US Army Corps of Engineers ®
Galveston District

Appendix I

Ecological Modeling

for

Coastal Texas Protection and Restoration Study

October 2020

Coastal Texas Protection and Ecosystem Restoration Feasibility Study

Ecological Modeling

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United States Army Corps of Engineers
Regional Planning and Environmental Center

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Table of Contents

List of Figures

List of Tables

Acronyms and Abbreviations

°F	degrees Fahrenheit
AAHUs	Average Annual Habitat Units
BEG	Bureau of Economic Geology
C-CAP	Coastal Change Atlas Program
CE/ICA	Cost Effectiveness/Incremental Cost Analysis
Coastal Texas Study	Coastal Texas Protection and Restoration Study
CSRM	coastal storm risk management
DIFR-EIS	Draft Integrated Feasibility Report and Environmental Impact Statement
ER	ecosystem restoration
ESRI	Environmental Systems Research Institute
FIFR-EIS	Final Integrated Feasibility Report and Environmental Impact Statement
FWOP	Future-without Project
FWP	Future-with Project
GIS	Geographic Information System
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
Gulf	Gulf of Mexico
HEAT	Habitat Evaluation and Assessment Tools
HEP	Habitat Evaluation Procedures
HSI	Habitat Suitability Index
HUs	habitat units
ICA	incremental cost analysis
LiDAR	Light Detection and Ranging
NAVD 88	North American Vertical Datum of 1988
NEPA	National Environmental Policy Act
NOAA	National Oceanographic and Atmospheric Administration
NRC	Natural Research Council
NWI	National Wetland Inventory
NWR	National Wildlife Refuge

ppt	parts per thousand
RSLC	relative sea level change
RSLR	relative sea level rise
SAV	submerged aquatic vegetation
SLR	sea level rise
TCEQ	Texas Commission on Environmental Quality
TPWD	Texas Parks and Wildlife Department
TY	target year
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geologic Survey
V	habitat variable
WVA	Wetland Value Assessment

1.0 INTRODUCTION

This appendix provides documentation of the habitat evaluation and quantification process that was conducted to evaluate potential adverse and beneficial impacts to various habitat types if the recommended plan of the Coastal Texas Protection and Restoration Feasibility Study (Coastal Texas Study) is implemented. Quantification is needed in the project planning process to evaluate benefits or impacts of project features because traditional benefit/cost evaluation is not applicable when valuing habitat.

1.1 STUDY DESCRIPTION

The U.S. Army Corps of Engineers, Galveston District (USACE), in partnership with the Texas General Land Office, have undertaken the Coastal Texas Study, which is examining coastal storm risk management (CSRM) and ecosystem restoration (ER) opportunities within 18 counties of the Texas Gulf coast (

Figure 1). This Study seeks to develop a comprehensive plan along the Texas coast to mitigate coastal erosion, relative sea level rise (RSLR), coastal storm surge, habitat loss, and water quality degradation.

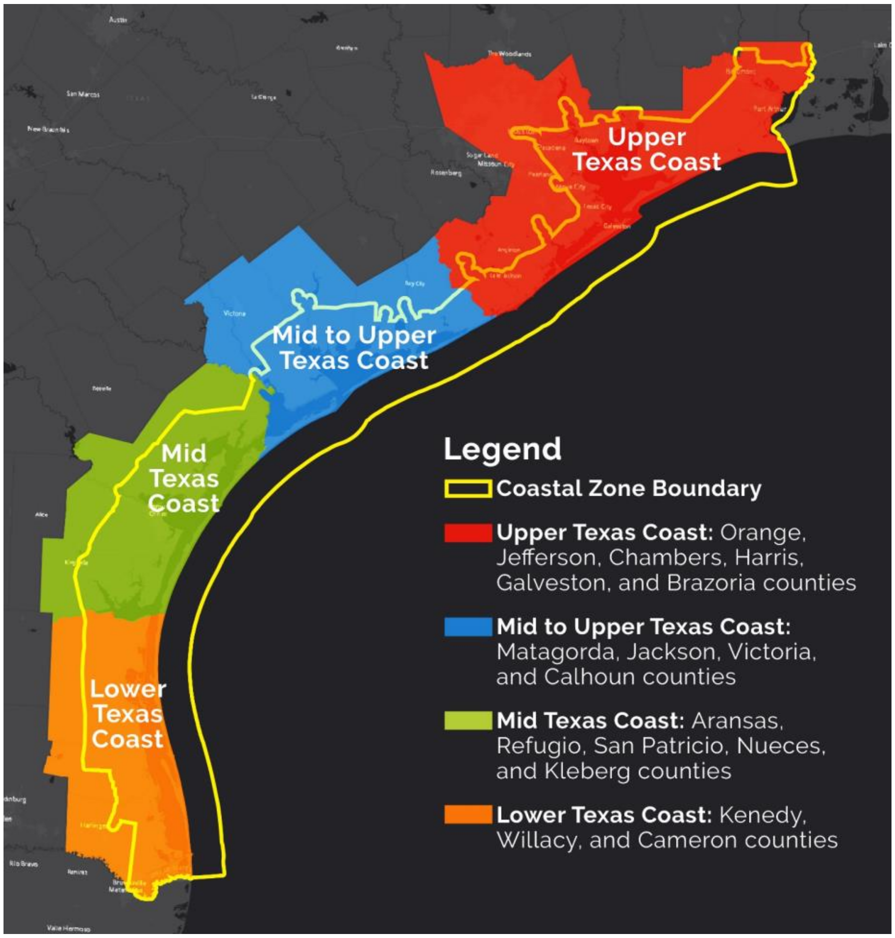

Figure 1. Coastal Texas Study Area

The Coastal Texas Study is following the Corps guideline of SMART Planning, with the exception of the cost of the study and time allotted. SMART Planning encourages risk-informed decision making and the appropriate levels of detail for conducting investigations, so that recommendations can be captured and succinctly documented and completed in a target goal of 3 years and for less than $3 million in compliance with the 3x3x3 rule. It reorients the planning process away from simply collecting data or completing tasks and refocuses it on doing the work required to reduce uncertainty to the point where the PDT can make an iterative sequence of planning decisions required to complete a quality study in full compliance with environmental laws and statutes. Because of the scale of the study area, complexity of the problems, and dual purpose scope (CSRM and ER), the study has an exemption for the time and money aspect, but has still maintained the risk-informed decision making aspect.

Also because of the uncertainty and complexity of a number of the potential solutions to the problems, the Study employs a tiered NEPA compliance approach, in accordance with the Council on Environmental Quality's (CEQ's) Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act (40 CFR 1500—1508, specifically 1502.20). Under this structure, rather than preparing a single definitive EIS as the basis for approving the entire project, the USACE will conduct two or more rounds – or "tiers" – of environmental review. For projects as large and complex as the Study, this approach has been found to better support disclosure of potential environmental impacts for the entire project at the initial phase. Subsequent NEPA documents are then able to present more thorough assessments of impacts and mitigation need as the proposed solutions are refined and more detailed information becomes available in future phases of the project. This tiered approach also provides for a timely response to issues that arise from specific, proposed actions and supports forward progress toward completion of the overall study.

A Tier One assessment analyzes the project on a broad scale, while taking into account the full range of potential effects to both the human and natural environments from potentially implementing proposed solutions. The purpose of the Tier One EIS is to present the information considered to selected a preferred alternative, describe the comprehensive list of measures, and identify data gaps and future plans to supplement the data needed to better understand the direct, indirect, and cumulative effects of the proposed solutions.

Once refinements and additional information is gathered, USACE will shift to a Tier Two assessment, which involves preparation of one or more additional NEPA documents (either an EIS or Environmental Assessment) that build off the original EIS to examine individual components of the Recommended Plan in greater detail. Whether an EIS or EA is developed will be dependent on the significance of impacts anticipated from the action. In either situation, Tier Two assessments will comply with CEQ Regulations, including providing for additional public review periods and resource agency coordination. The Tier Two document would disclose site specific impacts to the proposed solution and identify the avoidance, minimization, and compensatory mitigation efforts to lessen adverse effects.

1.2 ALTERNATIVES CONSIDERED

The study authorization directed the study team to evaluate ER and CSRM solutions. These two purposes recognize that the study area is vulnerable to both storm risk and the gradual coastal processes that wear away natural coastal areas and habitats. To enhance the resiliency, redundancy, and robustness of the proposed systems, measures were generally assembled to:

- **Form Multiple Lines of Defense:** This strategy recognizes the benefits natural landforms provide against coastal storms. By combining various lines of defense (e.g. barrier islands, living shorelines, coastal marshes, etc.), redundant levels of protection and restoration are provided for both humans and coastal ecosystems.
- **Be Comprehensive:** The CSRM alternatives were assembled within a systems approach to work in concert with other measures considered, connect to existing systems, and be adaptable over time.

Three primary iterations occurred during the planning process, as follows:

- **Conceptual Plans:** Evaluates potential measures and assesses effectiveness of combined ER and CSRM measures to achieve study objectives.
- **Tentatively Selected Plan (TSP) Selection:** Quantifies and compares benefits and impacts to identify the TSP (National Economic Development [NED] and National Ecosystem Restoration plans [NER]), supporting publication of the 2018 Draft Report.
- **Integration and Refinement:** Refining the TSP, considering public, agency, and technical comments, in addition to further technical refinement, to identify the Recommended Plan.

1.2.1 Ecosystem Restoration

For ER, the study team assembled a wide variety of potential measures, drawn from the GLO's Coastal Resiliency Master Plan, past USACE studies, NEPA public scoping, and resource agency suggestions. During the conceptual phase of screening, the restoration measures were evaluated and refined by an interagency team who screened them for performance, viability, and whether the measures would achieve the planning objectives. A total of eight ER measures in six different counties were retained (Figure 2). The following describes the measures that were carried forward:

- **G-28: Bolivar Peninsula and West Bay Gulf Intracoastal Waterway (GIWW) Shoreline and Island Protection**
    - Shoreline protection and restoration through the nourishment of 664 acres of eroding and degrading marshes and construction of 40.4 miles of breakwaters along unprotected segments of the GIWW on Bolivar Peninsula and along the north shore of West Bay,
    - Restoration of 326 acres (approximately 5 miles) of an island that protected the GIWW and mainland in West Bay, and

- Addition of oyster cultch to encourage creation of 18.0 acres (26,280 linear feet) oyster reef on the bayside of the restored island in West Bay.

- **B-2: Follets Island Gulf Beach and Dune Restoration**
    - Restoration of 10.1 miles (1,113.8 acres) of beach and dune complex on Gulf shorelines of Follets Island in Brazoria County.
- **B-12: West Bay and Brazoria GIWW Shoreline Protection**
    - Shoreline protection and restoration through nourishment of 551 acres of eroding and degrading marshes and construction of about 40 miles breakwaters along unprotected segments of the GIWW in Brazoria County,
    - Construction of about 3.2 miles of rock breakwaters along western shorelines of West Bay and Cow Trap lakes, and
    - Addition of oyster cultch to encourage creation of 3,708 linear feet of oyster reef along the eastern shorelines of Oyster Lake
- **M-8: East Matagorda Bay Shoreline Protection**
    - Shoreline protection and restoration through the nourishment 236.5 acres of eroding and degrading marshes and construction of 12.4 miles of breakwaters along unprotected segments of the GIWW near Big Boggy National Wildlife Refuge (NWR) and eastward to the end of East Matagorda Bay,
    - Restoration of 96 acres (3.5 miles) of island that protects shorelines directly in front of Big Boggy NWR, and
    - Addition of oyster cultch to encourage creation of 3.7 miles of oyster reef along the bayside shorelines of the restored island.
- **CA-5: Keller Bay Restoration**
    - Construction of 3.8 miles of rock breakwaters along the shorelines of Keller Bay in order to protect submerged aquatic vegetation (SAV), and
    - Construction of 2.3 miles of oyster reef along the western shorelines of Sand Point in Lavaca Bay by installation of reef balls in nearshore waters.
- **CA-6: Powderhorn Shoreline Protection and Wetland Restoration**
    - Shoreline protection and restoration through the nourishment of 529 acres of eroding and degrading marshes and construction of 5.0 miles of breakwaters along shorelines fronting portions of Indianola, the Powderhorn Lake estuary, and Texas Parks and Wildlife Department (TPWD) Powderhorn Ranch.

- **SP-1: Redfish Bay Protection and Enhancement**
    - Construction of 7.4 miles of rock breakwaters along the unprotected segments of the GIWW along the backside of Redfish Bay and on the bayside of the restored islands
    - Restoration of 391.4 acres of islands including Dagger, Ransom, and Stedman islands in Redfish Bay, and
    - Addition of oyster cultch to encourage creation of 1.4 miles of oyster reef between the breakwaters and island complex to allow for additional protection of the Redfish Bay Complex and SAV.
- **W-3: Port Mansfield Channel, Island Rookery, and Hydrologic Restoration**
    - Restoration of the hydrologic connection between Brazos Santiago Pass and the Port Mansfield Channel by dredging 6.9 miles of the Port Mansfield Channel, providing 112,864.1 acres of hydrologic restoration in the Lower Laguna Madre,
    - 9.5 miles of beach nourishment along the Gulf shoreline north of the Port Mansfield Channel using beach quality sand from the dredging of Port Mansfield Channel, and
    - Protection and restoration of Mansfield Island with construction of a 0.7-mile rock breakwater and placement of sediment from the Port Mansfield Channel to create 27.8 acres of island surface at a n elevation of 7.5 feet (NAVD 88).

The remaining ER measures were combined into alternatives based upon specific planning objectives and strategies. These strategies generated six ER alternatives (Table 1), which include selected subsets of the measures in Alternatives 2 thorough 6, and all measures in Alternative 1 (Table 2).

