Appendix C-8

Habit Evaluation Procedures and Wetland Value Assessment Modeling Report

Job No. TGL18185

APPENDIX C-8

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HABITAT EVALUATION PROCEDURES AND WETLAND VALUE ASSESSMENT MODELING REPORT
FOR THE
COASTAL TEXAS PROTECTION AND RESTORATION STUDY

Prepared for:

U.S. Army Corps of Engineers
and
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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

The U.S. Army Corps of Engineers (USACE) and its non-Federal sponsor the Texas General Land Office (GLO) entered into a cost share agreement in November 2015 to begin studying the feasibility of constructing projects for coastal storm risk management (CSRM) and ecosystem restoration (ER) along the Texas coast. The Coastal Texas Protection and Restoration Study (Coastal Texas Study) involves engineering, economic, and environmental analyses on large-scale projects that provide a long-term approach to enhance resiliency in coastal communities and improve our capabilities to prepare for, resist, recover from, and adapt to coastal hazards.

The USACE and its stakeholders used Habitat Evaluation Procedures (HEP) to evaluate the ecological impacts of proposed ER and CSRM measures and to assess the feasibility of proposed mitigation plans formulated to offset the potential impacts from the CSRM measures. HEP evaluated 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 HEP analyses, the following steps were completed in the assessment of the study's proposed ER, CSRM, and mitigation designs:

1. Building a multidisciplinary evaluation team.
2. Defining the proposed ER and CSRM measures.
3. Setting goals and objectives and defining a project life and target years.
4. Selecting species-based Habitat Suitability Index (HSI) models and a community-based Wetland Value Assessment (WVA) model (a modification of HEP) to evaluate ecological impacts.
5. Calculating baseline conditions and forecasting Future-without Project (FWOP) and Future-with Project (FWP) conditions.
6. Reporting the results of the analyses.

This report focuses on HEP analyses, as applied to the final list of ER measures. For potential CSRM measures being carried forward, HEP analyses will be conducted following the Agency Decision Milestone, and the results will be incorporated into this report for the Final Integrated Feasibility Report and Environmental Impact Statement (FIFR-EIS). The following sections summarize the Coastal Texas Study application plan formulation process and the application of the HEP techniques to the study's ER measures.

1.1 USING HEP TO ASSESS ECOLOGICAL IMPACT AND ECOSYSTEM RESPONSE

In response to the growing need to evaluate ecological impacts associated with Federal projects, in the 1970s and 1980s, the U.S. Fish and Wildlife Service (USFWS) and other Federal agencies developed a standard habitat evaluation system, known as HEP, to integrate ecological principals into the planning process. HEP employs a species-based approach to assess ecosystems and provides a tool for planners, resource managers, and biologists to evaluate changes in habitat quality and quantity over time under proposed alternative scenarios (USFWS, 1980). The Habitat Evaluation and Assessment Tools (HEAT) software was developed to conduct HEP and allows the user to establish habitat units (HUs), the common form of currency when assessing project impacts and benefits, and to determine Average Annual Habitat Units (AAHUs) to capture future project changes for specific project timescales (Burks-Copes et al., 2012).

Similarly, the WVA model, a modification of HEP developed by the USFWS, is a quantitative, community-based assessment developed to estimate anticipated environmental impacts or benefits to fish and wildlife resources (USFWS, 2012). Though not always necessary, these two models can work in conjunction to produce outputs that allow users to evaluate the effects of changing conditions on ecosystems as the result of implementation of proposed alternative scenarios.

Both models (HEAT and WVA) are supported by computed-based programming modules that accept the input of mathematical details and data comprising the specified index model (either species-based or community-based), and through their applications in HEP, calculate identifiable outputs in response to proposed alternative scenarios. These models allow for rapid assessment of changing habitat conditions and the implications of those changes on species, communities, and ecosystems (USFWS, 1980).

USACE Civil Works policy requires that only standard habitat models previously certified by the USACE Ecosystem Planning Center of Excellence be used to determine ecological benefits and/or impacts and mitigation (USACE, 2005). In a memo dated July 11, 2017, the use of HEP, HEAT, and WVA were approved by the USACE Headquarters Model Certification Panel to be used in support of the Coastal Texas Study.

