidate for Federal listing

[1] Counties within the project area include Brazoria, Calhoun, Cameron, Chambers, Galveston, Harris, Kenedy, Matagorda, Nueces, and Willacy.

golden orb, smooth pimpleback, Texas fawnsfoot, and Texas pimpleback. The CSRM and ER measures are not expected to have an impact on the following listed species: slender rush-pea, South Texas ambrosia, Texas ayenia, Attwater's greater prairie chicken, ocelot, Gulf coast jaguarundi, blue whale, fin whale, humpback whale, sei whale, sperm whale, leatherback sea turtle, and candidate species: red crowned parrot, golden orb, smooth pimpleback, Texas fawnsfoot, and Texas pimpleback (see Section 5.4.4.2.1 below) (USFWS, 2018g). Species not affected by the CSRM and ER measures lack suitable habitat within the project areas. They are found farther inland in upland, forested woodlands, or freshwater riverine habitat (see Section 2.4.5.2). The species life history, habitat preference, and potential effects of the project on Federally protected species are considered in more detail in the Biological Assessment provided in Appendix C-3.

5.4.4.2.1 Species Not Part of this Impact Section

The Preferred Alternative is not expected to affect slender rush-pea, South Texas ambrosia, Texas ayenia, Attwatter's prairie chicken, red-crowned parrot, Gulf coast jaguarundi, ocelot, leatherback sea turtle, golden orb, smooth pimpleback, Texas fawnsfoot, and Texas pimpleback. Slender rush-pea, South Texas ambrosia, and Texas ayenia are endemic plant species typically found in small, well-documented tracts in upland grassland, coastal prairie, or mesquite savannah habitats in Texas. Most of the CSRM and ER measures are located near the coast in open water, upland, developed, or wetland habitat (USFWS, 2006a, 2009, 2010a, 2016c, 2017c). There are no suitable habitats for the four listed plant species within the CSRM or ER project footprint, and the project is anticipated to have no effect on these plant species.

Attwater's prairie chicken are primarily found in tallgrass coastal prairie habitats within a limited range. Prairie chickens were introduced to the Texas City Prairie Preserve in 1999 but the population failed to establish. There have been no recent Texas City reintroductory releases (USFWS, 2010c). The remaining prairie chickens were moved to a preserve in south Texas. There is no suitable habitat for the prairie chicken in the project area, and the species would not be impacted by the CSRM or ER measures.

Populations of red-crowned parrots have recently been found within urban areas along the Lower Rio Grande Valley such as McAllen, Harlingen, and Brownsville (eBird, 2018a; USFWS, 2011b). It is unlikely that red-crowned parrot habitat would be impacted by CSRM and ER measures; it is anticipated that the project would have no effect on these species.

The Gulf coast jaguarundi and ocelots are small felines that are found within scrubby thorn forests and oak grassland habitats in South Texas. The small mammals are extremely rare and prefer woodlands with thick canopy. The CSRM and ER project footprints do not have the specific habitat requirements needed by the mammals (USFWS, 2013h, 2016b, 2017c). The CSRM and ER measure is unlikely to impact jaguarundi and ocelot habitat, and no effect on the population is anticipated.

Cetaceans such as blue whales, fin whales, humpback whales, sei whales, and sperm whales are usually found in the deeper waters of the Gulf and not usually found within Galveston Bay or near the Gulf coast in nearshore waters (NOAA, 2012). It is anticipated that no effects to cetaceans are anticipated from the project. Leatherback sea turtles are pelagic sea turtles that usually nest on the Virgin Islands, Puerto Rico, and Florida; they are not

typically sighted along the Texas coast and do not typically nest on Texas shores (NPS, 2015b). Leatherback sea turtles are unlikely to occur within the project area (NOAA, 2012; USFWS, 2017c).

Freshwater mussel species such as golden orb, smooth pimpleback, Texas fawnsfoot, and Texas pimpleback are limited to freshwater riverine habitats in the Colorado, Brazos, Nueces, and Guadalupe-Frio drainage basins (Howells, 2014). The CSRM and ER project areas occur only in coastal environments with saline and brackish conditions and do not affect riverine habitats (USFWS, 2011c). It is highly unlikely that the mussel species would occur within the project area; therefore, no effect on the species is expected from the projects.

5.4.4.2.2 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier would consist of floodwalls, levees, surge barrier gate structures, and seawalls, which are expected to impact threatened and endangered species that are found around the Galveston Bay region. The impacts discussed below describe the Federally listed species that might be impacted by the Coastal Barrier system. The Coastal Barrier would result in the loss of 1,521 acres of developed/upland, 850 acres of emergent wetlands, and 2,154 of open water.

During the construction phase, dredging and other marine construction activities in Galveston Bay and along the Houston Ship Channel could potentially impact sea turtles and manatees around the bay. The construction of the surge barrier gates across the bay could impair and prevent manatee and sea turtle migration, feeding, and reproductive behavior between the Gulf and Galveston Bay. Construction can produce underwater vibrations and noise at many different low and high frequencies, which could disrupt marine mammal communication (Peng et al., 2015). During construction, increased traffic with between construction vehicles, ships, and barges through the Houston Ship Channel may increase the likelihood of collisions with slower-moving species such as sea turtles and manatees (Department of Environmental Resources Management, 1995; NOAA, 2017k). The dredging of fill material for levees can injure or kill sea turtles, and increased turbidity can impede foraging ability of visual predators like sea turtles, piping plovers, red knots, and least terns (Greene, 2002). Precautionary measures, such as limiting dredging activity to winter, biological monitoring, and using sea turtle deflecting devices could reduce incidental take of sea turtles and manatees from construction activities (Michel et al., 2013; NMFS, 2018). Construction activity near tidal flats and sand dunes may affect the behavior of overwintering piping plovers and red knots, if present. Construction activities on the beach and tidal areas within the critical habitat may also cause an increase in noise and light, which may disturb individuals, decrease nesting success, and impact foraging for species such as piping plovers, red knots, and sea turtles. Increased artificial lighting on the construction beachfront may potentially disorient nesting and hatching sea turtles. Sea turtles lured towards parking lots, streets, and other developed areas risk dehydration, vehicle collision, and depredation (NOAA, 2014b). Disorientation of nesting female turtles and hatchlings and injury to sea turtles can be avoided by turning off or shielding visible lights facing nesting beaches, switching to low-pressure sodium vapor-lighting or amber-colored lights, tinting windows, and closing the curtains or blinds to cover windows facing the beach (Sea Turtle Conservancy, 2017).

Once the project is complete, the operation of the surge barrier gates may potentially affect sea turtles and shorebirds within the area by changing the hydrology and salinity characteristics of the bay (see sections 5.2.2.2 and 5.2.4). The gate structures may impede movement or strike marine mammals and sea turtles travelling between Galveston Bay and the Gulf (Department of Environmental Resources Management, 1995; NOAA, 2017k). Upon completion, the levee is expected to shield a small amount of light from the bay side of the levee. This may benefit some threatened and endangered species sensitive to light pollution. Piping plover and rufa red knots could benefit from the CSRM since the project would help protect their habitats from coastal storms and RSLR. The completed levee and floodwalls along the coast may limit recreational vehicle access to tidal flats and beach areas on Bolivar Peninsula and Galveston Island, which could potentially decrease shorebird and sea turtle disturbance. The Coastal Barrier is expected to benefit Federally listed species along the Galveston Bay system by protecting critical wetland and coastal shoreline habitat from RSLR and erosive wind and wave forces.

There are potential direct impacts to critical habitat for threatened and endangered species. Piping plover critical habitat is found within the Coastal Barrier system. Physical alterations to piping plover critical habitat can include grubbing, levelling, sediment borrowing, and discharge of fill on loafing, nesting, and foraging areas. Although there is no Federally designated rufa red knot critical habitat within the Coastal Barrier project area, red knots are commonly found on tidal flats, salt marshes, and coastal dunes during the winter months on Galveston Island and Bolivar Peninsula (USFWS, 2017c). They occupy similar habitat to piping plovers and potential impacts may be similar (eBird, 2018a). The Coastal Barrier would directly impact 89 acres of designated piping plover critical habitat at the southern tip of Galveston Island, Unit TX-34: San Luis Pass during construction of the levee barrier (USFWS, 2017c). Portions of critical habitat would be permanently impacted from the footprint of the levee barrier. Adjacent critical habitat would be temporarily impacted by earthmoving activity, placement of fill material, and burial of resources. Impacts to piping plovers can be minimized by avoiding foraging grounds and roosting areas, reduction of oil and gas leaks from vehicles, restricting activities within coastal foredunes, and avoidance of driving within the swash zones (USFWS, 2009). Once completed the levee barrier feature would provide storm protection and shoreline stabilization for piping plover critical habitat.

South Padre Island CSRM Measure

The South Padre Island CSRM measure would be placed on the Gulf side of South Padre Island. It is expected to impact piping plovers, red knots, and sea turtles due to placement of fill material on tidal flats and beach, which could bury foraging and roosting habitat. Construction contracts should include instructions to avoid impacts on threatened and endangered species and their nests from construction-related activities by avoiding nesting season and hatchling season. Dredging of fill material from offshore sources could injure or kill sea turtles and manatees or increase turbidity, potentially impairing feeding efficiency (Greene, 2002). Construction windows will be constrained to time frames when protected and listed species are less likely to be present in the project area; those construction windows will be identified through collaboration with the interagency team. In addition, turtle deflecting devices will also be utilized to avoid impacts (NOAA, 2017k). Construction activity and noise from bulldozers and heavy machinery used to shape the dunes and beach can disrupt piping plovers, least terns, northern aplomado falcons, red knots, and sea turtles foraging, nesting, and roosting behavior (Bottalico et al., 2015; Greene, 2002). Artificial beach-front lighting from construction vehicles that can cause disorientation of nesting

females and hatchlings can be reduced by covering or shielding lights and windows or substituting with alternative bulbs (Sea Turtle Conservancy, 2017). Constructed beach profiles are expected to mimic the natural slope and sand composition (grain size, shell content, etc.) of the beach to promote sea turtle nesting (Brock et al., 2007). Coarse sediments or high in shell content, potentially associated with dredged material, may inhibit shorebird ability to probe and extract macroinvertebrates and food particles from the sand (Greene, 2002); however, beach-quality sand would likely be used for the nourishment. Benthic macroinvertebrates impacted by the placement of fill material are expected to return to pre-construction conditions a year after placement (Michel et al., 2013).

Beach nourishment is expected to benefit sea turtles by restoring eroded beach nesting habitat (Greene, 2002). The South Padre CSRM measure is expected to benefit green, Kemp's ridley, and loggerhead sea turtles that are known to nest on the island (Turtle Island Restoration Network, 2018). Studies have shown no major differences between nourished and non-nourished beaches in the number of eggs per nest, emergence of hatchlings, and survival of young turtles (Greene, 2002). Federally listed shorebirds and sea turtles are expected to benefit from the project since beach habitat would be expanded for nesting, foraging, and roosting habitat.

There is no piping plover critical habitat designated near the South Padre Island CSRM measure (USFWS, 2017c). There are no temporary or permanent impacts to critical habitat anticipated from this measure.

ER Measures

Revetment/Breakwater. The construction and placement of riprap for revetment and breakwater could potentially disturb marine mammals and sea turtles in the water and Federally listed birds nearshore. Movement of construction vehicles and barges with riprap or revetment material along the GIWW could potentially increase the risk of a collision with an animal (NOAA, 2017k). Navigational lighting on revetments or breakwaters may also disorient sea turtles (NOAA, 2014b). There are no known sea turtle nesting sites along the GIWW due to lack of suitable habitats; therefore, impacts to sea turtles from the ER features are not expected (Turtle Island Restoration Network, 2018). Revetments and breakwaters are expected to benefit Federally listed shorebirds such as piping plovers, red knots, and least terns. Breakwater and revetment structure would provide a hard surface for oysters and clams to colonize. Colonized hard structures such as breakwaters can provide habitat for fish, crabs, and invertebrates, which would attract red knots and whooping cranes (see Section 5.4.2.2; Cornell Lab of Ornithology, 2018). Accretion of sand and sediments behind the breakwater structure would increase tidal flat areas for foraging and loafing shorebirds such as piping plovers (USFWS, 1996). Revetment/breakwater ER features would also indirectly benefit Federally listed shorebirds and inland species by providing coastal shoreline protection from erosive wave action from barge traffic or rising sea levels.

The construction of revetments and breakwaters are expected to impact approximately 4 acres of piping plover critical habitat (USFWS, 2017c). The impacts to Unit TX-37: Rollover Pass are expected to be permanent with riprap or revetment structures and placement. However, the breakwater would stabilize the shoreline and prevent further erosion from storms and ship wake. The ER measure is expected to provide a net benefit to critical habitat and undesignated piping plover and rufa red knot habitat by protecting vulnerable habitat from erosion.

Island Restoration. Due to lack of suitable habitat, there are no known sea turtle nesting locations along the GIWW (Turtle Island Restoration Network, 2018). Impacts to sea turtles are not expected to result from island restoration measures. Prey species, such as marine worms, small crustaceans, and small mollusks that piping plovers and red knots rely on may become buried with sediment placement on islands (Michel et al., 2013). These impacts would be temporary as studies have shown that macroinvertebrate species were able to recover quickly following beach disturbance. Other impacts include disruption of shorebirds from construction noise and increased turbidity from the placement of sediments on the island. Turbidity is expected to be localized to the placement area and would quickly disperse or settle down (Greene, 2002). In the long term, piping plovers, red knots, and northern aplomado falcons would benefit from the ER features due to increased island size and stability for foraging, nesting, roosting, and hunting (Greene, 2002; Schreiber and Schreiber, 1978). No long-term effects are anticipated from island restoration ER features.

Marsh Restoration. There are four ER measures that are proposed to restore approximately 1,871 acres of marsh along the Texas Gulf coast. Wetlands are highly productive and provide habitat for many species including endangered whooping cranes and prairie dawn-flower. Potential impacts to Federally listed species would primarily occur during the construction phase when placement of fill, construction vehicle activity, and noise can disturb wildlife and create turbidity (Greene, 2002). Prairie dawn-flowers are primarily found at the base of pimple mounds or in barren areas on slightly saline soils. Avoiding and minimizing the alteration of the hydrology and physical characteristics of these structure should be considered when operating construction vehicles and constructing containment levees for marsh restoration (USFWS, 1989). Post-construction, threatened and endangered species would benefit from the restored wetlands and marshes. Although whooping cranes are not usually found within the area designated for marsh restoration, the improved habitat would provide necessary resources that would support the cranes. A restored marsh would attract blue crabs, and amphibians, and provide cover and nesting habitat for whooping cranes (Cornell Lab of Ornithology, 2018). Overall, restored marsh and wetlands would provide improved habitat for plants and wildlife and a coastal buffer from RSLR and storms.

The marsh restoration ER measure is expected to impact approximately 7 acres of piping plover critical habitat within Unit TX-37: Rollover Pass (USFWS, 2017c). Temporary impacts to critical habitat include bulldozing, placement of dredge material, and burying. No marsh plantings are expected to occur. There are no anticipated permanent impacts to critical habitat from marsh restoration.

Out-year Marsh Nourishment 2065. The proposed out-year marsh nourishment ER features are expected to increase and stabilize wetlands and marshes along the GIWW from RSLR and wave erosion. The measure would consist of construction of a containment levee, placement of fill material within the containment levee, creating sinuous channels and compressing the soil with marsh buggies, and plantings with smooth cordgrass. During the construction phase of the ER measures, construction activity, noise, and turbidity may disturb wildlife within the area. However, effects on Federally listed species are not expected since most out-year marsh nourishment areas are away from critical habitat (USFWS, 2017c). There are no reports of sea turtles, piping plovers, red knots, or whooping cranes reported near the GIWW or marsh nourishment footprints. Piping plovers and red knots are usually found in sandy coastal tidal flats, whooping cranes are normally located near the Aransas NWR, and there is no sea turtle nesting habitat along the GIWW (Cornell Lab of Ornithology, 2018; Turtle Island Restoration

Network, 2018; USFWS, 2018g). After construction is complete, there may be potential foraging and wintering habitat available for whooping cranes (Cornell Lab for Ornithology, 2018).

Out-year marsh nourishment is expected to impact approximately 2 acres of piping plover critical habitat within the Unit TX-37: Rollover Pass tract (USFWS, 2017c). Impacts to the critical habitat would include earth moving, placement of fill material, and burial of vegetation and habitat. The impacts are expected to be temporary, and conditions along the designated critical habitat are expected to improve and return to historic conditions once construction is completed. These ER features are expected to improve and stabilize marsh functionality, which would provide additional resources for the plovers.

Oyster Reef Creation. Approximately 43 acres of oyster cultch would be placed in the subtidal zone. Oyster cultch placement via boat or barge would produce localized turbidity, boat traffic, and construction noise. These actions could temporarily affect Federally listed species but would be limited to the period of construction only (Greene, 2002; Peng et al., 2015). Oyster reefs are not expected to impact sea turtles in the area. Oyster reefs would be placed below the tide line and therefore would not represent an obstacle for navigating sea turtles. Oyster reefs provide habitat and attract a variety of fish, crustaceans, and invertebrates. Piping plovers, red knots, whooping cranes, and sea turtles would directly benefit from additional food resources and improved water quality from oysters (NOAA, 2018f). The overall benefits from oyster reefs are expected to outweigh short-term construction impacts. In addition, oyster reefs also provide shoreline protection from waves, floods, and tides.

Dune/Beach Restoration. The ER feature would include the construction of dunes that would be the same general height and shape as the natural dunes within the vicinity. Northern aplomado falcons are typically found in sand ridges in coastal prairies along the barrier islands (USFWS, 1990). By constructing sand dunes, additional hunting and nesting habitat would be available for aplomado falcons. Sea turtles are known to nest on South and North Padre Islands and therefore would be temporarily impacted by the ER feature. The beach on the north and south side of the Port Mansfield Channel is an important nesting site for Kemp's ridley sea turtles and is a designated critical habitat for piping plovers. It is important that bulldozing and shaping of the beach after nourishment mimics the natural profile. Beach profile and sand composition (grain size, grain shape, and compaction, etc.) are important for sea turtle nesting preferences on nourished beaches. Bulldozing and sediment placement should also be completed before spring nesting season to avoid crushing eggs and disturbing nesting females. Piping plovers, red knots, and other shorebirds may be temporarily disturbed by pipelines, bulldozers, and other construction activities during the placement of sediment material and beach shaping. Sediment composition and shell content of the fill material can also affect foraging efficiency for plovers (Greene, 2002). These ER features would directly impact piping plover critical habitat (USFWS, 2017c). Disturbances to listed species are expected to be short term; the species are expected to return and recolonize beaches and dunes once construction is completed. Restored dunes and beaches are also expected to indirectly benefit threatened and endangered species by protecting coastal habitat and providing a barrier to erosive wave action and RSLR.

Dune and beach restoration is expected to impact approximately 388 acres of piping plover habitat from Unit TX-36: Bolivar Flats and Unit TX-34: San Luis Pass (USFWS, 2017c). Impacts to critical habitat would be temporary and would include construction activities associated with beach nourishment and environmental restoration (e.g.,

placement of dredge material, contouring using bulldozers, and planting of dunes with native species). There are no anticipated permanent impacts to critical habitat associated with the project. Tidal areas and beach habitat would be enhanced and continue to provide foraging, nesting, and loafing habitat for piping plovers.

Summary. The ER measures are expected to have a net positive effect on threatened and endangered species. Beach nourishment, island restoration, oyster reef creation, and marsh restoration features would enhance and improve habitat for Federally listed species. Compared to the No-Action Alternative, the benefits from the ER measures would outweigh potential impacts to sea turtles.

5.4.4.2.3 Bay Rim Alternative

Bay Rim CSRM System

The Bay Rim would consist of surge barrier gates, levee/floodwalls along the bay rim, improvements to the Texas City Hurricane Protection System, and the West Extension of the Texas City Hurricane Flood Protection System. The Bay Rim would result in the loss of 1,371 acres of developed/upland, 399 acres of emergent wetlands, and 564 of open water. The Bay Rim along the west side of Galveston Bay would primarily be constructed along previously developed roadways, levees, railroad ROW, and hard-structure shorelines along Texas City and La Porte.

Sea turtles and manatees may be disturbed by construction activities related to the Bay Rim. Construction noise and turbidity from construction of navigational gates between Hog and Spillmans islands can disturb individuals and limit visibility, potentially affecting foraging and migrating sea turtles and marine mammals within Galveston Bay. It is hypothesized that a salinity difference between the Gulf and the bay may create a barrier to migration (Plataforma, 2008). Nesting habitat for sea turtles would not be impacted since there are no sandy beaches or suitable habitat found along the west side of Galveston Bay (Turtle Island Restoration Network, 2018). According to eBird (2018a), a northern aplomado falcon was sighted at the Texas City Prairie Preserve in 2017 for a few days. Construction noise and activity around the Texas City Prairie Preserve could potentially disturb aplomado falcons and other migratory birds within the area (Bottalico et al., 2015). Construction activity is also expected to disturb populations of Federally listed shorebirds such as piping plovers, rufa red knots, and least terns that have been observed foraging and loafing along the Texas City Dike, Tarpey Park, and Pine Gully Park. Construction noise and turbidity associated with the placement of fill near the bay can inhibit communication between the birds and decrease foraging rates (Bottalico et al., 2015; Greene, 2002). The effects are expected to be localized and temporary (Michel et al., 2013).

After construction, the operation of the surge barrier gates can potentially impede or harm migrating sea turtles attempting to traverse upstream to the San Jacinto River. There are no anticipated impacts to Federally listed birds, mollusks, fish, amphibians, cetaceans, or mammals after the completion of the Bay Rim. A greater portion of the Bay Rim is developed and would impact less wetland and beach habitat.

The Bay Rim would result in less impact to threatened and endangered species and their critical habitat when compared to the Coastal Barrier since much of the area is developed. There are no anticipated impacts to any Federally designated critical habitat for whooping cranes or piping plovers (USFWS, 2017c).

South Padre Island CSRM Measure and ER Measures

Impacts to threatened and endangered species because of the construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.4.4.3 Migratory Birds

The MBTA of 1918 (as amended) extends Federal protections to migratory bird species. Among other activities, nonregulated "take" of migratory birds is prohibited under this Act in a manner similar to the ESA prohibition of "take" of threatened and endangered species. Additionally, Executive Order 13186 "Responsibilities to Federal Agencies to Protect Migratory Birds" requires Federal agencies to assess and consider potential effects of their actions on migratory bird species (including but not limited to, ducks, cranes, geese, shorebirds, hawks, and songbirds) (USFWS, 2017b).

The Galveston Bay system provides many different habitat types such as mud flats, marshes, forested wetlands, and grasslands for migratory birds. Federal wildlife refuges, State parks, and WMAs, and private sanctuaries are destinations for migrating birds and bird watchers. According to eBird data (2018b), more than 330 bird species have been sighted in Galveston County.

5.4.4.3.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

Construction of the Coastal Barrier, the surge barrier gates at Bolivar Roads, the GIWW, Clear Lake, Dickinson Bayou, and Offatts Bayou (Galveston ring levee/floodwall) can temporarily indirectly affect migratory birds. Clearing and grubbing vegetation prior to levee construction can directly harm migratory species and reduce available habitat for roosting and nesting. Any construction clearing activities should be conducted during the fall or winter to minimize impacts to nesting migratory birds, when practicable (USFWS, 2017b). Activity, lighting, and noise during the construction of the levee, gates, and floodwalls can disturb, disorient, and harm migratory birds. Construction noise can mask bird calls and reduce their abilities to communicate. Construction activity near tidal flats and beach areas can displace shorebirds and gulls (Bottalico et al., 2015). Turbidity from dredging activities and sediment placement in the water column can decrease foraging rates and cause birds to relocate to adjacent habitats (Greene, 2002). Migratory birds relocating to adjacent, undisturbed habitats may be forced to compete for resources with other local wildlife. Construction contracts would include instruction to avoid impacts on migratory birds and their nests from construction-related activities.

The completed levees and the surge barrier gates are not expected to directly impact migratory birds. The height of the levees would not interfere with the flight pattern of birds. The changes to the hydrology and salinity of

Galveston Bay when the surge barrier gates are closed may indirectly affect fisheries and the foraging habits of shorebirds (see Section 5.4.2). Migratory birds may benefit from the Coastal Barrier by long-term protection of habitat from coastal storms. The levee on Bolivar Peninsula would maintain the historical coastal dune habitat characteristic and provide nesting habitat for migratory plovers and sandpipers (TPWD, 2018b). Completed levee barriers and floodwalls along the coast could limit recreational vehicular traffic to tidal flat and beach areas, which could limit human disturbance to birds. Once operational, however, lighting could disorient migrating birds and the structures could also increase the risk of bird strikes.

South Padre Island CSRM Measure

The South Padre Island CSRM measure placement area is along a residential and commercially developed beachfront area. The area has been previously disturbed due to human recreation along the beach. This measure can potentially impact migratory birds due to placement area burying foraging and roosting habitats. Benthic macroinvertebrates that plovers and sandpipers feed on are expected to return to pre-construction conditions a year after project completion (Michel et al., 2013). Construction activity and noise from bulldozers and heavy machinery shaping the dunes may disturb roosting and foraging birds (Bottalico et al., 2015). Increased turbidity and sediments in the water column can impede foraging capabilities and cause birds to relocate to adjacent habitats. Impacts to turbidity would be localized and are expected to normalize once dredging and construction is completed (Greene, 2002; Wilber et al., 2010). Beach nourishment every 10 years would cause short-term water-column turbidity during placement activities.

Benefits from the South Padre Island CSRM measure include an expanded shoreline for foraging, nesting, and roosting for migratory shorebirds and coastal habitat buffer from future storm events. Excluding short-term impacts associated with nourishment efforts to the beach every 10 years, no long-term negative impacts are anticipated.

ER Measures

Revetment/Breakwater. In the short term, construction of revetments and placement of breakwaters can disturb migratory birds roosting or loafing within the vicinity (Dufour, 1980). Turbidity within the water column can decrease foraging efficiency of birds (Greene, 2002). Once completed, breakwater and revetment structures can provide hard structures for oyster colonization and habitat for fish, crustaceans, and mollusks, which would provide food for migratory birds such as oystercatchers, sandpipers, and plovers (see Section 5.4.2). The structures would likely be used by birds for staging, loafing, or nesting. The structures would indirectly benefit migratory birds by protecting vulnerable beaches, wetlands, and tidal flats from wave action and erosion. There are approximately 105 miles of revetment and breakwaters associated with the ER measures. The structures would protect marsh, SAV, and oyster reef habitat from eroding, which in turn, would protect marshes, beaches, and other valuable nursing grounds, loafing, and foraging habitat for migratory birds (Swann, 2008). There are no long-term impacts to migratory birds expected from the construction of revetments and breakwaters.

Island Restoration. The islands along the coast are at risk of rising sea levels that will erode shoreline and potentially inundate nesting grounds and foraging habitat used by migratory birds. Possible short-term impacts to

island reconstruction can include increased turbidity from sediment placement and bird disturbance from construction activity. Construction contractors should be careful to avoid placement of material during nesting and chick-rearing season (Greene, 2002). Overall, island restoration is expected to benefit migratory bird species. The expansion and restoration of functionality to islands along the Texas coast can increase available habitat for nesting, foraging, and roosting for migratory birds. The construction of nesting platforms and native shrub plantings can attract birds to establish rookeries on the islands (Schreiber and Schreiber, 1978). There are no long-term impacts expected with the restoration of islands.

Marsh Restoration/Out-year Marsh Nourishment 2065. There are four ER measures that are planned to restore approximately 1,871 acres of wetlands. Marsh is highly productive habitat and can serve as an important stopover area for migratory bird species. Wetland construction is expected to last 8 years. During the periods of construction, migratory birds may be disturbed by human activity and relocate to adjacent habitats (Bottalico et al., 2015). After construction is completed, wetland restoration measures would benefit migratory birds by providing forage, roosting, and nesting habitat for birds (Stewart, 2016). The restored wetlands and marshes would provide an important stopover habitat for migratory birds.

Out-year marsh nourishment features are expected to increase and stabilize vulnerable wetlands along the GIWW from rising sea levels. The measures are designed to nourish existing marsh with fill material and stabilize the fill with plantings of smooth cordgrass and native wetland vegetation. The construction of wetlands would substantially improve migratory bird habitat along the coast (Schreiber and Schreiber, 1978; Stewart, 2016). Construction of containment levees and pumps, placement of fill within the levees, and creating sinuous circulation channels and pond with marsh buggies are expected to disturb and disrupt migratory birds (Bottalico et al., 2015; Michel et al., 2013). Construction of levees and placement of fill would temporarily increase turbidity around the local marsh and within the GIWW. Once the marsh restoration project is complete, the habitat would quickly be recolonized by birds, reptiles, amphibians, and invertebrates (Rewa, 2007). The restored marsh would provide shelter, forage, roost, and nursery habitat for migratory bird species (Stewart, 2016). Once construction of the out-year marsh nourishment features is complete, the out-year marsh nourishment would provide more-productive habitat than the open water.

Oyster Reef Creation. Construction of the oyster reefs are expected to be away from the shoreline and would not affect migratory birds near beach or wetland areas. Placement of oyster reef balls may disturb the bay bottom and create localized turbidity. Turbidity would be temporary, and conditions are expected to normalize after reef construction is complete (Greene, 2002). Oyster reefs can indirectly benefit migratory birds similarly to breakwaters, by providing fisheries, crustacean, and benthic macroinvertebrate habitats, and stabilizing shoreline (see Section 5.4.2). Oyster reefs can provide food for migratory species, such as oystercatchers, godwits, and plovers. In addition, oyster reefs and living shorelines can reduce erosive wave action and protect bird habitat such as rookery islands and marsh (Swann, 2008). There are no anticipated long-term impacts to migratory birds from oyster reef creation.

Dune/Beach Restoration. Shorebirds such as plovers, sandpipers, and terns use beaches and dunes as breeding grounds or overwintering habitat for nesting, foraging, and roosting habitat (TPWD, 2018b). Noise associated

with construction can disturb waterfowl and other migratory birds (Bottalico at al., 2015). Sand dunes are also natural barriers for wave and wind action that could potentially erode the shoreline and fragile habitats (United Nations Environment Programme, 2018). Disturbances to wildlife are expected to be a short-term and wildlife species are expected to return and recolonize beaches and dunes once construction is completed. Benthic macroinvertebrates provide important forage for shorebirds. Dredging impacts to benthic macroinvertebrates can be minimized by using similar grain-sized fill materials and avoiding the placement of fill during peak periods of larval recruitment (Wilber et al., 2010).

Summary. The ER measures proposed are expected to have a net positive effect on migratory birds. In addition to improved coastal resiliency the measures are expected to improve bird habitat and increase productivity. Impacts associated with the measures are expected to be short term and associated with construction. When comparing the ER measures to a No-Action Alternative, the benefits of the project as a coastal barrier against rising sea level and storm surges far outweigh the construction impacts that would be expected.

5.4.4.3.2 Bay Rim Alternative

Bay Rim CSRM System

The section of levees and floodwalls constructed along the west Galveston Bay rim of the Bay Rim is not likely to affect many migratory bird species. The area is largely developed with residential, commercial, and industrial property and is not likely to provide suitable habitat for migratory shorebirds, warblers, and other species. Revetments and bulkheads currently along the bay rim are unlikely to provide suitable habitat for many migratory birds. Gates across Dickinson Bayou and the surge barrier gate across the Houston Ship Channel to Spillman Island could change the hydrology and fisheries communities in Galveston Bay and indirectly affect migratory birds (see Sections 5.2.4 and 5.3.2). Most of the impacts to migratory birds would occur along the West Extension of the Texas City Hurricane Flood Protection System. Most of the Texas City West Extension CSRM measures would be located close to existing roadway, railroads, and levee structures. These areas have been previously fragmented. Construction activity and noise could potentially interfere with migratory birds (Bottalico et al., 2015; Dufour, 1980). Grubbing and clearing vegetation along the levee footprint would remove habitat used by migratory birds for nesting and roosting. Construction contractor should use careful consideration and planning to avoid incidental take of any migratory bird species (USFWS, 2017b).