Table 1. ER Alternative Strategies

Alternative/Scale	Strategy/Description
No-Action	No-Action
Alternative 1	Coastwide All-Inclusive Restoration Alternative
Alternative 2	Coastwide Restoration of Critical Geomorphic or Landscape Features
Alternative 3	Coastwide Barrier System Restoration
Alternative 4	Coastwide Bay System Restoration
Alternative 5	Coastwide ER Contributing to Infrastructure Risk Reduction
Alternative 6	Top Performers

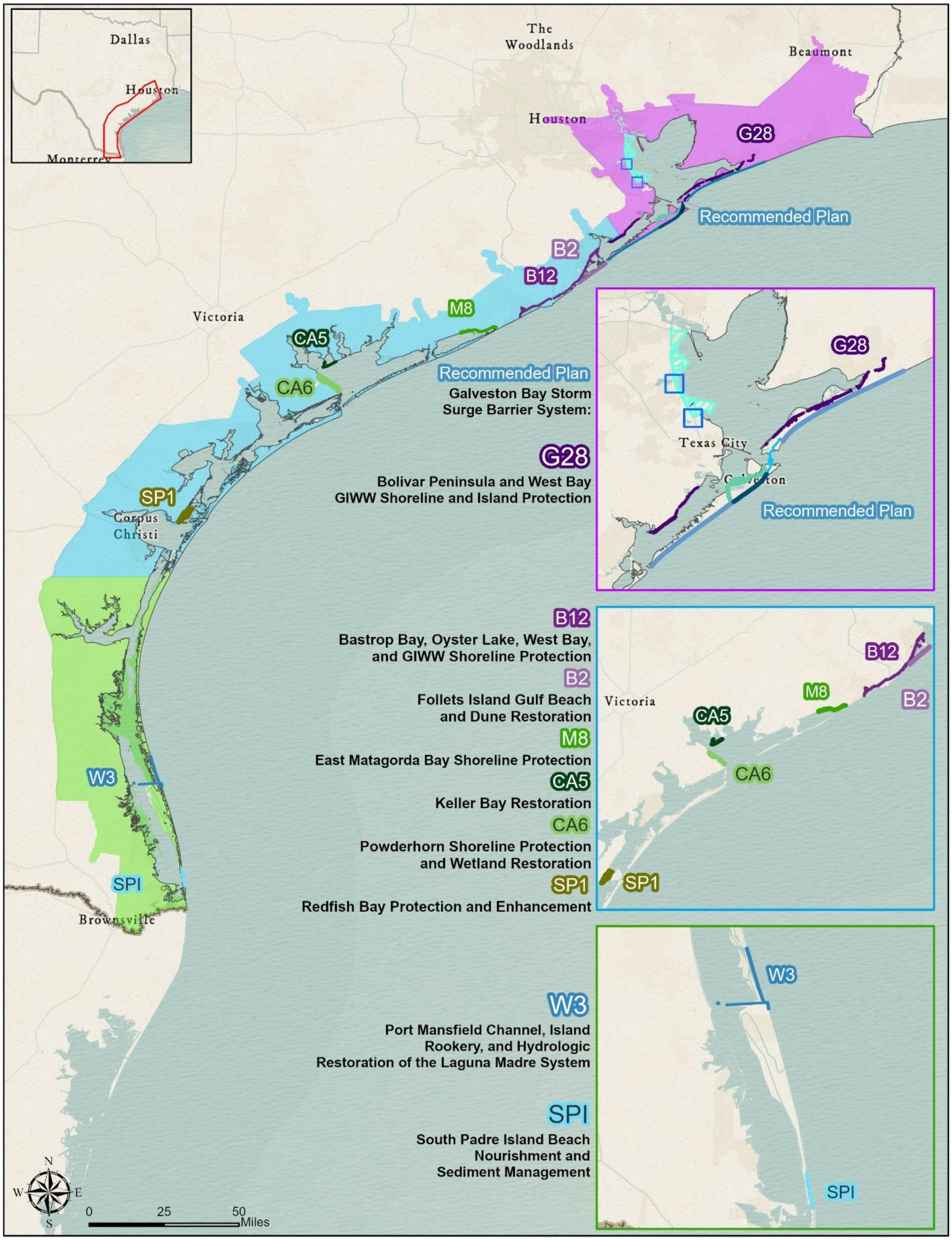

Figure 2. ER Measures retained

Table 2. Measures in each ER Alternatives

Alternative	G-28	B-2	B-12	M-8	CA-5	CA-6	SP-1	W-3
Alt 1	●	●	●	●	●	●	●	●
Alt 2		●	●			●		●
Alt 3	●	●						●
Alt 4	●		●	●	●	●	●	
Alt 5	●	●	●					
Alt 6	●	●	●		●			

The final screening iteration to identify the National Ecosystem Restoration (NER) plan requires estimation of the ecological life, or benefits, between the future without- (FWOP) and future with-project (FWP) condition for each alternative in Average Annual Habitat Units (AAHUs). The modeling and results described in this appendix provide critical information needed to complete the cost effective analysis that will ultimately help identify the cost effective and "Best Buy" plans from which a final recommended plan can be selected.

1.2.2 Coastal Storm Risk Management

For CSRM, plan formulation was undertaken in a systems framework, to assemble and evaluate features using National Economic Development (NED) procedures into a comprehensive plan that reduces coastal storm risk damages and enhances resiliency in the region. Efforts focused on providing risk reduction within the lower Texas coast and the upper Texas Coast, after assessing need across the entire coast.

1.2.2.1 Lower Texas Coast

On the lower Texas coast, South Padre Island (SPI) is vulnerable to coastal storms and is included as a hydrologically separable CSRM feature. The region was included because of the City's dense concentration of structures and risk from coastal storms. A history of beneficial use placements have occurred since 1988 to counter ongoing erosion and maintain sediment within the coastal zone along a heavily used stretch of coast. However, when timing and funding are limited, the structures and population remain at risk along the study area.

The initial planning evaluation focused only on beach and dune measures because revetments, seawalls, rock groins, or offshore breakwaters would have detrimental impacts to the longshore and cross-shore sediment transport processes. Nonstructural measures were initially considered but not carried forward since many nonstructural measures (flood proofing of structures, implementing flood warning systems, flood preparedness planning, establishment of land use regulations, development restrictions and elevated development) are already being implemented.

Analysis and refinements of beach nourishment alternatives confirmed that the NED scale alternative included 2.9 miles of beach nourishment to establish a 12.5 ft (NAVD88) dune and

100-foot-wide berm from Reach 3 through 5 (Figure 2). The economic analysis confirms that beach nourishment is cost effective when considering construction costs and benefits, and recreation benefits, but may be infeasible due to the real estate costs to acquire easements for privately owned portions of the dune and beach.

1.2.2.2 Upper Texas Coast

On the upper Texas coast, the Galveston Bay system represents the most at risk area not being presently addressed by other programs, such as the Sabine Pass to Galveston Bay ER and CSRM project. In general, CSRM features were formulated in systems along two alignments: one along the Gulf and one along the Bay. The outermost system (or Gulf Alignment) was formulated to reduce the penetration of Gulf surge across the gulfward land masses and into the Bay. The alternative alignment (or Interior Alignment) reduces the penetration of storm surge from the Bay into the region's surrounding areas by placing the system around the Bay's landward perimeter. The alternatives considered in the conceptual screening phase included:

- **Conceptual Alternative A – Coastal Barrier:** This alternative prevents storm surge from entering Galveston Bay with a levee system across Bolivar Peninsula and west Galveston Island and a closure at Bolivar Roads.
- **Conceptual Alternative B – Coastal Barrier:** This alternative is similar to Alternative A, but avoided the barrier islands and used existing landscape features such as the GIWW disposal dikes and the Texas City Dike as the tie-ins for the closure.
- **Conceptual Alternative C – Mid Bay Barrier:** This alternative avoids some of the navigation impacts at Bolivar Roads by placing a surge barrier near the middle of Galveston Bay. The system started on the east side of Galveston Bay near Smith Point, and continued across the bay, crossing the ship channel, and tying into the existing Texas City Levee System.
- **Conceptual Alternative D1 – Upper Bay (State Highway 146)/Nonstructural System:** The proposed a levee system on the west side of Galveston Bay along State Highway 146 from Texas City to the Fred Hartman Bridge. Communities between State Highway 146 and the Bay are left out of the system and would require nonstructural treatment.
- **Conceptual Alternative D2 – Upper Bay (State Highway 146)/Nonstructural System:** This alternative proposed the levee system along the Bay rim from Texas City to the Fred Hartman Bridge, which enclosed the 10,000 structures that were left out of the system in Alternative D1.

After comparing the relative performance of the alternatives and the potential cost or environmental impacts, Alternatives B and C were screened out since Alternative A provided comparable if not better performance in terms of reduced risk, with fewer negative impacts. Similarly, Alternative D1 was screened out since Alternative D2 provided better performance in terms of reduced risk, with fewer negative impacts.

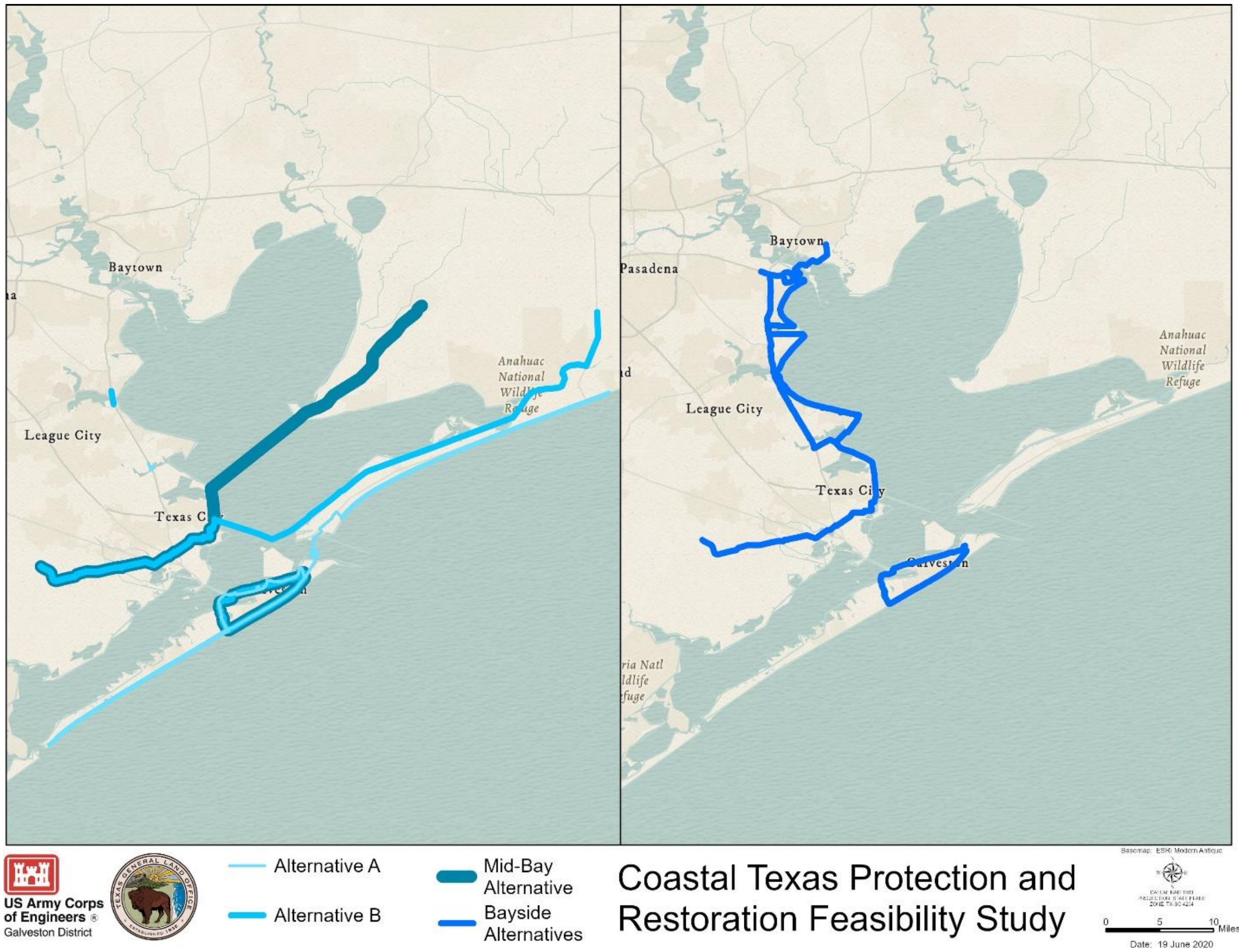

Figure 3. Comparison of Alternatives

The comparison of the gulfward Alternative A and interior Alternative D2 required standard benefit evaluation procedures for damage reduction (NED) be used to compare system-level alternatives and identify the TSP. The certified model applied to quantify NED benefits is HEC-FDA, a risk-based model that combines water surface elevation estimates for a representative storm suite and dollar damage assessments for resources within the study area. Additional NED benefits for recreation and extended Gross Domestic Product impacts were then estimated as part of the selection of the Recommended Plan. Both Alternative A and Alternative D2 included a ring barrier around the central portion of Galveston Island to protect against back-bay flooding.

When compared to Alternative D2, Alternative A has:

- **Higher net benefits –** Under all RSLR Scenarios and cost ranges.
- **Lower residual risk –** A lower residual risk in the event of extreme overtopping events because Alternative A is set farther away from the developed areas of the study area.
- **Greater flexibility and greater focus on critical infrastructure –** Alternative A takes a systems approach when reviewing the regions larger system context. The Gulfward alignment encloses critical infrastructure within the risk reduction system and enhances

resiliency in the region. Also, by establishing the first line of defense on an outermost alignment, greater adaptive options are possible to manage risk over time.

Figure 4 shows the spatial relationship between the Gulf and Bay lines of defense of Alternative A. Measures which make up Alternative A include:

- The Bolivar Roads Gate System, across the entrance to the Houston Ship Channel, between Bolivar Peninsula and Galveston Island (Figure 5);
- 43 miles of beach and dune improvements on Bolivar Peninsula and West Galveston Island that work with the Bolivar Roads Gate System to form a continuous line of defense against Gulf of Mexico surge, preventing or reducing storm surge volumes that would enter the Bay system (Figure 5);
- Improvements to the existing 10-mile Seawall on Galveston Island to complete the continuous line of defense against Gulf surge (Figure 5);
- An 18-mile Galveston Ring Barrier System (GRBS) that impedes Bay waters from flooding neighborhoods, businesses, and critical health facilities within the City of Galveston;
- 2 surge gates on the west perimeter of Galveston Bay (at Clear Lake and Dickinson Bay) that reduce surge volumes that push into neighborhoods around the critical industrial facilities that line Galveston Bay; and
- Complementary non-structural measures, such as home elevations or floodproofing, to further reduce Bay-surge risks along the western perimeter of Galveston Bay.