2.0 THE COASTAL TEXAS INTERAGENCY TEAM

The Coastal Texas Study interagency team worked together to establish baseline and future conditions of the project sites, evaluate and select HSI and WVA models, and conduct HEP forecasting and model evaluations for the study. The interagency team includes representatives from Federal, State, and local agencies, Indian tribes, the non-Federal sponsor, and engineering and National Environmental Policy Act (NEPA) consultants and included the technical expertise necessary to support the planning, design, and management phases of the project.

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3.0 DEFINING THE ECOSYSTEM RESTORATION MEASURES

An ER measure is a structural element or feature that requires construction, a nonstructural action, or activity that can be combined with other measures to form alternatives. ER measures were specifically developed to capitalize upon opportunities that best address the problems related to the current trend of ecosystem degradation throughout the Texas coast.

ER measures were derived from a variety of sources including the NEPA public scoping process; consideration of the existing and FWOP conditions; development of a conceptual ecological model; previously executed restoration projects; analysis of reports and projects with similar problems, needs, and opportunities; coordination with other resource management agencies, private, local governmental, or landowner groups; information from prior studies; and professional judgment of the interagency team.

An initial list of 33 ER measures went through an extensive screening process with the interagency team. ER measures were removed from further consideration if the measures:

- Were anticipated to be studied or constructed under another authority or program;
- Did not meet the goals or objectives of the study; or
- Did not meet screening criteria independent of other measures.

A final list of nine measures was carried forward for further analysis and they include:

1. G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration
    - Restoration of Gulf shorelines from High Island to the Galveston East Jetty and restoration of island shorelines west of the Galveston seawall.
2. G-28 – Bolivar Peninsula and West Bay Gulf Intracoastal Waterway (GIWW) Shoreline and Island Protection
    - Shoreline protection and restoration through the nourishment of eroding and degrading marshes and construction of breakwaters along unprotected segments of the GIWW on Bolivar Peninsula and along the north shore of West Bay,
    - Out-year marsh nourishment in areas that are expected to convert to open water or unconsolidated shoreline over the period of analysis due to relative sea level rise (RSLR),
    - Restoration of an island that protected the GIWW and mainland in West Bay, and
    - Addition of oyster cultch to encourage creation of oyster reef on the bayside of the restored island in West Bay.
3. B-2 – Follets Island Gulf Beach and Dune Restoration
    - Restoration of the beach and dune complex on Gulf shorelines of Follets Island in Brazoria County.
4. B-12 – West Bay and Brazoria GIWW Shoreline Protection

- Shoreline protection and restoration through the nourishment of eroding and degrading marshes and construction of breakwaters along unprotected segments of the GIWW in Brazoria County,
- Construction of rock breakwaters along western shorelines of West Bay and Cow Trap lakes,
- Addition of oyster cultch to encourage creation of oyster reef along the eastern shorelines of Oyster Lake, and
- Out-year marsh nourishment in areas that are expected to convert to open water or unconsolidated shoreline over the period of analysis due to RSLR.

5. M-8 – East Matagorda Bay Shoreline Protection
    - Shoreline protection and restoration through the nourishment of eroding and degrading marshes and construction 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 an island that protected shorelines directly in front of Big Boggy NWR,
    - Addition of oyster cultch to encourage creation of oyster reef along the bayside shorelines of the restored island, and
    - Out-year marsh nourishment in areas that are expected to convert to open water or unconsolidated shoreline over the period of analysis due to RSLR.
6. CA-5 – Keller Bay Restoration
    - Construction of rock breakwaters along the shorelines of Keller Bay in order to protect submerged aquatic vegetation (SAV),
    - Construction of oyster reef along the western shorelines of Sand Point in Lavaca Bay by installation of reef balls in nearshore waters, and
    - Out-year marsh nourishment in areas that are expected to convert to open water or unconsolidated shoreline over the period of analysis due to RSLR.
7. CA-6 – Powderhorn Shoreline Protection and Wetland Restoration
    - Shoreline protection and restoration through the nourishment of eroding and degrading marshes and construction of breakwaters along shorelines fronting portions of Indianola, the Powderhorn Lake estuary, and Texas Parks and Wildlife Department (TPWD) Powderhorn Ranch.
8. SP-1 – Redfish Bay Protection and Enhancement
    - Construction of rock breakwaters along the unprotected segments of the GIWW along the backside of Redfish Bay,
    - Restoration of Dagger, Ransom, and Stedman islands in Redfish Bay,
    - Construction of breakwaters on the bayside of the restored islands, and

- Addition of oyster cultch to encourage creation of oyster reef between the breakwaters and island complex to allow for additional protection of the Redfish Bay Complex and SAV.