The Bay Rim would have less of an impact on wetland and upland habitats than the Coastal Barrier. After the construction of the Bay Rim is completed, migratory birds would continue to traverse across the levee barrier. The levee barrier would be routinely maintained: mowed and trees prevented from growing on the structure. This would reduce the amount of habitat available for bird species that prefer trees. Migratory shorebirds and grassland birds would be unaffected from routine maintenance of the levee barrier. No long-term impacts are anticipated from the Bay Rim.

South Padre Island CSRM Measure and ER Measures

Impacts to migratory birds associated with the construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.4.4.4 Essential Fish Habitat

Table 2-25 lists the species that NMFS and the Gulf of Mexico Fisheries Management Council identify in the study area as EFH. The categories of EFH that occur within the study area include estuarine water column, estuarine mud and sand bottoms (unvegetated estuarine benthic habitats), estuarine shell substrate (oyster reefs and shell substrate), estuarine emergent wetlands, seagrasses, and mangroves. EFH and all impacts associated with the project are described in detail in Appendix C-4. The following sections provide a brief summary of the impacts described in the EFH Assessment (see Appendix C-4).

5.4.4.4.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

Impacts from the Coastal Barrier on Federally managed species would be the same as those described in Section 5.3.2.1 and Section 4.2.1 of Appendix C-4.

The reduction of cross-section area at Bolivar Roads could impede the migrations and movements of various life stages of fish into and out of the Galveston Bay system. Tidal amplitude reduction means less of the marsh would be flooded, resulting in a loss of marsh surface area available for aquatic organisms to use as nursery habitat, which could impact Federally managed species and their prey. Turbidity during construction would cause temporary disturbances but is generally localized and short lived. No impacts from the slight decrease in average salinity are expected. Benthic organisms would be removed during construction of the Coastal Barrier but would be expected to recover over time.

No mapped oyster reefs fall in the direct footprint of the Coastal Barrier system; therefore, no direct impacts are anticipated. Water-column turbidity increases that are expected during construction could temporarily affect survival or growth of oysters nearby. Lower salinity regime due to the reduced flow of water into and out of the bay and the longer retention times could indirectly affect oyster reef habitat. No long-term impacts to oyster reefs in the Galveston Bay system are expected.

South Padre Island CSRM Measure

Impacts to Federally managed species would be the same as those described in Section 5.3.2.1 and Section 4.2 of Appendix C-4 and include increased water-column turbidity and sediment placement that would be expected during construction activities. No long-term impacts to the aquatic community are anticipated resulting from the South Padre Island CSRM measure.

ER Measures

Impacts to Federally managed species would be the same as those described in Section 5.3.2.1 and Section 4.2 of Appendix C-4. Bay bottom habitat and open bay habitat would be permanently lost, temporary disturbances to water-column turbidity would occur, but no long-term impacts to Federally managed species are anticipated. Although open bay and bay bottom habitat would be lost resulting from constructing ER features, the habitats created would benefit Federally managed species by attracting fish and invertebrate communities, and structures would protect valuable EFH habitats such as marsh, SAV, and oyster reef habitat from eroding, in turn protecting valuable nursery grounds for the many fish and shellfish species that live within these estuaries. The overall benefits from construction of the ER measures outweigh any short-term construction impacts and work together in the multiple lines of defense strategy to help protect the Texas coast.

5.4.4.4.2 Bay Rim Alternative

Bay Rim CSRM System

Impacts to Federally managed species resulting from construction of the Bay Rim would be similar to those described for the Coastal Barrier Alternative but on a smaller scale.

Direct impacts associated with constructing the Bay Rim would be similar to those described for the Coastal Barrier (see Section 5.3.2.1), with the exception of the smaller open water impacts. The Bay Rim has much less open water impacts compared to the Coastal Barrier. Minimal indirect impacts are anticipated with this alternative. Temporary disturbances to water column turbidity and construction impacts would occur, but turbidity is expected to return to normal once construction is completed. Although no modeling was conducted for the Bay Rim, similar effects to salinity and velocities caused by the Coastal Barrier may be expected. Aquatic organism exchange between upper Galveston Bay and Tabbs/Upper San Jacinto/Burnet bays and Buffalo Bayou could be impeded with construction of the Bay Rim. However, due to this measure being located in the upper portions of Galveston Bay, impacts would not be as great as those seen with the Coastal Barrier, which reduces flow to the entire bay complex. A total of 0.03 acre of oyster reef falls in the direct footprint of the Bay Rim and would be lost resulting from this measure, and impacts would be the same as those described for the Coastal Barrier Alternative.

South Padre Island CSRM Measure and ER Measures

Impacts to Federally managed species resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.4.4.5 Marine Mammals

West Indian Manatee. While the number of manatee migrating into Texas is small, construction activities or the presence of a physical barrier may discourage migrant or stray individuals from taking refuge in Galveston Bay due to similar disturbance concerns outlined above for bottlenose dolphin. In the event of a manatee sighting near the construction zone, mitigation measures should include a plan to immediately report the sighting to the USFWS

and Texas Marine Mammal Stranding Network and to follow the USFWS (2011d) guidelines, "Standard Manatee Conditions for In-Water Work." A more-detailed discussion of potential impacts to manatee are covered in Section 5.4.4.2.

Bottlenose Dolphin. Knowledge of population biology, health status, and critical behavior patterns of marine mammal populations is essential to evaluating impacts from environmental disturbance and anthropogenic activities. Direct threats to bottlenose dolphins from construction and operational activities may include damage caused by noise exposure (permanent or temporary threshold shifts), and collisions with increased vessel traffic and equipment. Additional consequences may initially appear less severe, but occur more frequently and are often more important over the long term on a population level. These may include temporary or permanent changes to habitat availability, behavioral changes affecting energy budgets, changes to physical properties of waters (i.e., decreased salinity), and indirect temporary (e.g., construction) or long-term loss of aquatic habitat, and indirect effects on aquatic prey organisms. The biological significance of these effects depends on links among individual behavioral response, health consequences, and overall vital rates (survivability and reproduction) of the population (Fleishman et al., 2016; New et al., 2013). Importantly, short-term behavioral response to disturbance is not necessarily indicative of long-term population level effects, as there may be no substantial changes to health or vital rates, and conversely, long-term negative population trends may occur even where immediate behavioral reaction of individuals is not evident. Quantifying impacts on a population is further complicated by the need to define case-specific, biologically meaningful effects and tolerable levels of change for the population in question prior to the onset of disturbance (Fleishman et al., 2016).

Potential construction and operational impacts vary based on geographical project location, seasonality, and activity type. Preliminary assessments of impacts of highest concern to marine mammals from construction and operational project activities are categorized below. The types of impacts resulting from each proposed activity would be similar, but the location, extent, seasonality, and impacted stock will vary. As engineering plans develop, impacts to marine mammals at each location of proposed CSRM and ER measures should be specifically evaluated for severity and take potential. Efforts to minimize and mitigate impacts should include consideration of sound mitigating construction techniques and materials, dredging, and vessel traffic protocols, scientifically and statistically sound pre-project studies, and long-term adaptive monitoring of impacted stocks to validate take. Some examples of commonly used mitigation measures to minimize impacts to marine mammals are provided below in the summary table (see Table 5-17).

Noise. Sound plays a critical role in the life of most marine mammals and the impacts of noise are of increasing concern in the aquatic environment. Potential impacts on bottlenose dolphin populations utilizing Texas waters, include 1) the physiological effects of high-intensity sound exposure; 2) masking of biologically important sounds; and 3) behavioral disruptions that may result in a decline in vital rates.

High-intensity sound exposure from pile driving can cause direct physical injury to marine mammals in the form of permanent or temporary threshold shifts. Permanent threshold shifts are a permanent, irreversible increase in the threshold of audibility at a specified frequency, while temporary threshold shifts are a temporary reversible increase in the threshold of audibility at a specified frequency. In addition to direct physiological effects of

acoustic disturbance, anthropogenic noise can mask important sounds used by marine mammals (Clark et al., 2009; Jensen et al., 2009; Nowacek et al., 2007). Dolphins rely heavily on sound for communication, navigation, predator avoidance, and foraging, using both active echolocation and passive listening for detection of prey (Allen et al., 2001; Nowacek et al., 2007; Tyack, 2008). Therefore, increased noise pollution in an important habitat could cause disruption to dolphin activities. Severity of behavioral disruption is often contextual to the acoustic environment and behavioral state of the animals when exposed and may result in 1) effects on energy budgets and critical behaviors such as feeding and socializing; 2) temporary or permanent habitat abandonment; and 3) increased risk of predation, injury, and stranding (Ellison et al., 2012).

Due to the extensive pile driving expected with construction of the surge barrier gates, an in-depth noise assessment would be necessary to map the acoustic environment and the "zone of influence" for potential physical injury and behavioral disruption resulting from project activities. Southall et al. (2007) provide scientific recommendations for structuring noise exposure assessments, and NOAA (NMFS, 2016f) provides additional guidance for applying these recommendations.

Marine mammals are placed into functional hearing groups for determining noise response thresholds based on their hearing frequency range. Bottlenose dolphins are considered "mid-frequency cetaceans," hearing in the range of 0.15 to 160 kilohertz. Underwater noise injury thresholds (permanent threshold shifts) for impact pile driving are 230 dB peak and 185 dB (cumulative sound level, accounting for duration of exposure over a 24-hour period). The permanent threshold shifts threshold is 198 dB for vibratory pile driving. Determination of behavioral disturbance thresholds would depend on establishing levels of background noise in the construction zone. Noise reduction measures are necessary where unmitigated sound levels exceed desired thresholds. The effectiveness of noise mitigation measures is highly site specific and must be chosen carefully and validated based on real-time conditions. Attainable noise reduction levels range from 6 to 20 dB peak sound pressure at a range of frequencies. Engineering plans will be developed to include noise reduction technology to minimize the zone of influence and reduce "take" numbers. Additional mitigation measures that may be used, but are not limited to, include: bubble curtains, double-walled piles, Hydro Sound Dampers, noise mitigation screens, cofferdams, "soft-start" operational procedures, and dolphin exclusion zones (Elmer and Savery, 2014; Reinhall et al., 2015; Stokes et al., 2010; Würsig, Green, and Jefferson, 2000).

Dredging. Noise, vessel activity, sediment suspension, and habitat modification are all concerns surrounding dredging activities with the potential to cause negative consequences to dolphin populations. Pirotta et al. (2013) found that higher intensities of dredging, even in an area of high baseline industrial activity, caused bottlenose dolphins to spend less time in the important foraging site of Aberdeen Harbor, Scotland. While few studies have focused on the effects of dredging on marine mammals, Todd et al. (2015) provide a review of available data and conclude that effects are likely to vary by location and equipment type. Furthermore, they suggest that management procedures such as proper capture and removal of sediment will reduce direct physical effects, with remaining concerns including acoustic masking, short-term behavioral response, and alterations to prey availability. Dredge activities should be planned to avoid sensitive benthic communities and fish spawning seasons to reduce fisheries impacts. Seasonal and/or diurnal timing of dredge activities may be advisable for some locations as an effective mitigation measure.

Increased Vessel Traffic. Vessel traffic is expected to increase temporarily during construction due to vessel-based construction activities. Dolphins are known to change their behavior in response to vessel traffic (Allen and Read, 2000; Bejder et al., 2006; Nowacek et al., 2001; Piwetz and Würsig, 2015). While there are many factors that play into how vessels may affect behavior, a common trend implies that smaller vessels quickly changing speed and direction have more of an immediate behavioral effect than larger vessels on a steady path such as cargo ships. Short-term responses to vessels can range from attraction (bow riding) to changes in behavioral state, dive patterns, and orientation. Repeated vessel disturbance could lead to a change in energy budgets and/or habitat use. Reactions to vessel traffic appear to be highly related to the environment and dolphin behavior, necessitating site-specific observations to validate assumptions made from other studies. Potential mitigation options include controlling the speed of work vessels and providing 'safe' zones outside of the construction area with vessel speed limits.

Physical Barrier. The operational presence of the surge barrier gates has the potential to act as a hindrance to dolphin movements. There is a documented instance where dolphins may have been functionally "trapped" in an area where the only passage was under a low-clearance bridge (Mullin et al., 2015). Operational closing of the gates for emergency hurricane preparations would entirely close off the pass. These closures have a potential for injury, noise disturbance, separation of social groups, effects on prey items, and disruption of foraging. The frequency and duration of maintenance closures and storm-related closures is currently undetermined but would dictate the level of potential disturbance.

Prey Source. Dredging, changes in tidal prism, water quality, and the effects of physical barriers can all impact recruitment through passes by fish and shellfish, which are important prey sources for Texas bottlenose dolphin BSE stocks. Potential impacts to fisheries are discussed in Section 5.4.2. Table 5-15 lists the species most vulnerable to flow constriction and includes many of the most common prey species of bottlenose dolphins. Future modeling of fisheries impacts will be vital to determining impacts to foraging efficiency for the dolphin population.

5.4.4.5.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier Alternative includes construction of surge barrier gates at Bolivar Roads and at inlets to Offatts Bayou, Clear Creek, and Dickinson Bayou. The location and size of the Bolivar Roads reach makes it the most likely structure to impact dolphin populations. The importance of the other bayou habitats is not currently known, but dolphins are likely to utilize these bayous on occasion, and impacts to travel in and out of these areas should be evaluated. Construction sites in upper Galveston Bay may minimize impacts by timing operations to coincide with periods of reduced utilization of these habitats during November to April by dolphins. The extended construction time and geographical extent of pile driving necessary to build the Bolivar Roads reach will make noise an important consideration for marine mammal stocks utilizing this region, as discussed above.

The proposed Bolivar Roads surge barrier gates have the potential to hinder dolphin movements in and out of the inlet. If dolphins are hesitant to pass through the vertical lift gate openings, functional passage may be restricted

to the Houston Ship Channel surge barrier gate where there is the potential for vessel traffic impacts. Where gates are placed at Offatts, Clear Creek, and Dickinson bayou inlets, they may restrict movement in and out of those bayous.

McAlpin et al. (2018) performed hydrodynamic and salinity modeling for the Coastal Barrier at Bolivar Roads. The hydrodynamics at gate locations indicate that the proposed structures have the potential to restrict the flow and limit the volume of water moving in and out of the bay at Bolivar Roads. The velocity magnitudes vary little between with- and without-project conditions. The mean surface and bottom velocity magnitude generally drops when the project is in place, but this change is 0.16 foot per second or less. The change from the without-project condition is greatest in areas at and immediately around the structures. Eddies are also expected on the back-side of the gate structures. Additionally, reduced conveyance of flow through the pass is expected to create a reduction in tidal prism within Galveston Bay.

Increased holding times of water in the bay due to reduced tidal flow results in less turnover of water in the bay, which would affect salinity regimes and increase potential exposure time to bacteria and toxic pollutants introduced from nonpoint source pollution and freshwater runoff. According to McAlpin et al. (2018), "The salinity was analyzed at 23 locations along the Houston Ship Channel and in the surrounding bays. On average, the salinity did not vary by more than 2 ppt between with and without project conditions at any location." Most sites exhibited declines in salinity when compared to the No-Action Alternative for the same time periods (e.g., present and future [2085]). Mean salinity isohaline plots indicate that some areas of the bay that dolphins frequent may already be considered marginal dolphin habitat, dipping below the 11 ppt threshold for at least a portion of the year. Dolphin habitat use and health in these zones could be affected by even a small decrease in salinity under project conditions.

Storm surge reductions in the bay afforded by the Coastal Barrier may provide protection to dolphins residing within the Galveston Bay estuary by reducing the risk of these dolphins being stranded "out of habitat" during a storm.

South Padre Island CSRM Measure

Impacts to marine mammals due to activities for the South Padre Island CSRM measure would be as described above for dredging operations and would be expected to occur during initial construction and renourishment of the measure every 10 years throughout the period of operation. Due to the Gulf coast location of this measure, minor disturbance may be expected for the Western Coastal Stock and possibly the Laguna Madre BSE stock. However, no long-term impacts to marine mammals are anticipated resulting from the South Padre Island CSRM measure.

ER Measures

ER measure impacts to marine mammals are expected to vary based on geographical location, seasonality, and activity type. ER features, including rock breakwaters and marsh restoration that would occur behind these features and out-year marsh nourishment in 2065, incorporate land reclamation where bay bottom habitat and

open-bay habitat would be permanently lost. These losses have the potential to modify BSE dolphin habitat use and ranging patterns in the localized areas where they occur. Noise, dredging, and vessel activity during construction have the potential to cause short-term disruption to dolphin activities and possible temporary habitat abandonment as described above. Suspended sediment should be mitigated using silt curtains to avoid contamination of surrounding bay waters.

ER measures have direct benefits to marine mammals by providing improved water quality and enhanced production of prey organisms such as finfish, squid, and shrimp.

5.4.4.5.2 Bay Rim Alternative

The Bay Rim Alternative includes construction of surge barrier gates at inlets to Offatts Bayou, Clear Creek, Dickinson Bayou, and Tabbs Bay (Houston Ship Channel and San Jacinto River). The importance of these habitats to dolphins is not currently known, but they are likely to utilize them on occasion, and impacts to travel in and out of these areas should be evaluated. Construction sites in the upper bay may minimize impacts by seasonal timing of operations due to reduced utilization of these habitats during November to April by Galveston Bay dolphins. Potential threats and possible mitigation measures are outlined in Table 5-17 below.

South Padre Island CSRM Measure and ER Measures

The effects of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.4.4.5.3 Summary

Table 5-17 presents a summary of the potential impacts and mitigation for Coastal Barrier and Bay Rim alternatives.

5.4.5 Hazardous Wildlife Attractants on or Near Airports

Due to the increasing concern about aircraft-wildlife strikes, the Federal Aviation Administration has implemented standards, practices, and recommendations for holders of Airport Operating Certificates issued under Title 14, CFR Part 139, Certification of Airports, Subpart D (Part 139), to comply with the wildlife hazard management requirements of Part 139. Airports that have received Federal grant-in-aid assistance must use these standards.

When considering proposed dredged spoil, beneficial use features, and mitigation areas, developers must take into account whether the proposed action will increase wildlife hazards. The Federal Aviation Administration recommends minimum separation criteria for land-use practices that attract hazardous wildlife to the vicinity of airports. These criteria include land uses that cause movement of hazardous wildlife onto, into, or across the airport’s approach or departure airspace or air operations area.

Table 5-17
Potential Impacts and Mitigation Summary for the Coastal Barrier and Bay Rim Alternatives

Action	Potential Threat(s)	Possible Mitigation Measures
Pile Driving	• Sound-induced permanent threshold shifts/temporary threshold shifts • Acoustic masking and behavioral disturbance o Habitat abandonment, (*including critical foraging habitat in Bolivar Roads) o Effects on energy budgets o Increased risk of predation, injury and stranding	• Sound mitigation technology o Bubble curtains o Double-walled piles o Noise mitigation screen o Cofferdams o Hydro Sound Dampers • Dolphin exclusion zones • "Soft start" procedures • Seasonal and/or diurnal timing in some locations
Dredging	• Sediment disruption o Increased exposure to contaminants (if present) o Effects on prey • Acoustic masking and behavioral disturbance o Habitat abandonment, (*including foraging habitat in Bolivar Roads) o Effects on energy budgets o Increased risk of predation, injury, and stranding	• Silt curtains • Seasonal and/or diurnal timing in some locations
Vessel Traffic	• Collision, physical injury • Acoustic masking and behavioral disturbance o Habitat abandonment (*including critical foraging habitat in Bolivar Roads) o Effects on energy budgets o Increased risk of predation, injury, and stranding	• Vessel speed limits • "Safe" zones
Physical Barrier and other Actions	• Hindrance of travel in and out of pass* and bayou inlets by bottlenose dolphin • *Water quality consequences o Increased exposure to contaminants (if present) o Reduction of optimal habitat greater than 11 ppt or increased exposure to low-salinity water • Habitat modification and displacement • *Increased tidal flow velocity at gates and decreased overall tidal prism in bay • Potential indirect impacts to primary prey species (e.g., shrimp, drum, flounder) during spawning migrations of adults to the Gulf and as larvae/juveniles immigrating back into estuaries	• Construction and operational measures to minimize impacts should be explored and addressed in engineering plans
In-water ER measures	• Acoustic masking and behavioral disturbance o Temporary habitat abandonment o Effects on energy budgets o Increased risk of predation, injury, and stranding • Sediment disruption o Increased exposure to contaminants (if present) o Effects on prey • Habitat modification/land reclamation	• Vessel speed limits • "Safe" zones • Seasonal and/or diurnal timing in some locations • Silt curtains

* Potential threat only included for the Coastal Barrier Alternative

These separation criteria include:

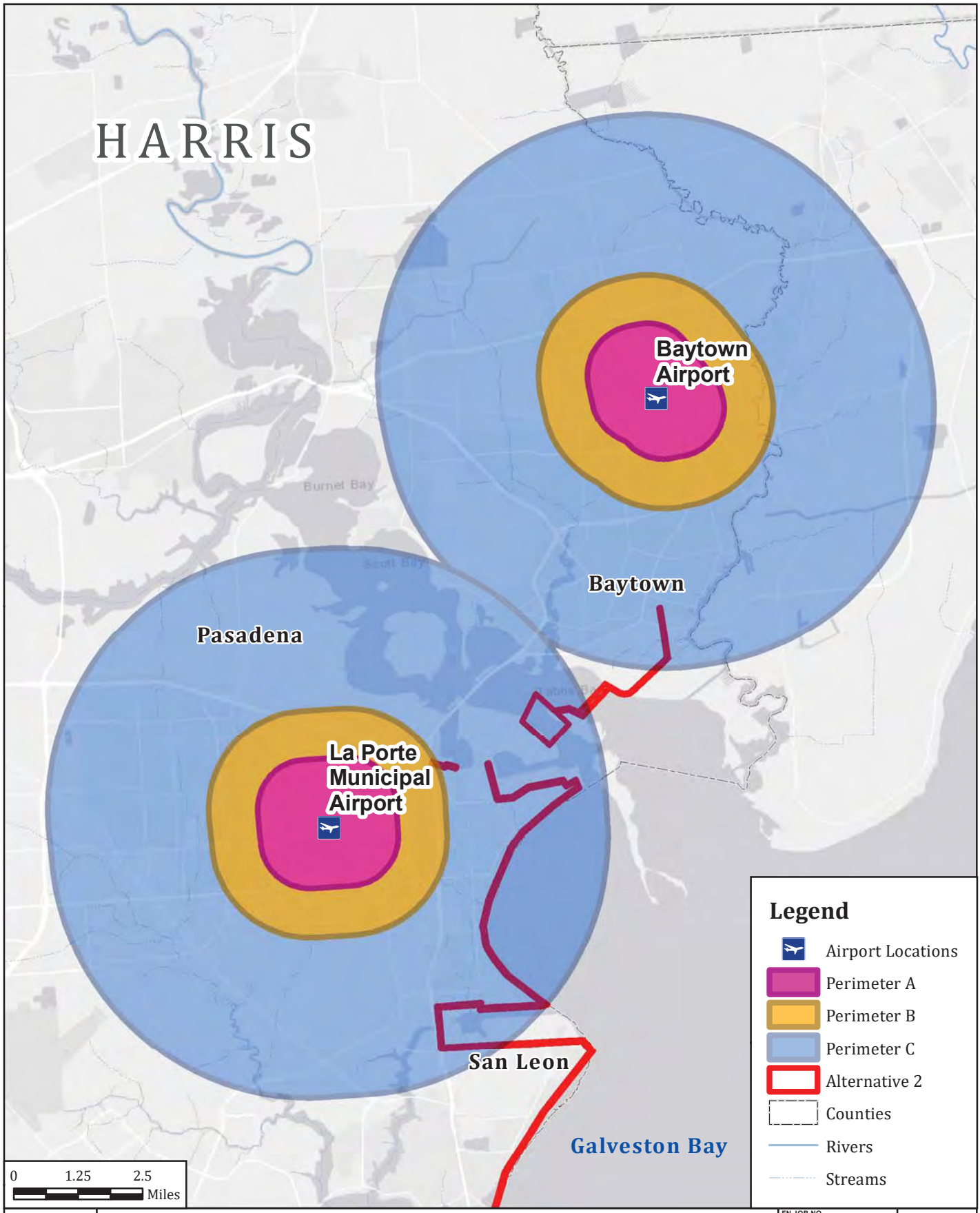
- Perimeter A: For airports serving piston-powered aircraft, hazardous wildlife attractants must be 5,000 feet from the nearest air operations area (includes one airport within the study area);
- Perimeter B: For airports serving turbine-powered aircraft, hazardous wildlife attractants must be 10,000 feet from the nearest air operations area (includes two airports within the study area); and
- Perimeter C: 5-mile range to protect approach, departure, and circling airspace (includes five airports within the study area).

Table 5-18 lists the public-use airports that fall within the study area, which must comply with these standards. Proposed land uses for the Preferred Alternative were evaluated to determine if they could increase wildlife aviation hazards in the study area. The airports in the study area include Baytown, La Porte Municipal, Scholes International, Mustang Beach, McCampbell-Porter, and the Charles R. Johnson (figures 5-8 through 5-11). All six airports sell Jet-A fuel, and it was assumed that a separation distance of 10,000 feet for any of the hazardous wildlife attractants would apply in addition to the 5-mile range to protect approach, departure, and circling airspace. Certain land-use practices, such as waste disposal facilities, water management facilities, golf courses, agricultural cropland, and dredged material placement areas can act as attractants to wildlife that pose a strike hazard. Some natural areas, such as wetlands, may attract wildlife associated with aircraft strikes. According to the Memorandum of Agreement between the Federal Aviation Administration and the USACE, the top five bird groups involved in damage-inducing aircraft strikes are gulls, geese, hawks, ducks, and vultures. In addition, white-tailed deer are by far the most commonly struck mammal species (Federal Aviation Administration, 2003)

Table 5-18
Public Use Airports in the Study Area

Name	Site Number	City	County	Perimeter	Nearby Action	Distance (miles)
Baytown Airport	23412.1*A	Baytown	Harris	C	Alt 2	3.9
La Porte Municipal	24190.*A	La Porte	Harris	C	Alt 2	1.9
Scholes International	23915.*A	Galveston	Galveston	A, B	Alt 1 and 2, ER Galv beach/dune	0.9, 1.1
Mustang Beach	24528.2*A	Port Aransas	Nueces	C	ER Redfish Bay	3.8
McCampbell-Porter	24096.62*A	Ingleside	San Patricio	C	ER Redfish Bay	3.9
Charles R. Johnson	24543.*A	Port Mansfield	Willacy	B, C	ER Port Mansfield, Island Rookery	0.7, 2.1

Project features of the Coastal Barrier and Bay Rim alternatives and the ER measures that could serve as attractants are bird islands, placement areas, and beneficial use marsh restoration areas. There are several project features that could serve as attractants within the separation perimeters of nearby airports.



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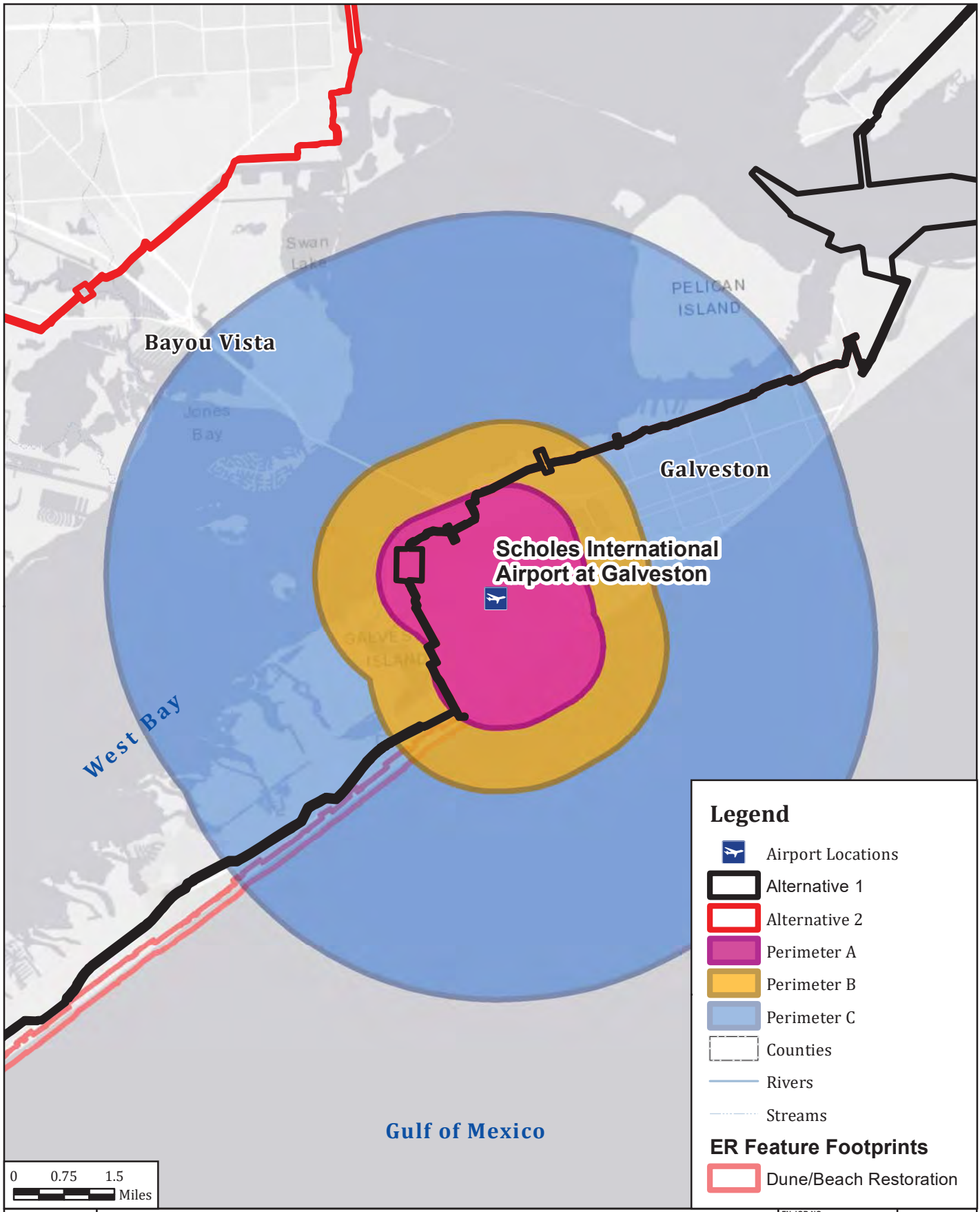
USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Hazardous Widlife Attractants on or Near Airports
La Porte Municipal Airport and Baytown Airport