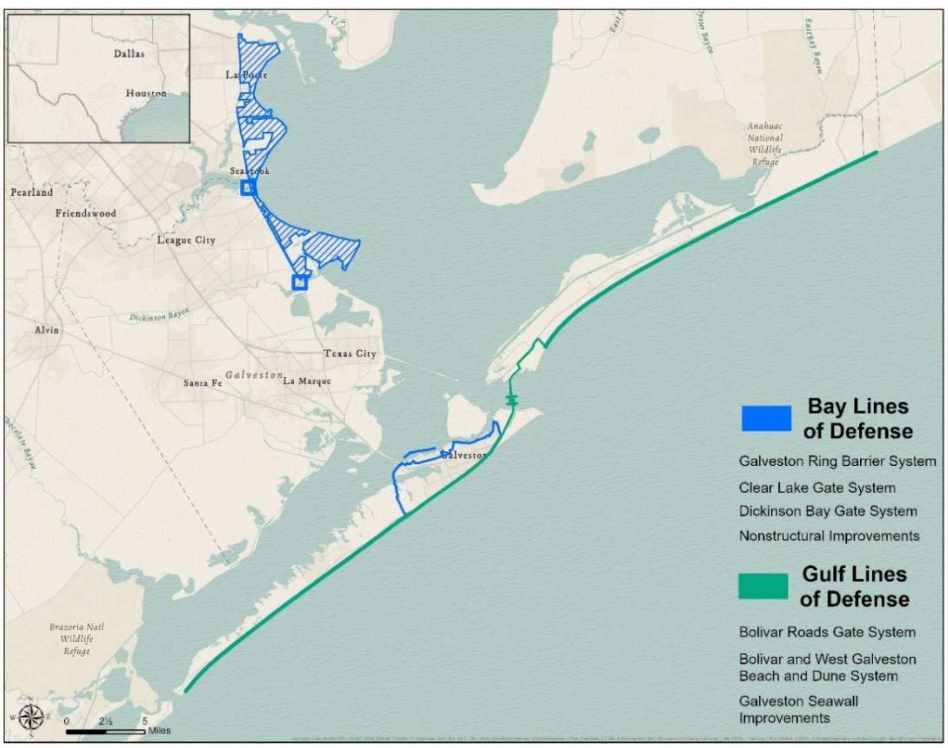

Figure 4. Galveston Bay Storm Surge System

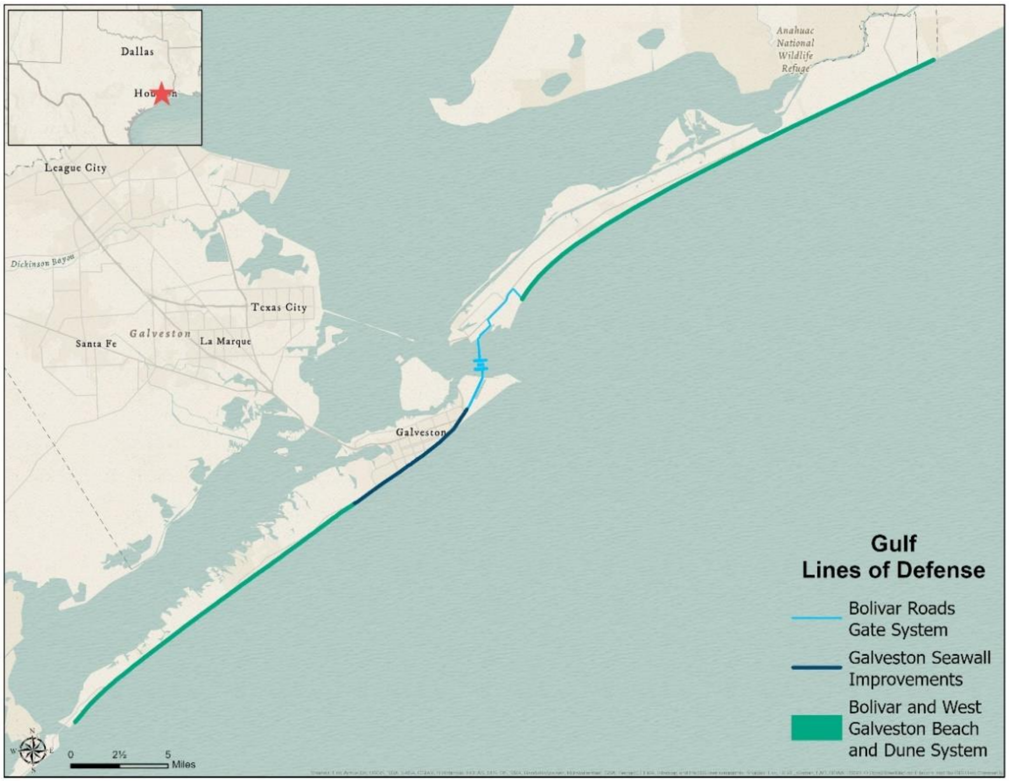

Figure 5. Gulf Lines of Defense of the Galveston Bay Storm Surge System

1.3 ECOLOGICAL COMMUNITIES IN THE PROJECT AREAS

The Texas Gulf coast is highly complex and ecologically diverse, with obvious differences in geomorphology between the upper, mid, and lower coast. The project areas consist of marine, estuarine, and freshwater coastal environments including: tidal waters, barrier islands, estuaries, coastal wetlands, rivers and streams, and adjacent areas that make up the interrelated ecosystems along the coast of Texas.

1.3.1 Upper Texas Coast

Within the upper Texas coast (Sabine Lake to east Matagorda Bay), wetland systems are like southwestern Louisiana marshes, where the elevation gradients are gradual, freshwater inflows are relatively higher, and transitional salinity gradients with freshwater wetlands inland transitioning into brackish and intermediate marsh with the gradient ending in the tidal salt marshes within the bays (Moulton et al. 1997).

Galveston Bay area is recognized as nationally significant by Federal designation of the Galveston Bay National Estuary Program. The broad range of salinities and flat topography allows 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 throughout the Galveston Bay complex. 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.

G-28, B-12, M-8, and all components of the Upper Texas Coast CSRM Alternative A would occur within the upper Texas coast regions and potentially impact tidal and freshwater coastal marshes, seagrass beds (submerged aquatic vegetation [SAV] habitats), oyster reefs, bird island rookeries, and beach and dune complexes.

1.3.2 Mid to Upper Texas Coast

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 forms 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 (NWR) (TNC, 2016a). Like many areas in the upper coast, the broad range of salinities and flat topography allows 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 occurs 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.

CA-5 and CA-6 are the two ER measures that occur in this region. Both potentially impact tidally-influenced marshes, seagrass beds, and oyster reefs.

1.3.3 Mid Texas Coast

The mid Texas coast is also characterized by large bays and estuaries, with river inflows. However, unlike in the upper and mid to upper Texas coast regions, less freshwater inflow is experienced and the freshwater to salt marsh gradients is typically reduced relative to the upper coast areas. Additionally, coastal prairies become more dominant, with less forested wetlands than the two upper regions (Moulton et al., 1997).

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 National Parks Service (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.

SP-1 is the only ER measure found in the mid Texas coast region. The measure has the potential to impact seagrass beds, oyster reefs and bird island rookeries.

1.3.4 Lower Texas Coast

The lower Texas coast is characterized by the Upper and Lower Laguna Madre, which is one of the few hypersaline lagoons in the world. High overall temperatures and evaporation rates, combined with low rainfall and freshwater input, drive the high salinity (Tunnel 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 (Tunnel 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.

Abundant tidal flats in this region provide important habitat for a variety of coastal wildlife from migratory waterfowl, shorebirds, 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 formations only exist in several locations worldwide, including the Persian Sea, Red Sea, and eastern Mediterranean Sea (Morton and Holmes, 2009).

W-3 is within the lower Texas coast region and could potentially impact SAV habitat, rookery islands, and beach and dune complex.

2.0 ECOLOGICAL MODELING

The USACE and its stakeholders used a suite of habitat models to evaluate the ecological impacts of proposed CSRM, ER, and mitigation measures. The models evaluate potential changes to the complex ecosystem processes and patterns operating at the local, regional, and landscape levels across the Texas coast. To summarize the overall process, the following steps were completed in the assessment of the study's proposed ER, CSRM, and mitigation designs:

- Building a multidisciplinary evaluation team.
- Defining the proposed ER and CSRM measures.
- Setting goals and objectives and defining a project life and target years.
- Selecting ecological models to evaluate ecological impacts.
- Calculating baseline conditions and forecasting Future-without Project (FWOP) and Future-with Project (FWP) conditions.
- Reporting the results of the analyses.

2.1 HABITAT EVALUATION PROCEDURES (HEP)

Before any impacts can be identified, a baseline assessment using the Habitat Evaluation Procedure (HEP) was required. HEP involves 1) defining the study area, 2) delineating habitats (i.e. cover types) within the study area, 3) selecting HEP models and/or evaluation species; and 4) characterizing the study area based on the results of the HEP.

HEP was developed by the US Fish and Wildlife Service (USFWS) in order to quantify the impacts of habitat changes resulting from land or water development projects (USFWS 1980). HEP is based on suitability models that provide a quantitative description of the habitat requirements for a species or group of species. HEP models use measurements of appropriate variables to rate the habitat on a scale from 0.0 (unsuitable) to 1.0 (optimal).

Habitat quality is estimated through the use of species models developed specifically for each habitat type(s). Each model consists of a 1) list of variables that are considered important in characterizing fish and wildlife habitat, 2) a Suitability Index graph for each variable, which defines the assumed relationship between habitat quality and different variable values, and 3) a mathematical formula that combines the Suitability Index for each variable into a single value for habitat quality. The single value is referred to as the Habitat Suitability Index (HSI).

The Suitability Index graph is a graphic representation of how fish and wildlife habitat quality or "suitability" of a given habitat type is predicted to change as values of the given variable change. It also allows the model user to numerically describe, though the Suitability Index, the habitat quality of an area for any variable value. The Suitability Index ranges from 0.1 to 1.0, with 1.0 representing optimal condition for the variable in question.

After a Suitability Index has been developed, a mathematical formula that combines all Suitability Indices into a single HSI value is constructed. Because the Suitability Indices range from 0.1 to 1.0 the HSI also ranges from 0.1 to 1.0, and is a numerical representation of the overall or "composite" habitat quality of the particular habitat being evaluated. The HSI formula defines the aggregation of Suitability Indices in a manner that is unique to each species depending on how the formula is constructed.

2.1.1 Species Model Selection

An Interagency Team made up of state and federal natural resource agencies selected the HEP models to be used for this study. The team reviewed all USACE-certified species' models based on the range of each modeled species, existing and future cover types, and specific habitat requirements described by the models and selected from the certified lists. For cover types where no certified model would work, species model development was considered.

Initially nine species models were identified as potentially applicable to identifying impacts and benefits. However, following further refinement during interagency workshops held in 2016 and 2017, the interagency team narrowed the selection to five certified HSI models which represent those species that were presumed to be the most responsive to the proposed CSRM and ER actions due to the sensitivity of the variables and the life history requisites. It was also agreed that one additional HSI model needed to be developed in order to address changes to beach and dune complexes because existing certified models did not meet the need. The final list of HSI models includes brown shrimp, American alligator, spotted sea trout, brown pelican, American oyster, and Kemp's ridley sea turtle. Each of the HEP models used are approved for regional or nationwide use in accordance with documented geographic range, best practices and its designed limitations, except for the Kemp's ridley sea turtle which is going through model certification for one-time use. The ECO-PCX and the resource agencies support use of these models.

Detailed methodologies regarding cover types, cover type mapping, and assumptions made for the applications of the HSI models are presented in Section 3.0. The following reasons support the final selection of each HSI model.

- **Brown Shrimp Model** (Turner and Brody, 1983) – Brown shrimp was selected to capture benefits to estuarine wetland and marsh. The HSI model variables were determined to be sensitive and responsive to marsh and wetland habitat restoration, and the model assumptions are consistent with USACE policy for habitat restoration.

- **American Alligator** (Newsom et al., 1987) – American alligator was selected to capture impacts to non-tidal palustrine wetland and marsh for analysis of the CSRM measures only. American alligator was removed from the ER model evaluation because the model application is limited to land tracts larger than 12 acres that are not isolated. All land tracts identified by the land cover datasets for the ER measures were less than 1 acre and were isolated. By consensus of the interagency team, the palustrine wetland and marsh cover types were merged with the estuarine cover type.

- **Spotted Seatrout** (Kostecki, 1984) – Spotted seatrout was selected to capture benefits to SAV. The HSI model variables were determined to be sensitive and responsive to SAV habitat restoration, and the model assumptions are consistent with USACE policy for habitat restoration.
- **Brown Pelican** (Hingtgen et al., 1985) – Brown pelican was selected to capture benefits to bird rookery islands. The HSI model variables were determined to be sensitive and responsive to island habitat restoration, and the model assumptions are consistent with USACE policy for habitat restoration.
- **American Oyster** (Swannack et al., 2014) – The American oyster model is designed as a spatially explicit, grid-based model that calculates habitat suitability for restoration of oysters.
- **Kemp's Ridley Sea Turtle** (Citation, 2020) – The Kemp's ridley sea turtle model was developed by the interagency team to address beach and dune complexes since other certified models were not responsive to the anticipated changes. The model is going through the ECO-PCX certification process for one-time use.

2.2 DATA COLLECTION

A judgment-based method, supported by the scientific and professional expertise of the interagency team, was used to forecast the changes in the natural ecosystems and evaluate the effectiveness of the proposed alternative scenarios, rate project performance, and determine many other important aspects of the FWOP and FWP conditions.