9. W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration
   - Restoration of sediment transport across the Port Mansfield Channel to the Gulf shoreline north of the Port Mansfield Channel jetties; this would allow for reoccurring nourishment of the North Padre Island beach and dune complex,
   - Restoration of Mansfield Island,
   - Construction of additional rock breakwaters around Mansfield Island, and
   - Restoration of the hydrologic connection between Brazos Santiago Pass and the Port Mansfield Channel via dedicated dredging of the Port Mansfield ship channel.

ER measures are described in detail in Section 4.0 of the Draft IFR-EIS (DIFR-EIS) and include measure descriptions, project needs, and a generalized summary of the FWOP and FWP conditions.

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4.0 PROJECT LIFE AND 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;
- **TY 1 (2035):** Selected to capture 10 years of vegetative growth under the proposed with-project conditions and refers to the end of the construction and the beginning of the operation period;
- **TY 31 (2065):** 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):** Selected to capture 20 years of vegetative growth under the with-project conditions and refers to the end of the period of operation.

In HEP, the outputs generated by HEAT and/or WVA, referred to as HUs, are annualized over the period of analysis by summing all years and dividing the cumulative HUs by the number of years in the project life (2035 to 2085) (Burks-Copes and Webb, 2010). Additionally, the net change in AAHUs due to project action is calculated by finding the difference between with-project and without-project AAHUs, and the results of this calculation represent the final model output. To facilitate optimization, each ER measure was run separately in either HEAT or WVA, and the net AAHU output (annualized over 50 years) was summed to provide a comparison of net AAHUs for each ER measure and ER alternative (Section 7.0).

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5.0 MODEL SELECTION

5.1 USACE APPROVED MODELS

Nine HEP models (using the HEAT software) and one WVA model were approved by the USACE to conduct the FWOP and FWP project analyses to determine HSI values, HUs, and AAHUs for the ER and CSRM measures. The following HSI models were selected and approved for use with the HEAT software to evaluate the changes in habitat conditions across the Texas coast:

1. Red Drum (*Sciaenops ocellatus*) (Buckley, 1984)
2. Clapper Rail (*Sterna antillarum*) (Lewis and Garrison, 1983)
3. American Alligator (*Alligator mississippiensis*) (Newsom et al., 1987)
4. Spotted Seatrout (*Cynoscion nebulosus*) (Kostecki, 1984)
5. Brown Pelican (*Pelecanus occidentalis*) (Hingtgen et al., 1985)
6. Least Tern (*Sternula antillarum*) (Carreker, 1985)
7. Eastern Meadowlark (*Sturnella magna*) (Schroeder and Sousa, 1982)
8. Gulf Menhaden (*Brevoortia patronus*) (Christmas et al., 1982)
9. American Oyster (*Crassostrea virginica*) (Swannack et al., 2014)

The WVA Barrier Island Community Model was selected and approved for use to evaluate the changes in habitat conditions for the barrier island systems, specifically for ER measures pertaining to beach and dune restoration (USFWS, 2012).

5.2 HEAT MODEL SELECTION

Following further refinement during interagency workshops held in 2016 and 2017, the interagency team narrowed the selection to five HSI models from the above list and added the brown shrimp (*Farfantepenaeus aztecus*) model. Brown shrimp was ultimately selected to capture benefits to wetland and marsh habitats in place of red drum and Gulf menhaden. The brown shrimp 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. The Gulf menhaden model was screened out, because it is only applicable to “near catastrophic conditions,” and it was determined that the variables lacked sensitivity and would not demonstrate changes in habitat conditions from the proposed ER actions. Red drum was removed because the model introduced concepts that would require complex assumptions to be made that were not consistent with USACE policies for habitat restoration (pers. com., Interagency Workshop, July 11, 2017).

Eastern meadowlark was screened out, because it was determined by the USACE and the GLO that true, non-modified coastal prairie land tracts did not exist where the ER measures are proposed. Similarly, least tern was eliminated from further consideration because tidal flats, or unconsolidated shorelines, were combined with open water habitat, per the definition outlined in the National Oceanographic and Atmospheric Administration (NOAA) Coastal Change Atlas Program (C-CAP) Regional Land Cover Classification Scheme manual (NOAA, 2017a).