FN JOB NO	TGL18185
FILE NAME	Figure5_1.mxd
DATE	6/1/2018
SCALE	
DESIGNED	KLC
DRAFTED	02588

5-8
FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



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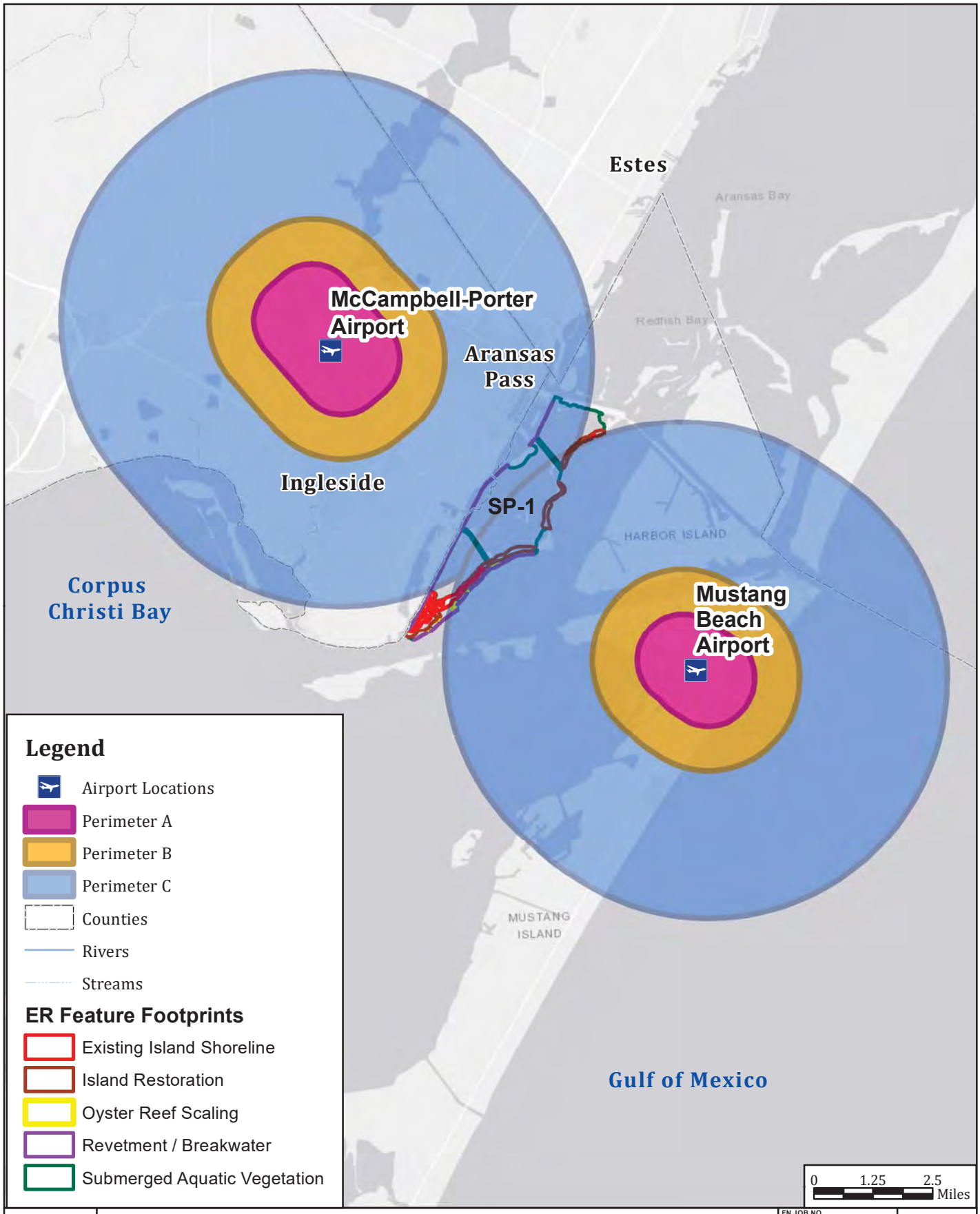
USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Hazardous Widlife Attractants on or Near Airports
Scholes International Airport at Galveston

FN JOB NO	TGL18185
FILE NAME	Figure5_2.mxd
DATE	6/1/2018
SCALE	
DESIGNED	KLC
DRAFTED	02588

5-9
FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



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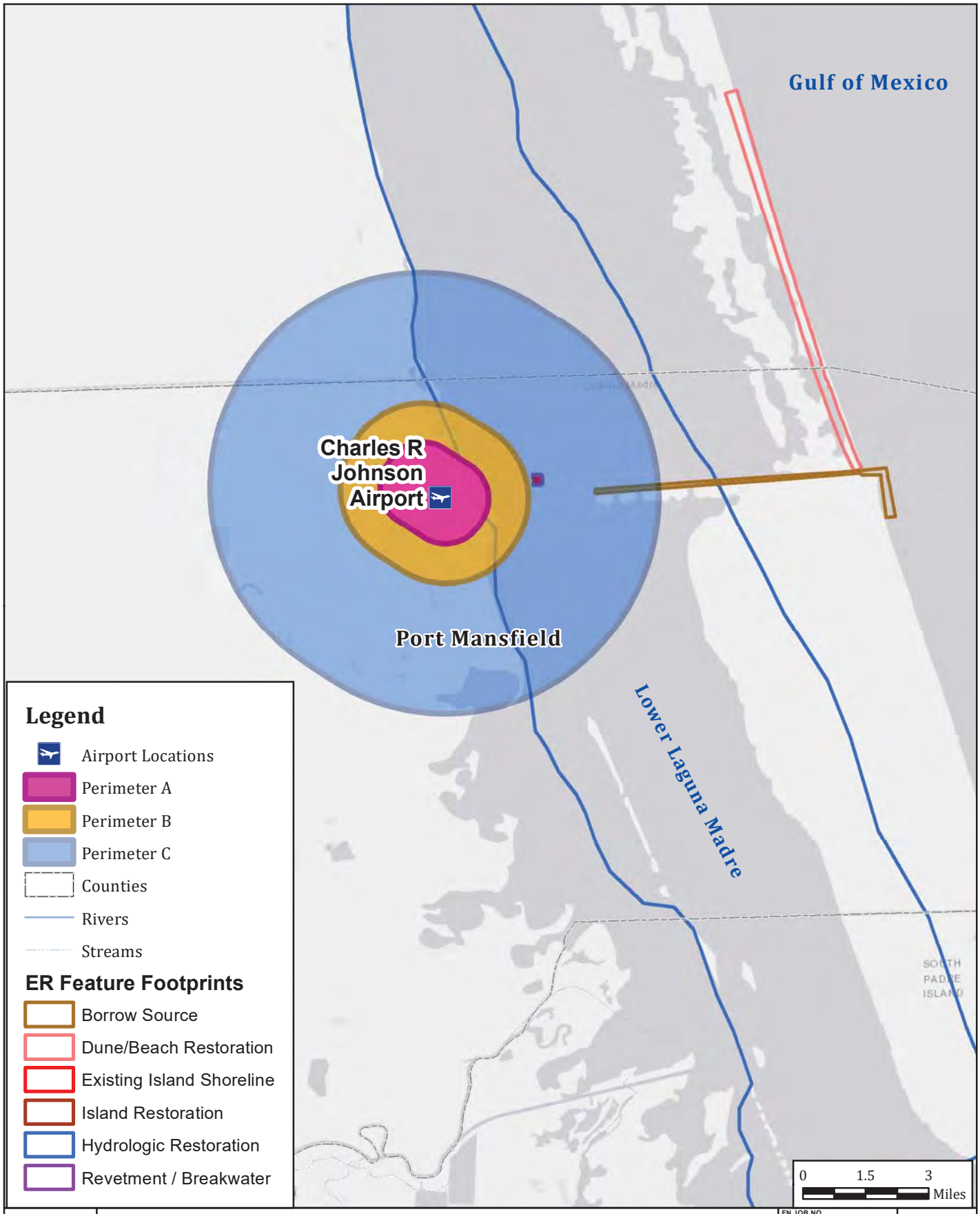
USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Hazardous Widlife Attractants on or Near Airports
McCampbell-Porter Airport and Mustang Beach Airport

FN JOB NO	TGL18185
FILE NAME	Figure5_3.mxd
DATE	6/1/2018
SCALE	
DESIGNED	KLC
DRAFTED	02588

5-10
FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



N

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

Hazardous Widlife Attractants on or Near Airports
Charles R Johnson Airport

FN JOB NO	TGL18185
FILE NAME	Figure5_4.mxd
DATE	6/1/2018
SCALE	
DESIGNED	KLC
DRAFTED	02588

5-11
FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet

The Redfish Bay Protection and Enhancement (SP-1) ER measure is located within the 10,000-foot and 5-mile perimeter of Mustang Beach and McCampbell-Porter airports. In addition, Port Mansfield Channel, Island Rookery, and Hydrologic Restoration (W-3), the goal of which is to improve bird nesting, is located approximately 2.1 miles from Charles R. Johnson Airport, which is between the 10,000-foot and 5-mile perimeters. This project would likely increase the number and species of birds associated with aircraft strikes. Project features for the Coastal Barrier and Bay Rim alternatives and Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration (G-5) ER measure are within the separation buffers of Baytown, Scholes International, and La Porte Municipal airports; however, the infrastructure or action is not expected to serve as an attractant for wildlife species. A copy of the DIFR-EIS and notification letter will be sent to the Federal Aviation Administration.

5.5 CULTURAL RESOURCES

There are over 5,200 recorded prehistoric and historic cultural resources located within the study area. A preliminary assessment of the cultural resources within a broad regional study area over 18,000 square miles of the Texas coast was conducted using a desktop review of the databases maintained by the Texas Historical Commission and the Texas Archeological Research Laboratory for terrestrial and marine cultural resources as well as the shipwreck and obstruction databases of the NOAA and the Bureau of Ocean Energy Management. This search was then narrowed to an area within 1,000 feet of each CSRM measure (Coastal Barrier and Bay Rim, including the South Padre Island CSRM) and within the direct footprint of each ER measure and is considered the project area for the cultural resource discussion below. This assessment identified 210 previously recorded cultural resources including 96 archeological sites, 11 cemeteries, and 88 possible submerged archeological resources. There are also 20 recorded NRHP properties within the project area. These resources are summarized by alternative or measure in tables 5-19 to 5-21.

Table 5-19
Archeological Resources within the CSRM Measures

Coastal Barrier	Bay Rim	South Padre Island
41GV6, 41GV69, 41GV71, 41GV73, 41GV74, 41GV95, 41GV99, 41GV112, 41GV119, 41GV140, 41GV151, 41GV170, 41GV172, 41GV173, 41GV175, 41GV176, 41HR90, 41HR91, and 18 possible submerged archeological sites.	41GV2, 41GV18, 41GV34, 41GV35, 41GV36, 41GV69, 41GV95, 41GV112, 41GV119, 41GV140, 41GV175, 41HR47, 41HR91, 41HR107, 41HR408, 41HR418, 41HR420, 41HR421, 41HR422, 41HR683, 41HR827, 41HR1036, and 39 possible submerged archeological sites.	None

Table 5-20
NRHP Properties within the CSRM Measures

Coastal Barrier	Bay Rim	South Padre Island
Trueheart-Adriance Building, Marschner Building, Pier 19 Mosquito Fleet Berth, Ashbel Smith Building, *ELISSA*, The Breakers, East End Historic District, Fort Travis, The Strand Historic District, Denver Court Historic District, Silk Stocking Historic District, Galvez Hotel, Galveston Seawall, Lost Bayou Historic District	Trueheart-Adriance Building, Marschner Building, Pier 19 Mosquito Fleet Berth, Ashbel Smith Building, S. Ross Sterling House, *ELISSA*, Sylvan Beach Pavilion, Walker House, Morgan's Point Historic District, East End Historic District, The Strand Historic District, Denver Court Historic District, Silk Stocking Historic District, Galvez Hotel, Galveston Seawall, Lost Bayou Historic District	None

Table 5-21
Cemeteries within the CSRM Measures

Coastal Barrier	Bay Rim	South Padre Island
Patton Cemetery, Port Bolivar Community, Simpton, Sun Oil, Flake Atkinson Family, Crenshaw Family, Lakeview, Rosewood	Morgans Point, Seabrook, Beasley, San Leon, Lakeview, Rosewood	None

The primary consideration concerning cultural resources is the threat to archeological and historic sites from construction of CSRM and ER features and the associated staging and borrow areas. Additionally, there is a potential for direct impacts to submerged resources from dredging, the erosion of sites due to landscape modification, and visual impacts to historic buildings, structures, or districts from aboveground construction.

5.5.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier includes a levee/floodwall along Bolivar Peninsula and Galveston Island, improvements to the Galveston seawall, a ring levee around the city of Galveston, and flow control structures across the Houston Ship Channel at Bolivar Roads, Offatts Bayou, Dickinson Bayou, Clear Creek, and the GIWW at High Island. The upland areas along Galveston Island and the Bolivar Peninsula, outside of the city of Galveston, that have not been developed have a moderate to high probability for encountering intact prehistoric and historic archeological sites. Impacts from earth moving, levee/floodwall construction, and staging areas have a potential to impact historic properties in these upland areas. The material used to construct levees will be dredged from offshore in the Gulf, which poses a risk to submerged archeological resources. Within the city of Galveston, the construction of the ring levee and improvements to the Galveston seawall have a potential to impact both the physical aspects of adjacent historic properties and the historic setting, or view shed of historic buildings, structures, and districts. Additionally, there is a moderate to high probability for encountering historic archeological sites within the city of Galveston. Finally, the entrance to Galveston Bay at Bolivar Roads and the entire bay system have been used extensively throughout the nineteenth and twentieth centuries for navigation. The construction of the surge barrier

gates, including flow-control structures and temporary bypass channels, across submerged lands at Bolivar Roads and portions of Galveston Bay has a moderate to high probability to impact submerged archeological resources. The surge barrier gate is also close to Fort Travis, a historic coastal fort built in 1899. However, the conceptual alignment for the levee and barrier was intentionally drawn to avoid any impacts to the fort.

South Padre Island CSRM Measure

The project area along South Padre Island includes the construction of a coastal dune along approximately 4 miles of beach with beach nourishment over subsequent years. The upland areas along this portion of South Padre Island have been extensively developed for residential and commercial use, and there is a low probability for encountering intact archeological deposits. However, there is a potential for encountering shipwrecks along the beach and in the shallow waters adjacent to the beach. Furthermore, beach nourishment material will be dredged from existing offshore dredged material placement areas that have a moderate to high probability for encountering submerged archeological resources, even if they have been previously investigated.

ER Measures

There are nine ER measures proposed along the Texas coast. Although the majority of these areas have not been previously investigated for cultural resources, there are previously recorded cultural resources within the project area (Table 5-22). The impacts from these ER measures include beach nourishment, dune construction, island construction, marsh nourishment, breakwater construction, and oyster reef construction. The probability for encountering intact archeological resources in the upland portions of these ER measures is moderate to high. These archeological resources may consist of prehistoric or historic terrestrial sites that may be exposed on shorelines or shallowly submerged. Activities in these upland areas such as nourishment of marshes and beaches (G-5, G-28, B-2, B-12, M-8, and W-3) are expected to have a minimal impact on the integrity of intact resources. However, beach nourishment material will be obtained by dredging material from offshore and there is a moderate to high potential for impacting submerged archeological sites in those areas. Earth-moving activities in the uplands that involve dune building and modifications to existing islands and landforms (G-5, G-28, B-2, CA-6, M-8, and SP-1) have a potential to adversely affect historic properties. Additionally, some measures include impacts to submerged lands including breakwaters and oyster reefs (G-28, B-12, CA-5, CA-6, M-8, and SP-1), as well as dredging in the Laguna Madre (W-3).

The Area of Potential Effect for the proposed undertaking includes the footprint of all areas of direct impacts and a 1,000-foot buffer for indirect impacts to standing structures or buildings as a result of new construction, construction of staging and access areas, ER features, offshore dredging, and project maintenance activities. Based on the current information for the Coastal Barrier Alternative, there is a potential to affect historic properties. These affects consist of direct impacts to upland and submerged areas, both inshore and offshore, from construction and maintenance of storm and flood risk management features, the construction and maintenance of ER features, and offshore dredging for beach nourishment. The USACE recommends intensive cultural resources investigations to identify and evaluate any historic properties within proposed areas of direct and indirect impacts. The scope of these investigations will be determined in concert with the Texas State Historic Preservation Officer

and Native American Tribes and in accordance with the Draft Programmatic Agreement for this project. The Programmatic Agreement is currently being coordinated with applicable agencies. Once executed, it will be included in future planning and design phases of the project.

Table 5-22
Cultural Resources within Ecosystem Restoration Measures

ER Measure	Archeological Sites	National Register Properties	Cemeteries	Possible Shipwrecks
G-5	3	The Breakers	None	3
G-28	24	None	None	None
B-2	1	None	None	1
B-12	8	None	None	4
CA-5	1	None	None	None
CA-6	1	None	Indianola	None
M-8	16	None	None	None
SP-1	2	None	None	3
W-3	6	King Ranch	Port Isabel	20

5.5.2 Bay Rim Alternative

The Bay Rim includes construction of a levee/floodwall along the western rim of Galveston Bay, improvements to the Galveston seawall, the ring levee around the city of Galveston, and flow control structures across the Houston Ship Channel at Bolivar Roads and the Morgan's Point Cut, Clear Creek, Dickinson Bayou, Offatts Bayou, and the Highland Island Diversion Channel. The western rim of Galveston Bay has seen extensive development for residential, industrial, and commercial use. The potential for encountering intact prehistoric archeological sites is low to moderate. However, there is a moderate to high probability for encountering historic-age buildings, structures, and archeological sites. Impacts from the ring levee and improvements to the Galveston seawall, as well as impacts to submerged lands, are the same as for the Coastal Barrier.

South Padre Island CSRM Measure and ER Measures

Impacts to cultural resources resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.6 SOCIOECONOMICS

5.6.1 Coastal Barrier Alternative

The potential socioeconomic resource impacts with the Coastal Barrier measure and the South Padre Island measure under the Coastal Barrier Alternative would be a reduction in risks associated with damages from hurricane storm surge events to housing units, public facilities, and commercial structures located within areas

where the barrier or dune/beach nourishment would be implemented. These risk reduction measures would allow businesses and industries to resume normal operations in a shorter period following a storm event. There would also be an overall improvement in the health and safety of those residents living within those areas. This would potentially enhance the stability and sustainability of communities located behind the features.

It is anticipated that local building codes would be in place, requiring the elevation of future construction in the area to address impacts from RSLR. As discussed in Section 4.4, the Coastal Barrier Alternative would also include nonstructural measures along the westside of Galveston Bay to address residual damages from wind-driven bay surges. Currently, increasing the elevation of structures is a common approach presently in place by residents and businesses in the study area and would likely be the main focus of nonstructural features to be developed in future planning and design phases. Structure owners could be responsible for ineligible costs associated with the structure elevation, including temporary relocation costs and any costs for moving out of the eligible structure during construction of the nonstructural measures. The ability of lower income groups to participate in the features could be impacted by these out-of-pocket expenses including the costs associated with temporary relocation during structure elevation, and any additional costs that would be required in order to meet the eligibility criteria, (i.e., costs associated with any necessary structural repair or asbestos abatement). This could potentially help offset the risk reduction in overall social vulnerability for lower income communities. These concerns are also reflected in Section 4.3.4.1. As nonstructural measures are further developed in future planning and design phases, additional considerations related to community cohesion and environmental justice concerns in minority populations and low-income populations along the west side of Galveston Bay will be reviewed. Community cohesion and Environmental Justice concerns were less of a concern with the construction of the proposed barrier and dune/beach nourishment features. The construction of the features may have minimal short-term impacts to residences located behind the system, but these impacts would be the same regardless of race or income.

It is not expected that the CSRM measures directly impact public facilities or services; however, when applying nonstructural measures, such as floodproofing or elevating structures, public facilities could have temporarily interrupted services and users could be inconvenience until the project is completed. Indirect impacts would include the reduced risk of damage from hurricane storm surge for public facilities and services.

There would be no substantial direct impacts to the area's transportation infrastructure. Rather, there would be minor temporary impacts in the form of increased vehicular congestion along roads, highways, and streets during construction, which would cease upon construction completion. There would also be a degradation of the transportation infrastructure, primarily local roads and highways, because of the wear and tear from transporting construction materials. Indirect impacts would include a lower risk of storm-related damages to the transportation infrastructure of areas protected by the proposed barrier or dune/beach nourishment.

The ER measures would reduce adverse impacts to socioeconomic resources that are resulting from continued land loss and habitat fragmentation and degradation, especially with regard to the vulnerability of existing transportation (navigation and roads), oil and gas infrastructure, and recreational and commercial fishing opportunities. In the short-term the area's social vulnerability would be reduced, to some extent, by increasing

wetland EFH habitat for aquatic species associated with recreational and commercial fishing. In addition, the proposed action would increase marsh-related leisure and recreational and commercial fishing opportunities thereby having a localized, positive economic impact. The long-term benefits of marsh restoration, shoreline protection, bank stabilization, and beach and dune restorations would improve coastal habitats, which would subsequently improve or slow the loss of leisure and recreation opportunities and contribute to regional economic growth and sustainability.

5.6.2 Bay Rim Alternative

Bay Rim CSRM System

The socioeconomic resource impacts associated with the South Padre Island CSRM and ER measures would be the same as the Coastal Barrier Alternative. However, the location of the Bay Rim would have socioeconomic impacts in the upper coast region.

There is a potential for induced flooding in the communities of Baytown and Santa Fe. Also, many of the structures in the rural areas of the study area (east side of Galveston Bay) and structures along the barriers (west Galveston Island and Bolivar Peninsula), including public facilities and services, would still receive damages from hurricane surges. This leads to future community cohesion impacts and environmental justice concerns. Overtopping of the levee by storm surge during extreme events would immediately inundate vulnerable populated areas and key emergency service routes. This risk is a key concern for communities such as La Porte, Santa Fe, and La Marque, where the Social Vulnerability Index is high and includes a large number of households with low-income, elderly, or minority populations.

The Bay Rim Alternative leaves many of the region's critical roadways at risk. The alignment near the bay rim would have direct impacts to the area's transportation infrastructure. There are notable impacts to the Port Facilities along the bay rim since roadway and railway gates would have to be built to maintain water access. Unlike the Coastal Barrier Alternative, where the barrier is proposed in less-dense residential and commercial areas, the Bay Rim Alternative would include major impacts associated with increased vehicular congestion along roads, highways, and streets during construction. There would also be degradation of the transportation infrastructure, resulting from transporting construction materials on the local roads.

5.7 NAVIGATION

5.7.1 Commercial and Waterborne Commerce

5.7.1.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

The Coastal Barrier would maintain the existing geomorphic features with levee/floodwall systems at Bolivar Peninsula and the west end of Galveston Island, which would allow for continued protection of the GIWW against storm-induced wave and surge effects. The Coastal Barrier is further enhanced with improvements to the

Galveston seawall and construction of surge barrier gates at Bolivar Roads to prevent storm surge from entering into Galveston Bay. Overwash and other storm-related sediment deposition in Galveston Bay would be reduced, potentially reducing future storm-event-driven maintenance dredging requirements of the GIWW. Additional flow control structures of the Coastal Barrier system are proposed for Offatts Bayou, Dickinson Bayou, and Clear Creek.

The Bolivar Roads surge barrier gates consist of surge barrier gates to be closed during storm surge events, but remain open all other times. The proposed surge barrier gates consist of thirty-nine 100-foot-wide gates with sill elevations ranging from –30 feet MLLW to –15 feet MLLW, and the surge barrier gates are proposed to be 1,200 feet wide (total) with a sill elevation of –60 feet MLLW. The surge barrier gates at Clear Creek, Dickinson Bayou, and Offatts Bayou are proposed to each consist of a single opening with a width of 112 feet. Sill elevations are –10 feet MLLW at Clear Creek, –9 feet MLLW at Dickinson Bayou, and –15 feet MLLW at Offatts Bayou.

At Bolivar Roads, the structural elements of the surge barrier gates would reduce the cross-sectional area of the inlet by 27.5 percent, constricting inlet tidal flows, and increase current velocities. Per McAlpin et al. (2018), it is expected that within the inlet the maximum bottom velocities would increase from approximately 4.3 feet per second (FWOP) to 6.2 feet per second (FWP), and the maximum surface velocities would increase from approximately 6.6 feet per second (FWOP) to 8.5 feet per second (FWP). The magnitudes of expected increases in mean bottom and surface velocities between with- and without-project conditions are smaller than the reported maximum velocity changes. Ship simulations will be required to determine if FWOP/FWP changes to the inlet's maximum and mean velocities would impact deep-draft vessel transits through the ship channel.

For the rest of Galveston Bay, the velocity magnitudes vary little between with- and without-project conditions, with the mean surface and bottom velocity magnitude generally decreasing by less than 0.33 foot per second from FWOP to FWP conditions. Therefore, current velocity changes within Galveston Bay induced by the Coastal Barrier system should not impact commercial and recreational navigation.

Construction of the surge barrier gates across Bolivar Roads would require constructing, to the north of the existing channel, a temporary bypass for navigation, with bypass channel geometry of 800 feet width at the toe and –48-foot MLLW depth. The alignment of the bypass channel would cut through the existing anchorage areas, temporarily impacting the utilization of these ship anchorages. Future ship simulation of the bypass channel alignment would ascertain vessel movement impacts and would inform decisions to adjust alignments to reduce impacts.

The USACE (2017a) reported that in 2015 the Houston Ship Channel served the arrival of 8,325 oceangoing vessels including break bulk, bulk carrier, containers, roll-on/roll-off, tankers, tug tow, and vehicle carriers. It is expected inbound transit of a similar number and mix of vessels would continue during and after construction of the surge barrier gates. Risks to navigation safety are expected to increase due to a reduction in vessel operating margin of error associated with the temporary bypass channel constrictions, outbound recreational and commercial vessel traffic, and mobilized construction platforms and constrictions associated with the constructed surge barrier gates and outbound recreational and commercial vessel traffic.

The gate at Dickinson Bayou may induce slight increases in velocity by partially constricting tidal flows, potentially impacting smaller commercial vessels transiting the gates.

Summary. Overall, the potential impacts of deep-draft vessel operation caused by changes to tidal velocities and constricted channel geometries located at Bolivar Roads is offset by a reduction in risk to navigation infrastructure from storm surges. The Coastal Barrier would reduce the probability of overwash sediments being transported into the GIWW, therefore potentially reducing storm-event-driven maintenance dredging requirements.

South Padre Island CSRM Measure

The CSRM measure proposed for South Padre Island is not expected to have a noticeable impact on navigation. The dune/beach fill features of the South Padre Island measure would require sand to construct the features. A possible borrow material source is located within the Brazos Island Harbor Entrance Channel. Harvesting of sediments from the Brazos Island Harbor Channel would beneficially contribute to maintaining the channel's operating depths.

Sediments placed for the dune/beachfill features are expected to migrate northward with the littoral drift, to be impounded by the Port Mansfield immediately south of the jetty. Ultimately, the sediment buildup immediately south of the jetty would migrate into the entrance of the Port Mansfield Channel and add to the shoaling of the channel. The Port Mansfield Channel is a Federally authorized channel eligible for Federal maintenance. Nevertheless, the USACE no longer prioritizes the Port Mansfield Channel for maintenance dredging since the purpose of the channel has evolved over time to become primarily recreational. However, the shoaling of the Port Mansfield Channel contributed by the South Padre Island CSRM measure would be offset by the need to dredge sediments from the channel as an ER measure feature to hydrologically restore Laguna Madre, with the added benefit of renourishing the shoreline of Padre Island National Seashore with dredged material.

ER Measures

Revetment/breakwaters, island restoration, marsh restoration/out-year marsh nourishment 2065, and oyster reef creation would contribute to protecting the GIWW and its barge traffic against wind-induced wave energy. There may be temporary impacts to navigation traffic within the GIWW during mobilization and positioning of floating construction platforms to construct the revetments/breakwaters. The stabilized shoreline systems from the revetment/breakwaters are anticipated to reduce shoaling into the GIWW. The reduction would fluctuate based on location and proximity to inlets and bay/GIWW interconnections. Sediments to restore islands, wetlands, and marshes may be harvested from the GIWW, which would contribute to the long-term maintenance of the waterway's operating depths.

Dune/Beach Restoration. Additional sediments would become available in the natural system and allow natural processes such as reworking, erosion, and deposition to take place and enhance sediment availability for longshore transport. Increase in shoaling through longshore transport can be expected at navigation entrance channels downdrift of ER beach and dune features. Locations of anticipated shoaling increases due to proposed ER beach and dune restoration features include Bolivar Roads and San Luis Pass. An anticipated impact from the Follets

Island Gulf Beach and Dune Restoration (B-2) feature is an increase in shoaling within the entrance channel at Port Freeport resulting from longshore transport. For Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration (G-5), additional volume of sediments would be available for overwash to nourish bay marshes and for redistribution on Bolivar Peninsula and Galveston Island. An increase in shoaling within the GIWW, from these expected overwash events, would induce an increase in maintenance dredging requirements of the waterway.

Hydrologic Restoration. The hydrologic restoration of the Lower Laguna Madre includes the dredging of the Port Mansfield Channel to improve the tidal circulation between the Laguna Madre and the Gulf. Sediments dredged from the Port Mansfield Channel would be beneficially used for island restoration within Laguna Madre and for the nourishment and widening of approximately 10 miles of shoreline along the Padre Island National Seashore starting immediately north of the Port Mansfield north jetty. There may be temporary impacts to navigation traffic within the Port Mansfield Channel during mobilization, positioning, and operation of floating construction platforms to dredge the channel to improve hydrologic connection between the Laguna Madre and the Gulf. Utilizing the Port Mansfield channel as a sediment source for ER restoration measures would contribute to maintaining the channel depths for continued navigation.

Summary. The impacts due to the ER implementation would result in protected, created, and/or restored Gulf and bay island shorelines and marsh fringes. Long-term effects of sediment placement on Gulf shorelines may include increase in shoaling at Bolivar Roads, San Luis Pass, and the Port Freeport Entrance Channel, while decreasing localized shoaling in the GIWW. Temporary impacts to navigation traffic may be experienced during construction of ER measure features, particularly within the GIWW when floating construction platforms are mobilized and operated during construction activities. When compared with the No-Action Alternative, the implementation of the ER measures would have a net positive impact by providing added protection to the GIWW and its barge traffic against wind-induced wave energy.

5.7.1.2 Bay Rim Alternative

Bay Rim CSRM System

The Bay Rim Alternative would not change existing geomorphic features at Bolivar Peninsula and the west end of Galveston Island. Impacts to the GIWW would remain the same as the No-Action Alternative as it relates to navigability and surge effects. With the Bay Rim Alternative in place, overwash and other storm-related sediment deposition in Galveston Bay would also be similar to the No-Action Alternative and hence result in the same storm-event-driven maintenance dredging requirements of the GIWW. The Bay Rim is further enhanced with improvements to the Galveston seawall and surge barrier gates farther in-bay at Tabbs Bay to prevent storm surge from entering into the upper reaches of the Houston Ship Channel. Additional surge barrier gates of the Bay Rim Alternative are proposed for Offatts Bayou, Dickinson Bayou, and Clear Creek, with geometries similar to the gates proposed under the Coastal Barrier Alternative, for the same locations.

The closure structures system for Tabbs Bay crosses Tabbs Bay to Hog Island then to the Spillman Island Placement Area, a distance of 9,870 feet. The Tabbs Bay crossing consists of combi-wall and a series of 100-foot

environmental gates to connect the north bank of the bay with Hog Island. A 3,070-foot crossing at the Houston Ship Channel would consist of combi-wall and a surge barrier gate to accommodate the existing channel width of 530 feet.

McAlpin et al. (2018) reported mean surface and bottom current velocities increased minimally from without- to with-project conditions at locations farther upstream within Galveston Bay for the Coastal Barrier system. Although not modeled, it is anticipated based on the Coastal Barrier system hydrodynamic analysis findings that the Bay Rim measure may induce slight increases in velocity by partially constricting tidal flows within Tabbs Bay and Dickinson Bay with the closure structures system. Ship simulations may be used to determine if FWOP/FWP changes to the Tabbs Bay current velocities would impact deep-draft vessel transits through the inlet's ship channel.

Throughout the rest of Galveston Bay, the velocity magnitudes are expected to vary little between with- and without-project conditions. Therefore, current velocity changes within Galveston Bay induced by the Bay Rim measure should not impact commercial and recreational navigation. The Bay Rim would have impacts on interactions between deep-draft ships and shallow-draft tugs and barges. The navigation channel at Tabbs Bay currently includes a north- and southbound shallow-draft channel adjacent to the deep-draft channel.