A series of workshops were held with the interagency team to characterize baseline conditions and forecast future conditions of cover type and variable data for the HEP analysis. A large percentage of the variables were determined using Geographic Information System (GIS), including calculating cover type acreages and measuring distances from locations along the coast. However, not all future projections were substantiated in this way, and some projections were based on best professional judgment and collective knowledge from the interagency team.

A variety of resources were utilized in the desktop analysis to obtain baseline data, including TPWD water quality data for salinities and water temperatures; land cover datasets for marshes, oyster reefs, and seagrass; Light Detection and Ranging (LiDAR) elevation data; and NOAA sea level rise (SLR) scenarios. Per USACE guidance, field sampling was not conducted for the Coastal Texas Study on the justification that all data necessary for the HEP analyses would be acquired through readily available data or applications in GIS.

2.2.1 Cover Type Mapping

The HEP model allows a numeric comparison of baseline conditions to each future condition and provides a combined quantitative and qualitative estimate of project-related benefits or impacts on ecosystem resources. To quantify the applicable habitat conditions within each project site, the HEP process requires that the cover types within each project footprint (i.e., ER or CSRM measure) be quantified in terms of acres (quantity) and variables (quality) per each corresponding HSI model. The process of quantifying acres, referred to as "cover typing," allows the user to define the differences between vegetative cover types and clearly delineate these distinctions on a map.

The NOAA C-CAP 2010 and Marsh Migration land cover datasets were used to evaluate and identify cover types for each existing, FWOP, and FWP condition for areas within the project footprint and areas indirectly affected beyond the footprint (NOAA, 2017b; pers. com. N. Herold [NOAA], 2017). Other land cover datasets (such as USFWS National Wetland Inventory [NWI], U.S. Geologic Survey [USGS] land cover, and TPWD land cover) were considered for evaluation (TPWD, 2017; USFWS, 2017; USGS, 2017). However, it was determined that the NOAA land cover datasets would be most applicable because they provide future conditions that incorporate migration of plant communities due to RSLR and allow for consistency and repeatability of the model evaluations (NOAA 2017a, 2017c).

The USACE guidance (USACE 2013, USACE 2014) specifies the procedures for incorporating climate change and RSLR into planning studies and environmental/engineering design projects. The proposed projects must consider measures that are formulated and evaluated for a wide range of possible future rates of relative sea level change (RSLC). The guidance requires that alternatives be evaluated using either “low,” “intermediate,” or “high” rates of future RSLC, as defined below:

- **Low –** Low rates of local sea level change are determined by identifying the historical rate of local mean sea level change, which are best determined by local tide records.
- **Intermediate –** Intermediate rates of local sea level change are estimated using the modified Natural Research Council (NRC) Curve I, which is corrected for the local rate of vertical land movement.
- **High –** High rates of local sea level change are estimated using the modified NRC Curve III, which is corrected for the local rate of vertical land movement.

As discussed earlier, the Texas coast was divided into four planning regions that each serve as a spatial framework for the research, assessment, and management of both ecosystem components and CSRM components. For the purposes of cover typing, the four regions allowed incorporation of historical rates of RSLC using the USACE intermediate SLR curve. The four regions and CSRM and ER measures that occur within that region are described below:

The USACE computed future rates of RSLC were predicted for the years 2017 to 2085 for each of the four regions (USACE, 2017). Table 3 shows the relationship between the USACE intermediate SLR curve and the NOAA land cover dataset used to determine future conditions for each target year across each region (NOAA 2017b; USACE, 2017; pers. com. N. Herold [NOAA], 2017).

Table 3. Relationship between USACE Intermediate SLR Curve and NOAA Landcover Datasets

Calendar Year	TY	Region 1 – Intermediate		Regions 2 and 3 – Intermediate		Region 4 – Intermediate	
		USACE-RSLC (feet)	Corresponding NOAA Output (feet)	USACE-RSLC (feet)	Corresponding NOAA Output (feet)	USACE-RSLC (feet)	Corresponding NOAA Output (feet)
2017	0	0.00	C-CAP 2010	0.00	C-CAP 2010	0.00	C-CAP 2010
2025		0.56	0.50	0.50	0.50	0.32	0.25
2034		0.89	1.00	0.80	1.00	0.57	0.75
2035	1	1.07	1.00	0.89	1.00	0.68	0.75
2045		1.36	1.25	1.15	1.25	0.88	1.00
2055		1.67	1.75	1.42	1.50	1.11	1.00
2065	31	2.00	2.00	1.71	1.75	1.35	1.25
2075		2.35	2.50	2.02	2.00	1.60	1.50
2085	51	2.72	3.00	2.34	2.50	1.88	1.75

Source: NOAA (2017b); USACE (2017); pers. com. N. Herold (NOAA), 2017.

Additional data for the cover type evaluations were provided by the GLO for the TPWD oyster locations data, which were used to capture the effects to oyster reefs with the proposed CSRM and ER measures. The Texas Commission on Environmental Quality (TCEQ) Office of Water provided the Galveston Bay Estuary's Status and Trends Atlas for seagrass locations along the Texas coast (Texas A&M University, 2017).

Footprints containing all areas directly and indirectly benefitting from or adversely affected by proposed ER and CSRM measures were developed in GIS and applied to the NOAA C-CAP and NOAA Marsh Migration land cover datasets to identify all applicable cover types, including estuarine and palustrine wetland, open water, and developed/upland areas. Each HSI model was associated with a cover type to evaluate the project-related benefits on ecosystem resources within the project footprints of the CSRM and ER measures (Table 4).

Table 4. HSI Model Applied to Each Measure

Model	Cover Type	Measure Location Where Model Applied
Brown Shrimp	Estuarine Wetland and Marsh	G-28, B-12, M-8, CA-5, CA-6, Bolivar Roads Gates, Galveston Ring Barrier, Dickinson Surge Gate, Clear Lake Surge Gate
American Alligator	Palustrine Wetlands	Bolivar Roads Gates, Galveston Ring Barrier
Spotted Seatrout	SAV	CA-5, SP-1, W-3
Brown Pelican	Bird Rookery Islands	G-28, M-8, SP-1, W-3
American Oyster	Oyster Reefs	G-28, B-12, M-8, CA-5, SP-1, W-3, Dickinson Surge Gate, Clear Lake Surge Gate
Kemp's ridley sea turtle	Beach/Dune	B-2, W-3

2.3 COORDINATION

The Coastal Texas Study interagency team worked together to establish baseline and future conditions of the project sites, evaluate and select HSI models, and conduct forecasting and model evaluations for the study. The interagency team includes representatives from Federal, State, and local natural resource agencies, the non-Federal sponsor, and technical experts from the consulting firm assisting with modeling analysis. Monthly meetings were held to discuss the models and impacts/benefits of each of the measures. Consensus was reached on model use, variable assumptions, and variable forecasting before proceeding with running the models and calculating the change from the action. After the models were run, the results were presented to the team and consensus was reached on the soundness of the results. Where necessary modifications to variable assumptions or inputs were recommended by the team to better describe the anticipated changes based on previous experience and best professional judgement.

2.4 HISTORY OF ECOLOGICAL MODELING

In 2019, a draft Integrated Feasibility Report and EIS (DIFR-EIS) was published for public review, which included an appendix describing the modeling efforts completed for the study to that point. The modeling at that time employed the use of Habitat Evaluation and Assessment Tools (HEAT) software to calculate the benefits of ER measures. Following publication of the DIFR-EIS, the USACE decided to forgo the use of the HEAT software and instead developed certified HEP/HSI spreadsheet models for each of the species specific models. The HEAT software had limitations in how the results were presented which made it difficult to assess impacts and benefits or to see where and why certain values were being generated. All data in the HEAT software was migrated to the spreadsheets without revision.

The 2019 DIFR-EIS also assessed impacts to beach and dune communities using a Wetland Valuation Assessment (WVA) Barrier Island Community Model, a community-based HEP model. In the monthly interagency meetings that followed the 2018 Draft Report members of the team expressed dissatisfaction with the performance of the WVA model in predicting ecological benefits for beach and dune system in Texas. To improve the quality of the ecological modeling, the team developed the Kemp's Ridley sea turtle nesting model to calculate benefits and impacts from proposed beach and dune ER and CSRM measures. The model is being submitted to the USACE Ecosystem Planning Center Community of Practice for certification.

3.0 HEP MODEL ASSUMPTIONS AND VARIABLES

This section describes the methodology used to determine existing, FWOP, and FWP conditions for each HSI model and each project area. The habitat variables (V) of each model are briefly described here. The existing and FWOP condition modeling assumptions apply to ER, CSRM, and mitigation locations. The FWP assumptions for ER are also applied to the mitigation sites as these areas would be restored and result in long-term benefits, while the CSRM features have varying assumptions because of the long-term loss anticipated. Based on the assumptions described below, it is likely that the benefits for ER and mitigation sites have been underestimated, while the CSRM sites have been overestimated to err on the side of the resource and assume worst-case scenarios (i.e. ER benefits may not be fully realized to what the interagency team and USACE actually think will occur; CSRM features may not have as extreme of loss but don't actually know so assume the worst to ensure sufficient mitigation of net losses).

3.1 PERIOD OF ANALYSIS/TARGET YEARS

Federal projects are evaluated over a period of time that is referred to as the "project life," which is defined as the period of time between the time that the project becomes operational and the end of the operational lifespan as dictated by the construction effort or the lead agency (Burks-Copes and Webb, 2010). Given the goals and objectives of the Coastal Texas Study (see Section 1.0 of the DIFR-EIS), the USACE designated a "project life" of 50 years and developed a series of target years within the 50-year setting to guide the projections of both FWOP and FWP actions. Four target years (TY) were defined:

- **TY 0 (2017):** Refers to the baseline conditions for both the CSRM and ER evaluations;
- **TY 1 (2035):** For CSRM measures, selected to capture 1 year of impacts under the proposed with-project conditions; for ER measures, selected to capture 1 year of vegetative growth under the proposed with-project conditions; refers to the end of the construction and the beginning of the operation period;
- **TY 31 (2065):** For CSRM measures, selected to capture 30 years of impacts under the with-project conditions; for ER measures, selected to capture 30 years of vegetative growth under the with-project conditions and refers to the period of out-year marsh nourishments; and
- **TY 51 (2085):** For CSRM measures, selected to capture 50 years of impacts under the with-project conditions; for ER measures, selected to capture 50 years of vegetative growth under the with-project conditions; refers to the end of the period of operation.

3.2 BROWN SHRIMP MODELING

Marsh vegetation and open water acreages were based on a classification conducted using the appropriate NOAA Marsh Migration land cover dataset for each SLR scenario (see Table 1). Brown shrimp was modeled using the estuarine wetland and marsh cover type. Changes in water temperature, salinities, and substrate composition were also considered over the period of analysis.

3.2.1 V_1 – Percentage of Estuary Covered by Vegetation

Persistent emergent vegetation within an estuary offers both a concentrated source of food and a refuge from predators for brown shrimp, which depend heavily on these environments. In the brown shrimp model, a bay, estuary, or hydrologic unit that is 100 percent covered by marshes or submerged grasses is assumed to have an optimal HSI of 1.0. Habitat suitability decreases in a linear fashion if cover is below this value (Turner and Brody, 1983). For the purposes of this study, “estuary,” which was not defined in the model document in terms of geographic scope, was defined as the total ER measure footprint and variables were evaluated at that scale.

Existing Conditions. Existing (baseline) total marsh and open water acreages of each affected wetland area were based on acreages measured in ArcGIS and classified using the NOAA C-CAP 2010 land cover dataset. The percentage of estuary covered by vegetation was computed from the ratio of marsh to open water acreages within the estuary to determine the existing condition for this variable.

FWOP Conditions. Acreages were reclassified for each target year using the NOAA Marsh Migration land cover dataset to determine FWOP conditions. The ratio of marsh to open water changed at each target year with an increasing amount of open water and a decreasing amount of marsh. Where applicable, erosion rates were calculated for unprotected segments of the GIWW to capture the marsh acres lost in the FWOP conditions (i.e., no breakwaters) due to erosional processes.

FWP ER/Mitigation Conditions. The ratio of marsh to open water acreages within the estuary was computed to determine the FWP conditions for each target year. The initial construction footprints for marsh were digitized in GIS and represent areas of degrading or eroding marsh inland or immediately adjacent to the GIWW. It is assumed that construction will end in 2035 and that all wetlands within the initial construction footprint are restored.

FWP CSRM Conditions: The ratio of marsh to open water acreages within the estuary was computed to determine the FWP condition for each target year. It was assumed that by TY 1 (2035), the CSRM alternative has been constructed and all estuarine emergent wetland has been lost through the end of the project life (2085).

3.2.2 V_2 – Substrate Composition

Brown shrimp prefer soft bottom substrates. This variable contributes to the food and cover component in the model and is important in determining shrimp distribution throughout the estuarine system. Soft bottoms with decaying vegetation were assigned the highest SI, while areas with substrates composed of muddy sands, coarse sands, or shell and/or gravel were assigned lower values (Turner and Brody, 1983).

Existing Conditions. Existing substrate composition was determined using collective knowledge from the interagency team. Class 1 (soft bottom) and Class 2 (muddy or fine sands) were the two classifications used in the analyses to represent substrate composition across the Texas coast.

FWOP Conditions. This variable was held constant through the 50-year period of the project life for FWOP conditions because it was concluded that future changes due to no project action would not lead to significantly different substrate compositions across the Texas coast.

FWP ER/Mitigation Conditions. This variable was held constant through the 50-year period of the project life for FWP conditions because it was concluded that future changes due to project action would not lead to significantly different substrate compositions across the Texas coast.

FWP CSRM Conditions. This variable was held constant through the 50-year period of the project life for FWP conditions because there is not an option in the model that would describe the infrastructure substrates that would be constructed with the CSRM alternative.