The final list of HSI models represents those species that were presumed to be the most responsive to the proposed ER actions due to the sensitivity of the variables and the life history requisites. The final list of HSI models includes American alligator, American oyster, brown pelican, brown shrimp, and spotted seatrout.

Detailed methodologies regarding cover types, cover type mapping, and assumptions made for the applications of the HSI models are presented in Section 6.0. The following reasons support the final selection of each HSI model for use in the HEAT software.

- **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.

These HSI models were applied to the following ER measures' project footprints:

- G-28 – Bolivar Peninsula and West Galveston Bay GIWW Shoreline and Island Protection
- B-12 – West Bay and Brazoria GIWW Shoreline Protection
- M-8 – East Matagorda Bay Shoreline Protection
- CA-5 – Keller Bay Restoration

- CA-6 – Powderhorn Shoreline Protection and Wetland Restoration
- SP-1 – Redfish Bay Protection and Enhancement
- W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration

5.3 WVA MODEL SELECTION

The WVA methodology relies on the use of the Coastal Marsh Community Models, which were developed by the Coastal Wetlands Planning, Protection, and Restoration Act Environmental Work Group to determine the suitability of marsh and open water habitats in the Louisiana coastal zone. The WVA was developed for application to several habitat types along the Louisiana coast, and community models were developed for fresh marsh, intermediate marsh, brackish marsh, saline marsh, swamp, barrier island, and barrier headlands (USFWS, 2012).

The Barrier Island Community Model within the WVA was certified for use for the entire Texas coast and was used to characterize benefits to the barrier island systems from the proposed beach and dune restoration measures for the Coastal Texas Study (USFWS, 2012). The WVA model was applied to the following ER measures at the project footprint scale:

- G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration
- B-2 – Follets Island Gulf and Beach Dune Restoration
- W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration

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6.0 MAPPING THE APPLICABLE COVER TYPES AND IDENTIFYING DATA

To develop plans for a community or region, it is necessary to predict short- and long-term future conditions of the environment evaluated and compare those conditions to the existing environment.

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 HEAT and WVA. 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 HEAT and WVA analyses would be acquired through readily available data or applications in GIS.

6.1 COVER TYPE MAPPING FOR HEAT ANALYSIS

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 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 (2013, 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 in Section 4.1.1 of Chapter 4 of the DIFR-EIS, 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 ER measures that occur within that region are described below:

- **Upper Coast (Region 1)**: Sabine Lake to East Matagorda Bay, including Galveston Bay (NOAA Tide Gauge Station 8771450, Galveston Pier 21, Texas)
  - G-28
  - B-12
  - M-8
- **Mid to Upper Coast (Region 2):** Matagorda Bay (NOAA Tide Gauge Station 8774770, Rockport, Texas)
  - CA-5
  - CA-6
- **Mid Coast (Region 3):** San Antonio Bay to Corpus Christi Bay (NOAA Tide Gauge Station 8774770, Rockport, Texas)
  - SP-1
- **Lower Coast (Region 4):** Lower Laguna Madre (NOAA Tide Gauge Station 8779770, Port Isabel, Texas)
  - W-3

The USACE computed future rates of RSLC were predicted for the years 2017 to 2085 for each of the four regions (USACE, 2017). Table 1 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 1
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 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).

Each HSI model was associated with a cover type to evaluate the project-related benefits on ecosystem resources within the project footprints of the ER measures (Table 2). The following describes which cover type was applied to which HSI model:

- Brown shrimp – estuarine wetland and marsh
- American alligator – palustrine wetland and marsh (non-tidal)
- Spotted seatrout – SAV
- Brown pelican – bird rookery islands
- American Oyster – oyster reefs

American alligator will be used in the analysis of the CSRM measures only, and the results will be incorporated into this report for the FIFR-EIS once model evaluations are complete.

Table 2
HSI Model Evaluations per ER Measure

HSI Model	G-28	B-12	M-8	CA-5	CA-6	SP-1	W-3
Brown Shrimp	X	X	X	X	X		
Spotted Seatrout				X		X	X
Brown Pelican	X		X			X	X
American Oyster	X	X	X	X		X	

6.2 HEAT MODEL ASSUMPTIONS AND METHODOLOGIES

Direct benefits from the proposed initial construction and out-year marsh nourishment features were considered under each ER measure for evaluations in HEAT. For the purposes of this study, direct benefits are those that would result from shoreline protection and restoration through the nourishment of eroding and degrading marshes, construction of living shorelines (i.e., revetments/breakwaters), nourishment of identified out-year marsh areas, restoration of bird rookery islands, or creation of oyster reef habitat. Footprints containing all areas directly and indirectly benefitting from the proposed ER 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.