To construct the gate structures across the Houston Ship Channel at Tabbs Bay, a temporary bypass channel would first be constructed between the north bank and Hog Island. At Tabbs Bay, risks to navigation safety are expected to increase due to a reduction in vessel operating margin of error associated with the temporary bypass channel constrictions, outbound recreational and commercial vessel traffic, mobilized construction platforms, and permanent constrictions associated with the constructed surge barrier gates and outbound recreational and commercial vessel traffic. To construct the gate structures across Dickinson Bay, a bypass channel or a temporary disruption in access will be necessary. Current users of Dickinson Bay include shallow-draft vessels and some large recreational vessels.

The Bay Rim would leave navigation infrastructure at risk to storm surges, since many of the ports and channels would be outside of the risk reduction system. Storm surge can move large amounts of sediment into the deep-draft navigation channel during an event, adding to the annual cost of maintenance dredging.

Summary. Overall, the potential impacts of deep-draft vessel operation caused by constricted channel geometries located at the Houston Ship Channel in Tabbs Bay is offset by a reduction in risk to navigation infrastructure from storm surges. The Bay Rim would reduce the probability of overwash sediments being transported into the shallow-draft GIWW, therefore potentially reducing storm-event-driven maintenance dredging requirements. However, hurricane storm surges would move large quantities of sediments into the deep-draft navigation channel potentially increasing storm-event-driven maintenance dredging requirements.

South Padre Island CSRM Measure and ER Measures

Impacts to the commercial navigation resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.7.2 Recreational

5.7.2.1 Coastal Barrier Alternative

Coastal Barrier CSRM System

Impacts to recreational navigation would be similar to those described for commercial navigation including temporary bypass channel access, higher velocities, and some constricted access, but accentuated due to generally smaller vessel sizes relative to current velocities. Additional temporary impacts to recreational navigation traffic would be induced by construction of the flow control structures at Clear Creek, Dickinson Bayou, and Offatts Bayou, which are proposed to each consist of a single opening.

South Padre Island CSRM Measure and ER Measures

Impacts to recreational navigation resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.7.2.2 Bay Rim Alternative

Bay Rim CSRM System

Impacts to recreational navigation would be similar to those described for commercial navigation. Additional temporary impacts to recreational navigation traffic would be induced by construction of the flow control structures at Clear Creek and Offatts Bayou, which are both proposed to consist of a single opening. The structure at Dickinson Bay will consist of a navigation gate and environmental gates. The levee proposed along the bay perimeter would temporarily impact availability of recreational piers and permanently change the access from homes requiring stairs or walkovers across the levee to the piers.

South Padre Island CSRM Measure and ER Measures

Impacts to recreational navigation resulting from construction of the South Padre Island CSRM and ER measures would be the same as those described for the Coastal Barrier Alternative.

5.8 FLOOD RISK REDUCTION

5.8.1 Texas City Hurricane Flood Protection Project

Intersection with the Coastal Barrier or Bay Rim Alternatives. Texas City HFPP is part of the Bay Rim Alternative with the line of protection being extended on either end of the current project. There will be no alterations to the Texas City alignment under the Coastal Barrier Alternative. However, the construction of the coastal barrier will increase the robustness of the entire coastal system by reducing coastal storm risk in the area.

5.8.2 Lynchburg Pump Station

Intersection with the Coastal Barrier or Bay Rim Alternatives. No changes or impacts are anticipated to the Lynchburg Pump Station with the construction of the Coastal Barrier or Bay Rim alternatives.

5.8.3 Colorado River Flood Protection at Matagorda

Intersection with the Coastal Barrier or Bay Rim Alternatives. No changes or impacts are anticipated to the Colorado River Flood Protection at Matagorda with the construction of the Coastal Barrier or Bay Rim alternatives. However, the construction of either alternative will increase the robustness of the entire coastal system by reducing coastal storm risk in the area.

5.9 ENVIRONMENTAL CONSEQUENCES SUMMARY

Table 5-23 presents the alternatives comparison table that includes the plan comparison design details and potential impacts to the physical and biological resources evaluation criteria.

5.10 CUMULATIVE IMPACTS

NEPA regulations require that cumulative impacts of a proposed action be assessed and disclosed in an EIS or Environmental Assessment (EA). The Council on Environmental Quality (CEQ) regulations define cumulative impacts as:

> *"…the impacts on the environment which result from the incremental impact of the action (project) 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. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time"* (40 CFR 1508.7).

For purposes of this analysis, cumulative impacts are evaluated if the indirect and direct impacts of the TSP have substantial temporary adverse or positive impacts to the resource, when considering past, present, and reasonably foreseeable future actions. Table 5-23 provides a summary of the direct and indirect impacts of the TSP. Potential impacts of the past, present, and reasonably foreseeable future actions include both potential direct effects (caused by the actions and occurring at the same time and place as the Preferred Alternative), and indirect effects (caused by the action but removed in distance and later in time, and reasonably foreseeable).

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Table 5-23
Alternatives Comparison Table – Potential Impacts to Evaluation Criteria

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
DESCRIPTION	No surge risk reduction would occur in the upper Texas coast in the vicinity of Galveston or in the lower Texas coast along the South Padre Island shoreline.	**Coastal Barrier CSRM Measure**: Includes a CSRM system on the upper Texas coast with a complementary system of nonstructural measures and consists mainly of a barrier system across Bolivar Peninsula, a closure at Bolivar Roads, improvements to the Galveston seawall, and a barrier along the west end of Galveston Island. Additionally, there would be navigation gates, environmental gates, and combi-wall at the Houston Ship Channel, Clear Creek Channel, Dickinson Bayou, Offatts Bayou, and Highland Bayou Diversion Channel. **South Padre Island CSRM Measure**: Approximately 2.2 miles of CSRM dune and beach system (Reaches 3 and 4) would be aligned, parallel to the existing beach and dune system, and would start 2 miles from the Brazos Santiago Pass North Jetty system and end 4.2 miles from the Brazos Santiago Pass North Jetty system. **ER Measures:** Restore, create, protect, and/or enhance habitat suitability along nine locations on the entire Texas coast.	**Bay Rim CSRM Measure**: Includes a CSRM system to potentially avoid a majority of the navigation impacts by focusing on a levee system on the west side of Galveston from Texas City to the Fred Hartman Bridge instead of trying to address surges at the Gulf interface. Consists of a levee, floodwall, highway and railroad gates, and drainage closure structures. Additionally, there would be navigation gates, environmental gates, and combi-wall at the Houston Ship Channel, Clear Creek Channel, Dickinson Bayou, Offatts Bayou, and Highland Bayou Diversion Channel. **South Padre Island CSRM Measure**: Approximately 2.2 miles of CSRM dune and beach system (Reaches 3 and 4) would be aligned, parallel to the existing beach and dune system, and would start 2 miles from the Brazos Santiago Pass North Jetty system and end 4.2 miles from the Brazos Santiago Pass North Jetty system. **ER Measures:** Restore, create, protect, and/or enhance habitat suitability along nine locations on the entire Texas coast.
PLAN COMPARISON DESIGN DETAILS			
Differences			
Approximate Total Length	--	76 miles	79 miles
Total Floodwall and Levee	--	74 miles	79 miles
Total Floodwall	--	20 miles	43 miles
Total Levee	--	54 miles	36 miles
Estimated Quantities (cy) for Levees	--	10,000,000 cy	15,500,000 cy
Estimated Vehicle Gates Required	--	93	138
Estimated Railroad Gates Required	--	4	19
Estimated Drainage Structures Required	--	80	38
Estimated Pump Stations Required	--	5	14
Deep-Draft Navigation Gates Required	--	1	1
Size of Deep-Draft Navigation Gates	--	1,200	1,200
Shallow-draft Gates	--	4	3
Total Pipeline Relocations	--	30	55
Temporary Work Area Easements	--	545 acres	656 acres
Estimated Number Property Tracts Impacted	--	1,709	1,703
Estimated Number Owners	--	1,214	1,423
Comparison			
Comparison of Design Details	--	Complex design only focused on large navigation structure	Complex design due to multiple tie-ins
Construction Schedule and Benefit Assumptions	--	Lower acquisition risk	High acquisition risk
Environmental Impacts	--	High indirect environmental risk (Galveston Bay)	Localized direct and indirect risk (smaller waterbodies)
Potential Induced Flooding	--	Localized manageable risk	Localized to levee tie-in points
Navigation Impacts	--	Potential impacts to deep-draft operation but reduces risk to navigation infrastructure from storm surges	Potential impacts to both deep-draft and shallow-draft operations and navigation infrastructure still at risk from impacts from storm surges
Critical Infrastructure	--	Highway and navigation infrastructure included in the system	Critical highway and navigation infrastructure left out of the system
Relative Sea Level Rise Scenario	--	Limited cost for adaptation (Galveston Bay storage)	Substantial cost for adaptation (floodwall modification)

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
Project Cost	--	Low cost range – high cost range: $14.2 – $19.9 billion	Low cost range – high cost range: $18.2 – $23.8 billion
Net Benefits ($ millions) and Benefit-Cost Ratios	--	Range: High RSLR and Low Cost - Low RSLR and High Cost Without GDP Impacts: $571 – ($294) and 1.8–0.6 With GDP Impacts: $1,192 – $14 and 2.7–1.0	Range: High RSLR and Low Cost - Low RSLR and High Cost Without GDP Impacts: $255 – ($544) and 1.3–0.5 With GDP Impacts: $923 – ($237) and 2.0–0.8
Residual Risk	--	Galveston Bay's storage capacity mitigates risk	Risk from exceedance surge events and rainfall events
DIRECT ECOLOGICAL COVER TYPE ACRES			
Coastal Barrier CSRM			
Palustrine Emergent Wetland (Non-tidal)	--	512.5	227.1
Estuarine Emergent Wetland (Tidal)	--	338.0	172.0
Oyster Reef	--	--	0.035
Open Water	--	2,154.0	564.0
Dune	--	--	--
Supratidal	--	--	--
Intertidal	--	--	--
Developed/Upland	--	1,520.9	1,371.2
Total Footprint	--	4,525.3	2,334.3
South Padre Island CSRM			
Palustrine Emergent Wetland (Non-tidal)	--	--	
Estuarine Emergent Wetland (Tidal)	--	--	
Oyster Reef	--	--	
Open Water	--	358.5	
Dune	--	0.5	
Supratidal	--	2.1	
Intertidal	--	0.1	
Developed/Upland	--	4.6	
Total Footprint	--	365.8	
ER Measures (total acres for all ER measures combined)			
Estuarine Emergent Wetland (Tidal)	--	1,214.4	
SAV	--	3,406.2	
Oyster Reef	--	29.6	
Open Water	--	7,096.0	
Dune	--	1,050.3	
Supratidal	--	725.8	
Intertidal	--	61.0	
Islands/Bird Rookeries	--	147.7	
Developed/Upland	--	1,148.0	
EVALUATION CRITERIA - PHYSICAL RESOURCES			
Geomorphology and Coastal Processes			
Sediment Transport	Increased sediment transport in bays due to increased tidal amplitude and velocities resulting from higher water surface elevation with RSLR	**Coastal Barrier CSRM:** *Indirect*: Reduction of sediment exchange in Galveston Bay due to reduced natural nourishment from storm-induced sediment overwash and smaller tidal prism; Gulfside erosion expected to increase thus increasing nourishment of beaches and dunes **South Padre Island CSRM:** *Indirect*: Sediments placed to construct measure would be transported northward to the Port Mansfield south jetty; beachfill component of feature would provide a source of sediments that would be	**Bay Rim CSRM:** *Indirect*: Reduction of sediment exchange between Galveston Bay and the bay's watersheds expected; overwash during storms, when coupled with ER measures, additional volume of sediments would be available to nourish marshes and the barrier island; increase in shoaling of GIWW from overwash events; increase in storm-induced shoreline erosion along the western edge of Galveston Bay **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
		transported by aeolian processes to beneficially nourish existing and newly constructed dunes by supplying sand for foredune accretion; during storm events, sand would wash over, beneficially redistributing throughout the barrier island **ER Measures:** *Direct*: Increased suspended sediments during construction *Indirect*: The addition of sediment to the system for marsh and sand/dune restoration would increase the overall sediment budget in the system; increased shoaling at Bolivar Roads, San Luis Pass, and Port Freeport Entrance Channel	
Shoreline Change	Increased shoreline erosion due to increased tidal amplitude and velocities resulting from higher water surface elevation with RSLR; prone to future erosion, fragmentation, and loss resulting from continued coastal development and reduced sediment delivery affecting the natural processes to sustain these features	**Coastal Barrier CSRM:** *Indirect*: Increases to Gulfside erosion rates expected because beach/dune and marsh habitat fronting the barrier would experience increased impacts from storms and erosion thus causing an increase in shoreline retreat, especially along Bolivar Peninsula; due to reduced exchange of flow through Bolivar Roads, sediments contributed from the bay to the longshore transport along the Gulf shoreface would be reduced **South Padre Island CSRM:** Sediments used to construct this measure would eventually be transported north by littoral drift and impounded by the Port Mansfield south jetty **ER Measures:** Increased suspended sediments during construction; increased shoaling at Bolivar Roads, San Luis Pass, and Port Freeport Entrance Channel; net positive impact by protecting, creating, and restoring shorelines and marsh fringes	**Bay Rim CSRM:** *Indirect*: Reduced watershed-based sediments transported into Galveston Bay; during storms, scouring expected in from the structure would increase suspended sediments in the bay; with RSLR slight increase in erosional patterns along the shoreline of Bolivar Peninsula due to increased surge; increased shoreline retreat within the non-protected bay rim areas **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Storm Surge Effects	Increased storm surge heights due to increased tidal amplitude and velocities resulting from higher water surface elevation with RSLR	**Coastal Barrier CSRM:** *Indirect*: Storm surge reductions along the northern and eastern sides of Galveston Bay, with slight increases in surges along the southwestern edge of Galveston Bay for a Category 3 storm; storm surge reduced for entire Galveston Bay during Category 4 storm; ring levee not overtopped by surge during a storm **South Padre Island CSRM:** *Indirect*: Acts as a natural barrier to absorb the impact of storm surges and wave attacks to help reduce flooding and damages to inland structures and infrastructure **ER Measures:** *Indirect*: Protect and stabilize existing and restored island shorelines and marsh fringes and would contribute to absorbing storm surges	**Bay Rim CSRM:** *Indirect*: No major differences in maximum storm surge for Category 3 storm; reduction landward on the southwestern portions of Galveston Bay with Category 4 storm; ring levee not overtopped by surge during a storm **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Physical Oceanography			
Tides, Currents, Circulation	Due to higher water surface elevations with RSLR, could increase tidal range, volume of tidal prism, storm surge heights	**Coastal Barrier CSRM:** *Indirect*: Reduces the cross-sectional area of Bolivar Roads by 27.5 percent and tidal prism by 16.5 percent; Houston Ship Channel Entrance Channel would experience an increase in tidal amplitude due to the reduction in flow area at Bolivar Roads and water piling up on the Gulf side of the project features; current velocities are expected to increase slightly; localized circulation changes are expected near the surge barrier gate structures including high velocity magnitudes, eddy formation, and large water surface elevations (McAlpin et al., 2018) **South Padre Island CSRM:** Not expected to have an appreciable impact **ER Measures:** Not expected to have an appreciable impact	**Bay Rim CSRM:** *Indirect*: Tidal prism and amplitude are expected to remain unchanged except near Tabbs Bay where the surge barrier gates are proposed and could be nominally impacted; could be a slight increase in current velocities induced by the gate structures partially constricting tidal flows; localized circulation changes near Tabbs Bay surge barrier gates **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Salinity	Expected to change due to higher water surface elevations with RSLR: increased tidal exchange could increase salinities in some bays; flooding estuaries with Gulf waters	**Coastal Barrier CSRM:** *Indirect*: Salinity expected to be reduced by less than 2 ppt throughout Galveston Bay; due to increased residence time of water in the bay, salinities could remain lower for longer periods; salinities at Clear Creek, Dickinson Bayou, and Offatts Bayou predicted to decrease 1 ppt (McAlpin et al.,	**Bay Rim CSRM:** *Indirect*: Salinities are not expected to differ by more than 0.4 ppt in the bay system and would have the least impact on bay salinities; salinities at Clear Creek, Dickinson Bayou, and Offatts Bayou predicted to decrease 1 ppt (McAlpin et al., 2018)

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
	followed by extended periods of drought could increase salinities, particularly in the middle coast	2018) **South Padre Island CSRM:** No effects on salinities **ER Measures:** *Direct*: Localized and temporary changes during construction of measures G-28, B-12, M-8, CA-5, CA-6, and SP-1 *Indirect*: Hydrologic restoration at W-3 should positively affect salinities in the Lower Laguna Madre by decreasing salinities	**South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Water and Sediment Quality			
	Not expected to be affected; increased flooding from storms may mobilize contaminants and transport them into estuaries; may be affected by treatment of municipal and industrial wastewater and management of nonpoint-source pollution; increase in ocean acidity and reduced oxygen concentrations due to climate change	**Coastal Barrier CSRM:** *Indirect*: Reduced flushing and mixing of Galveston Bay System expected to impact pollutants entering the bay and contribute to low dissolved oxygen levels; increased retention times may increase sediment deposition and development of low dissolved oxygen conditions upstream of the barriers; reduced tidal flushing may alter nutrient balance by reducing phosphorous input into and nitrogen transport out of the bay; increased retention times in developed areas may allow effects of high algal productivity, low oxygen, and potentially harmful algal blooms to be expressed more widely and frequently in these areas of the bay **South Padre Island CSRM:** *Direct*: Localized increases in turbidity at the Gulf associated with dredging and placement; release of low oxygen water, high ammonia, and nutrients at the borrow source location as sediments are dredged but are temporary and localized, ending when dredging is completed **ER Measures:** *Direct*: Temporary and localized increases in turbidity and releases of low oxygen water and nutrients at sediment borrow and beach placement locations experienced every 5 to 10 years; increases in turbidity with construction of ER measures; out-year marsh nourishment or restoration (G-5, B-12, M-8, CA-5, CA-6) may experience more impacts from additional periods of elevated turbidity and depressed oxygen levels associated with extended periods of construction and dredged material placement	**Bay Rim CSRM:** *Indirect*: Intensity, frequency, and severity of impacts may be greater since most of the waste load enters the bay upstream of the Bay Rim, the area for mixing and volume for dilution is reduced, and this area experiences the poorest water quality in the system; most water-quality problems in the western, urbanized portion of the bay's watershed; reduction of heavy metal and chlorinated organic compounds in sediments would be reduced with mixing of Gulf waters; Fish and Shellfish Consumption Advisories are in effect for the Houston Ship Channel and the San Jacinto River from upstream of the Fred Hartman Bridge to the Lake Houston Dam for the San Jacinto River, Upper Galveston Bay, and throughout Galveston Bay; fewer pollutants and potential pathogens would be transported past the surge barrier gates, which could result in improved water and sediment quality downstream **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Hydrology			
	Increased usage for agriculture, municipal, industrial, and commercial sources would diminish reservoir storage and freshwater inflows to coastal bays and estuaries; RSLR and saltwater intrusion into bays, rivers, and creeks causing habitat changes; river flows could be impacted	**Coastal Barrier CSRM:** *Indirect*: Localized impacts where the surge barrier gates connect to the shore that could influence the direction of rainfall runoff and influence water levels at that location; may increase localized flooding upstream and downstream of the surge barrier gates at Offatts Bayou, Dickinson Bayou, Clear Lake, and the GIWW near High Island; the Galveston ring levee would block some rainfall runoff from drainage channels and sheetflow from the watershed into the bay **South Padre Island CSRM:** No effects on hydrology **ER Measures:** *Direct*: If containment levees are built on uplands during construction of marsh restoration and out-year marsh nourishment patterns of sheet flow from rainfall runoff towards the bay could change, but these impacts would be temporary and local only during construction *Indirect*: Localized effects on the direction of flow of rainfall runoff into the bay adjacent to revetments could cause flooding on upstream side of the structure if water exchange is blocked; ER measures would provide an overall positive benefit to the ecosystem	**Bay Rim CSRM:** *Indirect*: Increase localized flooding upstream and downstream of surge barrier gates during extreme rainfall runoff events or water level fluctuations in the bay (extreme high tides or storm-generated waves); rainfall runoff in drainage channels and as sheet flow is expected to be intercepted by the levees and forced into areas not typically inundated or into different channels for additional stormwater runoff; hydrological modifications would be required to channel flood flows to the pump stations **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
Soils (Prime and Other Important Unique Farmland)			
	Continued degradation and loss of soil resources as well as prime and unique farmlands due to RSLR, saltwater intrusion, repeated inundation, tidal wetland conversion to open water, and development	**Coastal Barrier CSRM:** *Direct*: Convert 2.3 acres into a levee barrier, construction activities that will cause impacts include grubbing and clearing, levelling, borrow, and piling fill material; construction access roads and staging areas may temporarily impact additional land *Indirect*: Levees may affect fragmentation, soil compaction, and development; benefit other prime farmlands by providing a buffer and protective barrier against rising sea level and erosive wind/wave action that could potentially wash out prime farmland soils **South Padre Island CSRM:** *Indirect*: Benefit to soils and prime farmlands in the future by providing a storm buffer and protecting soils from erosive wave and wind action **ER Measures:** *Direct*: Convert 1.6 acres to revetment/breakwaters, 0.9 acre for marsh restoration, and 20.4 acres for out-year marsh nourishments; construction during marsh restoration and out-year nourishments of temporary containment levees and placement of fill material could impact prime farmlands around the measure *Indirect*: Overall benefit from shoreline protection, stabilization, providing a buffer area for rising sea level and storm surges, and prevent washing out of soils	**Bay Rim CSRM:** *Direct*: Convert 332 acres located on the west extension of the Texas City HFPS and along the western edge of Galveston Bay *Indirect*: Benefit by providing a buffer and protective barrier against rising sea level and erosive wind and wave action that could potentially wash out prime farmland soils **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Energy and Mineral Resources			
	Subject to increased exposure and reduced protection due to loss of natural shoreline buffers would increase susceptibility of oil and gas infrastructure to rupture or damage	**Coastal Barrier CSRM:** 1,267 oil and gas wells are located within 1 mile with 57 intersecting the footprint; 49 pipelines are located within 1 mile with 36 intersecting the footprint **South Padre Island CSRM:** No oil and gas wells and pipelines are located within 1 mile or intersect the footprint **ER Measures:** 2,826 oil and gas wells are located within 1 mile with 1,223 intersecting the footprint; 164 pipelines are located within 1 mile with 65 intersecting the footprint	**Bay Rim CSRM:** 3,813 oil and gas wells are located within 1 mile with 89 intersecting the footprint; 206 pipelines are located within 1 mile with 103 intersecting the footprint **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Hazardous, Toxic, and Radioactive Waste			
	RSLR and storm surges would increase degradation of natural and man-made protection leaving facilities more susceptible to damage	**Coastal Barrier CSRM:** 112 HTRW sites were identified within 1 mile with 13 intersecting the footprint; half of the sites identified within 1 mile are TCEQ Petroleum Storage Tank sites **South Padre Island CSRM:** 8 HTRW sites were identified within 1 mile with none intersecting the footprint; most of the sites identified within 1 mile are TCEQ Petroleum Storage Tank sites **ER Measures:** 61 HTRW sites were identified within 1 mile with 1 intersecting the footprint; the majority of the sites identified within 1 mile are EPA Facility Registry Service and TCEQ Petroleum Storage Tank sites	**Bay Rim CSRM:** 147 HTRW sites were identified within 1 mile with 8 intersecting the footprint; half of the sites identified within 1 mile are EPA Facility Registry Service and TCEQ Petroleum Storage Tank sites **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Air Quality			
	Continued degradation due primarily to increasing populations, commercialization, industrialization, increased use of motor vehicles, continued oil and gas exploration and refinement operations, and continued loss of	*Direct*: Air contaminant emissions from construction activities would result in temporary and localized impacts on air quality in the immediate vicinity of the project site as they are considered one-time activities; temporary impacts to air quality would continue due to maintenance and renourishment activities; VOC and NOx emissions from these activities can combine under the right conditions to form	*Direct*: Air contaminant emissions from the construction activities associated with this alternative would also result in an increase in emissions above those from the existing inventory of emissions sources in the affected counties; the estimated increase in emissions may also result in corresponding impacts on air quality in the immediate vicinity of the project area; it is anticipated impacts would be less for the Bay Rim

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
	vegetation in wetlands and forests, which may decrease the removal rate of gaseous pollutants from the atmosphere	ozone, possibly increasing the concentration in the region *Indirect*: Minor increase in air contaminant emissions above those for existing emissions sources in Galveston County from operation of the surge barrier gate A General Conformity Determination is required	Alternative than the Coastal Barrier Alternative due to the need for construction of a larger surge barrier gate and the larger area for the Coastal Barrier; temporary impacts to air quality would continue due to maintenance and renourishment activities *Indirect*: Minor increase in air contaminant emissions above those for existing emissions sources in Galveston County from operation of the surge barrier gate A General Conformity Determination is required
Noise			
	Noise generated by existing noise sources (e.g., waterborne transportation, automobile and train transportation, recreation and commercial enterprises, industrial operations, port activities) would continue	**Coastal Barrier CSRM:** *Direct*: Noise impacts to residential, recreational, and worship areas are expected during initial construction of the levee/floodwall and during periodic maintenance activities, these impacts would be temporary; noise impacts from construction of the surge barrier gates at Bolivar Roads are not expected due to the distance from residential and recreational areas; construction of gates at Clear Lake, Dickinson Bayou, and Offatts Bayou, and pump stations would likely result in temporary, short-term noise impacts to a small number of residences nearby *Indirect*: A reduction in noise near noise-sensitive receivers is expected in residential areas, and from a decrease in infrastructure damage and subsequent construction/rehabilitation activities **South Padre Island CSRM:** Same as described for the Coastal Barrier CSRM **ER Measures:** *Direct*: Temporary impacts during construction from equipment to recreational fishermen, boaters, and recreational areas immediately adjacent to the ER areas	**Bay Rim CSRM:** *Direct*: Temporary and minor noise impacts related to construction along the proposed levee/floodway are expected, these impacts would be greater than for the Preferred Alternative due to the length of the features; temporary impacts expected during construction in the developed, urban areas with high concentrations of residences in the cities of Galveston, Hitchcock, Texas City, San Leon, Bacliff, Kemah, Seabrook, and La Porte; temporary impacts during construction of the surge barrier gates and pump stations expected **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
EVALUATION CRITERIA - ECOLOGICAL AND BIOLOGICAL RESOURCES			
Wetlands			
Non-Tidal Wetlands (Freshwater)	Continued loss mainly due to development; also from increased water demand, hydrologic alterations of watersheds and floodplains, population growth, RSLR converting wetlands to a more halophytic plant community	**Coastal Barrier CSRM:** *Direct*: 512.5 acres are expected to be altered or damaged due to construction of this measure; project features to be built on Bolivar Peninsula and Galveston Island would require clearing, grubbing, levelling, and filling of wetland and marsh habitats; during construction the potential for erosion and increased sedimentation could affect water quality and bury/damage adjacent marshes; best management practices would be used to prevent sediment from entering wetlands. *Indirect*: Levees would act as hydrological barriers potentially leading to loss of sheet flow, marsh and wetland degradation, and fragmentation of the ecosystem; marsh habitats located south of the project footprint would be exposed to higher salinities for longer periods during storm events; levee would provide some level of protection to wetlands serving as a barrier from saltwater intrusion during storm events; the cross-sectional constriction at Bolivar Roads would lead to marsh habitats being regularly or seasonally flooded, which could convert wetland areas to ephemeral wetlands or uplands; increased residence time would allow greater dilution of freshwater inflows that could result in a conversion of plant communities and an expansion of freshwater wetlands on the bayside of the structure; 3,375 acres are expected to be indirectly impacted resulting from altered hydrology primarily leading to eventual deterioration of those habitats and will require 7,818 acres of mitigation **South Padre Island CSRM:** No impacts to non-tidal wetlands	**Bay Rim CSRM:** *Direct*: 227.1 acres are expected to be altered or damaged due to construction of this measure, most occurring on private land; during construction the potential for erosion and increased sedimentation could affect water quality and bury/damage adjacent marshes, best management practices would be used to prevent sediment from entering wetlands *Indirect*: Similar to those described for the Preferred Alternative **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
		ER Measures: *Direct*: Increased sedimentation and decreased water quality during construction, dredging, and placement activities would be temporary *Indirect*: Revetment/breakwaters, island restoration, and oyster reef creation would protect marsh complexes from erosion caused by RSLR and increased wave energy from vessel traffic and storms; marsh restoration/out-year marsh nourishments would have an overall benefit by improvement of water quality, flood attenuation, aesthetics, and recreational opportunities, as well as mitigating for RSLR and impacts to coastal infrastructure and ecosystems from storm events	
Tidal Wetlands/Seagrass	Urban and industrial development on the coastline, which would reduce wetland habitat and prevent tidal wetlands from migrating inland. RSLR impacts include changes to hydrology, nutrient inputs, flood or tide timing and intensity. Potential migration inland in response to RSLR, which could result in an increase Current trends of decreases and increases in seagrass would continue. With predicted climate changes, increasing frequency and strength of coastal storms and hurricanes can damage or bury seagrass meadows with sediments at a higher frequency or intensity. It is possible that seagrass could migrate in response to SLR	**Coastal Barrier CSRM:** *Direct*: 338.0 acres are expected to be altered or damaged due to construction of this measure; remaining impacts same as for non-tidal wetlands **South Padre Island CSRM:** No impacts to tidal wetlands **ER Measures:** *Direct*: 1,214.4 acres are expected to be impacted due to construction, dredging, and placement of G-28, B-12, M-8, and CA-6 *Indirect*: Protection of intertidal marsh and seagrass	**Bay Rim CSRM:** *Direct*: 172.0 acres are expected to be altered or damaged due to construction of this measure, most occurring on private lands; remaining impacts same as for non-tidal wetlands **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Aquatic Resources			
Freshwater Habitats and Fauna	Continued loss of freshwater habitats across the coast would continue due to channelization, development, and water demands. RSLR has increased saltwater flooding of coastal freshwater marshes	**Coastal Barrier CSRM:** *Indirect*: Areas upstream of the barrier would have lower salinities and remain fresher for longer periods of time and could allow temporary expansion of freshwater fish, invertebrate, and plant communities into those areas; may reduce access of American eel to the bay system and tributaries, which provide habitat for maturing eel; when salinities are low, the barriers at Dickinson Bay, Clear Lake, and Offatts Bayou may inhibit movement of freshwater fish and shellfish **South Padre Island CSRM:** No impacts to freshwater habitats and fauna **ER Measures:** *Direct*: Possible impacts at measures G-28, B-12, M-8, CA-5, and CA-6 if salinities fall below 8 to 10 ppt during restoration and/or nourishing activities *Indirect*: Breakwaters may create barriers to movement of American eels and alligator gar but are not expected to impair their movement through the estuaries; if salinities are below 8 to 10 ppt, some species of freshwater organisms could be in the marsh and would be impacted by increased turbidity, possible increased temperatures, increased ammonia, and lowered oxygen in the marsh enclosed by the marsh restoration levees	**Bay Rim CSRM:** *Indirect*: Would have the least impact on American eel because they do not utilize habitats in this area; lower salinity conditions expected upstream of the barrier should benefit freshwater organisms; when salinities are low, the barriers at Dickinson Bay, Clear Lake, and Offatts Bayou may inhibit movement of freshwater fish and shellfish **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Estuarine Habitats (Open Bay, Bay Bottom, Oyster Reef, Commercial and Recreational Fisheries)	Climate change stressors (SLR, temperature increases, salinity changes, and wind and water circulation changes), storm severity and frequency, and USACE dredging and maintenance dredging operations would continue to have an impact on the aquatic	**Coastal Barrier CSRM:** *Direct*: Permanent loss of 2,154 acres of open water and bay bottom habitat, the majority at Bolivar Roads; temporary and localized increased turbidity and concentrations of suspended sediments during construction could affect phytoplankton/algal assemblages, disrupt foraging patterns, feeding habits, reproduction, and respiration in benthic organisms and juvenile and adult finfish and shellfish; bay bottom habitat would be lost during construction activities	**Bay Rim CSRM:** *Direct*: Permanent loss of 564 acres of open water and bay bottom habitat, half of that occurring at Fred Hartman Bridge, which would also permanently convert to deeper-water habitat resulting from the underwater footprint needed to construct the surge barrier gates; a total of 0.03 acre of oyster reef falls in the direct footprint of the Bay Rim and would be lost, mitigation for these acres is described in Appendix C-9; impacts associated with construction of the Bay Rim would be similar to