3.2.3 V_3 – Mean Water Salinity during Spring

Salinities in bays and estuarine systems are important to brown shrimp during the spring season. Salinities within the range of 10 to 20 parts per thousand (ppt) are optimal for brown shrimp (Turner and Brody, 1983). Salinities were determined using TPWD water quality data from 2007 to 2016 (pers.com M. Fisher [TPWD, 2017]).

Existing Conditions. Existing conditions were determined by averaging spring salinities from 2007 to 2016 within each of the ER measure footprints. Spring months included March, April, and May.

FWOP Conditions. Data to forecast and evaluate changes in salinity with no project action were not readily available; as a result, the interagency team determined that a 20 percent increase to baseline salinities should be applied for the FWOP conditions to capture the potential change in salinities over the period of analysis.

FWP ER/Mitigation/CSRM Conditions. As described above, a 20 percent increase was applied to baseline salinities for the FWP conditions to capture the potential change in salinities over the period of analysis.

3.2.4 V_4 – Mean Water Temperature during Spring

Temperature represents a localized habitat variable in the water quality component for the brown shrimp model. Optimal temperature for brown shrimp is between 68 and 86 degrees Fahrenheit [°F] (Turner and Brody, 1983). Data for this variable were determined using TPWD water quality data from 2007 to 2016 (pers. com. M. Fisher [TPWD], 2017).

Existing Conditions. Existing conditions were determined by averaging spring water temperatures from 2007 to 2016 within each of the ER measure footprints. Spring months included March, April, and May.

FWOP Conditions. Although climate change indicates water temperatures will rise in the future, it is not believed that the temperature rise will raise mean spring temperatures above 86°F, at which point the SI value would be negatively impacted (pers. com. GLO and

USACE, 2017). For these reasons, temperature was assumed to be held constant for the FWOP conditions through the project life.

FWP ER/Mitigation/CSRM Conditions. As described above, it is not believed that the water temperature rise due to climate change will raise mean spring temperatures above 86°F, at which point the SI value would be negatively impacted (pers. com. GLO and USACE, 2017). For these reasons, temperature was assumed to be held constant for the FWP conditions through the project life.

3.3 AMERICAN ALLIGATOR

Impacts to palustrine emergent wetland were evaluated using the American alligator model for the post-TSP CSRM analysis. The model was developed to determine the suitability of coastal wetlands as habitat for American alligators. Wetland vegetation and open water acreages were based on a classification conducted using the appropriate NOAA Marsh Migration land cover dataset for each SLR scenario. Changes in percentage of open water, ponding and hydroperiods, and interspersion were considered over the period of analysis. The data were then input into the modified HEP/HSI model spreadsheets to generate HSI, HU, and AAHU outputs.

3.3.1 V_1 – Percentage of wetland that is open water

Alligators are known to breed in relatively deep, open water. Suitability of an area as breeding habitat is influenced by the amount and type of open water versus vegetated wetland. Open water is defined in the model as an area that maintains less than 10 percent canopy cover of emergent vegetation. Optimal breeding and nesting habitat for alligators is assumed to be an area that maintains 20 to 40 percent open water and 60 to 80 percent vegetated wetland; this percentage range is assumed to have an optimal HSI of 1.0. Habitat suitability decreases in a linear fashion if the percentage of open water is either less than 20 percent or greater than 40 percent (Newsom et al., 1987). For the purposes of this study, “wetland area”, which was not defined in the model document in terms of geographic scope, was defined as the total CSRM measure footprint and variables were evaluated at that scale.

Existing Conditions. Existing (baseline) total palustrine wetland and open water acreages of each wetland area were based on acreages measured in ArcGIS and classified using the NOAA C-CAP 2010 land cover dataset. The percentage of wetland area covered by vegetation was computed from the ratio of palustrine wetland to open water acreages within the project footprint to determine the existing condition for this variable.

FWOP Conditions. Acreages were reclassified for each target year using the NOAA Marsh Migration land cover dataset to determine FWOP conditions. The ratio of palustrine wetland to open water remained generally consistent at each target year with a steady amount of open water versus wetland, and therefore, the variable HSI remained the same through the end of the project life.

FWP CSRM Conditions. The ratio of marsh to open water acreages within the estuary was computed to determine the FWP conditions for each target year. It was assumed that by TY

1 (2035), the CSRM alternative has been constructed and all palustrine emergent wetland has been lost through the end of the project life (2085).

3.3.2 V_2 – Percentage of open water that is bayous or canals

Deepwater areas in bayous, canals, ponds, and lakes are known to be essential habitat components for adult alligators during breeding seasons and for immature/juvenile alligators throughout the year. However, shallow water areas must also be present to support prey species as a food resource. Habitat suitability is optimal when 10 to 20 percent of the open water is bayous, canals, or deeper than 1.2 meters in ponds or lakes. Suitability decreases as this value increases above 20 percent and habitat becomes unsuitable when bayous, canals, and deep water represent 100 percent of open water within the wetland area (Newsom et al., 1987).

Existing Conditions. Best professional judgement was used to determine the assumptions associated with this variable for baseline conditions. It was assumed that 5 percent of open water is bayous, canals, or deeper than 1.2 meters in ponds or lakes.

FWOP Conditions. This variable was held constant through the 50-year period of the project life for FWOP conditions. It was concluded that future changes that would affect open water that is bayous, canals, or deeper than 1.2 meters in ponds and lakes would not change significantly with RSLR.

FWP CSRM Conditions. It was assumed that by TY 1 (2035), the CSRM alternative has been constructed and all open water within the project footprint has been lost through the end of the project life (2085).

3.3.3 V_3 – Interspersion

Nesting alligator habitat is known to be directly related to the degree of interspersion of water bodies within vegetated wetland areas. Optimal habitat maintains a high interspersion of water and vegetation (10-15 ponds per 15 acres) and is assumed to have an HSI of 1.0. The variable has a categorical response with decreasing degrees of suitability between high, medium, and low interspersion (Newsom et al., 1987).

Existing Conditions. Best professional judgement was used to determine the assumptions associated with this variable for baseline conditions. It was assumed that low interspersion occurs throughout the CSRM measure footprint (2 or fewer ponds per 15 acres, or highly eroded and fragmented marsh).

FWOP Conditions. Best professional judgement was used to determine the assumptions associated with this variable for baseline conditions. It was assumed that low interspersion occurs throughout the CSRM measure footprint (2 or fewer ponds per 15 acres, or highly eroded and fragmented marsh).

FWP CSRM Conditions. Best professional judgement was used to determine the assumptions associated with this variable for baseline conditions. It was assumed that low interspersion occurs throughout the CSRM measure footprint (2 or fewer ponds per 15 acres, or highly eroded and fragmented marsh).

3.3.4 V_4 – Percentage of ponded area with water ≥ 15 cm deep

Ponds or lakes that dry out during the spring and summer tend to restrict the travel and mobility of alligators and increase the vulnerability of the young/juvenile alligators to predation. It is assumed that at least 15 centimeters of water must be present throughout the nesting period for alligators to use a pond. Habitat suitability increases as the percentage of ponds retaining this water depth increases (Newsom et al., 1987).

Existing Conditions. Best professional judgement was used to determine the assumptions associated with this variable for baseline conditions. It was assumed that 10 percent of ponds retain equal to or more than 15 centimeters of water during the spring and summer.

FWOP Conditions. Best professional judgement was used to determine the assumptions associated with this variable for baseline conditions. It was assumed that 10 percent of ponds retain equal to or more than 15 centimeters of water during the spring and summer. This variable was held constant for the FWOP conditions throughout the life of the project because it was assumed that the ponds would not likely become dry during the spring or summer.

FWP CSRM Conditions. Best professional judgement was used to determine the assumptions associated with this variable for baseline conditions. It was assumed that 10 percent of ponds retain equal to or more than 15 centimeters of water during the spring and summer. This variable was held constant for the FWP conditions throughout the life of the project because it was assumed that the ponds would not likely become dry during the spring or summer.

3.4 SPOTTED SEATROUT MODELING

The spotted seatrout model considers habitat suitability for the egg, larval, and juvenile life stages. These three life stages are considered the most sensitive to environmental variations and are the most responsive to restoration of SAV. The model assumes two primary factors, or life history requisites, for determining habitat quality of a project site: water quality (including temperature and salinity) and food/cover (Kostecki, 1984).

3.4.1 V_1 – Lowest Monthly Average Winter-Spring Water Salinity

Lowest monthly average winter-spring salinity represents the minimum value of the 4 monthly mean salinities determined for each year of data between the months of December and March (Kostecki, 1984). This variable was determined using TPWD water quality data from 2007 to 2016 (pers. com. M. Fisher [TPWD], 2017).

Existing Conditions. Existing conditions were determined by calculating the average monthly salinity for the months of December, January, February, and March, and taking the minimum of those values.

FWOP Conditions. Data to forecast and evaluate changes in salinity with no project action were not readily available; as a result, the interagency team determined that a 20 percent increase to baseline salinities should be applied for the FWOP conditions to capture the potential change in salinities over the period of analysis.

FWP ER Conditions. As described above, a 20 percent increase was applied to baseline salinities for the FWP conditions to capture the potential change in salinities over the period of analysis.

3.4.2 V_2 – Highest Monthly Average Summer Water Salinity

Highest monthly average summer salinity represents the maximum value of the 3 monthly mean salinities determined for each year of data between the months of June and September (Kostecki, 1984). This variable was determined using TPWD water quality data from 2007 to 2016 (pers. com. M. Fisher [TPWD], 2017).

Existing Conditions. Existing conditions were determined by calculating the average monthly salinity for the months of June, July, and August, and taking the maximum of those values.

FWOP Conditions. Data to forecast and evaluate changes in salinity with no project action were not readily available; as a result, the interagency team determined that a 20 percent increase to baseline salinities should be applied for the FWOP conditions to capture the potential change in salinities over the period of analysis.

FWP ER Conditions. As described above, a 20 percent increase was applied to baseline salinities the FWP conditions to capture the potential change in salinities over the period of analysis.

3.4.3 V_3 – Lowest Monthly Average Winter Water Temperature

Lowest monthly average winter water temperature represents the minimum value of the 4 monthly mean temperatures determined for each year of data between the months of December and March (Kostecki, 1984). This variable was determined using TPWD water quality data from 2007 to 2016 (pers. com. M. Fisher [TPWD], 2017).

Existing Conditions. Existing conditions were determined by calculating the average monthly water temperature for the months of December, January, February, and March, and taking the minimum of those values.

FWOP Conditions. This variable was held constant through the 50-year project life.

FWP ER Conditions. This variable was held constant through the 50-year project life.

3.4.4 V_4 – Highest Monthly Average Summer Water Temperature

Highest monthly average summer water temperature represents the maximum value of the 3 monthly mean salinities determined for each year of data between the months of June and September (Kostecki, 1984). This variable was determined using TPWD water quality data from 2007 to 2016 (pers. com. M. Fisher [TPWD], 2017).

Existing Conditions. Existing conditions were determined by calculating the average monthly water temperature for the months of June, July and August, and taking a maximum of those values.

FWOP Conditions. This variable was held constant through the 50-year project life.

FWP Conditions. This variable was held constant through the 50-year project life.

3.4.5 V_5 – Percentage of Study Area that is Optimal Cover

The preferred habitat of juvenile spotted seatrout is the shallow, vegetated area of estuarine environments, and most ideally near the edges of grass flats, which provide shelter, protection, and an abundance of food resources. Cover, including submerged and/or emergent vegetation, submerged islands, oyster beds, or shell reef, over more than 50 percent of the total area indicates an optimal HSI of 1.0. Cover below this mark decreases in a linear fashion, where no cover indicates suboptimal HSI of 0 (Kostecki, 1984).

Existing Conditions. For baseline conditions, this variable was determined by evaluating historical maps and aerial photographs using Google Earth aerial imagery (2016) and gaining consensus from the interagency team.

FWOP Conditions. For FWOP conditions, it was assumed that existing seagrass beds within a project area were depleted due to increased energies and increased water depth as a result of SLR.

FWP Conditions. For FWP conditions, it was assumed that existing seagrass beds within a project area remain due to protective actions (i.e., the installation of breakwaters, creation of oyster reef, or restoration of marshes) and optimal conditions occur at the end of construction (2035) and remain through the period of analysis.

3.5 BROWN PELICAN MODELING

Eastern brown pelican colonies occur on coastal islands small enough to be free from human habitation and recreation, and far enough from the mainland to be inaccessible to potential predators (Hingtgen et al., 1985). Along the Texas coast, brown pelicans use both natural and man-made islands, specifically dredged material placement areas along the GIWW.

3.5.1 V_1 – Island Surface Area

The total island surface area is assumed to be an indication of its accessibility to opportunistic predators. Islands larger than 20 acres may be able to support resident populations of predators and are assumed to have a suboptimal SI of 0.4. Likewise, islands smaller than 5 acres do not have the capacity to accommodate brown pelican colonies, which average about 100 nests or more per every 2.5 acres (Hingtgen et al., 1985).

Optimal habitat suitability depends on several components, including accommodating colony size at a density of 100 nests per every 2.5 acres, and having enough area for loafing and drying (about 2.5 acres per colony). In order to achieve the highest habitat suitability, islands must be 4.9 to 19.8 acres in size (Hingtgen et al., 1985).

Existing Conditions: Total island surface area at existing conditions was determined by measuring island size using Google Earth aerial imagery (2016). Class 1 (islands less than 4.9 acres in size) and Class 3 (island greater than 19.8 acres in size) were the two classifications used in the analyses to represent island size of the four project areas across the Texas coast. Both classifications represent a suboptimal HSI of 0.4.

FWOP Conditions: Acreages were reclassified for each target year and, where applicable, erosion rates were calculated for islands located along unprotected segments of the GIWW to capture the acres lost in the FWOP conditions (i.e., no breakwaters or oyster cultch). It was assumed that by 2065 all island acres are lost to SLR with no action.

FWP ER Conditions: The USACE provided typical cross sections and dimensions for each island creation and restoration action. It is assumed that construction would end in 2035, and that all acreages within the island restoration footprints are restored. Some loss due to RSLR was assumed at each target year, and the slopes derived from the island cross sections were used to determine the acreage loss as a result of the increase in water levels.