To facilitate the analysis of benefits attributed to the ER measures, two scales were applied to model wetland and marsh acreages. Scale 1 consists of the initial construction features completed in 2035, which include marsh restoration, island restoration/creation, oyster reef restoration/creation, SAV protection/creation, and shoreline stabilization via revetments/breakwaters. Scale 2 represents the combination of the initial construction and out-year marsh nourishment features. The out-year marsh nourishment features were implemented to mitigate against future SLR and to create a more-resilient ER measure that would be sustainable through the end of the project life. Scales 1 and 2 were evaluated in HEAT, and the outputs were compared on a unit-by-unit basis.

The methodology to determine existing, FWOP, and FWP conditions, as described below, applies to all ER measures assessed with specific HSI models. Habitat variables (V) for each HSI model are also discussed. Detailed methodologies and assumptions that describe how each variable within each HSI model was determined per ER measure scale are available upon request. Additionally, results for the FWOP and FWP project analyses, including HSI values, HUs, and AAHUs for each ER measure, are available upon request.

6.2.1 Brown Shrimp Modeling – Procedures and Assumptions

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. The data were then input into HEAT to generate HSI, HU, and AAHU outputs.

6.2.1.1 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 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. Under the Scale 1 scenario, it is assumed that construction will end in 2035 and that all wetlands within the initial construction footprint are restored. Marsh areas immediately adjacent to the GIWW are assumed to be maintained with maintenance dredging material from the GIWW or other adjacent navigation channels through 2085. Under the Scale 2 scenario, the out-year marsh nourishments represent areas that were identified by the NOAA SLR viewer as becoming unconsolidated shoreline or open water by 2065. It is assumed that these areas are fully restored in 2065 and are maintained through 2085.

6.2.1.2 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 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.

6.2.1.3 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 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.

6.2.1.4 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 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.

6.2.2 American Oyster Modeling – Procedures and Assumptions

Oyster reef acreages were based on a classification conducted using the TPWD oyster locations data to evaluate benefits to oyster from the proposed ER 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. The data were then input into HEAT to generate HSI, HU, and AAHU outputs.

6.2.2.1 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 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.

6.2.2.2 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 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.

6.2.2.3 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 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.

6.2.2.4 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 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.

6.2.3 Brown Pelican Modeling – Procedures and Assumptions

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. For the Coastal Texas Study, habitat suitability for brown pelicans was evaluated for the following areas:

- Islands south of the GIWW in West Galveston Bay as part of the G-28 ER measure,
- Islands south of the shoreline directly in front of Big Boggy NWR as part of the M-8 ER measure,
- Dagger, Ransom, and Stedman islands within the Redfish Bay Complex, and
- Mansfield Island in the Lower Laguna Madre as part of the W-3 ER measure.

6.2.3.1 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 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. Attachment A describes the proposed engineering specifications for each bird rookery island.

6.2.3.2 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 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.

6.2.3.3 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 navigation 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 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.

6.2.3.4 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 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.

6.2.4 Spotted Seatrout Modeling – Procedures and Assumptions

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).

6.2.4.1 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 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.

6.2.4.2 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 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.

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

6.2.4.4 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.

6.2.4.5 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.

6.3 WVA MODEL ASSUMPTIONS AND METHODOLOGIES

The Coastal Texas Study applied the WVA Barrier Island Community model to calculate benefits from the proposed beach and dune restoration actions along the Gulf shorelines of Bolivar Peninsula, Galveston Island, Follets Island, and North Padre Island.

The WVA Barrier Island Community model contains a set of variables that are important in characterizing habitat qualities and quantities of coastal ecosystems relative to fish and wildlife communities, which are dependent on those environments. In general, those variables include dune habitat, intertidal habitat, supratidal habitat, percentage of vegetative cover, percentage of woody species, interspersion, and beach/surf zone (USFWS, 2012).