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
	communities. Migration of marsh and SAV could impact fish and shellfish either positively or negatively. Fish species could benefit from larger areas of available habitat if marshes migrate due to RSLR. Oyster reefs would continue their current decline. Maintenance dredging activities would continue to increase water-column turbidity and bury benthic organisms	resulting in permanent loss in some areas and changes in community structure, composition, and function in areas that would be able to recover; construction lasting for extended time periods could cause estuarine habitats and fauna in those areas to take longer to recover to pre-construction conditions; potential long-term direct impacts to fish and shellfish with larval and juvenile life stages that depend largely on passive transport could result from the cumulative impacts of the Coastal Barrier *Indirect*: Bay bottom habitat in areas that can recover will likely see changes in community structure, composition, and function; average of 2 ppt decrease in bay salinities, no adverse effects expected; reduced flow and high velocities through Bolivar Roads could impede the migrations and movements of various life stages of fish into and out of the Galveston Bay system; reduction in tidal amplitude would result in loss of marsh surface area available for aquatic organisms to use as nursery habitat, which could reduce overall populations of fish and shellfish densities in the bay; the slight decrease in salinity could benefit oysters by reducing exposure to oyster predators and pathogens; loss of fish and shellfish larval and juvenile life stage that depend on passive transport could result from 1) reduced numbers entering the bay proportional to the reduced volume flowing into the bay; 2) loss of individuals trapped in eddies that could form on the backside of the gate structures; 3) increased exposure to predation while migrating across the open bay to the marshes due to reduced velocities and increased transport times; and 4) reduced area of accessible marsh caused by reduced tidal amplitude. **South Padre Island CSRM:** *Direct*: A total of 358.5 acres of open water would be impacted; impacts could occur in the Gulf portions of the South Padre Island CSRM measure due to increased water-column turbidity and sediment placement that can be expected during construction activities and would be the same as those described for the Coastal Barrier CSRM; renourishment every 10 years would cause short-term water-column turbidity and impacts to benthos during placement activities; no long-term impacts anticipated **ER Measures:** *Direct*: Permanent loss of 802 acres of open water and bay bottom habitat; impacts associated with bay bottom habitat loss and temporary disturbances to water column turbidity on estuarine habitat and fauna would be the same as those described above for the Coastal Barrier CSRM *Indirect*: Gain of rocky areas provides habitat for oyster colonization and associated biological communities; protection of marsh, SAV, and oyster reef habitat from eroding, protecting nursery habitat; restored marsh habitats and nourishment benefits outweigh initial impacts associated with construction; oyster reef creation expected to protect restored islands, prevent breaching of islands and shorelines, protect SAV, and increase oyster populations	those described for the Preferred Alternative, with the exception of the smaller open water impacts *Indirect*: Minimal impacts are anticipated **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Wildlife Resources			
	Continued human development and encroachment into wildlife habitat, RSLR, and invasive species could decrease species diversity and abundance	**Coastal Barrier CSRM:** *Direct*: Construction activity and noise can potentially disrupt and disturb wildlife behavior and their ability to hear *Indirect*: Construction of the levee barrier would further limit and fragment the wildlife corridors between adjacent habitats from the Gulf-bay side of Bolivar Peninsula and east-west through wetlands and pastures near Anahuac NWR; shorebirds and coastal wildlife would be most impacted by the Coastal Barrier due to the proximity of construction along the Gulf coast; wildlife displaced during construction would recolonize the earthen levee and access corridors to adjacent	**Bay Rim CSRM:** *Direct*: Construction activities and noise could interfere with wildlife behavior and their use of corridors *Indirect*: Levee barrier could potentially fragment the north-south migration corridor of wildlife from West Bay to developed areas north near Hitchcock and FM 2004 **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
		habitat; would benefit in the long-term risk reduction from coastal storms **South Padre Island CSRM:** *Direct*: Construction and fill placement could temporarily increase turbidity and bury productive foraging habitat within the surrounding area; turbidity could potentially inhibit bird foraging; beach bulldozing could cause sand compaction and impact populations of sand and ghost crabs *Indirect*: Would benefit from additional habitat and stabilized shoreline for foraging, nesting, and roosting **ER Measures:** *Direct*: Temporary and localized turbidity increases are expected during construction, dredging, and placement activities for revetment/breakwaters, island restoration, marsh restoration/nourishments, oyster reef creation; during marsh restoration/nourishment construction, wildlife may relocate but would return once complete; noise during construction would disrupt sensitive wildlife *Indirect*: Would benefit by slowing the rate of shoreline erosion for habitats used for foraging, nesting, and roosting; concrete blocks placed for island restoration can impair nesting and foraging habitat; species diversity expected to increase as restored islands mature; restored habitats expected to enhance wildlife habitat	
Protected Resources			
Protected Lands	Continued upland and tidal wetland loss, tidal conversion to open water, land loss, shoreline erosion would occur	**Coastal Barrier CSRM:** *Direct*: The proposed levee system is expected to result in permanent loss of approximately 100 acres of potential wetlands and marshes along the eastern and southern border of Anahuac NWR within the structure footprint and temporary impacts to wetlands and marshes due to construction of access roads and staging sites; approximately 70 acres within Galveston Island State Park are expected to be directly impacted by construction operations including potential grubbing and clearing, levelling, and piling of fill material *Indirect*: Changes to wildlife migration patterns and natural topography and drainage patterns of Anahuac NWR; several Federal, State, and privately owned protected lands within the Galveston Bay region would benefit from the coastal levee protection measures by gaining risk reduction from storm surges and RSLR **South Padre Island CSRM:** No impacts to protected lands **ER Measures:** *Direct*: Approximately 35 acres of the Anahuac NWR, 113 acres of the Brazoria NWR, 13 acres of the Justin Hurst WMA, 68 acres of the San Bernard NWR, and 9 acres of the Big Boggy NWR of bay bottom habitat would be converted to revetment/breakwaters; approximately 31 acres of the Anahuac NWR, 2 acres of the Muddy Marsh Bird Sanctuary owned by TNC, 320 acres of the Brazoria NWR, 15 acres of the Justin Hurst WMA, 130 acres of the San Bernard NWR, and 5 acres of the Big Boggy NWR would be temporarily impacted during marsh restoration activities; approximately 2,500 acres of the Anahuac NWR, 30 acres of the McFarlane Marsh owned by TNC, 6,250 acres of the Brazoria NWR, 2,000 acres of the Justin Hurst WMA, 6,000 acres of the San Bernard NWR, and 1,700 acres of the Big Boggy NWR would be impacted during out-year marsh nourishment activities; approximately 2 acres of bay bottom habitat within the Brazoria NWR would be impacted during oyster reef creation; approximately 70 acres of McFaddin NWR, 330 acres of Anahuac NWR, 20 acres of Bolivar Flats Shorebird Sanctuary, 130 acres of Galveston Island State Park, and 1,400 acres of the Padre	**Bay Rim CSRM:** *Direct*: No protected lands fall within the footprint of this measure *Indirect*: Water velocities could potentially increase near the structures and decrease exchange into and out of Galveston Bay, which could increase erosional effects along the northern portion of Atkinson Island WMA; San Jacinto Battleground and Battleship Texas State Historic site may experience inundation and drainage issues when the gates are closed during storm surge events **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
		Island National Seashore would be temporarily impacted during dune/beach restoration activities *Indirect*: Restored marsh habitats and created oyster reefs would provide numerous benefits including improvement of water quality, flood attenuation, aesthetics, and recreational opportunities, as well as mitigating for RSLR and impacts to coastal infrastructure and ecosystems from storm events; out-year marsh nourishment features would provide a long-term approach to enhance resiliency of coastal communities and improve our capabilities to prepare for, resist, recover, and adapt to coastal hazards	
Threatened and Endangered Species	RSLR, shoreline erosion, and loss of coastal prairie would reduce sea turtle, piping plover, rufa red knot habitat and Attwater's prairie chicken habitat	**Coastal Barrier CSRM:** *Direct*: Construction activities could impair and prevent manatee and sea turtle migration, feeding, and reproductive behavior between the Gulf and Galveston Bay; underwater noise could disrupt marine mammal communications; dredging of fill material for levees can injure or kill sea turtles, and increased turbidity can impede foraging ability of visual predators like sea turtles, piping plovers, red knots, and least terns; construction activity near tidal flats and sand dunes may affect the behavior of overwintering piping plovers and red knots; construction activities on the beach and tidal areas within the critical habitat may also cause an increase in noise and light, which may disturb individuals, decrease nesting success, and impact foraging for species such as piping plovers, red knots, and sea turtles; artificial lighting on the construction beachfront may potentially disorient nesting and hatching sea turtles; critical habitat for piping plover could be altered by grubbing, levelling, sediment borrowing, and discharge of fill on loafing, nesting, and foraging areas; 89 acres of designated piping plover critical habitat would be directly impacted; portions of critical habitat would be permanently impacted from the footprint of the levee barrier *Indirect*: Operation of the surge barrier gates may potentially affect sea turtles and shorebirds within the area by changing the hydrology and salinity characteristics of the bay; gate structures may impede movement or crush manatees, marine mammals, and sea turtles travelling between Galveston Bay and the Gulf; the levee is expected to shield a small amount of light from the bayside that may benefit species sensitive to light pollution; the measure could benefit piping plover and rufa red knots by protecting their habitats from coastal storms and RSLR; may limit recreational vehicle access to tidal flats and beach areas on Bolivar Peninsula and Galveston Island, which could potentially decrease shorebird and sea turtle disturbance; benefit Federally listed species along the Galveston Bay system by protecting critical wetland and coastal shoreline habitat from RSLR and erosive wind and wave forces **South Padre Island CSRM:** *Direct*: Piping plovers, red knots, and sea turtles impacted due to placement of fill material on tidal flats and beach, which could bury foraging and roosting habitat; dredging of fill material from offshore sources could injure or kill sea turtles and manatees or increase turbidity, potentially impairing feeding efficiency; construction noise can disrupt piping plovers, least terns, northern aplomado falcons, red knots, and sea turtles foraging, nesting, and roosting behavior; lighting from construction vehicles can cause disorientation of nesting female sea turtles and hatchlings *Indirect*: Constructed beach profiles are expected to mimic the natural slope and sand composition to promote sea turtle nesting; restoration of eroding beach would benefit sea turtle nesting habitat **ER Measures:** *Direct*: Construction and placement for ER measures could	**Bay Rim CSRM:** *Direct*: Impacts to sea turtles and marine mammals would be the same as those described for the Coastal Barrier CSRM; a salinity difference between the Gulf and bay may create a barrier to migration of sea turtles; construction noise and activity could impact the northern aplomado falcon and other migratory birds around the Texas City Preserve; construction noise and turbidity associated with the placement of fill near the bay can inhibit communication between the birds and decrease foraging rates *Indirect*: Operation of the surge barrier gates can potentially impede or harm migrating sea turtles attempting to traverse upstream to the San Jacinto River; would result in less impacts to threatened and endangered species and their critical habitat than the Coastal Barrier. **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
		potentially disturb marine mammals and sea turtles in the water and Federally listed birds nearshore, increase the risk of collision with an animal, noise disturbances to shorebirds and nesting sea turtles; piping plover critical habitat to be impacted at Rollover Pass includes 4 acres for revetments/breakwaters, 7 acres for marsh restoration, and 2 acres for out-year marsh nourishment; dune/beach restoration is expected to impact 388 acres of piping plover critical habitat at Bolivar Flats and San Luis Pass *Indirect*: Benefit shorebirds such as piping plovers, red knots, and least terns by providing habitat for prey items, provide shoreline protection from erosion wave action from barge traffic, rising sea levels; accretion of sand and sediments behind the breakwater structure would increase tidal flat areas for foraging and loafing shorebirds such as piping plovers; increased island size would increase stability for foraging, nesting, roosting, and hunting; restore 1,871 acres of highly productive marsh that would provide habitat for many species including endangered whooping cranes and prairie dawn-flower	
Migratory Birds	Population increase, development, and RSLR would continue to encroach on wetlands and marshes, which provide habitat and resources for migratory birds as they overwinter or stopover along their migration routes	**Coastal Barrier CSRM:** *Direct*: Clearing and grubbing vegetation prior to levee construction can harm migratory species and reduce available habitat for roosting and nesting; activity, lighting, and noise during construction can disturb, disorient, and harm migratory birds; increased water column turbidity during construction can decrease foraging rates and cause birds to relocate to adjacent habitats *Indirect*: Changes to the hydrology and salinity of the Galveston Bay when the surge barrier gates are closed may indirectly affect fisheries and the foraging habits of shorebirds; would benefit from the long-term protection of habitat from coastal storms; completed levee barriers and floodwalls along the coast can limit recreational vehicular traffic to tidal flat and beach areas, which can limit human disturbance to birds **South Padre Island CSRM:** *Direct*: Potential impacts during placement area burying foraging and roosting habitats; benthic organisms they feed on would be disturbed during construction but return to pre-construction conditions once the project is complete; construction activity and noise may disturb roosting and foraging birds; increased turbidity and sediment in the water column during construction can impede foraging capabilities and cause birds to relocate to adjacent habitats *Indirect*: Benefit from expanded shoreline for foraging, nesting, and roosting for migratory shorebirds and coastal habitat buffer from future storm events **ER Measures:** *Direct*: During construction increased turbidity and noise can decrease foraging efficiency of birds and displace and disturb birds *Indirect*: Benefits by protecting vulnerable beaches, wetlands, and tidal flats from wave action and erosion in turn increasing available habitat for nesting, foraging, and roosting for migratory birds; measures would increase available habitat for nesting, foraging, and roosting for migratory birds	**Bay Rim CSRM:** *Direct*: Construction activity and noise could potentially interfere with migratory birds; grubbing and clearing vegetation along the levee footprint would remove habitat used by migratory birds for nesting and roosting *Indirect*: Could change the hydrology and fisheries communities in Galveston Bay and indirectly affect migratory birds **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Marine Mammals	Continue to be exposed to environmental conditions, habitat, resources, and stressors as modified by increased human populations, urbanization, and different climatic conditions. The major additional factors that may influence dolphin stocks are climate change	**Coastal Barrier CSRM:** *Direct*: Noise from pile driving during construction can cause direct physical injury to marine mammals in the form of permanent or temporary threshold shifts; anthropogenic noise can mask important sounds used by marine mammals; increased noise pollution in an important habitat could cause disruption to feeding and socializing behaviors, temporary or permanent habitat abandonment, and increased risk of predation, injury, and stranding; noise, vessel	**Bay Rim CSRM:** Same as the Coastal Barrier CSRM except for impacts directly described at Bolivar Roads **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
	stressors (SLR, temperature increases, salinity changes, and wind and water circulation changes) and projected water demand that would reduce freshwater inflows	activity, sediment suspension, release of toxic compounds (if present in the sediment), and habitat modification from dredging are all concerns surrounding dredging activities with the potential to cause negative consequences to dolphin populations; increased vessel traffic during construction can cause changes in behavioral state, dive patterns, and orientation *Indirect*: Potential to hinder dolphin movements in and out of Bolivar Roads and bayous with the physical barrier of the surge barrier gates; tidal flow is known to influence dolphin movements and foraging patterns; dolphin habitat use and health in these zones could be affected by even a small decrease in salinity under project conditions; storm surge reductions in the bay may provide protection to dolphins residing within the Galveston Bay estuary by reducing the risk of these dolphins being stranded "out of habitat" during a storm; impacts to prey species of marine mammals can impact prey availability for marine mammals **South Padre Island CSRM:** *Direct*: Same as those described for the Coastal Barrier CSRM for dredging operations and during renourishment cycles *Indirect*: Minor disturbances may be expected for the Western Coastal Stock and possibly the Laguna Madre bay, sound, and estuary stock **ER Measures:** *Direct*: Noise, dredging, and vessel activity during construction have the potential to cause short-term disruption to dolphin activities and possible temporary habitat abandonment as described for the Coastal Barrier CSRM *Indirect*: Potential to modify bay, sound, and estuary dolphin habitat use and ranging patterns in the localized areas where they occur; benefits to marine mammals by providing improved water quality and enhanced production of prey organisms	
Essential Fish Habitat	Climate change stressors (SLR, temperature increases, salinity changes, and wind and water circulation changes), storm severity and frequency, and USACE dredging and maintenance dredging operations would continue to have an impact on the aquatic communities. Migration of marsh and SAV could impact fish and shellfish either positively or negatively. Fish species could benefit from larger areas of available habitat if marshes migrate due to RSLR. Oyster reefs would continue their current decline. Maintenance dredging activities would continue to increase water-column turbidity and bury benthic organisms	**Coastal Barrier CSRM:** Impacts would be the same as those described for Estuarine Habitats **South Padre Island CSRM:** Impacts would be the same as those described for Estuarine Habitats **ER Measures:** Impacts would be the same as those described for Estuarine Habitats	**Bay Rim CSRM:** Impacts would be the same as those described for the Coastal Barrier Alternative but on a smaller scale **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative
Cultural Resources			
	Submerged cultural resources would continue to be at risk from future dredging activities, shifting bars, and wave damage for shallow sites and from high-energy storms that can dislodge wrecks from the seafloor or impact wrecks on beaches or in shallow water Upland historic and prehistoric sites would	**Coastal Barrier CSRM:** *Direct*: Moderate to high probability for encountering intact prehistoric and historic archeological sites in upland areas along Galveston Island and Bolivar Peninsula; greatest threat from construction and associated staging and borrow areas; impacts to submerged resources from dredging, the erosion of sites due to landscape modification, and visual impacts to historic buildings, structures, or districts from aboveground construction; moderate to high probability of encountering sites throughout the project area; moderate to high probability for encountering historic archeological sites within the city of Galveston	**Bay Rim CSRM:** *Direct*: Low to moderate potential for encountering intact prehistoric archeological sites along the western rim of Galveston Bay; moderate to high probability for encountering historic-age buildings, structures, and archeological sites **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
	continue to be at risk from shoreline erosion and commercial, industrial, and residential development	**South Padre Island CSRM:** *Direct*: Low probability for encountering intact archaeological deposits; potential for encountering shipwrecks along the beach and in the shallow waters adjacent to the beach; beach nourishment material will be dredged from existing offshore dredged material placement areas that have a moderate to high probability for encountering submerged archeological resources **ER Measures:** *Direct*: Moderate to high probability of encountering intact archaeological resources in the upland portions; beach nourishment material will be obtained by dredging material from offshore and there is a moderate to high potential for impacting submerged archeological sites; potential to adversely affect historic properties during construction activities in upland areas	
Socioeconomics			
	Population expected to increase, which would increase employment, business, and industrial activity; increased potential for flood damage to structures due to RSLR; critical infrastructure, community cohesion, and other social effects at greater risk from hurricane storm surge and RSLR	*Direct*: Construction of the features may have minimal short-term impacts to residences located behind the system, but these impacts would be the same regardless of race or income; temporary impacts in the form of increased vehicular congestion along roads, highways, and streets during construction, which would cease upon construction completion *Indirect*: Reduction in risks associated with damages from hurricane storm surge events to housing units, public facilities, and commercial structures; overall improvement in the health and safety of those residents; community cohesion and Environmental Justice concerns were less of a concern with the construction of the proposed barrier and dune/beach nourishment features; public facilities could have temporarily interrupted services and could inconvenience users until the nonstructural measures are completed; reduce adverse impacts that are resulting from continued land loss, and habitat fragmentation and degradation especially with regard to the vulnerability of existing transportation (navigation and roads), oil and gas infrastructure, and recreational and commercial fishing opportunities; social vulnerability would be reduced by increasing wetland EFH habitat for aquatic species associated with recreational and commercial fishing	*Direct*: Impacts would be the same as those described for the Coastal Barrier Alternative, except the Bay Rim would have socioeconomic impacts in the upper coast region; alignment near the bay rim would have direct impacts to the area's transportation infrastructure; major impacts to the Port Facilities along the bay rim since roadway and railway gates would have to be built to maintain water access *Indirect*: Potential for induced flooding in the communities of Baytown and Santa Fe; many of the structures in the rural areas of the study area would still receive damages from hurricane surges; overtopping of the levee by storm surge during extreme events would immediately inundate vulnerable populated areas and key emergency service routes; leaves the region's critical roads at risk;
Navigation			
Commercial and Waterborne Commerce and Recreational	Economy expected to grow placing greater demands on port infrastructure and efficiency of transport; increased safety concerns as population and shoreline development increase; expect increase in cargo throughput with expanded Panama Canal	**Coastal Barrier CSRM:** *Direct*: Ship simulations will be required to determine if FWOP/FWP changes to the inlet's maximum and mean velocities would impact deep-draft vessel transits through the ship channel *Indirect*: Overwash and other storm-related sediment deposition in Galveston Bay would be reduced, potentially reducing future storm-event-driven maintenance dredging requirements of the GIWW; risks to navigation safety are expected to increase due to a reduction in vessel operating margin of error associated with the temporary bypass channel constrictions, outbound recreational and commercial vessel traffic, and mobilized construction platforms and permanent constrictions associated with the constructed surge barrier gates and outbound recreational and commercial vessel traffic; temporary impacts to recreational navigation traffic would be induced by construction of the flow control structures at Clear Creek, Dickinson Bayou, and Offatts Bayou, which are proposed to each consist of a single opening **South Padre Island CSRM:** *Indirect*: Sediments placed for dune/beachfill features are expected to migrate northward with the littoral drift, to be impounded by Port Mansfield Channel immediately south of the jetty, with sediments migrating into the entrance of the Port Mansfield Channel and adding to the shoaling of the channel	**Bay Rim CSRM:** Similar to those described for the Preferred Alternative **South Padre Island CSRM and ER Measures:** Same as Preferred Alternative

Alternatives	No-Action Alternative	Coastal Barrier Alternative (TSP/Preferred Alternative)	Bay Rim Alternative
		ER Measures: *Direct*: Temporary impacts to navigation traffic within the GIWW during construction. *Indirect*: Measures would provide protection to the GIWW and its barge traffic from wind-induced wave energy	
Flood Risk Reduction			
	Protection provided by hurricane flood protection, pump stations, and flood protection projects would continue	Texas City HFPP is part of the Bay Rim (Bay Rim Alternative) with the line of protection being extended on either end of the current project. There will be no alterations to the Texas City alignment under Coastal Barrier Alternative No changes or impacts are anticipated to the Lynchburg Pump Station with the construction of the Coastal Barrier or Bay Rim alternatives No changes or impacts are anticipated to the Colorado River Flood Protection at Matagorda with the construction of the Coastal Barrier or Bay Rim alternatives	

The cumulative effects analysis considers the magnitude of the cumulative effect on the resource health. Health refers to the general overall condition, stability, or vitality of the resource and the trend of that condition. Laws, regulations, policies, or other factors that may change or sustain the resource trend were considered to determine if stress on the resource is likely in the foreseeable future. Cumulative impacts may also occur when the occurrence of disturbances is so close that the effects of one are not dissipated before the next occurs, or when the timings of disturbances are so close that their effects overlap. The general approach provided in the CEQ's C*onsidering Cumulative Effects Under the National Environmental Policy Act* was used to conduct the analysis (CEQ, 1997).

This cumulative impact analysis was scoped with a temporal boundary of approximately 100 years in the past (1918), from the beginning of the study, and approximately 50 years into the future (2085), from construction completion. This timeframe accounts for the period of time when significant hydrologic modifications occurred within the focused study area. This period of analysis also captures the period of time when a significant number of environmental laws were enacted in which resource protection became a priority. The future timeframe aligns with the planning and economic period of analysis, and the Habitat Evaluation Procedures modeling.

For a spatial boundary to scope this cumulative impact analysis, projects or actions considered were mostly bounded by Galveston Bay to the Rio Grande. Some projects or actions within Jefferson County and Sabine Lake region were included as they have the potential to contribute beneficial effects to nearby ER measures in Chambers and Galveston counties. In addition, some inland projects were also considered as they have potential to affect the TSP and contribute to cumulative impacts (e.g., Harris County and Houston-area flood damage reduction projects).

5.10.1 Past or Present Actions

5.10.1.1 Upper Coast

GIWW Maintenance. The USACE Galveston District published "Maintenance Dredging, Gulf Intracoastal Waterway, Texas Section – Main Channel and Tributary Channels" (an EIS) in October 1975. This document identified and evaluated the environmental impacts of continued maintenance dredging of the GIWW Texas Section and tributary channels. The proposed action was continued maintenance by periodic dredging of shoal deposits. The main channel was authorized at a 12-foot depth and a 125-foot bottom width. The typical means of dredging is by hydraulic pipeline dredge, with the exception of the Port Mansfield Channel that can be maintained by either pipeline or hopper dredge. At the time of the 1975 EIS, the environmental impact and adverse environmental effects of the proposed action were addressed based on the best available information (USACE, 1975).

Sabine-Neches Waterway Channel Improvement Project. The Sabine-Neches Waterway is a 64-mile-long Federally constructed deep-draft navigation project serving Jefferson and Orange counties in Texas and Cameron and Calcasieu parishes in Louisiana. The Sabine-Neches Waterway is home to 2 of our Nation's 17 Department of Defense's Strategic Seaports. The Port of Beaumont at the upstream end of the channel and the Port of Port Arthur closer to the downstream end of the channel. The existing waterway consists of a jettied entrance channel,

42 feet deep and 500 to 800 feet wide from the Gulf; a channel 40 feet deep and 400 feet wide to Beaumont via the Neches River; and a channel 30 feet deep and 200 feet wide to Orange via the Sabine River. The USACE's recommended plan includes modifying the existing waterway by deepening the channel to 48 feet to avoid congestion and delays, increase safety, and improve efficiency and throughput capacity. The Sabine-Neches Waterway Channel Improvement Project was authorized for construction in Section 7002 of Water Resources Reform and Development Act 2014. However, the project economics excluded the latest investments that were under construction along the waterway at the time with more than $30 billion in improvements to the Sabine-Neches Waterway's refining and petrochemical industries. In April 2013, the Sabine-Neches Navigation District requested and was granted a modified design agreement that allowed for a reevaluation of the economics during preconstruction, engineering, and design. The Limited Reevaluation Report for the Sabine-Neches Waterway was completed in October 2016 and confirms the increased national economic significance of the Sabine-Neches Waterway. This economic analysis resulted in a benefit-cost ratio of 2.28 (using the FY 16 Federal interest rate of 3.125 percent), demonstrating that improvements to the Sabine-Neches Waterway will increase navigational efficiency while maintaining the ecological value of coastal and estuarine resources within the project area (USACE, 2018a).

McFaddin NWR Beach Dune Restoration. Jefferson County is acting to restore 104,150 linear feet of dune ridge and beach face along the 20 miles of beach along McFaddin NWR. Offshore 1.5 miles from the beach, a 241-acre borrow site will serve as the source for sand. The beach nourishment and dune creation would involve the discharge of approximately 4.1 mcy of sandy material into 1,004.16 acres of tidally influenced beach and open water. The proposed beach widths would range from 20 to 300 feet and the dune crest heights would be approximately +6 to +9 feet NAVD 88. The design criterion for dune elevation and beach height and width is intended to reduce inundation events into the NWR marshes, reduce shoreline erosion rates, and return sandy sediment to the littoral system. As of June 2017, approximately 3 miles of beach and dune restoration have been completed (SWG-2015-00444).

Smith Oaks Bird Sanctuary Rookery Island Restoration and Enhancement. The Texas Audubon Society has proposed bird sanctuary improvements to the Smith Oaks Bird Sanctuary on High Island. Excavation and fill activities will impact 3.2 acres of wetland habitat, and 6,791 cubic yards (cy) will be discharged into wetlands during the process. Material will be used to create two bird rookery island sites, one in each pond, and to form emergent and shrub-scrub fringe wetland habitat (SWG-2017-00277).

East Bay and GIWW Shoreline Protection and Restoration. The Galveston Bay Foundation joined the USFWS along with other partners to protect the Anahuac NWR bay shorelines from continued erosion. The work began in 2006 and was completed through three phases in 2011. Rock breakwaters, reef dome breakwaters, and ReefBLK breakwaters were utilized to achieve the desired shoreline protection goals. The combined project phases had the effect of protecting 56,770 feet of refuge shoreline, and thousands of acres of marsh habitat. In addition, 5.5 acres of intertidal marsh was created through the planting of smooth cordgrass by volunteers.

Bolivar Peninsula Beach/Dune Restoration. Galveston County has ongoing efforts to improve the beaches and dunes on the Gulf side of Bolivar Peninsula primarily through nourishment activities on the beach front. Early

efforts included the use of dredged sand from Rollover Bay for use in geo-tubes, while recent permit updates include sourcing sand from upland borrow sites on Bolivar Peninsula. The county plans to dredge approximately 300,000 cy of material for use in beach nourishment from Rollover Pass to beyond High Island (SWG-2007-00391).

Burnet Bay Marsh Mound Creation. Aerial imagery dating back to the early 1900s shows extensive marsh loss due to an estimated 5–8 feet of subsidence in Burnet Bay, west of Baytown. In response, the Galveston Bay Foundation discharged approximately 34,000 cy of material to construct an additional 15 marsh mounds within a 43.9-acre area on the northwest side of Burnet Bay. The mounds were constructed by hydraulically pumping sediment from nearby borrow areas, one previously authorized borrow area, and another newly proposed. The mounds add to an existing mound complex and provide additional habitat and ecological benefits (SWG-2008-00127). Upon completion of the project, volunteers planted wetland vegetation on the newly created mounds.

Houston Ship Channel Dredging and Bulkhead Construction. Kinder Morgan Terminals performed dredging, filled 3.25 acres of open water, and constructed 2,400 linear feet of bulkhead in the process of expanding operations at an existing liquid bulk cargo facility. Approximately 250,000 cy of material was dredged, 80,000 cy of which was placed into 3.25 acres of open water for the construction of two additional storage tanks. The remaining dredged material was placed in authorized privately owned placement areas (SWG-2014-00023).

Barbours Cut Ethane Terminal Improvements. Enterprise Products Operating LLC created a new vessel terminal, mooring locations, and bulkhead, and performed dredging to accommodate discharging and loading vessels. Terminal construction involved dredging to a depth of –45 feet mean low tide, and impacted 12.6 acres of open water, including 0.48 acre of estuarine intertidal emergent wetlands, and 0.84 acre of oyster reef. Approximately 421,000 cy of material was placed in approved placement areas. A new bulkhead was also constructed along the shoreline of Spillman's Island to maintain stability from dredging activities (SWG-2014-00905).

Bayport Ship Channel Container Terminal Dredging. The Port of Houston Authority dredged 7,000 linear feet of ship berths adjacent the Bayport Ship Channel Container Terminal in an area totaling 36.2 acres. The previously authorized depth of –40 feet was increased to –45 feet mean low tide, plus 2 feet of advanced maintenance and 2 feet of allowable overdepth, for a maximum of –47 feet. Approximately 1,231,000 cy of material was removed and placed in nearby placement areas adjacent the ship channel (SWG-1998-01818).

Dickinson Bayou Wetland Restoration and Protection. The TPWD teamed with numerous partners to accomplish a wetland restoration, creation, and protection project along the shoreline of Dickinson Bayou, which protected 17.7 acres of wetlands, and created approximately 12.3 acres of intertidal wetland complex. Marsh creation was achieved through the beneficial use of dredge material from three borrow areas in the Dickinson Bayou Channel. Earthen berms totaling 3,000 linear feet were placed around the created wetlands, and riprap was placed along the bayou-facing sides for erosion protection. The new wetlands were planted and seeded with smooth cordgrass (SWG-2013-00148).