3.5.2 V_2 – Distance from the Mainland

Optimal distance from the mainland is assumed to be about 0.25 mile or more for nesting brown pelicans (Hingtgen et al., 1985).

Existing Conditions. This variable was determined by measuring the distance from the centroid of the island to the mainland using Google Earth aerial imagery (2016). Habitat suitability for each project area in terms of distance from the mainland ranged from suboptimal at 0.09 mile to optimal at 1.55 miles.

FWOP Conditions. This variable was held constant for each target year until zero island acres remained as a result of RSLR.

FWP ER Conditions. This variable was held constant through the 50-year period of the project life for FWP conditions. Distance was initially measured from the centroid of the island, and it was concluded that the restoration of the islands would not lead to significantly different distances from the mainland.

3.5.3 V_3 – Distance from Human Activity

The principle source of eastern brown pelican nesting failure is direct and indirect human interference with nesting colonies. Islands that have permanent human inhabitants or are visited by humans for recreational or commercial purposes during breeding season are assumed to have suboptimal habitat suitability (Hingtgen et al., 1985). Optimum distance of nesting colonies from centers of human activity is assumed to be 0.25 mile or more.

For the purposes of this study, the closest urban development on the mainland was considered "human activity." Although the model document lists commercial activity as a human activity center, the GIWW or nearby seawall channels were not considered as threats to nesting brown pelican colonies for this evaluation.

Existing Conditions. This variable was determined by measuring the distance from the centroid of the island to the closest urban development using Google Earth aerial imagery (2016). Habitat suitability for each project area in terms of distance from human activity was considered optimal, with distances ranging from a minimum of 0.6 mile to a maximum of 8.1 miles.

FWOP Conditions. This variable was held constant for each target year in the FWOP conditions because predictions regarding future urban development in proximity to the project areas were not considered.

FWP ER Conditions. This variable was held constant for each target year in the FWP conditions because predictions regarding future urban development in proximity to the project areas were not considered.

3.5.4 V_4 – Nesting Coverage/Island Elevation

Brown pelicans that nest along the Texas coast usually do so on the ground or in small shrubs. Island elevation and the density of shrubs available for potential nesting habitat are two important components in the success of these colonies. Nesting vegetation that covers at least 50 percent or more of an island is assumed to be optimal for this model (Hingtgen et al., 1985).

Existing Conditions. Nesting coverage and island elevation for existing conditions were evaluated using Google Earth aerial imagery (2016). In general, islands evaluated under this study had abrupt slopes due to erosional processes, and the total island acreage was assumed to be nesting habitat (defined as areas higher than 2 feet in elevation). Therefore, habitat suitability was considered optimal.

FWOP Conditions. The nesting coverage variable was considered optimal if there were remaining island acres that had not been converted to open water. Once the island was completely overcome by SLR, the nesting coverage variable fell to zero.

FWP ER Conditions. Nesting coverage and island elevation for FWP conditions was calculated using GIS and evaluated using several sources of data, including Google Earth aerial imagery, the typical island cross sections, and the USACE intermediate SLR curve. The model document defines nesting coverage as all existing portions of island that are 2 feet or higher in elevation (North American Vertical Datum of 1988 [NAVD88]). The USACE intermediate SLR curve was used to determine the water elevation at the end of construction (calendar year 2035). Then, using the engineering assumptions developed for each island feature, the remaining island area was calculated.

3.6 AMERICAN OYSTER MODELING

Oyster reef acreages were based on a classification conducted using the TPWD oyster locations data to evaluate benefits/impacts to oyster from the proposed measures. Changes in oyster reef habitat associated with each NOAA SLR scenario were determined by consensus from the interagency team. Changes in salinities and substrate composition were also considered for the period of analysis and are described below.

3.6.1 V_1 – Percent Cultch

Percent cultch represents the percent of bottom covered with hard substrate. It is assumed that hard substrate (cultch), such as existing oyster reef, or other hard surfaces (limestone, concrete, granite, etc.) are optimal for oyster larvae to settle on and utilize as habitat (Swannack et al., 2014).

Existing Conditions. Existing conditions were determined by calculating the amount of oyster reef for each ER measure footprint, using the TPWD oyster locations data. It was assumed that if no oyster reef existed within the project footprint, then the percent cultch was suboptimal (SI = 0.0). Alternatively, any amount of oyster reef existing within the project footprint was assumed to provide optimal bottom substrate (SI = 1.0).

FWOP Conditions. Data to forecast and evaluate future changes in oyster reef habitat were not readily available. As a result, it was assumed that all oyster reef habitat, and therefore cultch, was eliminated with no project action due to SLR, increased bay energies, and changes in freshwater inflows and salinities.

FWP ER/Mitigation/CSRM Conditions. Oyster habitat restoration or creation actions were assumed to be completed in 2035. Therefore, it was assumed that the creation or restoration actions would result in optimal SI of 1.0 through the end of the project life.

3.6.2 V_2 – Mean Water Salinity during May–September

Mean water salinity during the spawning season for oysters represents the mean monthly salinity from May to September and reflects the optimal salinities required for spawning and larval stages (Swannack et al., 2014).

Existing Conditions. Existing conditions were calculated by averaging monthly values of salinity from May 1 through September 30 within the project footprint using TPWD water quality data from 2007 to 2016 (pers. com. M. Fisher [TPWD], 2017).

FWOP Conditions. Data to forecast and evaluate changes in salinity with no project action were not readily available; as a result, the interagency team determined that a 20 percent increase to baseline salinities should be applied for the FWOP conditions to capture the potential change in salinities over the period of analysis.

FWP ER/Mitigation Conditions. As described above, a 20 percent increase was applied to baseline salinities for the FWP conditions to capture the potential change in salinities over the period of analysis.

FWP CSRM Conditions. Salinity changes as a result of the gates were assumed to be minor and would be captured within the 20 percent increase applied to baseline salinities to capture potential change in salinities over the period of analysis.

3.6.3 V_3 – Minimum Annual Water Salinity

Minimum annual salinity represents the minimum value of the 12 monthly mean salinities determined for each year of data. This variable reflects freshwater impacts (e.g., high rainfall years or freshwater diversions) on oysters and is an indication of the frequency of freshwater floods that are fatal to oysters (Swannack et al., 2014).

Existing Conditions. Existing or baseline conditions were calculated by averaging monthly values of salinities to determine the minimum annual salinity from 2007 to 2016 using TPWD water quality data (pers. com. M. Fisher [TPWD], 2017).

FWOP Conditions. Data to forecast and evaluate changes in salinity with no project action were not readily available; as a result, the interagency team determined that a 20 percent increase to baseline salinities should be applied for the FWOP conditions to capture the potential change in salinities over the period of analysis.

FWP ER/Mitigation Conditions. As described above, a 20 percent increase was applied to baseline salinities for the FWP conditions to capture the potential change in salinities over the period of analysis.

FWP CSRM Conditions. Salinity changes as a result of the gates were assumed to be minor and would be captured within the 20 percent increase applied to baseline salinities to capture potential change in salinities over the period of analysis.

3.6.4 V_4 – Annual Mean Salinity

Annual mean salinity represents the range of suitable salinities that adult oysters can tolerate and are viable. Salinities within the range of 10 to 15 ppt are assumed to be optimal for oysters (Swannack et al., 2014).

Existing Conditions. Existing, or baseline, conditions were calculated by averaging monthly salinity values to determine the annual mean salinity from 2007 to 2016 using TPWD water quality data (pers. com. M. Fisher [TPWD], 2017).

FWOP Conditions. Data to forecast and evaluate changes in salinity with no project action were not readily available; as a result, the interagency team determined that a 20 percent increase to baseline salinities should be applied for the FWOP conditions to capture the potential change in salinities over the period of analysis.

FWP ER/Mitigation Conditions. As described above, a 20 percent increase was applied to baseline salinities for the FWP conditions to capture the potential change in salinities over the period of analysis.

FWP CSRM Conditions. Salinity changes as a result of the gates were assumed to be minor and would be captured within the 20 percent increase applied to baseline salinities to capture potential change in salinities over the period of analysis.

3.7 KEMP'S RIDLEY SEA TURTLE

The Kemp's ridley sea turtle is considered a sentinel species for Texas' marine ecosystems, meaning, their abundance, distribution, and health are reflective of environmental conditions (NPS 2017). Additionally, researchers recently found statistical evidence to support the conclusion that specific variabilities in beach and dune geomorphologies influence Kemp's ridley nest site selection on Padre Island, TX, United States (Culver *et al*. 2020). This research provided key information that allowed the Study Team to develop the habitat suitability index for Kemp's ridley nesting.

The model was developed through a collaborative process that was headed by USACE and included input from the GLO, the FWS, the National Park Service, and the Texas Parks and Wildlife Department. This habitat suitability model includes the geomorphic variables that were identified by Culver *et al.* (2020) as having the highest predictive power influencing nest site location. These influential geomorphic parameters include: the maximum dune slope, the average beach slope, and the elevation at the line of vegetation (a frequent nest location), which is closely associated with the toe of the dunes (change in steepness that indicates a transition between beach and dune habitats).

The interagency team also used a conceptual model developed by Dunkin *et al.* 2015, which identified categories and parameters that influence loggerhead sea turtle (*Caretta caretta*) nesting, to identify other non-geomorphic variables that would influence nesting habitat suitability. While the biology and nesting behaviors differ between loggerheads and Kemp's ridleys, Dunkin *et al.*'s (2015) conceptual model helped the team identify two additional variables which were carried forward into the model. The two additional non-geomorphic variables are artificial light (dune shade) and beach use.

R (R Core Team 2017) was used to investigate the distributions of the geomorphic variables in the dataset used by Culver *et al.* (2020) to assign index scores for the variable ranges. Density plots were used to identify breaks in ranges which then correspond to assigned index scores.

There are several assumptions that were made to run this model. Most of the assumptions apply to both FWOP and FWP scenarios including:

- All beach and dune areas are considered nesting habitat.
- Shoreline change trends identified in the Bureau of Economic Geology's Shoreline Change Atlas were applied to all the reaches.
- The Bolivar Peninsula and West Galveston Beach and Dune measure includes re-nourishment, so shoreline losses and effects from RSLC were not detracted for the FWP scenario
- Where the predicted shoreline erosion caused a complete loss of beach surface area for a reach before the end of the 50-project analysis, the predicted erosion was not continued into the dune habitat (basically, the analysis did not predict loss of dune habitat).
- Mean Sea Level (MSL) and Mean Higher High Water (MHHW), which are known to vary along the Texas Coast, play important roles in habitat suitability and in determining the extent of the "wet beach" for a region. Culver *et al.* (2020) used NOAA station 8775870, the tide gauge at Bob Hall Pier in Corpus Christi which reports the local MSL as 0.48-foot NAVD 88 and Mean Higher High Water (MHHW) as 1.18-foot NAVD 88. The datums from NOAA station 8771510, the Galveston Pleasure Pier was used to compare Region 4 with Region 1. The Galveston Pleasure Pier Station reports MSL as 0.5-foot NAVD88 and MHHW as 1.4-foot NAVD88. After comparing the values from the two stations, no adjustments were made because MSLs were very close and even though Galveston had a MHHW that was 0.22-foot NAVD88 higher than Corpus Christi, the Dune Toe Elevation Variable was still suboptimal in that range.

- The beach use variable assumes that proximity to a beach access point and whether or not diving is allowed correlates to the amount of human recreational activity that would occur in a particular reach.

3.7.1 V_1 – Average Beach Slope

The research shows that Average Beach Slope is an important parameter influencing nest site selection Culver *et al.* (2020). Kemp's Ridley nests were far less dense on beaches with a steep average slope or those that were relatively flat. Using quantiles and the standard deviations from the distribution used by Culver *et al.* (2020), five scoring ranges were derived, and the relative nesting densities for those ranges were used to determine the scores for these ranges. The optimal range for the Average Beach Slope was determined to be within 4.2 º and 2º.

Existing Conditions. Using GIS software and LiDAR datasets, the project areas were broken up into 100-meter-wide segments (reaches). The Average Beach Slopes, reported in degrees, were calculated for all reaches.

FWOP Conditions. It is acknowledged that coastal processes (e.g. tides, wind, longshore forcing, and waves) are highly variable and would affect beach length and ultimately beach slope in the future; however, due to the uncertainty in the timing and extent of change, it was assumed the angle of repose of sand and water (proxy for slope) would not change in the future. Therefore, the FWOP slope was the same as the existing condition for all TYs.

FWP ER/CSRM Conditions. The Average Beach Slope was calculated utilizing the design templates for the beach and dune measures. The Average Beach Slope was calculated for each reach at TY1 and applied to all TYs. The design template width, which creates sub-optimal conditions, is temporary and would be expected to be shaped by coastal processes into optimal conditions in the future; however, the team could not project how long it would take for this to occur so the design template widths were applied to all TYs.

3.7.2 V_2 – Maximum Dune Slope

Like the results for the Average Beach Slope variable, Kemp's ridley nests were far less dense on beaches with steep or shallow values for Maximum Dune Slope. This makes sense because escarpments (very steep) have been correlated to false crawl behavior in nesting sea turtles. Additionally, some evidence suggests that many nesting Kemp's ridley's prefer to nest near the toe of the dune and if the maximum dune slope is too flat the toe of the dune may not be as discernable.

Existing Conditions: Using GIS software and LiDAR datasets, the project areas were broken up into 100-meter-wide segments (reaches). The Maximum Dune Slopes, reported in degrees, were calculated for all segments.

FWOP Conditions. Similar to the FWOP for V_1, it is assumed the maximum slope would not change in the future because the angle of repose of sand and water is assumed to remain constant.

FWP Conditions. Similar to the FWP for V_1, the Maximum Dune Slope was calculated utilizing the design templates for the beach and dune measures and took into account the angle of repose for sand and water. The Maximum Dune Slope was calculated for each reach for TY1 and applied to all TYs.