One of the first steps in preparing a WVA for a barrier island restoration project is to determine the total project area size and the acreage of each of the habitat components (e.g., dune, supratidal, and intertidal). For the Coastal Texas Study, the model was applied at the project footprint scale, and elevation (best available LiDAR data) and habitat data (NOAA C-CAP 2010 land cover dataset) were used to characterize the habitat variables within each project footprint.

The Bureau of Economic Geology (BEG) Texas Shoreline Change Project data were used to incorporate the erosion rates for each barrier island system and were applied to the FWOP and FWP scenarios to illustrate the migration of habitats through the 50-year period of analysis (BEG, 2017). The project footprint boundaries were determined using BEG shoreline retreat data for the period of analysis and the beach profiles developed by the USACE.

The variables included in the WVA Barrier Island Community Model are described below, as well as the methodology that was used to determine each value. The specific data for each variable, including acreages, and the model results are available upon request. Additionally, results for the FWOP and FWP project analyses, including HSI values, HUs, and AAHUs for each ER measure are available upon request.

6.3.1 Dune Habitat

Dune habitats are dynamic ecological systems located along coastal shorelines, which play a significant role in protecting human and non-human environments, by acting as resilient barriers to high-energy storms and the destructive forces of wind and waves. For the purposes of the WVA model, dune habitat includes foredune, dune, and reardune, and was delineated as subaerial habitat that was greater than or equal to 5 feet in elevation (NAVD88).

Existing Conditions. Baseline conditions were determined using NOAA LiDAR elevation data for each of the beach and dune restoration measures at a project-footprint scale. The NOAA C-CAP 2010 land cover dataset was used to determine developed/upland areas within the project footprint that were assumed to remain constant through the period of analysis. Additionally, open water was developed from the NOAA SLR dataset at 0 foot in elevation and was used to override habitat classifications that were generated purely from elevation data or developed data for future scenarios.

FWOP Conditions. It is assumed that with no action, all dune habitat would be lost through the end of the period of analysis due to anthropogenic development along coastal shorelines, erosional processes, and SLR.

FWP Conditions. It is assumed that by 2035 (end of construction), the dune and beach profile seaward of the mean high tide line would be reconstructed with fill obtained from offshore sources. The assumptions developed for the dune and beach profiles include a total footprint width of 295 feet, with 50-foot width for the dune field, 175-foot width for the beach berm (supratidal habitat), and a 70-foot width for the front slope (intertidal habitat). During WVA modeling of FWP conditions, it was observed that there are locations where the NOAA SLR models show open water forming behind the proposed beach and dune profile. In these instances, it was assumed that these areas do not transition into open water due to the presence of the created beach and dune profile (and resulting sedimentation from aeolian processes). These areas are expected to be naturally maintained and transition to interdunal swales with elevations between 0 and 2 feet above mean sea level once the beach and dune profile is constructed.

6.3.2 Supratidal Habitat

Supratidal habitat is often the favored habitat for foraging by a diverse community of wading birds, including piping plover (*Charadrius melodus*), a threatened species that winters along the Gulf coast (USFWS, 2012). Supratidal habitat includes swale and low-elevation dune and beach habitat and was delineated as the subaerial habitat that was 2.0 to 4.9 feet in elevation (NAVD88).

Existing Conditions. Baseline conditions were determined using NOAA LiDAR elevation data for each of the beach and dune restoration measures at a project-footprint scale. The same assumptions were applied for supratidal habitat that were applied for dune habitat.

FWOP Conditions. It is assumed that with no action, all supratidal habitat would be lost through the end of the period of analysis due to anthropogenic development along coastal shorelines, erosional processes, and SLR.

FWP Conditions. The same assumptions were applied for supratidal habitat that were applied for dune habitat, where a 175-foot-wide beach berm would be constructed to function as supratidal habitat as part of the overall restored beach profile.

6.3.3 Intertidal Habitat

Intertidal habitat adjacent to barrier island systems is important in providing foraging habitat for shorebirds of many species and harboring several species of wading birds. In Texas, intertidal habitat is known to attract 38 different species of foraging shorebirds, including Forster’s terns (*Sterna forsteri*) and laughing gulls (*Leucophaeus atricilla*) (USFWS, 2012; Withers, 2002). Additionally, certain fish and invertebrate species, including Gulf menhaden, brown shrimp, and blue crabs (*Callinectes sapidus*), use the intertidal zone as nursey habitat to avoid predation and for food resources (Minello and Rozas, 2001; Modde and Ross 1981).