Moses Lake Shoreline Protection. The Galveston Bay Foundation has proposed the construction of 7,500 linear feet of limestone breakwaters along the western shoreline of Moses Lake. The breakwaters will be placed from

25 to 250 feet from the shoreline along the –2.0 feet NAVD 88 contour. The designed width of the breakwaters is 27 feet, and the crest elevation will be +2.0 feet NAVD 88. The project would utilize 16,670 cy of riprap, and three bird nesting pads would also be incorporated into the structures (SWG-2015-00687).

Swan Lake Restoration. In response to significant marsh loss over the past 50 years, a rock breakwater was constructed in 2003, and in 2007, 77 acres of marsh were restored in Swan Lake. Up to 200,000 cy of beneficial use dredge material was used for the marsh restoration effort. The material was pumped from a nearby source into habitat restoration cells and placed at a suitable elevation to support marsh planting. In response to ongoing habitat degradation, the TPWD and the GLO are planning to restore an additional 250 acres of intertidal marsh complex in Swan Lake.

Greens Lake Shoreline Erosion Protection. Ducks Unlimited Inc. has proposed the construction of a breakwater along the northern bank of the GIWW from the mouth of Carancahua Lake and extending 3.3 miles northeast to the Flamingo Isles development. Approximately 25,848 cy of graded riprap would be utilized for breakwater construction. The breakwaters would be 20 feet wide, have a 3-foot crest height, and be placed 10 to 150 feet from the existing bank. To accommodate tidal flushing and boat traffic, there would be two separate breakwaters, forming an opening at Greens Lake (SWG-2015-00415).

North Deer Island Protection and Restoration. North Deer Island, one of the few remaining natural islands in Galveston Bay, has undergone several attempts to protect the vital bird rookery habitat. Under Phase I a breakwater protecting 5,750 feet of shoreline was constructed in 2003 around the southwest portion of the island and benefiting 57 acres of marsh. Phase II of the effort was completed in 2008 and included an additional 3,600 feet of breakwater protection on the south end, groins along the northern shoreline near the GIWW, and a 900-foot breakwater on the northwest shoreline. Phase II improvements were expected to protect 49 acres of marsh and 25 acres of upland habitat. Approximately 8 acres of marsh were restored through beneficial use of sediments dredged from barge access channels and planted with marsh cordgrass.

Galveston Bay Oyster Reef Restoration. The TPWD completed oyster restoration efforts at four sites in Galveston Bay in 2017. The sites included Todd's Dump Reef, South Redfish Reef, and two locations on the north side of the Texas City Dike. Oyster cultch was distributed into 10-foot diameter mounds, with 10 to 15 feet of space between mounds. Maximum crown height of the reef mounds did not exceed 3 feet below MLLW elevation of 5 feet. Approximately 9,670 cy of oyster cultch was placed between the sites, at about 4 cy per mound (SWG-2016-00252, 00270).

Galveston Island Beach Nourishment. The Galveston Park Board and partners teamed to address ongoing erosion by placing over 1 mcy of sand hydraulically dredged from the Bolivar Roads south jetty along nearly 4 miles of beachfront. The beach was renourished between 12th and 61st streets and was completed in the spring of 2017, adding between 100 and 150 feet of beachfront after settling. This most recent project, combined with previous nourishment projects west of 61st Street, accounts for over 5 miles of beach nourishment on Galveston Island (SWG-2000-02888).

Pierce Marsh Restoration. The Galveston Bay Foundation has begun the process of using hydraulically dredged material from GIWW maintenance for placement in Basford Lake in West Bay, southwest of Bayou Vista, in an area known for marsh loss. In total, 1,464,000 cy of hydraulically dredged material will be placed into 364 acres of submerged bay bottom to support the restoration of marsh habitat. In addition, 50,000 cy of mechanically dredged material will be placed into 10.8 acres of submerged bay bottom for the creation of perimeter berms at +2.7 NAVD 88. The berms will be planted and constructed to protect the interior hydraulically dredged material (SWG-2015-00313).

Galveston Island State Park Marsh Restoration and Protection. The TPWD is constructing 12,900 linear feet of rock breakwater in the Carancahua Cove, Butterrowe Bayou, Oak Bayou, and Dana Cove areas. In addition, 400,000 cy of sandy material from a nearby borrow in West Bay was used to restore intertidal elevations in the marsh behind the breakwaters. The dredged material was used to create marsh mounds with a maximum elevation of +2.7 NAVD 88 (SWG-2009-00148).

Sweetwater Preserve Shoreline Protection and Oyster Habitat Enhancement. The Galveston Bay Foundation has constructed 1,900 linear feet of oyster hash breakwater and planted 1.75 acres of smooth cordgrass along the eastern shoreline of Sweetwater Lake. The breakwaters occupy approximately 0.35 acre of former open water (SWG-2014-00258).

Snake Island Restoration. Snake Island Cove is a 900-acre, shallow, marsh-lined cove located in Galveston Bay. Seagrass degradation and loss were cause for concern in the area, and in 2007 and 2011, 4,900 linear feet of geotextile tube breakwater was installed to protect 200 acres of estuarine intertidal marsh complex. The result was also the creation of over 75 acres of protected calm shallow water habitat, which has led to the reestablishment of seagrasses within the project area.

Gang's Bayou Marsh Restoration and Protection. The TPWD completed a marsh restoration and protection project in West Bay at Gang's Bayou, west of Sportsman Road. The 45,000 cy of sediment from an 88.4-acre borrow site and access channel was hydraulically dredged and placed as marsh mounds with a height of +2.5 feet NAVD 88. A 3,800-linear foot breakwater using 13,000 cy of riprap was also constructed to protect 17.4 acres of saltmarsh and the constructed marsh mounds (SWG-2015-00652).

Oyster Lake Habitat Protection and Marsh Restoration. The USFWS completed a multi-phased project addressing erosion protection between a narrow strip of shoreline and marsh between Oyster Bay and West Bay in the Brazoria NWR. Initial stages included the installation of 500 feet of reef ball breakwaters on either side of the shoreline in 2012. In 2015, 2,500 linear feet of riprap breakwater was constructed to the north and south of the existing reef balls. The long breakwater segments displaced approximately 2.6 acres of bay bottom with approximately 7,000 cy of material (SWG-2012-00679). Ultimately, the project resulted in the construction of a 4,786-foot riprap breakwater that protects 5,150 feet of shoreline. The breakwater also protects upwards of 60 acres of coastal habitat that are part of the Brazoria NWR. Behind the shoreline protection features, the project now has the potential to restore intertidal wetlands in a 14-acre calm-water protected area. As of 2016,

approximately 1.5 acres of this area has been planted with smooth cordgrass (Galveston Bay Estuary Program, 2016).

Surfside Beach Groins and Nourishment. The Village of Surfside Beach previously completed a beach nourishment project in March 2015 that placed 118,000 cy of sand from three upland sand pits along the beachfront, stretching 4,800 feet north from the Freeport jetties. The construction of two rock groins has been proposed, along with approximately 2,000 feet of beach nourishment on the northeast end. The rock groin footprint totals 1.7 acres and includes 1,650 cy of material (SWG-1998-02508).

Bryan Beach Renourishment. Using GLO Coastal Erosion Planning and Response Act (CEPRA) funds, the Town of Quintana has renourished approximately 0.37 mile of beachfront in an area called Bryan Beach. An upland sand pit near the Colorado River and south of Bay City was used to source 99,600 cy of sand for the 16-acre dune reconstruction and beach nourishment project (SWG-2013-00640).

GIWW Barge Facility Expansion and Maintenance. Texas Barge and Boat performed maintenance and expansion of their facilities located off the GIWW, northeast of the Brazos River floodgates. Work was performed without a permit, and the company filed for an after-the-fact permit to retain impacts to waters of the U.S. Approximately 100,602 cy of material was dredged from uplands, resulting in the creation of 6 acres of open water, and approximately 2,288 cy of dredge material was placed into wetlands and open water. The applicant also constructed approximately 856 linear feet of steel bulkhead and placed approximately 305 cy of riprap below the high tide line for erosion protection. Pipe piling mooring structure was also installed for 1,682 linear feet within the project area (SWG-2001-01994).

5.10.1.2 Mid to Upper Coast

Mad Island WMA Shoreline Protection. The TPWD has completed 1.8 miles of breakwater to protect the Mad Island WMA shoreline along the GIWW from erosion. The TPWD is proposing to construct an additional 0.57 mile east of the previously constructed breakwater to Culver Cut. The final length of the breakwater will be approximately 2.37 miles. Approximately 4,900 cy of graded riprap will be used for the remaining segment of the project; upon completion, 20,400 cy will have been used. The final segment of the breakwater has not been completed (SWG-2009-00124).

Half Moon Reef Restoration. The TNC and USACE Galveston District teamed to restore a large historic subtidal reef in Matagorda Bay. In 2014, construction was completed on the 60-acre restoration project of one of the largest oyster reefs in the Gulf. Recycled concrete in various sizes was placed in a specific pattern to encourage the reef to grow vertically and to create niches and passageways for all kinds of marine organisms.

Formosa Plastics Plant. Formosa currently operates eight plants and support facilities at a 2,500-acre complex in Point Comfort. The plant started operations in 1983 and was further expanded in 1994, 1998, and 2002. The facility has added several new plastics production units, a wastewater treatment facility, and power co-generation. The facility manufactures plastic resins and petrochemical products. The Formosa Plastics Receiving Water

Monitoring Program was established in 1993 and continues to monitor the discharge of treated wastewater into Lavaca Bay from the facility (Formosa Plastics Corporation USA, 2017).

Alcoa Alumina Plant. Alcoa operates one plant and support facilities at a 3,500-acre complex in Point Comfort. The plant has been in operation since 1948 and produces alumina and alumina chemicals. As of 2017, due to high imports of aluminum and high cost of power, the Point Comfort plant has been idled. The area around the plant was designated as a superfund site by the EPA in 1994 for its wastewater release of mercury. Portions of Lavaca Bay remain closed to finfish and crab harvest due to unsafe levels of mercury (EPA, 2017b).

GIWW. The GIWW is a shallow-draft, inland waterway used to transport cargo and goods throughout the Gulf coast. The channel stretches from St. Marks, Florida, to Brownsville, Texas, and was designed to be 12 feet deep by 125 feet wide. The GIWW West Matagorda Bay section (channel mile 454 to 473) is proposed to be rerouted from its original course to one farther north for safety and maneuverability. Dredging activities for the Matagorda Bay reroute have not started and are pending Federal funding (USACE, 2012b).

The Sanctuary at Costa Grande Mitigation Plan. D.H. Texas Development LP is proposing modifications to their mitigation plans for the Sanctuary at Costa Grande housing development. The development firm is amending the original permit and proposing to create 16 acres of freshwater wetlands instead of tidal wetlands and to relocate the planned 1.8-acre seagrass mitigation site to a site on the northeast point of Dewberry Island. The project is not yet completed (SWG-2005-00181).

5.10.1.3 Mid to Lower Coast

Park Road 13 Seawall Improvements. The TPWD is proposing to elevate approximately a 300-foot-long section of Park Road 13 (Trout Street) approximately 12 to 24 inches. The TPWD is also planning on constructing a 624-foot-long concrete seawall to tie in with the existing seawall on each side of the project site. The footprint of the design would require filling 0.261 acre below the annual high tide line and 0.0081 acre below the mean high water. The project has been approved but not yet completed (SWG-2003-01546).

Rockport Beach Nourishment Project. The project provided beach nourishment along Rockport Beach in Aransas County. The beach area experienced approximately 4,800 feet of shoreline erosion. Approximately 9,154 cy of sand was placed to repair the beach. Approximately 1.6 acres of sand was placed below the mean high water line, and 2.6 acres was placed below the annual high tide line. The project was completed in 2016 (SWG-1991-01789).

Rockport Harbor Maintenance Dredging. Aransas County Navigational District conducted maintenance dredging of Rockport Harbor. An estimated 109,876 cy was dredged from the harbor. Dredged materials were placed in an adjacent upland area. The project was completed in 2017 (SWG-2016-00194).

Ingleside Ethylene Cracking Plant. Occidental Chemical Corporation and Mexichem have completed construction on and have started up an ethylene cracking facility with the capacity to produce 1.2 billion pounds of ethylene per year. The ethylene will be used to manufacture vinyl chloride monomer and polyvinyl chloride. The plant was completed and started production in February 2017 (Chemical-Technology, 2017).

OXY Ingleside Energy Center. The OXY Ingleside Energy Center terminal has a total storage capacity of 2.1 million barrels and throughput capacity of 300,000 barrels per day. The facility can accommodate Aframax- and Suezmax-sized vessels. The crude oil storage and export terminal was completed and began operations in 2016 (Port of Corpus Christi, 2017a).

Corpus Christi Liquefaction Project. Cheniere Energy, through its affiliate, Corpus Christi Liquefaction LLC, is proposing the construction and operation of an LNG exporting facility on the La Quinta Ship Channel. The 1,000-acre site will include five liquefaction trains, marine tanker loading facilities, and 23 miles of pipeline. The marine loading berths will require dredging to create a turning basin and deepening of the La Quinta Channel. Project construction has begun and is in progress (Cheniere Energy, 2017).

Corpus Christi Ship Channel Improvements. The Port of Corpus Christi Authority is proposing to increase the capabilities of the existing ship channels. The Port of Corpus Christi Authority has already extended the channel 1.4 miles and deepened the La Quinta extension to –47 feet msl. The second phase is to widen the Corpus Christi Ship Channel to 530 feet and deepen the channel from –47 to –54 feet msl. The first phase of the project has been completed. The second phase of the project is pending (SWG-2005-01290).

Corpus Christi New Harbor Bridge. The city of Corpus Christi and TxDOT are currently in the construction phase of the new Harbor Bridge design. The new Harbor Bridge will have a main span of 3,285 feet and a vertical clearance of 205 feet. The new bridge will allow larger ships to enter the Corpus Christi Ship Channel. Construction on the bridge began in 2017 and is expected to be completed in 2020 (Flatiron Dragados USA, 2017).

Lake Padres Subdivision Canal. Gulf Shores Joint Venture is proposing to construct a canal-type connection between Lake Padre and the existing canal at Cruiser Street. The canal will extend under Park Road 22, along Padre Isles Golf Course. The project, as proposed, would impact a total of 122.6 acres of waters of the U.S., including 90.8 acres of wetlands, 20.1 acres of sand flats, and 11.8 acres of tidal open water (Lake Padre). Dredging of the wetlands and placement of fill for the project has started. The project is not yet complete (SWG-2000-02743).

5.10.1.4 Lower Coast

South Padre Island Beach Nourishment. South Padre Island beach has been nourished multiple times since the first nourishment in 1997, facilitated by CEPRA funding and through collaboration among the Texas GLO, USACE, and the Town of South Padre Island. CEPRA Cycle 1 funded the first nourishment and continues to support the long-term nourishment of South Padre Island beach. Beneficial use of dredged material from Brazos-Santiago Pass was utilized during routine maintenance dredging of the Brownsville Ship Channel. During Cycle 2, a total of 348,000 cy of sand was placed on 3,780 feet of shoreline using beneficial use of dredged material. An additional Cycle 2 project utilized 120,000 cy of sand harvested from Park Road 100 by TxDOT on 2,000 linear feet of beach. A Cycle 4 nourishment project saw another 7,100-cy taken from Park Road 100 and placed on the beach, and wind-blown sand from the road continues to be used for nourishment and to rebuild dunes. In 2016, a

USACE nourishment project moved 651,000 cy of beneficial use of dredged material from the Brownsville Harbor navigation channel to renourish approximately 0.75 mile of South Padre Island beach.

Adolph Thomae Jr. County Park Improvements. Cameron County has begun the process of improving facilities at the Adolph Thomae County Park, located near the mouth of the Arroyo Colorado River within the Laguna Atascosa NWR. The heavily used park has improved facilities and has begun shoreline repairs and stabilization efforts along the 2-mile stretch on the south bank of the river. The project will include 870 linear feet of precast concrete block wall with gravel backfill, 3,200 linear feet of habitat bench including riprap stone, 315 linear feet of articulated concrete block mattress, 200 linear feet of riprap breakwater, and riprap transitional sections between structures. Habitat bench installation will involve the discharge of approximately 6,100 cy of riprap, 3,415 cy of gravel backfill, and 3,200 cy of base stone below the high tide level elevation. An additional 0.156 acre of wetlands would be filled with base stone (SWG-2015-00602).

5.10.2 Reasonably Foreseeable Actions

5.10.2.1 Upper Coast

Texas Coastal Resiliency Master Plan. The GLO developed a master plan that identified critical coastal issues and potential projects to address those issues. Some of the common issues identified include altered or degraded habitats, Gulf beach erosion and dune degradation, bay shoreline erosion, coastal storm surge damages, coastal flood damages, water quality and quality degradation, impacts of other coastal resources, and abandoned derelict vessels, structures, and debris. To address these issues, the GLO identified several strategies including restoration of beaches and dunes, bay shoreline stabilization and estuarine wetland restoration, GIWW stabilization, freshwater wetlands and coastal uplands conservation, delta and lagoon restoration, oyster reef creation and restoration, and implementation of plans, policies, and programs. The Master Plan effort considered numerous projects to address coastal issues and ultimately identified a total of 59 coastal resiliency projects (during this iteration of the Master Plan), including 25 in the upper Texas coast, 12 in the mid to upper Texas coast, 16 in the mid to lower Texas coast, and 6 in the lower Texas coast. Future iterations of the Master Plan will reflect a greater depth and breadth of analysis as the planning process matures, and as additional data and analytical techniques are developed. Subsequent planning is also expected to include additional emphasis on life cycle and phasing aspects of recommended projects, an enhanced focus on storm surge defense and flood risk reduction, restoration of water quality, and community development and revitalization to achieve a more robust and resilient coast (GLO, 2017).

Texas GLO CEPRA Program. The GLO administers the CEPRA Program and it is intended to implement coastal erosion response projects and related studies to reduce the effects of and to understand the processes of coastal erosion as it continues to threaten public beaches, natural resources, coastal development, public infrastructure, and public and private property. CEPRA projects ultimately yield positive or beneficial effects to coastal resources. Some of the CEPRA Program reasonably foreseeable actions include the following beneficial coastal projects:

- Jamaica Beach Dune Restoration
- Rollover Pass Closure
- Rollover Recreational Amenities Plan
- Follets Island Nearshore Beach Nourishment
- Virginia Point Wetland Restoration and Protection
- West Galveston Island Bayside Marsh Restoration
- Beach Monitoring and Maintenance Plan Monitoring
- Bolivar Beach Restoration
- Dellanera Park Beach Nourishment
- GIWW-Rollover Bay Reach Beneficial Use Beach Nourishment
- Babes Beach Nourishment
- Texas Coastwide Erosion Response Plan Update 2018
- Indian Point East Shoreline Protection

Sabine Pass to Galveston Bay Coastal Storm Risk Management and Ecosystem Restoration. The USACE proposed to reduce the risks of tropical storm surge impacts by constructing the Orange 3 CSRM system in Orange County, and improving flood protection in Port Arthur, Freeport, and Hurricane Flood Protection systems in Jefferson and Brazoria counties. The Orange 3 project would consist of a 26.7-mile-long levee/floodwall system along the edge of the Sabine and Neches river floodplains from Orange to Orangefield, Texas. The Port Arthur and Freeport projects would raise or reconstruct 11.6 and 18.2 miles of existing levees/floodwalls, replace vehicular closures, construct navigable surge gates, and increase resiliency through erosion protection. The hydrologic condition of the area is not anticipated to be affected by the features of the TSP. The Orange 3 project would result in the loss of 69.5 acres of forested wetlands and 203 acres of estuarine marsh, as well as functional impacts to 2,137.2 acres of estuarine marsh. The impacts would result in the loss of 43 average annual habitat units for forested wetlands and 143 average annual habitat units for estuarine marsh. Mitigation would restore 453 acres of estuarine marsh and preserve 559.5 acres of forested wetlands to compensate for the impacts from the project (USACE, 2017a).

Jefferson County Ecosystem Restoration. The USACE, in partnership with Jefferson County and the Sabine Neches Navigation District, prepared an Integrated Feasibility Report and EA for the Jefferson County Ecosystem Restoration Study in Jefferson County, Texas (USACE, 2018b). In addition to the “no-action” alternative, four alternatives with varying levels of ER were evaluated, including the recommended plan. Implementation of the recommended plan would include restoration of 8,421 acres of marsh and construction of 6,592 linear feet (1.25 miles) of offset breakwaters that would be placed along the south bank of the GIWW. Dredged material used in the recommend plan would be provided during implementation of normal dredging operations or through the Sabine-Neches Waterway Channel Improvement Project. Marsh restoration would beneficially use material dredged from the Sabine-Neches Waterway to increase the marsh elevation in five restoration units. Renourishment would occur at approximately year 30 to increase the target elevation to provide resiliency and

sustainability in anticipation of projected RSLC (USACE, 2018c). The USFWS concurred that the recommended plan would not adversely affect any listed species. The NMFS issued biological opinions for normal dredging operations and the Sabine-Neches Waterway Channel Improvement Project in 2003 and 2007, respectively. Both Biological Opinions determined that the recommended plan will not jeopardize the continued existence of Federally listed species or adversely modify designated critical habitat. All terms and conditions resulting from previous consultations shall be implemented to minimize take of endangered species during dredging operations.

Cedar Bayou Navigation Improvements. The USACE has evaluated improvements to Cedar Bayou. Cedar Bayou is a coastal stream that originates in Liberty County, Texas, east of Houston. It becomes navigable on the north end and meanders south along the urbanized eastern portion of the city of Baytown before entering Galveston Bay and the Houston Ship Channel. The project is supported by the Port of Houston Authority, the busiest barge channel in the United States; Kirby Corporation, the largest barge company in the United States; and the community and the companies who rely on the channel for their business. Companies that utilize the channel now and plan to use it in the future include Bayer Material Science LLC, Koppel Steel, Walmart, Home Depot, Dorsett Brothers Concrete, Reliant Energy, and Angel Brothers Cemex, to name a few. The channel primarily serves chemical, aggregate, steel, and asphalt. The waterway currently carries more than 1.5 million tons per year. Recent economic updates project a significant increase in the future; increases that depend on a normalized channel with a depth of 11 feet and a width of 100 feet. Constructing the Locally Preferred Plan would extend the barge transport benefits up to Mile 11, reduce environmental impacts, create a safer channel for the increased future traffic, and serve anticipated heavy development along the channel. The additional channel depth will accommodate barge traffic using the Houston Ship Channel and the GIWW without light loading. In addition, the wider channel and the cutoff of the bend at Devil's Elbow will result in much safer transport of materials and an area for barge tie up. The previously authorized and improved portion of the navigation project extends from its junction with the Houston Ship Channel near Barbours Cut container terminal at Mile 25, eastward across Galveston Bay to the mouth of Cedar Bayou to a point 3 miles upstream. The project dimensions are 11 feet by 100 feet. The proposed and newly authorized project extends the channel by 8 miles to SH 146 (USACE, 2018a).

Trinity Bay Living Shoreline and Erosion Protection. Chambers County is proposing to install 1,571 linear feet of living shoreline at Fort Anahuac Park on the eastern shore of Trinity Bay. The living shoreline would be constructed of concrete or limestone riprap, and smooth cordgrass would be planted on the protected shoreward side. A total discharge of 0.54 acre of fill material is expected (SWG-2016-00260).

Trinity Bay Discovery Center Shoreline Protection and Habitat Creation. The Galveston Bay Foundation has proposed the installation of a 1,200-linear-foot breakwater on the eastern shoreline of Trinity Bay. The breakwater would be composed of riprap and recycled oyster shells and occupy 0.5 acre of bay bottom. The action would also result in 2,070 cy of fill material. To facilitate marsh creation, smooth cordgrass would be planted between the existing shoreline and the proposed breakwater (SWG-2017-00589).

Buffalo Bayou and Tributaries Flood Risk Management. The Addicks and Barker Dam and Reservoirs are part of the Buffalo Bayou and Tributaries flood risk management system located within the west side of the city of Houston. The Addicks and Barker Dams Dam Safety Modification Study by the USACE was the first (Phase 1)

of a two-phase effort to fully address all dam safety issues associated with the Addicks and Barker Dams/Reservoirs. The Phase 1 of the study was initiated in 2009 and completed to primarily to address the issues near the conduits. A follow-on the Phase 2 study is proposed to assess risks associated with flows around and over the auxiliary spillways at the ends of the dams and flood risk in the pool areas upstream of the Addicks and Barker reservoirs and downstream along Buffalo Bayou. The purpose of this Section 216 study will be to investigate flood risk management problems in the Buffalo Bayou watershed that are not part of the Addicks and Barker Dams Dam Safety Modification Study Phase 1 or 2, including non-breach risk from spillway flow, residual risk in the upstream pool areas and downstream of the dams, water drainage from Cypress Creek watershed, and the potential need for a third reservoir in the Cypress Creek watershed (USACE, 2018a). The hydrologic changes from the flood risk management features could be greater than the nominal salinity changes from the TSP features which restrict the flow of water between the bay and the Gulf.

Houston Regional Watershed Assessment. The USACE study area would include 22 primary watersheds within Harris County, 1,756 square miles encompassing Houston metropolitan region, each having unique flooding problems. These include Spring Creek, Little Cypress Creek, Willow Creek, Cypress Creek, Addicks, Barker, Buffalo Bayou, Clear Creek, Sims Bayou, Brays Bayou, White Oak, Greens Bayou, Hunting Bayou, Vince Bayou, Armand Bayou, Carpenters Bayou, San Jacinto River, Jackson Bayou, Luce Bayou, Cedar Bayou, Spring Gully and Goose Creek, and San Jacinto and Galveston Bay estuaries. Flooding problems in the watershed are frequent, widespread, and severe. Recent historical flooding in the region was documented in 1979, 1980, 1983, 1989, 1993, 1994, 1997, 2001, 2006, 2007, 2008, 2015, April 2016 with the loss of 8 lives, widespread damages to 5,400 homes and about $3 billion worth of damages to businesses, and most recently August 2017 with the loss of over 60 lives and billions in damages that are yet to be quantified. The principle purpose of the study is to develop a watershed management plan that would provide a system wide approach to water resources management. There is a significant opportunity to integrate and improve the operations of existing flood risk management systems and activities in Houston, Texas, the 4th largest metropolitan region in the Nation, while seeking opportunities to restore degraded ecosystems (USACE, 2018a). The hydrologic changes from the flood risk management features could be greater than the nominal salinity changes from the TSP features which restrict the flow of water between the bay and the Gulf.

Brays Bayou Flood Risk Management Project. The USACE authorized project consists of 4 detention basins (Sam Houston, Old Westheimer Road, Eldridge Road, and Willow Waterhole), enlargement or modification of 21.1 miles of earthen channel, replacement and/or lengthening of 27 bridges. The project is being implemented under the authority of Section 211(f) of Water Resources Development Act (WRDA) of 1996 where the work is accomplished by the NFS and following approval, the sponsor is reimbursed by the Federal Government for the Federal share. Direct benefits provided by the project are reduction of the 100-year return period floodplain by 97 percent. The project is about 80 percent complete and just beginning to reach critical life safety and health infrastructure in the community. This project will reduce the risk of flooding to the Texas Medical Center, which is the largest medical patient care, teaching, and research center in the world and includes patient's life and health in the 14 Texas Medical Center hospitals during major flood events due to staff and physicians not being able to travel through high water. The project will also reduce the risk of flooding along major traffic commuter routes such as SH 288, which is below ground level for much of its length crossing the Brays Bayou watershed. In

addition, the project will reduce the risk of high-water causing life safety concerns on feeder roads and adjacent roadways along I-45, a hurricane evacuation route through Houston and Harris counties (USACE, 2018a).

White Oak Bayou Flood Risk Management Project. The USACE evaluated flood risk management on White Oak Bayou. White Oak Bayou is a tributary of Buffalo Bayou which originates northwest of FM 1960 and flows generally toward the southeast. The watershed covers about 110 square miles and includes three primary streams: White Oak Bayou, Little White Oak Bayou, and Cole Creek. The existing Federal channel in the lower reach of White Oak Bayou was completed in the mid 1970s under the authorization of the Flood Control Acts of 1954 and 1965 for Buffalo Bayou and tributaries. In 1986 the project was reauthorized under Buffalo Bayou and tributaries (Upper White Oak Bayou) in the WRDA of 1986 Section 401(a) based on the Chief of Engineers report dated June 13, 1978. In 1990 the Upper White Oak project was included in WRDA 1990 Section 101(a)(21) for the authorization of Buffalo Bayou Tributaries, which included six separate flood damage reduction plans for the tributary streams of Carpenters, Greens, Halls, Hunting, Little White Oak, and Brays bayous. When the study was initiated in 1999, it began as a feasibility study of 9.2 miles of channel modifications on the upper reach of White Oak Bayou including nonstructural flood plain management of future suburban development. The sponsor, HCFCD District completed the General Reevaluation Report under Section 211(f) of WRDA 96 and received the Assistant Secretary of the Army (Civil Works) approval on August 28, 2014. The recommended plan includes earthen channel modification from Cole Creek to FM 1960; four detention basins of approximately 2,940 acre-feet of storm water storage; 4.99 acres of compensatory wetland credits in the Greens Bayou Wetlands Mitigation Bank; and approximately 12 miles of a linear bikeway. The proposed project reduces the extent of the 10 percent and 1 percent floodplain areas so that 1,285 and 1,511 structures, respectively, would now be located outside of the two reduced floodplain areas, leaving 48 and 4,563, structures, respectively, within the floodplains (USACE, 2018a). The hydrologic changes from the flood risk management features could be greater than the nominal salinity changes from the TSP features which restrict the flow of water between the bay and the Gulf.

Hunting Bayou Flood Risk Management Project. The USACE evaluated flood risk management on Hunting Bayou. The Hunting Bayou watershed is located in central Harris County, Texas, northeast of downtown Houston, and is about 30 square miles. Hunting Bayou runs approximately 15 miles from its headwaters west of U.S. Highway 59 to its confluence with Buffalo Bayou near the Houston Ship Channel. Flooding problems on Hunting Bayou are primarily the result of flat topography and channel inadequacy to discharge increased runoff from urban development that occurred prior to local watershed management policies. The existing flood risk impacts life, health and safety of many who live in Harris County. The infrastructure within the Hunting Bayou 0.2 percent floodplain includes Lyndon B. Johnson General Hospital, the State's busiest Level III trauma center, which serves some of the 4.1 million people living in and beyond the Hunting Bayou watershed. Infrastructure impacted within the Hunting Bayou watershed: public schools, water treatment plant, hospitals, clinics, police and fire stations, daycare centers, and elder care facilities. Regionally significant infrastructure: electrical transmission and oil and gas product pipelines and two major railroad yards traverse the Hunting Bayou and broader watershed. Access to freeways, major transportation routes, and connections to hurricane evacuation corridors such as I-610, U.S. Highway 59, and I-10, and emergency response for medical transportation, police and fire officials have been, and likely will be, significantly hindered during a major flood event. Sections of these facilities are in the Hunting Bayou watershed. Consequently, the interregional transportation system is compromised during intense rainfall

that accompanies tropical weather systems; freeway access flooding which precedes hurricane evacuation and can be a significant detriment to coastal residents fleeing low-lying areas for higher ground. The Hunting Bayou 1990 Authorized Plan is part of the Buffalo Bayou Tributaries, Texas, authorization found in Section 101(a)(21) of WRDA 1990. The approved General Reevaluation Report of December 2014 defines a Locally Preferred Plan of 3.8 miles of grass lined channel, 75 acres of detention basin, 14 bridge modifications, three railroad bridge replacements, and 5.16 acres of wetland credits at Greens Bayou Wetland Mitigation Bank. The EA demonstrates that the Selected Plan falls within the 1990 authorized footprint and intent for flood prevention along Hunting Bayou (USACE, 2018a). The hydrologic changes from the flood risk management features could be greater than the nominal salinity changes from the TSP features which restrict the flow of water between the bay and the Gulf.