3.7.3 V_3 – Dune Toe Elevation

Culver *et al.* (2020) found that nest elevation and distance from the nest site to the shoreline were two of the most predictive variables. It was challenging to find a way to score those variables because they were measured by individual nest and at first it was uncertain as to whether or not these variables were tied to a specific geomorphic characteristic. Culver *et al.* (2020) reported that the nest locations were frequently found along the potential line of vegetation which usually occurs at a geomorphic feature known as the "toe of the dune." Due to some of these assumptions, a large section of the elevation range was considered optimal (75% of the distribution). The optimal range for the toe of the dune was between 2.4- and 5-foot NAVD88.

Existing Conditions. Using GIS software and LiDAR datasets, the Dune Toe Elevation were calculated for all the segments and were reported in feet above 0 NAVD88.

FWOP Conditions. RSLC rates were applied to the Dune Toe Elevation variable by subtracting the 2018 elevations from the predicted RSLC elevation for the region and the TY. As RSLC is applied, the scores for this variable diminish.

FWP ER Conditions. The design template Dune Toe Elevation was applied to TY1. For future TYs, RSLC rates were applied to the TY1 elevation to project the future elevations using the same method as the FWOP condition.

FWP CSRM Conditions. The design template Dune Toe Elevation was applied to all TYs because renourishment cycles were assumed to occur at an interval that would keep up with RSLC.

3.7.4 V_4 – Artificial Light (Dune Shade)

Kemp's ridley sea turtles primarily nest during daylight hours in synchronized emergences, known as "arribadas." While the presence of artificial light on the beach wouldn't affect nesting behavior, it still could disorient hatchlings reducing their chances of reaching the gulf waters.

The presence of artificial light and the shading benefits provided by dunes (both FWOP and FWP) were determined using the 2018 Upper Coastal LiDAR dataset, to extract building locations and existing dune profiles. A simulated light source was set on each building at 10' below the maximum height to approximate the elevation of a porchlight. A viewshed analysis was run with each point set as an 'observer' against the 2018 DEM, and again against the modified DEM for FWOP and FWP conditions in place. The raster output of the viewshed showed where each point on the ground was visible from at least one light source. For each scenario, the raster was converted to a polygon, clipped to each beach sector, and the area of the viewshed polygon was compared against the area of the beach sector, giving the percentage of the beach that would be shaded from artificial light coming from the structures.

If a beach doesn't have houses or lamp posts within 0.25 miles of the reach a score of 1 is assumed for this variable.

Existing Conditions: The same light source locations and elevations were used for both the with and without project analyses. For this variable, the existing condition dune elevations included the additional shading provided by existing vegetation. This was accomplished by including the vegetation in the dune elevation analysis.

FWOP Conditions: It was assumed that no additional structures/light sources would be constructed in or near the analysis area in the future and the top of dune crest elevation and vegetation density/height would remain unchanged; therefore, the existing condition variable was applied to all TYs. It is acknowledged that, development could occur in the future resulting in an increase in artificial light sources. It is also acknowledged that dune crest elevations are trending toward dune elevation loss due to measured sediment deficits for all reaches of beach. However, forecasting these changes for specific beach reaches over the 50-year period of analysis would be too speculative for inclusion. By maintaining the existing condition, the assumption only risks overvaluing the FWOP condition which would undervalue the calculated benefits/impacts.

FWP ER/CSRM Conditions. The variable was calculated in the same manner as the FWOP condition, except the project template was simulated in front of the existing dunes. It was also assumed that vegetation on the dunes would be 2 feet above the crest of the dune, which is the average height of most plant species found on dunes in Texas. Note: No structures were within 0.25 miles of W-3.

3.7.5 V_5 – Beach Use Activity

This variable considers the adverse impacts that human beach activities can have on nesting Kemp's ridleys sea turtles and hatchlings. The adverse impacts to nesting sea turtles from automobiles driving on beaches have been well documented. Vehicles have been known to strike turtles, damage nests, increase sand compaction, and the head lights contribute to light pollution. Additionally, beaches that offer pedestrian access (non-vehicular) have been shown to have higher levels of discarded plastics than beaches with restricted access. Also, the mere presence of people could discourage nesting.

This variable scored Beach Use Activity by assessing the proximity of the reaches to beach access points and by considering whether or not driving is allowed on the beach. Reaches greater than 1.0 mile from an access point were scored a 1.0, while reaches less than 1.0 mile from an access point that only allowed pedestrian access (no driving) were scored a 0.5 and reaches that allowed driving were scored a 0.1.

Existing Conditions. Google Earth's measure tool was used to measure the distance from known beach access locations to each reach.

FWOP Conditions. It was assumed that the number and location of beach access points would remain the same in the future.

FWP Conditions. It was assumed that the number and location of beach access points would remain unchanged from the existing condition. Access locations may need to be modified in order to construct the dunes; however, to comply with the Texas Open Beaches Act, access must be maintained similar to the existing condition, so it is assumed the method of access would not be changed and location movements would be insignificant for purposes of this analysis.

4.0 MODELING RESULTS

Individual species HSI scores were generated for each measure location using the species-specific spreadsheet calculators. The HSI scores were then multiplied by the acreages to calculate the Habitat Units (HUs). HUs represent a numerical combination of quality (i.e. Habitat Suitability Index) and quantity (acres) existing at any given point in time.

HUs represent a single point in time; however, the impacts of any of the proposed actions would occur over the entire planning horizon (50 years). To account for the value of change over time, when HSI scores are not available for each year of analysis, the cumulative HUs are calculated using a formula that requires only the target year (TY) and the area estimates (USFWS 1980). The following formula was used:

$$\int_0^T HU\,dt = (T_2 - T_1)\left[\left(\frac{A_1H_1 + A_2H_2}{3}\right) + \left(\frac{A_2H_1 + A_1H_2}{6}\right)\right]$$

Where:

$$\int_0^T HU\,dt = Cumulative\ HUs$$

T1= first target year of time interval

T2 = last target year of time interval

A1 = area of available habitat at beginning of time interval

A2= area of available habitat as the end of time interval

H1 = Habitat Suitability Index at the beginning of time interval

H2 = Habitat Suitability Index at the end of time interval

3 and 6 = constants derived from integration of HSI x Area for the interval between any two target years

This formula was developed to precisely calculate cumulative HUs when either HSI or area or both change over a time interval, which is common when dealing with the unevenness found in nature. HU gains or losses are annualized by summing the cumulative HUs calculated using the above equation across all target years in the period of analysis and dividing the total (cumulative HUs) by the number of years in the planning horizon (i.e. 50 years). This calculation results in the Average Annual Habitat Units (AAHUs) (USFWS 1980).

The impact of a project can be quantified by subtracting the FWP scenarios benefits/impacts from the FWOP benefits/impacts. The difference in AAHUs between the FWOP and the FWP represents the net impact attributable to the project in terms of habitat quantity and quality, where a positive number results in net benefits and a negative results in net loss.

The following sections show the remaining and net change value of habitats within the study area under the FWOP and FWP at three TYs. Attachment A includes a copy of the spreadsheets used to calculate AAHUs.

4.1 ECOSYSTEM RESTORATION

Each of the eight alternatives presented in section **Error! Reference source not found.** contain ne or more of eight measures. Table 5 shows a summary of the AAHUs of all models for each measure, while Table 6 shows the AAHUs and Table 7 shows the acres for selected TYs for each measure by species model.

Table 5. Net Change in AAHUs by Measure

Measure	FWOP AAHUs	FWP AAHUs	Net Change in AAHUs	Acres (2085 FWP)
G-28	20,327	30,339	10,012	1,144
B-2	54	608	554	216
B-12	30,357	31,618	1,261	1,993
M-8	10,769	10,992	223	2,526
CA-5	1	266	265	1,176
CA-6	901	919	18	620
SP-1	11	2,201	2,190	3,679
W-3	14,911	22,307	7,396	41,883

Table 6. Modeling Results for Each Measure at Selected Target Years in HUs

Target Year (TY)	Existing Condition	TY 1 (2035)			TY 31 (2065)			TY 51 (2085)		
		FWOP	FWP	Change	FWOP	FWP	Change	FWOP	FWP	Change
G-28 Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection										
American Oyster	0	0	10	10	0	8	8	0	7	7
Brown Pelican	15	7	194	187	0	186	186	0	182	182
Brown Shrimp	45,707	49,182	50,427	1,246	13,966	14,789	823	0	62	62
B-2 Follets Island Gulf Beach and Dune Restoration										
Kemp's Ridley Sea Turtle	98	58	608	550	49	442	393	46	437	390
B-12 Bastrop Bay, Oyster Lake, West Bay, and GIWW Shoreline Protection*										
American Oyster	0	0	1	1	0	1	1	0	1	1.14
Brown Shrimp	63,493	67,926	68,859	933	23,872	25,335	1,463	0	147	147
M-8 East Matagorda Bay Shoreline Protection										
American Oyster	0	0	8	8	0	7	7	0	5	5
Brown Pelican	0	0	68	68	0	62	62	0	56	56
Brown Shrimp	16,394	17,997	18,106	109	11,359	11,553	194	467	558	91
CA-5 Keller Bay Restoration										
American Oyster	0	0	2	2	0	2	2	0	2	2
Spotted Seatrout	80	80	1,198	1,118	0	1,198	1,198	0	9,825	9,825
CA-6 Powderhorn Shoreline Protection and Wetland Restoration										
Brown Shrimp	611	1,136	1,197	61	1,137	1,137	0	124	124	0

Target Year (TY)	Existing Condition	TY 1 (2035)			TY 31 (2065)			TY 51 (2085)		
		FWOP	FWP	Change	FWOP	FWP	Change	FWOP	FWP	Change
SP-1 Redfish Bay Protection and Enhancement										
American Oyster	0	0	1	1	0	1	1	0	0	0
Brown Pelican	74	0	268	268	0	266	266	0	265	265
Spotted Seatrout	1,009	1,009	3,143	2,134	0	97,737	97,737	0	65,158	65,158
W-3 Port Mansfield Channel, Island Rookery, and Hydrologic Restoration										
Brown Pelican	2	0	18	18	0	18	18	0	18	18
Kemp's Ridley Sea Turtle	143	42	437	395	18	225	208	15	152	137
Spotted Seatrout	38,039	38,039	42,554	4,515	931,287	1,290,480	359,193	423,002	699,550	276,548

* B-12 does not include port-owned land tracts near Port Freeport.

Table 7. Acres of Habitat at Selected Target Years for Each Measure

Target Year (TY)	Existing Condition	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
G-28 Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection				
American Oyster	0	18	18	18
Brown Pelican	23	298	286	280
Brown Shrimp	49,033	52,551	25,185	846
B-2 Follets Island Gulf Beach and Dune Restoration				
Kemp's Ridley Sea Turtle	850	691	502	216
B-12 Bastrop Bay, Oyster Lake, West Bay, and GIWW Shoreline Protection*				
American Oyster	0	2	2	2
Brown Shrimp	70,759	74,422	40,794	1,991
M-8 East Matagorda Bay Shoreline Protection				
American Oyster	0	15	15	15
Brown Pelican	3	96	88	79
Brown Shrimp	17,852	19,524	14,796	2,432
CA-5 Keller Bay Restoration				
American Oyster	0	4	4	4
Brown Shrimp	1,110	1,613	1,613	876
Spotted Seatrout	296	296	296	296
CA-6 Powderhorn Shoreline Protection and Wetland Restoration				
Brown Shrimp	1,615	2,416	2,335	620
SP-1 Redfish Bay Protection and Enhancement				
American Oyster	0	2	2	2
Brown Pelican	118	423	421	419
Spotted Seatrout	3,028	3,258	3,258	3,258
W-3 Port Mansfield Channel, Island Rookery, and Hydrologic Restoration				
Brown Pelican	4	23	23	23
Kemp's Ridley Sea Turtle	979	497	256	173
Spotted Seatrout	46,810	56,333	47,320	41,687

The results presented in the previous tables were then used to determine the net change in AAHUs by alternative. The AAHU for each species model was added together for each TY. The AAHUs summed by measure (Table 5) were then appropriately added to each alternative (Table 8) to identify the total AAHUs of each alternative (Table 9). As can be expected, implementation of Alternative 1 would produce the most benefits because it has the most measures. These benefit values were used in the CE/ICA analysis. Discussion of the CE/ICA is available in Appendix E-3 of the Feasibility Main Report.

Table 8. ER Measures by Alternative

Alternative	G-28	B-2	B-12	M-8	CA-5	CA-6	SP-1	W-3
Alt 1	●	●	●	●	●	●	●	●
Alt 2		●	●			●		●
Alt 3	●	●						●
Alt 4	●		●	●	●	●	●	
Alt 5	●	●	●					
Alt 6	●	●	●		●			

Table 9. Net AAHUs for Each Alternative

Alternative	FWOP AAHUs	FWP AAHUs	Net Change in AAHUs	Acres (FWP 2085)
Alt 1	77,887	99,787	21,920	55,353
Alt 2	46,223	55,452	9,230	46,828
Alt 3	35,292	53,254	17,962	45,359
Alt 4	62,922	76,872	13,970	11,138
Alt 5	50,738	62,565	11,827	5,469
Alt 6	51,639	63,484	11,845	6,089

4.2 CSRM

CSRM impact assessments addressed direct and indirect impacts of implementing the action. Direct impacts are those that are caused by the action and occur at the same time and place, while indirect impacts are those caused by the action but occur later in time or further removed in distance.

4.2.1 Impact Assessment of Open Bay Bottom Habitat

Constructing and operating the Galveston Bay Storm Surge System would primarily impact open bay bottom habitat. Quantification of impacts to open bay bottom habitat are difficult because the subtidal bay bottom areas are part of a large and dynamic system for which no community-based models are available and species-specific models would only target specific habitats, not the whole system. As well, seasonal shifts in fauna and siltation further complicate selecting a species-specific model. The interagency team considered developing a model that would be better suited to quantifying open bay bottom impacts; however, concerns arose over how to mitigate for open bay bottom. In general, the quality of open bay bottom is consistent where present, so there are no locations where actions could be taken to create lift in the quality of the habitat. To mitigate for the loss, additional bay bottom would have to be created through removal of other habitat types, such as oyster reefs, sea grass meadows, or salt marshes, each of which are substantially more productive and a relatively scarce and significant habitat that would result in a net-loss that would require additional mitigation. Terrestrial habitat could also be converted to open bay bottom; however, this poses its own challenges for comparison of FWOP and FWP conditions.