For the purposes of this model, intertidal habitat includes intertidal marsh, mudflats, beach, and any other habitats within the elevation range of 0.0 to 1.9 feet (NAVD88) on either the Gulf or the bay side of the barrier island.

Existing Conditions. Baseline conditions were determined using NOAA LiDAR elevation data for each of the beach and dune restoration measures at a project-footprint scale. The same assumptions were applied for intertidal habitat that were applied for dune habitat.

FWOP Conditions. It is assumed that with no action, all intertidal habitat would be lost through the end of the period of analysis due to anthropogenic development along coastal shorelines, erosional processes, and SLR.

FWP Conditions. The same assumptions were applied for intertidal habitat that were applied for dune habitat, where a 70-foot-wide front slope would function as intertidal habitat as part of the overall restored beach profile.

6.3.4 Percentage Vegetative Cover

The percentage of vegetative cover of dune, supratidal, and intertidal habitats is intended to capture the significance of quality nesting and foraging habitat for fish and wildlife species that depend on these environments. It was assumed that vegetative cover between 65 and 85 percent of the total subaerial habitat area was representative of an optimal HSI of 1.0 (USFWS, 2012).

Existing Conditions. Percentage of vegetative cover was determined by the Environmental Systems Research Institute (ESRI) unsupervised classification analysis in ArcGIS 10.4.1 using Landsat 8 satellite imagery to derive existing, or baseline, conditions within each project area.

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 vegetative cover for the project areas.

FWP 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 vegetative cover for the project areas.

6.3.5 Percentage of Woody Species

The woody habitat component is intended to capture the functions of nesting habitat for certain species and stopover habitat for neotropical migratory birds on the barrier island systems. This variable is defined as the percent of subaerial vegetated area that consists of at least two or more woody species, such as black mangrove (*Avicennia germinans*), eastern baccharis (*Baccharis halimifolia*), wave myrtle (*Myrica cerifera*), and marsh elder (*Iva frutescens*) (USFWS, 2012). Cover by woody species should be a relatively small percentage of the total vegetative cover on a barrier island, with optimal habitat suitability ranging from 10 to 20 percent (HSI = 1.0) (USFWS, 2012).

Existing Conditions. Woody vegetation was determined by the ESRI unsupervised classification analysis in ArcGIS 10.4.1 using Landsat 8 satellite imagery to derive existing, or baseline, conditions within each project area.

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 woody habitat for the project areas.

FWP 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 woody habitat for the project areas.

6.3.6 Interspersion

Edge and interspersion are intended to capture the relative juxtaposition of intertidal, subaerial habitat (vegetated and unvegetated), and aquatic habitats such as ponds, lagoons, and tidal creeks associated with barrier island systems. Sample illustrations of varying degrees of interspersion are provided in the WVA model and were evaluated to determine which scenario most appropriately fit each project area. For each ER measure, Class 1 was designated as the appropriate classification and was held constant through the period of analysis for FWOP and FWP conditions. Class 1 is representative of unvegetated flats and healthy back-barrier marsh with a high degree of tidal creeks, tidal channels, ponds, and/or lagoons and is assumed to have optimal habitat suitability (USFWS, 2012).

Existing Conditions. Existing conditions were determined by examining recent aerial photography of the project areas and comparing each area to the interspersion classes illustrated in the WVA model. Class 1 was the classification used in the analyses to represent the degree of interspersion within the project areas.

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 classes of interspersion for the project areas within the period of analysis.

FWP 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 classes of interspersion for the project areas.