Bolivar Peninsula Debris Removal. The GLO has proposed to remove debris, pilings, and abandoned oil and gas infrastructure along the Gulf-facing beaches of Bolivar Peninsula. A barge mounted crane and material barge, in addition to smaller craft, would be utilized to retrieve and transport debris for disposal. The GLO plans to use RESTORE Act funds for the project (SWG-2016-00338).

Houston Ship Channel Expansion and Channel Improvement Project. As of August 2017, the USACE has produced a DIFR-EIS that identifies a plan to deepen and widen the Houston Ship Channel and several ancillary navigation channels. Several impacts were identified in the draft EIS. The proposed deepening project may result in a minor increase in bottom salinities farther up the channel. The project may also result in unavoidable temporary impacts to unvegetated estuarine bay and river bottom and permanent impacts to between 469 and 538 acres of oyster reef. Temporary avoidance and disturbance would occur during construction and maintenance dredging. The project may affect, but is not likely adversely affect, endangered sea turtles; a Biological Assessment is being coordinated with the NMFS and USFWS for concurrence. No specific cultural resource impacts have been identified; cultural resource investigations will be performed in the next planning phases. The USACE has determined that the TSP has the potential to cause effects on historic properties and will execute a Programmatic Agreement in coordination with the State Historic Preservation Officer to address the identification and discovery of cultural resources that may occur during the construction and maintenance of the project (USACE, 2017b).

Houston Ship Channel Barge Fleeting Expansion. The Port of Houston has proposed the expansion of a barge fleeting facility located near the confluence of the Houston Ship Channel and Old River. The expansion would include the dredging of approximately 550,000 cy of material from a 28.5-acre area, and the installation of 9 monopiles and 70 mooring structures. While the majority of dredged material would be moved to approved placement areas, 85,000 cy would be used to raise the grade at a site adjacent to the dredge area (SWG-2016-00441).

Buffalo Bayou Petroleum Storage and Marine Terminal. Magellan Terminal Holdings LP has proposed the construction of a 188-acre petroleum bulk storage marine facility to receive, store, and transport petroleum hydrocarbons. The terminal would be located on a former dredge material placement area and include up to 86 storage tanks and associated infrastructure, as well as ship and barge births and bulkheads. A total of 5,457,700 cy of material would be excavated, 1,200,700 on land, and 4,257,000 by dredging. One million cy of material would

be used on site to increase base elevation, and the remaining material would be placed in approved placement areas (SWG-2016-00635).

Bayport Turning Basin. The USACE will investigate the feasibility of assumption of maintenance for the Bayport Turning Basin. The Bayport Turning Basin was constructed in 2008 by the Port of Houston to accommodate the Post-Panamax and large container vessels. Current conditions require vessels to travel to the end of the Bayport Ship Channel in order to turnaround and exit to the Houston Ship Channel. The importance of this investigation is to identify an efficient option to reduce congestion delays and safety concerns with other vessels at the container, bulk, and petrochemical terminals. The study area includes the Bayport Turning Basin located on the south side of the Bayport Ship Channel. The Bayport Ship Channel is located along the west side of the Houston Ship Channel, southeast of the City of Houston along Texas State Highway 146 north of the City of Seabrook. The study will review the feasibility of assuming the operation and maintenance of the channel constructed by the Port of Houston Authority. The study will use existing economic, environmental, and dredging cost data to complete a rapid assessment of viability. The study will determine if the constructed channel and turning basin is economically justified, environmentally acceptable, and that they were constructed in accordance with applicable permits and appropriate engineering standards. The Port of Houston Authority has requested the USACE Galveston District to assess the scope of the required studies and work towards an expedited path to complete the study. Funds provided in fiscal year 2018 will be used to initiate and complete the feasibility study. The general scope of the study includes calculation of economic benefits associated with the facility, determination of environmental acceptability, estimation of future maintenance cost, and evaluation of facility design and construction (USACE, 2018a).

Galveston Channel Extension. WRDA of 1996 authorized the USACE to deepening and widening of the Galveston Harbor Channel from 40 feet deep to 45 feet. This deepening was completed in January of 2011; however, the deepening effort stopped at Station 20+000 of the Galveston Harbor exclusive of the last 2,571 feet at the most westward end to the Galveston Channel. At the time of the 1996 WRDA authorization, the remaining 2,571 feet had been evaluated for deepening to 45 feet but was determined to not be economically justified since there were no portside services facilities in place. In the intervening years, conditions changed and beginning in 2006 portside service facilities began operation and utilizing the 40-foot channel. A feasibility study is currently being conducted to investigate the feasibility of extending the 45-foot-deep Galveston Harbor Channel the additional 2,571 feet to reach the end of the limits of the existing 40-foot channel (USACE, 2018a).

Clear Creek Flood Risk Management. The USACE project provides flood risk management for an extensively developed urban area. There are 17 cities at least partially within the Clear Creek watershed including Houston, Pasadena, Pearland, Friendswood, Webster, and League City, some of the fastest growing cities in the Houston area. Flooding in 1973, 1976, twice in 1979, 1989, 1994, 2001, 2006, 2009, and 2017 (Harvey) caused extensive property damage. The authorized project consists of approximately 15.3 miles of channel enlargement and bend easing, more stringent regulations restricting development of the 100-year floodplain, and a second outlet channel with a gated structure between Clear Lake and Galveston Bay. In June 1986 a Local Cooperation Agreement was signed to execute the construction of the project. Under the Local Cooperation Agreement, the second outlet work structure and channel were constructed; however, environmental concerns were raised on the plan of construction

for the upstream reaches due to potential of induced flooding on the downstream reaches. Construction was placed on hold pending reformulation of the project under a General Reevaluation Report. The report was approved on February 11, 2013. The recommended plan includes conveyance improvements in high flood damaged reaches on Clear Creek, Mud Gully, Turkey Creek, and Mary's Creek and linear detention within the Clear Creek conveyance improvements. The local sponsors are the HCFCD and Galveston County (USACE, 2018a). The hydrologic changes from the flood risk management features could be greater than the nominal salinity changes from the TSP features which restrict the flow of water between the bay and the Gulf.

GIWW Coastal Resilience Study. The study area includes the section of the GIWW located in Brazoria and Matagorda counties, which experiences excessive shoaling following floods and hurricanes. Erosion of the barrier islands along this section of the GIWW allows sediment from Caney Creek and the Gulf inlet flow directly into the GIWW causing draft restrictions and traffic delays. The USACE would evaluate potential solutions to alleviate the excessive shoaling that could include training structures or jetties, replacing erosion of the barrier islands, increase advance maintenance to increase the dredging interval, locks to prevent high shoaling during heavy flows, and many others. These proposals are expected to greatly increase waterborne transit efficiency. The general scope of the study includes analyzing alternatives to reduce the channel sedimentation and protecting the inland waterway from the waves and currents from the Gulf. Replacement of these land losses will decrease the vulnerability of continued safe and reliable barge tow transit on the GIWW to disruption. Decreased vulnerability includes less exposure of the GIWW to the forces of the Gulf open sea conditions to shallow draft navigation. It also would reduce exposure of sedimentation from the Gulf, diminishing the frequency and volume of channel shoaling and associated maintenance dredge requirements. This would result in cost savings to the USACE GIWW channel maintenance program (USACE, 2018a).

Dickinson Bay Waterbird Rookery. The Galveston Bay Foundation has proposed the construction of an 8.9-acre bird rookery island to provide 4.5 acres of upland habitat and 1 acre of oyster reef habitat. The U-shaped island would be composed of material from either beneficial use of dredged material in the mid-bay reach of the Houston Ship Channel or fill from an unnamed borrow site. The base material would be surrounded by a rock breakwater on three sides to protect and stabilize the island. An opening on the northwestern side of the island would make room for a shallow-water beach and a submerged oyster reef to attenuate wave action (SWG-2015-00810).

Dollar Bay and Moses Lake Marsh Terraces. The Galveston Bay Foundation has proposed the placement of fill material into two sites for the creation of planted marsh terraces. Site 1 is 12.9 acres in Dollar Bay, and Site 2 is 4.53 acres in Moses Lake. The 46,900 cy of material would be placed into Site 1, and 14,400 cy would be placed into Site 2. Rock breakwaters would be installed at both sites to protect from wave erosion. The breakwaters would have a crest width of 3 feet and an elevation of +2 feet NAVD 88. Geotextile fabric would be used under the breakwater to limit scouring and settling (SWG-2017-00032, 00033).

Texas City Turning Basin Improvements. The Texas City Terminal Railway Company has proposed dredging, dock removal, and other shoreline improvements to the inner Port of Texas City. Extensive dredging would be performed in a 9.2-acre berthing area, and 2.2 acres of upland would be converted to open water, creating a total of 431,000 cy of material for placement. Other work includes the demolition of a 320-foot dock, three dry docks,

and 920 feet of existing bulkhead. A new 1,193-foot dock would be constructed, along with 840 feet of steel bulkhead, and 45,000 square feet of articulated concrete mat in front of the new bulkhead for erosion protection (SWG-2013-00042).

Spoonbill Bay Mixed Use Development. A mixed-use development is planned for a 115.37-acre tract in West Bay, 3 miles northeast of San Luis Pass. The proposed development will consist of a single marina, water front homes, access roads, and two channels. Approximately 10.76 acres of jurisdictional waters would be impacted; 6.08 acres of non-tidal wetlands, 1.53 acres of tidal wetlands, and 0.40 acre of sandflats. An additional 2.75 acres would be impacted through the dredging of the navigable channels, where 44,333 cy of material would be used to build up the site. The applicant has proposed on-site mitigation through the creation of 2.23 acres of non-tidal wetlands, 0.83 acre of living shoreline, and 6.52 acres of tidal wetlands (SWG-2007-01475).

San Luis Pass Dredge and Follets Island Nourishment. Brazoria County has proposed to dredge approximately 376,200 cy of sand material from West Bay and San Luis Pass for beach nourishment on the north end of Follets Island. The 160-foot-wide by 12,000-foot-long dredge area would improve vessel access through San Luis Pass and would be excavated to –9 NAVD 88. Sand would be placed nearshore, within the submerged portion of beach to reduce wave action and allow for onshore movement of material (SWG-2015-00306).

San Bernard River Mouth Restoration. Brazoria County has proposed to hydraulically dredge approximately 400,000 cy of material from the existing San Bernard River channel to restore consistent flow through the river mouth. A total of 30.1 acres is expected for the dredge footprint, with 21.6 acres of channel bottom, and 8.5 acres of side slope. Suitable dredge material would be beneficially used to restore marsh habitat along the GIWW, and sandy material would be placed in a 17.6-acre surf zone placement area. The two primary restoration areas are located in Cedar Lakes within the San Bernard NWR, and total 133.32 acres. Restored areas would also be planted with smooth cordgrass about 60 days after dredge material placement. A third 69.86-acre restoration area would be used after completion of areas 1 and 2 and involves shoreline protection with levees along the GIWW (SWG-2015-00603).

5.10.2.2 Mid to Upper Coast

Harbor of Refuge Bulkhead. The City of Port Lavaca is proposing to construct approximately 4,500 feet of bulkhead and remove and replace approximately 2,000 feet of existing bulkhead around the Harbor of Refuge. The construction will impact 1.82 acres of bay bottom and 0.17 acre of wetland. The 4 acres of saltmarsh has been constructed to mitigate the impacts. The project has not been completed (SWG-1995-02218).

Mid-Coast Bird Rookery Island. The TNC is proposing the construction of an 803-foot-long by 445-foot-wide bird rookery in San Antonio Bay. The plan calls for placing 239,500 cy of fill material and rock riprap shoreline armoring. The rookery island will provide 4 acres of bird habitat and 1 acre of submerged reef habitat. The project has not started (SWG-2017-00516).

Port of Port Lavaca-Point Comfort and Matagorda Ship Channel Expansion. The Calhoun Port Authority is proposing to construct an additional turning basin and deepen the existing berthing facilities to accommodate

larger ships at the port of Port Lavaca-Point Comfort from 36 to 44 feet. The Calhoun Port Authority is also proposing to deepen the channel from 36 to 44 feet and widen from 200 to 400 feet for the entire 26 miles of the ship channel. The project has not started (SWG-2006-00092).

Palacios Channel Maintenance Dredging. The Port of Palacios is proposing to maintain the Palacios Ship Channel. The channel will be dredged from a depth of 11 to 14 feet, and the bottom with be widened to 125 feet. Approximately 731,904 cy of material will be removed. Dredged material will be placed at a beneficial use of dredged material site near Sartwelle Lakes to restore hydrological function to the low-lying marsh. The project has not started (SWG-2014-00782).

5.10.2.3 Mid to Lower Coast

Port Bay Harbor Dredging. Landowners and developers plan to excavate a 3.973-acre harbor canal from an upland site. Approximately 58,000 cy of material will be removed and spread over the remaining upland areas. The 10-foot-deep harbor will be connected to an existing canal in Port Bay. The perimeter of the harbor will be capped-concrete bulkhead, and the created canal will be routinely dredged. The project has not been completed (SWG-2008-00997).

Aransas County Oyster Reef Restoration. The Harte Research Institute at Texas A&M University-Corpus Christi is proposing to construct a 1-acre educational oyster reef and 10 acres of restored oyster reef on State Tracts 67 and 68 in St. Charles and Aransas bays. The project will use reclaimed oyster shells from seafood wholesalers and restaurants, cleaned crushed concrete, limestone, river rocks, and other clean hard surfaces. The materials will be placed in 24-inch mesh bags containing approximately 3 gallons of oyster shells. The reef mounds will be 12 inches high by 10 yards wide by 60 yards long (SWG-2011-00365).

Fulton Beach Road Shoreline Stabilization Project. Aransas County is proposing the construction of 3,220 feet of breakwater to protect the shoreline and coastal wetlands from erosion. Each breakwater will measure 70 feet long, 26 feet wide at the base, a 4-foot-wide crest, 2:1 side slopes, and a total height of 4.5 feet. There will be 46 overlapping breakwaters covering an area of 1.3 acres. The area along the shoreline behind the breakwaters will be planted with smooth cordgrass and saltmeadow cordgrass. No work on the project has been completed, and a request to extend the time limit of the standard permit by 5 years has been submitted (SWG-2011-01237).

La Quinta-Ingleside Dredging. OXY Ingleside Energy Center is planning to use Berry Island, an existing confined area, as a dredged material placement area. The area will be used to place 1,200,000 cy of initially dredged material and 200,000 cy of maintenance material (every 3 to 5 years) afterwards from the La Quinta Ship Channel (SWG-1995-02221).

La Quinta Ship Channel Crude Condensate Storage and Marine Terminal. Cheniere Liquids Terminal, LLC is proposing a duAI vessel berthing area, two docks, an onsite dredged material placement area, and various supporting infrastructure (such as storage tanks, roads, parking areas, and administrative buildings). Approximately 2.6 mcy of stiff clay will be mechanically or hydraulically dredged including a 40-acre berthing basin and two marine docking structures. Work on the project has not yet started (SWG-2014-00848).

OXY Ingleside Energy Pier Dredging Activities. OXY Ingleside Energy Center, LLC is proposing the deepening of approximately 67 acres of channel depth adjacent to their east and west docking slips. Approximately 478,498 cy of dredged materials will be removed and placed in a dredged material placement area. Seagrasses are present in the west slip areas but are not expected to be disturbed. Work on the project has not yet started (SWG-1995-02221).

North Beach Sand Placement. The city of Corpus Christi is proposing beach nourishment activities on a 3,900-foot stretch of North Beach. The proposal calls for placing 130,000 cy of imported inland sand and 20,000 cy of excavated and redistributed sand from the accretional end of the existing beach. Beach nourishment activities for the project have not yet started (SWG-1998-00131).

McGee Beach Sand Placement. The city of Corpus Christi is proposing beach nourishment activities on a 1,700-foot stretch of McGee Beach. The proposal calls for placing 14,000 cy of beach quality sand over approximately 4.18 acres. Sand placement has not yet begun (SWG-2002-01934).

Nueces Bay Rookery Island Shoreline Armoring. Coastal Bay Bend and Estuaries Program is proposing to install shoreline protection measures for several bird island rookeries in Nueces Bay. The islands will be armored with articulated concrete blocks or rock riprap. Approximately 4,200 cy of fill materials will be used to protect the islands. The project has not begun (SWG-2013-01068).

Nueces Bay Shoreline Protection Measures. Coastal Bay Bend and Estuaries Program is proposing to construct 3,901 linear feet of concrete breakwater to provide shoreline protection to the Nueces Bay Delta. The breakwater system will consist of 12 structures and utilize approximately 1,008 cy of porous concrete (SWG-2014-00725).

Corpus Christi Channel Marine Terminal Expansion. Plains All-American Pipeline LP is proposing the construction of an import/export liquid terminal and storage facility along the Corpus Christi Channel large enough to support Aframax ships and oceangoing barges. The proposal calls for dredging 514,557 cy of material over 12.7 acres of water (SWG-2014-00260).

Magellan Crude and Hydrocarbon Bulk Storage Terminal. Magellan Terminal Holdings LP is proposing to construct a 95-acre bulk storage holding terminal and docking facility along the Corpus Christi Ship Channel. The facility will include 27 bulk storage tanks, 4 docking platforms, bulkheading, and shoreline protection (SWG-2016-00285).

Dagger Island Breakwater and Containment Area. TPWD is proposing to construct rock breakwaters parallel to the existing shoreline of Dagger Island. TPWD is also planning to construct a 28-acre containment area around a historic island footprint to accept dredged materials for beneficial use. The project has been proposed but construction has not started (SWG-2017-00295).

Pipelines. There are several pipeline projects that are reasonably foreseeable along the Corpus Christi Ship Channel. These include the 8.6-mile-long Oxy Viola station pipeline (SWG-2014-01002), 2-mile-long M&G Polymers plant pipeline (SWG-2015-00136), 3 parallel 16-mile-long Magellan pipelines across the Corpus

Christi Ship Channel (SWG-2014-00518), 70-mile-long Flint Hills Refinery pipeline (SWG-2016-00657), and 8.2-mile-long Gravity Midstream pipeline (SWG-2016-00032).

5.10.2.4 Lower Coast

Brownsville Resacas Ecosystem Restoration. The USACE has evaluated ER actions with Brownsville Resacas. The project is located along the Resaca Boulevard near the Rio Grande in the southern half of Cameron County, Texas. The Resaca consists of former channels of the Rio Grande that have been cut off from the river, having no inlet or outlet because of siltation of the oxbow channels, and loss of critical native aquatic and riparian habitat. The unique thorn scrub riparian vegetation associations of the resacas are found exclusively in Resaca and riparian corridors of the Lower Rio Grande Valley, and they have been designated by the TPWD as habitats critically imperiled with extinction or elimination. The Resaca and its associated thorn-scrub riparian habitat are listed in the draft USFWS Ocelot Recovery Plan as critical transportation corridors for dispersing ocelots. The USFWS has determined that close to 99 percent of this habitat has been degraded on the Lower Rio Grande Basin within the United States and Mexico. Before land development and water control, floodwaters from the Rio Grande drained into resacas from the surrounding terrain. The primary hydrologic function of the resacas was diversion and dissipation of floodwater from the river. Measures that would be implemented per the NER plan include dredging accumulated sediment (completed by sponsor at no cost to the project), restoring wetland habitats, and restoration of the imperiled riparian vegetation associations. Restoration of the resacas would potentially provide habitat benefits for the Federally endangered species ocelot, a Federally endangered cat, jaguarondi, a Federally endangered cat, black-spotted newt (amphibian), and Rio Grande Cooter (turtle). The NER Plan would provide a total of 5.4 average annual habitat units over the current 0.03 average annual habitat units of the degraded ecosystem (USACE, 2018a).

Brazos Island Harbor Improvement Project. The Port of Brownsville has proposed to deepen Brazos Island Harbor, thereby expanding local industry and opening the harbor to larger ships now utilizing the improved Panama Canal. The project has been approved by the USACE, but congressional authorization remains for Federal funding. The Brazos Island Harbor entrance channel and jetty channel are proposed to be deepened to –54 MLLW from a current depth of –42 MLLW. No channel widening is proposed; however, where necessary, the channel may be extended or varied to maintain the channel side slopes. Dredged material is to be placed into upland dredge material placement areas and placed for beneficial use onto a feeder berm offshore of South Padre Island (SWG-2016-00038).

Port of Brownsville LNG Terminal #1. Texas LNG Brownsville LLC has proposed construction of an LNG storage and export facility adjacent to the Brownsville Ship Channel. The 625-acre site is between the north side of the channel and SH 48, approximately 19 miles northeast of the city of Brownsville, in Port Isabel, Cameron County. The facilities would be composed of a terminal to liquefy and store natural gas and marine facilities to export LNG and serve as port for vessels during construction. Included in the project is the removal of an abandoned pipeline that runs parallel to the Brownsville Ship Channel (SWG-2015-00175).

Port of Brownsville LNG Terminal #2. Rio Grande LNG has proposed construction of an additional LNG export facility on Port of Brownsville land south of SH 48, bounded to the west by the Bahia Grande Channel. The 984-acre terminal site would have up to six liquefaction trains, natural gas pretreatment facilities, four LNG storage tanks, operational infrastructure, and truck-loading facilities. The LNG facility would also include marine loading berths for LNG vessels, and require dredging to create a turning basin adjacent to the loading berth. Rio Grande LNG is also proposing onsite restoration and enhancement for mitigation of unavoidable impacts to waters of the U.S. The primary objective is to fund and restore the widening of the Bahia Grande Channel, to improve the tidal connection with the Brownsville Ship Channel (SWG-2015-00114).

Port of Brownsville LNG Terminal #3. Annova LNG has proposed the construction of an LNG terminal on the south side of the Brownsville Ship Channel, across the channel from the Bahia Grande. The proposed 731-acre facility would include LNG and marine transfer facilities, in addition to an access road. The project would permanently impact 37.1 acres of wetlands, 0.1 acre of estuarine emergent marsh, 36 acres of palustrine emergent ponds, 0.5 acre of estuarine open water, and 1.2 acres of tidal flat. Temporary impacts would include 19.2 acres of wetlands for initial clearing and fencing construction. The applicant is developing a final mitigation plan that should consist of aquatic resource preservation onsite, enhancement, creation, and/or restoration (SWG-2015-00110).

Port of Brownsville Subsea 7 Spool Base Facility. The Brownsville Navigation District has proposed the construction of a 60-acre spool base facility on the south side of the Brownsville Ship Channel to load, store, and transport piping for pipe lay projects. The waterfront features of the project would include construction of a three-sided vessel slip with bulkhead, slope revetment, and installation of a mooring and a breasting structure. Other planned structures include buildings, a piperack for joining pipe units, drainage corridors, and an access road to SH 4. The 13-acre vessel slip would have dimensions of 1,000 feet long by 900 feet wide and accommodate 525-foot pipelay vessels. The vessel slip would be dredged to –35 feet mean low tide, and approximately 654,000 cy of dredge material would be removed and placed in approved placement areas. Project impacts include 7.6 acres of permanent impact from vessel slip dredging, and 3.03 acres of impact to jurisdictional features from onshore facilities (SWG-2017-00250).

Arroyo Colorado Aeration Structures. The Port of Harlingen has proposed the installation of three aeration water control structures in the main stem of the Arroyo Colorado River. Each structure is essentially a riprap weir meant to create a riffle, adding dissolved oxygen and improving water quality. Each structure would be 0.03 acre of impact to jurisdictional river bottom totaling 0.09 acre of permanent impacts (SWG-2016-00303).

East Wye Channel Widening. The Port Isabel-San Benito Navigation District has proposed to widen the East Wye Channel from 200 feet to approximately 350 feet in width. Additionally, the channel would be deepened to –38 NAVD 88 with 2 feet of overdepth. Approximately 195,630 cy of material is to be removed by hydraulic dredge from the 10.48-acre area and placed in the existing Dredge Disposal Area 3 Brazos Island Project. A 10-year maintenance dredge permit was also requested, which would result in an additional 20,000 cy of material removed over that time span. The applicant proposed the use of silt control measures, and to avoid all seagrass areas and oyster beds (SWG-2014-00849).

Bahia Grande Main Channel Project. The Brownsville Navigation District has proposed to widen and deepen the existing pilot channel between the Bahia Grande and the Brownsville Ship Channel. Approximately 200,000 cy of material would be excavated from the existing pilot channel and adjacent land and moved into adjacent placement areas. Permanent impacts include the conversion of 8.06 acres of jurisdictional area to open water, and 22.32 acres of jurisdictional area converted to upland, for a total of 30.38 acres. Affected jurisdictional features include tidal flats, open water, and palustrine emergent and palustrine scrub-shrub wetlands (SWG-2003-01954).

Long Island Village Residential Development. The estate of John Freeland has proposed to excavate 11.99 acres and place fill in 99.04 acres of jurisdictional waters to construct a residential canal subdivision in the Port Isabel area. The applicant proposed mitigation for the project, consisting of the onsite construction of a 22-acre mangrove and seagrass habitat area, and the preservation of 108.4 acres east of the project site. The protected area includes 89.6 areas of submerged seagrass habitat and 18.8 acres of mangrove wetlands (SWG-1999-02327).

South Padre Island Second Access. An additional access route to and from South Padre Island was proposed through a partnership among the Cameron County Regional Mobility Authority, TxDOT, and the Federal Highway Administration. The project consists of South Padre Island and mainland road improvements, and a bridge spanning the Laguna Madre. Approximately 139.14 acres of wetlands would be affected by the preferred Alternative 6, primarily due to bridge supports impacting Laguna Madre bay bottom. SAV in the form of seagrasses would also be affected. Construction is expected to begin in 2020.

5.10.3 Cumulative Impacts from TSP Implementation

The following portions of the cumulative impact analysis considers the primary drivers of change along the Texas coast, in the context of past, present, and reasonably foreseeable future actions. Understanding the main causes of coastal changes are necessary to frame the TSP and its potential effects (both positive and negative) and how they may contribute to cumulative impacts.

5.10.3.1 Primary Drivers of Change

The primary drivers of change in the various regions of the Texas coast are similar. Although petrochemical industries are more prevalent in the upper Texas coast, all regions of the coast include the presence and influence of the petrochemical industry. Also, each region of the Texas coast includes ports and navigation channels, with channel improvements proposed for each region. From the upper Texas coast to the lower Texas coast, the common primary drivers of change include:

- Petrochemical Industry
- Shipping, Ports, and Navigation
- Commercial Fishing
- Agriculture
- Recreation and Conservation

Land use and cumulative impacts in the Galveston Bay region are historically the result of the petrochemical and shipping industries (with commercial fishing, agriculture, and recreation and conservation playing a smaller role). In the upper Texas coast, much of the growth was facilitated by the development of the Houston Ship Channel and construction of the Texas City Dike and several dredge material placement islands. The upper Texas coast is home to one of the world's largest ports in the Port of Houston, and also encompasses the ports of Texas City, Freeport, Galveston, Cedar Bayou, Port Arthur, Beaumont, and Orange. Shipping is a vital industry to the region, and it relies heavily on the natural resource of the region's natural coastal bays. The Houston Ship Channel has been utilized to ship goods since the 1800s; however, in 1914 the newly dredged 25-foot-deep channel was officially opened for deep-water ships. Large-scale anthropogenic modification of bay physiography has resulted from numerous improvements, expansions, and dredging projects that have transformed the Houston Ship Channel into a massive industrial trade waterway, with a current depth of –45 feet and a width of 530 feet. Bay modifications have increased the salinity and changed the natural hydrology of Galveston Bay (Klinck et al., 2002). The ship channel includes barge bulk docks, liquid cargo ship piers, barge terminal, and multipurpose docks. Supported by the proximity to Texas oilfields and the Houston Ship Channel, the second-largest petrochemical complex in the world resides in this region and is a large part of the economy. The Houston Ship Channel and other navigation channels have also altered hydrosalinity and sedimentation dynamics in the area.

Within Matagorda Bay, much of the growth was facilitated by development of the Matagorda Ship Channel, GIWW, and other navigation channels (e.g., Victoria Barge Canal, Palacios Boat Channel). Shrimping and other commercial fishing is prevalent. Cotton and rice are historically produced in the region. Oil and gas productivity on the Eagle Ford Shale Formation has contributed to recent regional growth.

The Matagorda Ship Channel was completed in 1965 with numerous improvements from 1972 to 2004. Before the Matagorda Ship Channel Jetty was cut in 1963, Pass Cavallo was the only natural inlet into Matagorda Bay. The ship channel has since increased the salinity and changed the natural hydrology of the bay. The ship channel includes barge bulk docks, liquid cargo ship pier, barge terminal, and multipurpose docks. Exports from the Matagorda Ship Channel include oil, cotton, seafood, and cattle (Van Borssum, 2005). The Calhoun Port Authority is planning to improve approximately 26 miles of the Matagorda Ship Channel to allow for deeper-draft vessels and more ship traffic. The deeper channel can modify the hydrology, tidal circulation, and sediment patterns of the bay.

Large-scale changes to hydrology have also occurred in Matagorda Bay due to the manipulation of the Colorado River (Colorado River Diversion; Barcak et al., 2007). Although several large changes have occurred with the Colorado River in respect to Matagorda Bay (including a 40-mile log jam that created a delta and land bridge and dredging of the river to flow directly into the Gulf in 1935), the most recent large change occurred in 1992 when the USACE diverted 100 percent of the river into West Matagorda Bay and the Colorado River Lock System was implemented (Barcak et al., 2007; Simon, 2005). These primary activities, including noteworthy past projects (Colorado River Diversion, Formosa Plastics, Alcoa Point Comfort, and the South Texas Nuclear Project), have influenced land use and impacts in the region.

Land use and cumulative environmental impacts in the Corpus Christi Bay region are historically the result of growth of the petrochemical industry, related shipping, commercial/recreational fishing, and agriculture. Much of the growth resulted from the development of Aransas Pass, Corpus Christi Ship Channel, GIWW, and other navigation channels (e.g., both Lydia Anne Channel and LaQuinta Channel). Commercial fishing is prevalent, and Aransas Pass and Corpus Christi harbor commercial processing facilities. Cotton, sorghum, and wheat are historically produced in the region.

Aransas Pass was opened in 1910 by dredging, which led the way for shipping through Corpus Christi Bay. In 1925, the Corpus Christi Ship Channel was completed across the bay to the Corpus Christi Inner Harbor. In the 1930s the first industries began operations at the Port of Corpus Christi (World Port Source, 2017). Since then Corpus Christi has developed into a major hub for commercial and industrial facilities. The ship channel has been widened and deepened over the years to accommodate larger ocean-faring vessels. The Corpus Christi Ship Channel is currently 400 feet wide, with a depth of –45 feet msl. The Port Authority of Corpus Christi currently has plans to widen the channel to 530 feet and dredge to a depth of –54 feet msl (Port of Corpus Christi, 2017b). The ship channel improvement project has been approved and construction is pending. When the project is completed, the Corpus Christi Ship Channel will be able to handle larger bulk cargo ships and oil and gas bulk vessels (Port of Corpus Christi, 2017a). The deeper draft channel will further modify the natural hydrology, tidal circulation, and sediment patterns of the bay.

Of importance are the alterations to the Nueces River and its delta, and how these alterations have affected hydrosalinity gradients in Corpus Christi Bay. About 15 percent of the mean flow of the Nueces River has been diverted for water supply to agriculture and the city of Corpus Christi. With the continuing growth of the city and the increasing demand for water, the freshwater flow to the Nueces River Delta has decreased (Hodges et al., 2012). In combination, two reservoirs upstream of the delta have also reduced freshwater inflows, as well as nourishing sediments (CBBEP, 2009). This has led to saltwater intrusion and the conversion of freshwater wetlands to brackish or brackish marsh to open water. CBBEP is active in purchasing and managing tracts within the delta for conservation, restoration, and education. These primary activities and drivers, including noteworthy past projects (Corpus Christi Channel and LaQuinta Channel Improvements, Corpus Christi Liquefaction Project, OXY Ingleside, and other port-related activities), have influenced land use and impacts in the region.