The interagency team worked through these challenges and identified a strategy to quantify the impacts and calculate commensurate mitigation. The team decided to use a meta-analysis developed by the National Marine Fisheries Service (NMFS) that they use to determine compensation for interim losses related to oil spills and other environmental impacts. A meta-analysis is a statistical technique that combines the results of several studies and pools them to estimate the ratio of average productivity between pairs of estuarine habitats across all three trophic levels (Peterson *et al.* [Date]).

Another challenge encountered was what models or data would go into the meta-analysis. Initially, the team determined that use of species-specific models were the most appropriate approach to identifying the existing and FWOP conditions and opted to select only one species model for assessment. The team recognized that if more than one species model is used when trying to apply the meta-analysis, statistical complexities as different assumptions and variables/inputs are used with each model, which then causes the intervals to be a lot wider and makes the results more uncertain. The Southern Flounder HSI model (Enge & Mulholland 1985) was identified as the preferred model. However, it became apparent after further investigation into the model that the higher salinities observed near Bolivar Roads would have resulted in a suboptimal score for the existing condition, which might not be indicative of the health of the benthic communities located in those sediments. Since the quality of the open bay bottom habitats are challenging to assess, it was decided to forego a species-specific model and assume a surrogate optimal index score of 1.0 to reduce the risk of underestimating the impacts from the project.

Existing Conditions. The quality of the open bay bottom is assumed to have an HSI score of 1.0 (optimal conditions).

FWOP Conditions. The quality of the open bay bottom is unchanged in the future, despite RSLC. Subtidal open bay bottom is one of the few habitats where the quality is not expected to measurably change as a result of RSLC and projecting those changes would be highly speculative; therefore, the values were not adjusted for those expected changes.

FWP CSRM Conditions. Open bay bottom habitat loss (HSI score of 0.0) was assumed to occur at locations where subtidal habitat was converted to a permanent structure or other non-tidal habitat, such as at the islands containing the gates. This assumes the HUs for the open bay bottom impacts are equal to the acreage of the structure. It was also assumed that the hard substrate replacing bay bottom at the scour pad locations is expected to provide subtidal habitat for sessile organisms resulting in a conversion of subtidal habitat rather than a loss. It is also assumed that dredging disturbances are temporary in nature and recolonization of the substrates by interstitial species is highly likely, resulting in no loss of subtidal habitat just a temporary conversion.

After the area of permanent loss was identified at each location, the HUs were calculated by multiplying the acreage by 1.0. This resulted in the total HUs/AAHUs under the existing and FWOP condition and the loss expected under the FWP condition (Table 10).

Table 10. Net Change in AAHU to Open Bay Bottom

Measure	Existing/FWOP				FWP				Net Change (AAHU)
	Acres	HSI	HUs	AAHU*	Acres	HSI	HUs	AAHU	
Bolivar Roads Gate System	117	1.0	117	117	117	0.0	0.0	0.0	-117
Galveston Ring Barrier System	23	1.0	23	23	23	0.0	0.0	0.0	-23
Clear Lake Gate System	6.1	1.0	6.1	6.1	6.1	0.0	0.0	0.0	-6.1
Dickinson Bayou Gate System	15.5	1.0	15.5	15.5	15.5	0.0	0.0	0.0	-15.5
Total				**161.6**				**0.00**	**-161.6**

* HUs remain the same in all TYs; therefore, the AAHU is the same as the HU.

To these values, a ratio was applied to the number of open bay bottom HUs to determine the estimate of the equivalent HUs. Oyster reef was selected as the equivalent habitat because of its high productivity in the open bay bottom system. The ratio of average productivity across all three trophic levels between subtidal flat (open bay bottom) and oyster reef is estimated to be 8.9 to 1 (Peterson *et al.*[Date]), meaning that 8.9 HUs for open bay bottom would be equal to one habitat unit of oyster reef. A total of 17.4 AAHUs of equivalent oyster reef would require mitigation (Table 11).

Table 11. Results of without project condition habitat unit conversion for Open Bay Bottom without project

Measure	Open Bay Bottom Loss (Net AAHU)	Conversion Ratio (Open Bay Bottom : Oyster Reef)	Equivalent Oyster Reef (Net AAHU)
Bolivar Roads Gate System	-117	8.9:1	-13.1
Galveston Ring Barrier System	-23	8.9:1	-2.6
Clear Lake Gate System	-6.1	8.9:1	-0.7
Dickinson Bayou Gate System	-15.5	8.9:1	-1.7
Total:	**-161.6**		**-18.1**

4.2.2 Impact Assessment of Other Habitats

The post-TSP CSRM HEP analysis was performed on Alternative B Modified in February/March 2020 to evaluate impacts to ecological resources under baseline, FWOP, and FWP conditions. The Galveston Seawall Improvements and the non-structural features of the alternative would not have any impact to ecosystems since all work would be completed within urbanized areas and where existing hardened structures exist.

No modeling was completed for the South Padre Island or Bolivar Peninsula and West Galveston Island Beach and Dune Improvements components of the CSRM actions because these would not be expected to result in any adverse impacts that would require mitigation. Both measures would be expected to produce benefits similar to ER measures; however, the benefit to the habitat is considered an ancillary benefit and is therefore not included in calculating the NED plan.

Table 12. Net Change in AAHUs by Measure

	FWOP (AAHUs)	FWP (AAHUs)	Net Change (AAHUs)	Acres
Bolivar Roads Gate Structure			-23.8	
Galveston Ring Barrier			-42.3	
Dickson Bay Surge Gate			-4.7	
Clear Lake Surge Gate			-3.7	
Total for the Alternative				

Table 13. Modeling Results for Each Measure at Selected Target Years in HUs

Target Year (TY)	Existing Condition	TY 1 (2035)			TY 31 (2065)			TY 51 (2085)		
		FWOP	FWP	Change	FWOP	FWP	Change	FWOP	FWP	Change
Direct Impacts										
Bolivar Roads Gate Structure										
Brown Shrimp	7.5	12.5	0	-12.5	25	0	-25	7.5	0	-7.5
American Alligator	14.4	18.1	0	-18.1	1.85	0	-1.85	1.66	0	-1.66
Galveston Ring Barrier										
Brown Shrimp	14	41.5	0	-41.5	53.2	0	-53.2	3	0	-3
American Alligator	9.29	12.12	0	-12.12	1.9	0	-1.9	1.6	0	-1.6
Dickson Bay Surge Gate										
Brown Shrimp	4.56	4.23	0	-4.23	3.5	0	-3.5	3.24	0	-3.24
American Oyster	1.3	1.14	0	-1.14	0.9	0	-0.9	0.82	0	-0.82
Clear Lake Surge Gate										
Brown Shrimp	2.34	2.17	0	-2.17	1.79	0	-1.79	1.66	0	-1.66
American Oyster	2.41	2.1	0	-2.1	1.67	0	-1.67	1.52	0	-1.52
Indirect Impacts										
Tidal Amplitude										
Brown Shrimp	229.6	229.6	0	-229.6	1,070.1	0	-1,070.1	989.3	0	-989.3

As summarized in Table 14, a net loss in AAHUs indicates unavoidable impacts which would require mitigation. Based on the results of the modeling, mitigation will be required for 1,577.6 acres of direct and indirect impacts to wetlands, open bay bottom, and oyster reefs

All measures that have resulted in a net loss of AAHUs require further refinement in design and future NEPA analysis to confirm and/or add to the assessment of impacts. This would be completed in a Tier 2 Analysis at some point in the future. It is fully anticipated that when refinements are made and more information is available to better understand the impacts, these values are going to change. However, due to the conservative nature of engineering and economic assumptions used in the development of the Recommended Plan, it is anticipated that design refinements of the proposed structures will result in equal or lesser environmental impacts than estimated here.

Table 14. Impacts from Implementing the Storm Surge Barrier System

Impact	Acres	AAHUs
Direct		
Palustrine Wetlands	128	-11.8
Estuarine Wetlands	134	-59.9
Open Bay Bottom	161.6	-18.1
Oyster	6.0	-2.8
Total Direct Impacts	429.6	-92.6
Indirect		
Tidal Prism Change	1,148	-789
Total Indirect Impacts	1,148	-789
Total Impacts	1,577.6	-881.6

4.3 MITIGATION SITES

Compensatory mitigation is required for unavoidable impacts to the environment that are caused by the recommended plan. No mitigation is required for any of the ER measures, the South Padre Island Beach Nourishment or the Bolivar Peninsula and West Galveston Island Beach and Dune Improvements because no net loss in AAHUs was realized.

Implementation of the Bolivar Roads Gate Structure, Galveston Ring Barrier, Dickson Bay Surge Gate, and Clear Lake Surge Gate are expected to have unavoidable adverse impacts to various habitats as shown in the previous section (i.e. net loss in AAHUs). Impacted habitat types are estuarine emergent wetland, palustrine emergent wetland, oyster reef and open bay bottom. A Draft Mitigation Plan, which is included as Appendix J of the EIS, details proposed plans to replace the lost functions and values of the impacted areas through restoration activities that increase and/or improve the habitat functions and services within a mitigation site.

Potential locations for mitigation sites, as shown in Figure 6, have been developed with the interagency team but will be refined further during future Tier 2 assessments. Ultimately, the final size of the mitigation measures (width, length etc.) may change. This analysis was completed to confirm that sufficient mitigation locations exist and to understand the potential cost of mitigation in relation to overall project costs.

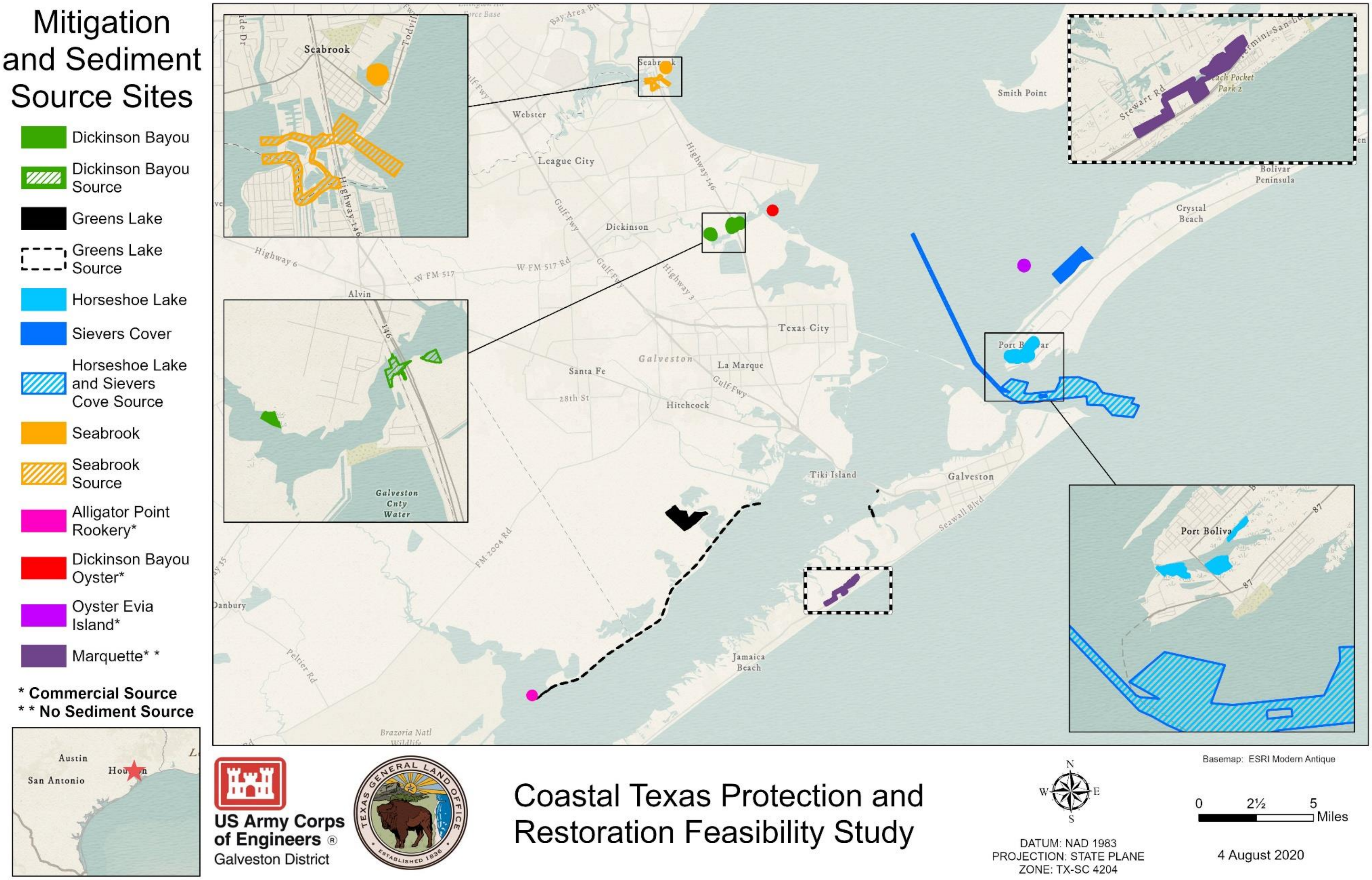

Figure 6. Potential Mitigation Sites

4.3.1 Results

Nine sites were identified as potential mitigation sites. The following results show the HEP analysis completed for each site.

Table 15. Potential Lift (Net Change in AAHUs) that Can Be Gained at Each of the Mitigation Sites

Mitigation Location	AAHUs	Acreage
Estuarine		
Horseshoe Lake Site 1-3	37.6	62
Sievers Cove	491.8	667
Greens Lake	340.7	562
Clear Lake	2.1	3
Dickinson Bayou	4	6
Palustrine		
Marquette	12.1	21
Oyster		
Evia Island	13.2	28
Dickinson Bayou	3	7
Alligator Point	4.9	10

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ATTACHMENT

ER Measure Forecasting Assumptions