Land use and cumulative environmental impacts in the Lower Rio Grande Valley and Laguna Madre are characterized by growth of the petrochemical industry, related shipping, commercial fishing, and agriculture. Much of the growth was facilitated by development of the Brownsville Ship Channel, GIWW, and other navigation channels. Conservation and recreation also drive land use in the region, and the area includes the Lower Rio Grande Valley NWR complex, the Laguna Atascosa NWR complex, and Las Palomas WMA. The region is seeing continued growth through the Port of Brownsville, primarily from the petrochemical industry. The Brownsville Ship Channel is also slated for channel improvements.

Each region is affected by the GIWW, which links all of the Texas coast. For portions of the upper Texas coast relevant to this study, the GIWW runs parallel to and behind Bolivar Peninsula, Galveston Island, and Follets Island before crossing the Brazos and San Bernard rivers. A floodgate system is in place at the intersection of the

GIWW and the Brazos River, which closes off the GIWW from sedimentation and high river flows. The GIWW and the floodgate system have altered hydrosalinity and sedimentation dynamics in the area. The GIWW was constructed parallel to the inland Matagorda Bay shoreline and intersects the Colorado River Lock System, the Palacios Boat Channel, and the Matagorda Ship Channel while crossing behind Matagorda Peninsula. The GIWW crosses the Victoria Barge Canal Seadrift as it crosses San Antonio Bay. The GIWW continues southward Corpus Christi Bay and the Corpus Christi Ship Channel, then through the Laguna Madre, then terminates at the Brownsville Ship Channel. Freshwater from rivers, tidal flows from the GIWW, and construction of other navigation channels, can change the natural salinity gradient and circulation of the bay.

Recreation and conservation lands (NWRs, WMAs, and State parks) are an important component of land use and local culture. In the upper Texas coast, Anahuac NWR, McFaddin NWR, Brazoria NWR, and San Bernard NWR are Federally owned and managed lands in the region. Atkinson WMA, Justin Hurst WMA, J.D. Murphree WMA, Galveston Island State Park, and Sea Rim State Park are all state-owned tracts of land in the region. The TNC also owns and manages the Texas City Prairie Preserve, a regional model for native prairie restoration. Within the mid Texas coast, Big Boggy NWR is a Federally owned and managed tract in the region. Matagorda Island WMA, Mad Island WMA, Guadalupe Delta WMA, Welder Flats WMA, and the proposed Powderhorn Ranch State Park are all State tracts of land in the region. The TNC also owns and manages the Mad Island Marsh Preserve. Several WMAs, NWRs, and national and state parks occur in the mid to lower portions of the Texas coast and protect and conserve large areas in the region. State parks include Goose Island State Park and Mustang Island State Park. WMAs include Matagorda Island WMA and Redhead Pond WMA. The TNC manages Shamrock Island Preserve, an important colonial bird nesting site. Padre Island National Seashore, managed by the NPS, is the largest stretch of undeveloped barrier island in the world. In the lower Texas coast conservation and recreation areas include the Lower Rio Grande Valley NWR complex, the Laguna Atascosa NWR complex, and Las Palomas WMA. These lands are intended for natural resource management, recreation, and conservation for the foreseeable future.

5.10.3.2 Synergy with the TSP and Potential Cumulative Impacts

The TSP would result in several direct and indirect positive and negative impacts to the environment. Some of these positive and negative impacts have the potential to result in positive and negative cumulative effects when considered in conjunction with past, present, and reasonably foreseeable future actions. Past, present, and reasonably foreseeable future actions that may contribute cumulative impacts with the TSP can be grouped into the following categories:

- Coastal Resources Restoration Actions
- Flood and Coastal Storm Risk Management Actions
- Navigation and Dredging Actions
- Petrochemical and Industrial Actions
- Developments and Roadway Transportation Actions

Each category of past, present, and reasonably foreseeable actions has the potential to contribute both positive and negative cumulative effects when considering the TSP. Below is explanation on how each category of actions may interact with the TSP. Table 5-24 provides a list of the past, present, and reasonably foreseeable actions, summarizes the potential resource that may be affected (positively or negatively, short- or long-term), and identifies synergy with the TSP and potential cumulative impacts.

Coastal Resources Restoration Actions. Actions or projects described in this category include a wide variety of potential restoration actions that also range in size. Some of the larger restoration actions include the recommendations within GLO's Texas Coastal Resiliency Master Plan, Jefferson County Ecosysterm Restoration, GLO's CEPRA Program, and large-scale beach nourishments for several barrier islands and peninsulas. In addition, there are numerous smaller marsh and oyster restorations, bird island projects, and shoreline protection projects coastwide. Also, worth mentioning is the RESTORE Act, since some projects considered in this analysis are funded by this Act. The RESTORE Act was passed by the U.S. Congress and signed into law on July 6, 2012. The RESTORE Act grants 80 percent of all money collected from the CWA fines into a RESTORE Trust Fund to be distributed to the five states impacted by the Deep-Water Horizon oil spill. Projects funded by RESTORE Act are intended to restore and protect coastal resources, just like the TSP. Similarly, the GLO's Texas Coastal Resiliency Master Plan was developed in conjunction and acknowledgment of the Coastal Texas Study and is intended to be synergistic and contribute beneficial cumulative effects to Texas coastal resources. Coastal restoration projects (both large and small), combined with the TSP, contribute to the concepts of coastwide restoration and protection, and beneficial cumulative impacts are anticipated (see Table 5-24).

Flood and Coastal Storm Risk Management Actions. The Texas coast has experienced several hurricanes and unprecedented flooding events in the recent past, which have highlighted the need for more flood and CSRM actions. All projects or actions described are being undertaken by the USACE. The largest is the Sabine Pass to Galveston Bay Coastal Storm Risk Management and Ecosystem Restoration project. This project recommends several levees, which support risk reduction along a broader extent of the Texas coast, and they complement the TSP's objectives. Direct compatibility of risk reduction efforts with the TSP would expand resiliency of the Texas coast and implementation of a systems approach to restoration and protection, yielding positive cumulative impacts (see Table 5-24). Within Harris County and the Houston area, the USACE has several authorizations to assess flood risk management (opportunities in Buffalo Bayou and Tributaries, Brays Bayou, Clear Creek, Hunting Bayou, and White Oak Bayou). Flood risk management efforts, which result from these authorities, will reduce risk from different damage mechanisms, such as precipitation. In combination with the TSP, they can complement a systems approach to risk reduction. Features designed to reduce inundation from rainfall could increase capacity, volume, and timing of water flow to rivers, bayous, and bays. The hydrologic changes from the flood risk management features could be greater than the salinity changes from the TSP features, which restrict the flow of water between the bay and the Gulf. It is anticipated that flood risk management actions would contribute to the TSP's purpose of CSRM and ER and would yield positive cumulative impacts (see Table 5-24).

Table 5-24
Cumulative Effect Impacts

Project or Action (Responsible Entity)	Location	Past or Present (PP) or Reasonably Foreseeable (RF)	Resource* Considered	Environmental Resource Issues that could be Cumulative	Interaction with the TSP and Potential Cumulative Impacts
Coastal Resources Restoration Actions					
Texas GLO Coastal Resiliency Master Plan Recommendations (GLO)	Coastwide	RF	1, 2, 3, 4, 10, 11, 12, 13, 17	1 – Geomorphology and Coastal Processes 3 – Water and Sediment Quality 10 – Wetlands 11 – Aquatic	The Master Plan identifies priority actions for GLO to enhance resiliency of the Texas coast. Recommended actions of the Master Plan evolve from collaboration with agency partners and support the TSP objectives. The likely cumulative impacts would be increased resiliency of resources from a systems approach to coast-wide restoration and protection of water and sediment quality and landscape features.
Jefferson County Ecosystem Restoration (USACE)	Jefferson County	RF	1, 3, 4, 10, 12, 13, 16	10 – Wetlands 12 – Wildlife Resources	Coastal restoration projects include oyster, marsh, beach, and rookery island restoration efforts. Some restoration efforts include erosion reduction. The likely cumulative impacts of these measures in combination with the TSP would be increased resiliency of resources from a systems approach to coastwide restoration and protection of water and sediment quality and landscape features. Potential short-term impacts of construction would be minimal in combination, and could be reduced through coordination and phased implementation.
McFaddin Beach Dune Restoration (Jefferson County)	Bolivar Peninsula	PP/RF	1, 2, 3, 4, 10, 12, 13	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource	
East Bay and GIWW Shoreline Protection and Restoration (Galveston Bay Foundation)	East Bay	PP	1, 2, 3, 4, 10, 11, 16	16 – Navigation 4 – Hydrology	
Bolivar Peninsula Beach/Dune Restoration (Galveston County)	Bolivar Peninsula	PP/RF	1, 2, 3, 4, 10, 11, 12, 13	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource	
Burnet Bay Marsh Mound Creation (Galveston Bay Foundation)	Galveston Bay	PP	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
Dickinson Bayou Wetland Restoration and Protection (TPWD)	Galveston Bay	PP	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
Moses Lake Shoreline Protection (Galveston Bay Foundation)	Galveston Bay	PP	3, 4, 10, 11, 12	10 – Wetlands 11 – Aquatic	
Swan Lake Restoration (TPWD)	Galveston Bay	PP	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
Greens Lake Shoreline Erosion Protection (Ducks Unlimited)	Galveston Bay	PP	2, 3, 4, 10, 11, 16	10 – Wetlands 11 – Aquatic	
North Deer Island Protection and Restoration (Galveston Bay Foundation)	Galveston Bay	PP	10, 11, 12,	12 – Wildlife Resources	
Galveston Bay Oyster Reef Restoration (TPWD)	Galveston Bay	PP	1, 3, 11	3 – Water and Sediment Quality 11 – Aquatic	
Galveston Island Beach Nourishment (Galveston Park Board)	Galveston Bay	PP	1, 2, 3, 4, 11, 12, 13, 15	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource 15 – Socioeconomics	
Pierce Marsh Restoration (Galveston Bay Foundation)	Galveston Bay	PP	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
Galveston Island State Park Marsh Restoration and Protection (TPWD)	Galveston Bay	PP	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
Sweetwater Preserve Shoreline Protection and Oyster Habitat Enhancement (Galveston Bay Foundation)	Galveston Bay	PP	1, 2, 3, 4, 10, 11	3 – Water and Sediment Quality 11 – Aquatic	

Project or Action (Responsible Entity)	Location	Past or Present (PP) or Reasonably Foreseeable (RF)	Resource* Considered	Environmental Resource Issues that could be Cumulative	Interaction with the TSP and Potential Cumulative Impacts
Snake Island Restoration (Galveston Bay Foundation)	Galveston Bay	PP	1, 2, 3, 4, 10, 11	3 – Water and Sediment Quality 10 – Wetlands 11 – Aquatic	
Gang's Bayou Marsh Restoration and Protection (TPWD)	Galveston Bay	PP	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
Oyster Lake Habitat Protection and Marsh Restoration (USFWS)	Galveston Bay	PP	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
Surfside Beach Groins and Nourishment (Village of Surfside)	Follets Island	PP	1, 2, 3, 4, 12, 13	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource	
Bryan Beach Renourishment (Town of Quintana)	Follets Island	PP	1, 2, 3, 4, 12, 13	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource	
Texas GLO CEPRA – Various Projects (GLO)	Coastwide	PP/RF	1, 2, 3, 4, 10, 11, 12, 13, 16	1 – Geomorphology and Coastal Processes 3 – Water and Sediment Quality 10 – Wetlands 11 – Aquatic	
Trinity Bay Living Shoreline and Erosion Protection (Chambers County)	Galveston Bay	RF	3, 10, 11	3 – Water and Sediment Quality 11 – Aquatic	
Trinity Bay Discovery Center Living Shoreline and Habitat Creation (Galveston Bay Foundation)	Galveston Bay	RF	3, 10, 11	3 – Water and Sediment Quality 11 – Aquatic	
Dickinson Bay Waterbird Rookery (Galveston Bay Foundation)	Galveston Bay	PP	11, 12	12 – Wildlife Resource	
Dollar Bay and Moses Lake Marsh Terraces (Galveston Bay Foundation)	Galveston Bay	PP	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
San Luis Pass Dredge and Follets Island Nourishment (Brazoria County)	Galveston Bay	RF	1, 2, 3, 4, 11, 13, 12	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource	
San Bernard River Mouth Restoration (Brazoria County)	Brazoria County	RF	1, 2, 3, 4, 11, 13	1 – Geomorphology and Coastal Processes 4 – Hydrology	
Mad Island WMA Shoreline Protection (TPWD)	Matagorda Bay	PP	1, 2, 3, 4, 10, 11, 12	12 – Wildlife Resource	
Half Moon Reef Restoration (TNC and USACE)	Matagorda Bay	PP/RF	1, 2, 3, 4, 11	3 – Water and Sediment Quality 11 – Aquatic	
Mid-Coast Bird Rookery Island (TNC)	San Antonio Bay	RF	11, 12	12 – Wildlife Resource	
Aransas County Oyster Reef Restoration (Texas A&M University – Corpus Christi)	Copano Bay	RF	1, 2, 3, 11	3 – Water and Sediment Quality 11– Aquatic	
Rockport Beach Nourishment Project (Aransas County)	Copano Bay	PP	1, 2, 3, 11, 12	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource	
North Beach Sand Placement (Corpus Christi)	Corpus Christi Bay	RF	1, 2, 3, 11, 12	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource	

Project or Action (Responsible Entity)	Location	Past or Present (PP) or Reasonably Foreseeable (RF)	Resource* Considered	Environmental Resource Issues that could be Cumulative	Interaction with the TSP and Potential Cumulative Impacts
McGee Beach Sand Placement (Corpus Christi)	Corpus Christi Bay	RF	1, 2, 3, 11, 12	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource	
Nueces Bay Rookery Island Shoreline Amoring (CBBEP)	Corpus Christi Bay	RF	11, 12	12 – Wildlife Resource	
Nueces Bay Shoreline Protection Measures (CBBEP)	Corpus Christi Bay	RF	1, 2, 3, 4, 10, 11, 12	12 – Wildlife Resource	
Dagger Island Breakwater and Containment Area (TPWD)	Corpus Christi Bay	RF	1, 2, 3, 4, 10, 11, 12	10 – Wetlands 12 – Wildlife Resources	
Adolph Thomae Jr. County Park Improvements (Cameron County)	Laguna Madre	PP/RF	1, 3, 15	15 – Socioeconomics	
Bahia Grande Main Channel Project (Brownsville Navigation District)	Laguna Madre	PP/RF	1, 2, 3, 4,	3 – Water and Sediment Quality 4 – Hydrology	
Arroyo Colorado Aeration Structures (Port of Harlingen)	Laguna Madre	RF	3	3 – Water and Sediment Quality	
South Padre Island Beach Nourishment (Town of South Padre Island)	South Padre Island	PP/RF	1, 2, 3, 4, 11, 12, 13, 15, 17	1 – Geomorphology and Coastal Processes 12 – Wildlife Resource 15 – Socioeconomics 17 – Flood Risk Reduction	
Brownsville Resaca Ecosystem Restoration (USACE)	Cameron County	RF	1, 3, 4, 10, 11, 17	3 – Water and Sediment Quality 4 – Hydrology	Resaca restoration efforts include hydrologic connectivity and habitat improvements. The likely cumulative impacts of these measures in combination with the TSP would be limited since resacas are not immediately within the coastal area. The hydrologic condition of the area will not be affected by the CSRM features of the TSP. No cumulative impacts are expected from restoration features of the improvements to resacas would be unlikely to flow into areas affected by the TSP.
Flood and Coastal Storm Risk Management Actions					
Sabine Pass to Galveston Bay Coastal Storm Risk Management and Ecosystem Restoration (USACE)	Sabine Lake to San Luis Pass	RF	1, 2, 3, 4, 10, 12, 13, 15, 16, 17	4 – Hydrology 17 – Flood Risk Reduction	Levees proposed within this project would reduce inundation from coastal storms. In combination with the TSP, the features provide comparable risk reduction to adjacent areas, and will provide beneficial risk reduction along a broader portion of the Texas coast. The hydrologic condition of the area is not anticipated to be affected by the features of the TSP.
Buffalo Bayou and Tributaries Flood Risk Management (USACE)	Harris County	RF	1, 3, 4, 10, 11, 15, 17	4 – Hydrology 17 – Flood Risk Reduction	Flood risk management efforts within the metro Houston and non-coastal areas will reduce risk from different damage mechanisms, such as precipitation. In combination with the TSP, they can complement a systems approach to risk reduction. Features designed to reduce inundation from rainfall could increase capacity, volume, and timing of water flow to rivers, bayous and bays. The hydrologic changes from the flood risk management features could be greater than the nominal salinity changes from the TSP features which restrict the flow of water between the bay and the Gulf.
Brays Bayou Flood Risk Management Project (USACE)	Harris County	PP/RF	1, 3, 4, 10, 11, 15, 17	4 – Hydrology 17 – Flood Risk Reduction	
Metro Houston Regional Watershed Assessment (USACE)	Harris County	RF	1, 3, 4, 10, 11, 15, 17	3– Water and Sediment Quality 4 – Hydrology 17 – Flood Risk Reduction	
Clear Creek Flood Risk Management (USACE)	Harris and Galveston counties	PP/RF	1, 3, 4, 10, 11, 15, 17	4 – Hydrology 17 – Flood Risk Reduction	
Hunting Bayou Flood Risk Management (USACE)	Harris County	RF	1, 3, 4, 10, 11, 15, 17	4 – Hydrology 17 – Flood Risk Reduction	

Project or Action (Responsible Entity)	Location	Past or Present (PP) or Reasonably Foreseeable (RF)	Resource* Considered	Environmental Resource Issues that could be Cumulative	Interaction with the TSP and Potential Cumulative Impacts
White Oak Bayou Flood Risk Management (USACE)	Harris County	RF	1, 3, 4, 10, 11, 15, 17	4 – Hydrology 17 – Flood Risk Reduction	
Navigation or Dredging Actions					
Houston Ship Channel Expansion and Channel Improvement Project (USACE)	Galveston Bay	RF	1, 2, 3, 4, 6, 8, 11, 12, 13, 15, 16	3 – Water and Sediment Quality 4 – Hydrology 11 – Aquatic Resources 16 – Navigation	Houston Ship Channel improvements will displace oysters and can increase the flow and amount of saline water into the bay through a deeper and wider channel. In combination with the TSP, tidal attenuation impacts from a coastal barrier may be reduced by a deeper and wider Houston Ship Channel. Beneficial use (BU) of sediment from Houston Ship Channel work may support a broad systems approach to coastwide restoration and protection.
GIWW Maintenance (USACE)	Coast-wide	PP/RF	1, 2, 3, 4, 6, 10, 11, 12, 13, 16	3 – Water and Sediment Quality 16 – Navigation	The TSP may reduce frequency of maintenance dredging through restoration measures that reduce erosion along the banks of the GIWW, and CSRM features may reduce large sediment deposition following storm events. Dredging sediment may be beneficially used for TSP restoration measures, supporting a systems approach to coastwide restoration and protection.
Sabine-Neches Waterway Channel Improvement Project (USACE)	Sabine Lake	PP/RF	1, 2, 3, 4, 6, 8, 11, 12, 13, 15, 16	3 – Water and Sediment Quality 4 – Hydrology 11 – Aquatic Resources 16 – Navigation	Navigation improvements can affect localized flow and salinity. BU of sediment may support a broad systems approach to coastwide restoration and protection.
Galveston Channel Extension (USACE)	Galveston Bay	RF	1, 2, 3, 4, 11, 16	3 – Water and Sediment Quality 16 – Navigation	
Cedar Bayou Channel Extension (USACE)	Galveston Bay	RF	1, 2, 3, 4, 11, 16	3 – Water and Sediment Quality 16 – Navigation	
Matagorda Ship Channel Expansion (USACE/Calhoun County Port Authority)	Matagorda Bay	RF	1, 2, 3, 4, 6, 8, 10, 11, 12, 13, 15, 16	3 – Water and Sediment Quality 4 – Hydrology 11 – Aquatic Resources 16 – Navigation	
Palacios Channel Maintenance Dredging (Port of Palacios)	Matagorda Bay	RF	2, 3, 10, 11, 16	3 – Water and Sediment Quality 16 – Navigation	
Corpus Christi Ship Channel Improvement Project (USACE)	Corpus Christi Bay	RF	1, 2, 3, 4, 6, 8, 10, 11, 12, 13, 15, 16	3 – Water and Sediment Quality 4 – Hydrology 11 – Aquatic Resources 16 – Navigation	
Bayport Ship Channel Container Terminal Dredging (Port of Houston Authority)	Galveston Bay	PP	2, 3, 11, 16	3 – Water and Sediment Quality 11 – Aquatic Resources 16 – Navigation	Navigation improvements can affect localized flow and salinity. BU of sediment may support a broad systems approach to coastwide restoration and protection.
GIWW Barge Facility Expansion and Maintenance (Texas Barge and Boat)	Freeport	PP	1, 2, 3, 4, 10, 11, 16	3 – Water and Sediment Quality 16 – Navigation	
Houston Ship Channel Barge Fleeting Expansion (Port of Houston Authority)	Galveston Bay	RF	2, 3, 16	3 – Water and Sediment Quality 16 – Navigation	
Bayport Turning Basin (USACE)	Galveston Bay	RF	1, 2, 3, 4, 11, 16	3 – Water and Sediment Quality 11 – Aquatic Resources 16 – Navigation	

Project or Action (Responsible Entity)	Location	Past or Present (PP) or Reasonably Foreseeable (RF)	Resource* Considered	Environmental Resource Issues that could be Cumulative	Interaction with the TSP and Potential Cumulative Impacts
Texas City Turning Basin Improvements (Texas City Terminal Railway Company)	Galveston Bay	RF	2, 3, 16	3 – Water and Sediment Quality 16 – Navigation	
Harbor of Refuge Bulkhead (City of Port Lavaca)	Matagorda Bay	RF	2, 3, 11	3 – Water and Sediment Quality 16 – Navigation	
LaQuinta - Ingleside Dredging (OXY Ingleside Energy Center)	Corpus Christi Bay	RF	2, 3, 16	3 – Water and Sediment Quality 16 – Navigation	
OXY Ingleside Energy Pier Dredging Activities (OXY Ingleside Energy Center)	Corpus Christi Bay	RF	2, 3, 16	3 – Water and Sediment Quality 16 – Navigation	
Port Mansfield, Texas Maintenance (USACE)	Laguna Madre	RF	2, 3, 16	3 – Water and Sediment Quality 16 – Navigation	
Brazos Island Harbor Improvement Project (Port of Brownsville)	Laguna Madre	RF	1, 2, 3, 4, 6, 10, 11, 12, 13, 15, 16	3 – Water and Sediment Quality 4 – Hydrology 11 – Aquatic Resources 16 – Navigation	
East Wye Channel Widening (Port Isabel – San Benito Navigation District)	Laguna Madre	RF	1, 2, 3, 4, 6, 10, 11, 12, 13, 15, 16	3 – Water and Sediment Quality 4 – Hydrology 11 – Aquatic Resources 16 – Navigation	
Petrochemical and Industrial Actions					
Houston Ship Channel Dredging and Bulkhead Construction (Kinder Morgan)	Galveston Bay	PP	1, 2, 3, 4, 9, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	Investment and expansion of existing infrastructure within the study area has potential to impact air, water and sediment quality, HTRW, and noise levels. There could be short-term impacts with the construction of TSP as other facilities operate within the study area at the same time. The combined impacts could be reduced through coordination and phased implementation. Investments into hardening infrastructure and facilities against coastal risk and damage may support the resiliency of the area targeted through TSP. Navigation improvements can affect localized flow and salinity. BU of sediment may support a broad systems approach to coastwide restoration and protection. No potential cumulative effect identified.
Barbours Cut Ethane Terminal Improvements (Enterprise Products)	Galveston Bay	PP	2, 3, 9, 10, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
Formosa Plastics Plant (Formosa Plastics Corporation)	Matagorda Bay	PP	2, 3, 8, 9, 11, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
Alcoa Alumina Plant (Alcoa)	Matagorda Bay	PP	2, 3, 7, 8, 9, 11, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
Ingleside Ethylene Cracking Plant (Occidental Chemical Corporation)	Corpus Christi Bay	PP	2, 3, 8, 9, 11, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
OXY Ingleside Energy Center (Occidental Petroleum)	Corpus Christi Bay	PP	2, 3, 8, 9, 11, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
Corpus Christi Liquefaction Project (Cheniere Energy)	Corpus Christi Bay	PP	2, 3, 8, 9, 11, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	

Project or Action (Responsible Entity)	Location	Past or Present (PP) or Reasonably Foreseeable (RF)	Resource* Considered	Environmental Resource Issues that could be Cumulative	Interaction with the TSP and Potential Cumulative Impacts
Buffalo Bayou Petroleum Storage and Marine Terminal (Magellan Terminal Holdings)	Galveston Bay	RF	1, 2, 3, 4, 8, 16	3 – Water and Sediment Quality 8 – Air Quality	
Corpus Christi Channel Marine Terminal Expansion (Plains All American Pipeline)	Corpus Christi Bay	RF	1, 2, 3, 4, 8, 16	3 – Water and Sediment Quality 8 – Air Quality	
Magelland Crude and Hydrocarbon Bulk Storage Terminal (Magellan Terminal Holdings)	Corpus Christi Bay	RF	3, 4, 8, 16	3 – Water and Sediment Quality 8 – Air Quality	
Port of Brownsville LNC Terminal #1 (Texas LNG Brownsville)	Laguna Madre	RF	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
Port of Brownsville LNC Terminal #2 (Rio Grande LNG)	Laguna Madre	RF	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
Port of Brownsville LNC Terminal #3 (Annova LNG)	Laguna Madre	RF	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
Port of Brownsville Subsea 7 Spool Base Facility (Brownsville Navigation District)	Laguna Madre	RF	1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 16	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise	
Private Developments and Roadway Transportation Actions					
Spoonbill Bay Mixed Use Development (Spoonbill Holdings)	Galveston Bay	RF	1, 2, 3, 4, 5,10, 11, 12	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise 10 – Wetlands 11 – Aquatic Resources	Investment and expansion of existing Private Developments and public infrastructure within the study area has potential to impact air, water and sediment quality, and noise levels. There could be short-term impacts with the construction of the TSP as other roads and private developments are constructed concurrently. The combined impacts could be reduced through coordination and phased implementation.
SH 87 Improvements (Rollover Pass to SH 124) (TxDOT)	Bolivar Peninsula	RF	1, 4, 5, 10, 11, 13, 17	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise 10 – Wetlands 11 – Aquatic Resources 17 – Flood Risk Reduction	
The Sanctuary at Costa Grande Mitigation Plan (DH Texas Development)	Espirtu Santo Bay	PP	1, 2, 3, 4, 10, 11, 12	3 – Water and Sediment Quality 8 – Air Quality 9 – Noise 10 – Wetlands 11 – Aquatic Resources	
Corpus Christi New Harbor Bridge (Corpus Christi)	Corpus Christi	PP/RF	4, 9, 11	9 – Noise 11 – Aquatic Resources	
Lake Padres Subdivision Canal (Gulf Shores Joint Venture)	Laguna Madre	PP	1, 2, 3, 4, 10, 11, 12	3 – Water and Sediment Quality 10 – Wetlands 11 – Aquatic Resources	

Project or Action (Responsible Entity)	Location	Past or Present (PP) or Reasonably Foreseeable (RF)	Resource* Considered	Environmental Resource Issues that could be Cumulative	Interaction with the TSP and Potential Cumulative Impacts
Long Island Village Residential Development (John Freeland)	Laguna Madre	PP	1, 2, 3, 4, 10, 11, 12	3 – Water and Sediment Quality 10 – Wetlands 11 – Aquatic Resources	
South Padre Island Second Access (Cameron County Regional Mobility Authority)	Laguna Madre	PP	4, 9, 10, 11, 12, 13	10 – Wetlands 11 – Aquatic Resources	
Residential Piers and Improvements	Coastwide	PP/RF	1, 2, 3, 4, 5,10, 11, 12	3 – Water and Sediment Quality 9 – Noise 10 – Wetlands 11 – Aquatic Resources	Shoreline vegetation change 8,965 permitting actions: riprap, shoreline work, restoration, piers, pipeline. These efforts have occurred in the past and are reasonably expected into the future. The permitting process is an opportunity to restrict efforts that create unnecessary impacts.

*1 – Geomorphology and Coastal Processes; 2 – Physical Oceanography; 3 – Water and Sediment Quality; 4 – Hydrology; 5 – Soils; 6 – Energy and Mineral Resources; 7 – HTRW; 8 – Air Quality; 9 – Noise; 10 – Wetlands; 11 – Aquatic Resources; 12 – Wildlife Resources; 13 – Protected Resources; 14 – Cultural Resources; 15 – Socioeconomics; 16 – Navigation; 17 – Flood Risk Reduction

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Navigation and Dredging Actions. Projects or actions involving navigation and dredging are common along the Texas coast. Some of these actions have the potential to contribute to the TSP's impacts, where many others may not result in any identified synergy with the TSP. One of the largest actions considered in this analysis is the Houston Ship Channel Expansion Channel Improvement Project. That project has not been authorized for construction at this time, but it is reasonable to expect that this or future investments will include deepening of entrance channels and interior harbor features at various ports in the area. Although the TSP would result in a tidal constriction at the Galveston Bay entrance due to the Coastal Barrier Alternative, a deeper and wider Houston Ship Channel may at times reduce impacts resulting from the TSP's tidal constriction. Many of the other larger channel deepening and widening projects, such as the Sabine-Neches Waterway Channel Improvement Project, Matagorda Ship Channel Expansion, Corpus Christi Channel Improvement Project, GIWW maintenance, GIWW Coastal Resilience Study, Brazos Island Harbor Improvement Project, and other shallow draft navigation channel maintenance, in conjunction with the TSP, may not have a direct negative or positive cumulative impact; however, BU opportunities arise from these projects (including marsh restoration, beach nourishment, bird islands, and shoreline protection) when sediment is used in the TSP restoration features (see Table 5-24).

Petrochemical and Industrial Actions. A major component of the Texas economy and coastal setting includes petrochemical and industrial actions and activities. Many of these actions include facilities, terminals, bulkhead construction, and dredging. Investment and expansion of existing infrastructure within the study area has potential to impact air, water and sediment quality, HTRW, and noise levels. Combination with the TSP could be short-term impacts of TSP construction as other facilities operate within the study area. The combined impacts could be reduced through coordination and phased implementation (see Table 5-24).

Private Developments and Roadway Transportation Projects. Investment and expansion of existing Private Developments and public infrastructure within the study area has potential to impact air, water and sediment quality, and noise levels. There could be short term impacts with the construction of the TSP as other roads and private developments are constructed concurrently. The combined impacts could be reduced through coordination and phased implementation.

SH 87 Improvements (Rollover Pass to SH 124). TxDOT will be raising SH 87 to 7.5 feet above sea level from Rollover Pass to SH 124 on Bolivar Peninsula. Efforts to increase the roadbed elevation will include the use of asphalt, beach nourishment, dune restoration, and roadway alignment reconfiguration. This increase in elevation should prevent roadway flooding during high tides and some storm events. Realignment would allow for more area for beach restoration and maintenance; 15.9 acres of wetlands would be filled because of the roadway improvement. The project will be constructed entirely within existing right-of-way, which is typically between 120 and 398 feet wide. Wetland impacts would be mitigated with credits from the Gulf Coastal Plains Mitigation Bank (SWG-2017-00359).

When considering some of the past, present, and reasonably foreseeable actions, TSP features may yield cumulative benefits to coastal resources. The potential for positive cumulative impacts is particularly likely for coastal restoration actions and flood and CSRM actions. For navigation and dredging actions, there may be opportunities for BU that would contribute to coastwide restoration and protection. Since the TSP is intended to

provide long-term benefits to coastal resources, cumulative impacts that may result from the TSP are likely to be positive or beneficial.