6.3.7 Beach/Surf Zone

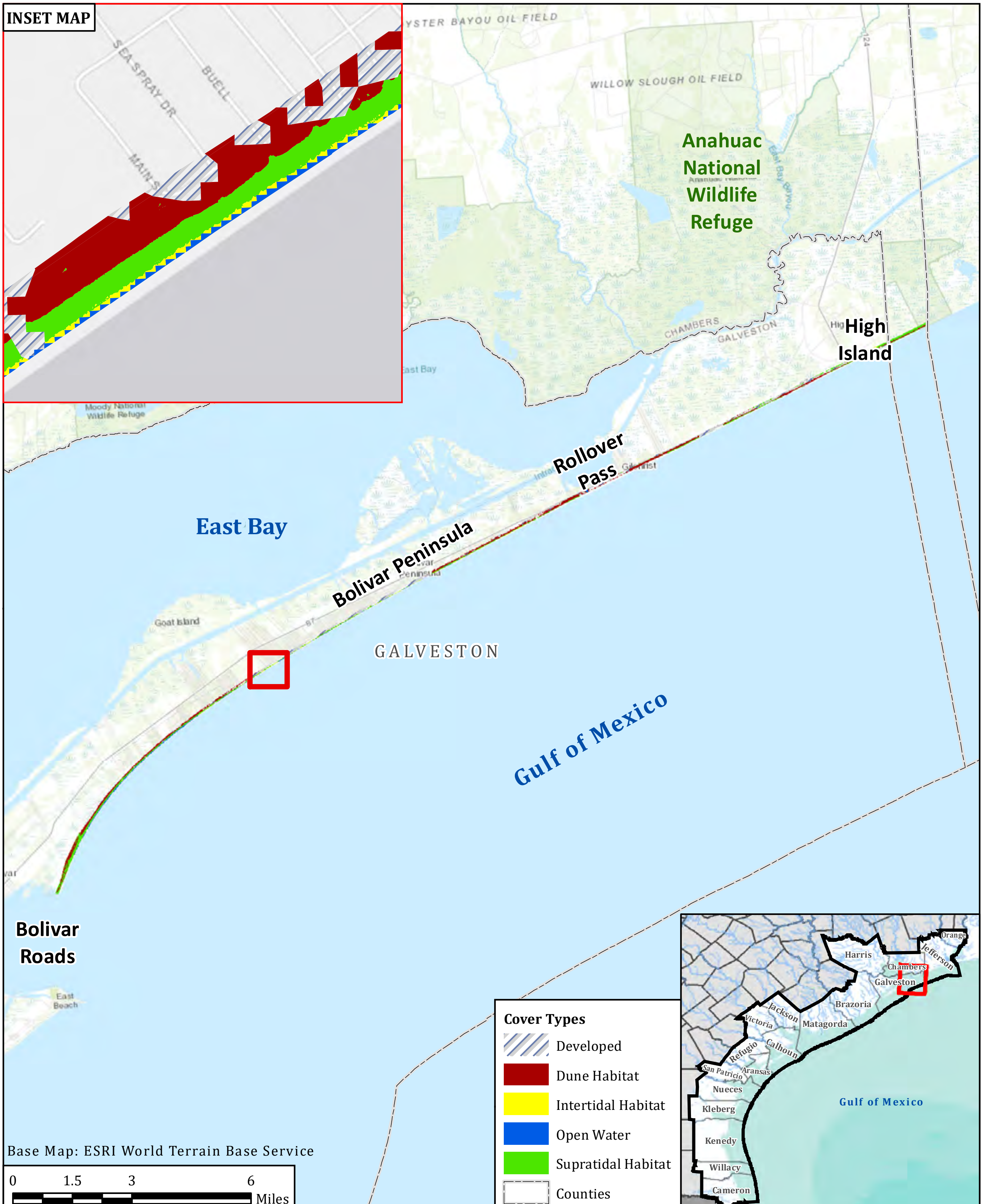
This variable is intended to capture the habitat value of the beach/surf zone. It is assumed that a natural beach/surf zone slope or profile denotes an optimal HSI of 1.0. Manufactured features such as breakwaters, revetments, containment dikes, and other shoreline protection structures provide suboptimal conditions. For each ER measure, Class 1 was designated as the appropriate classification and was held constant through the period of analysis for FWOP and FWP conditions. Class 1 is representative of a natural beach with unconfined disposal and is assumed to have optimal habitat suitability (USFWS, 2012).

Existing Conditions. Existing conditions were determined by examining recent aerial photography of the project areas. Class 1, natural beach/unconfined disposal, was the classification used in the analyses to represent the beach/surf zone within the project areas.

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 profiles for the project areas.

FWP 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 profiles for the project areas.

The baseline cover type maps for each ER measure were mapped using GIS and are provided in figures 1 through 9 below. The FWOP and FWP cover type maps for the 50-year period of analysis are available upon request.



USACE COASTAL TEXAS PROTECTION AND RESTORATION STUDY

G-5 - Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration Baseline Cover Types

FN JOB NO	TGL18185
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DATE	5/16/2018
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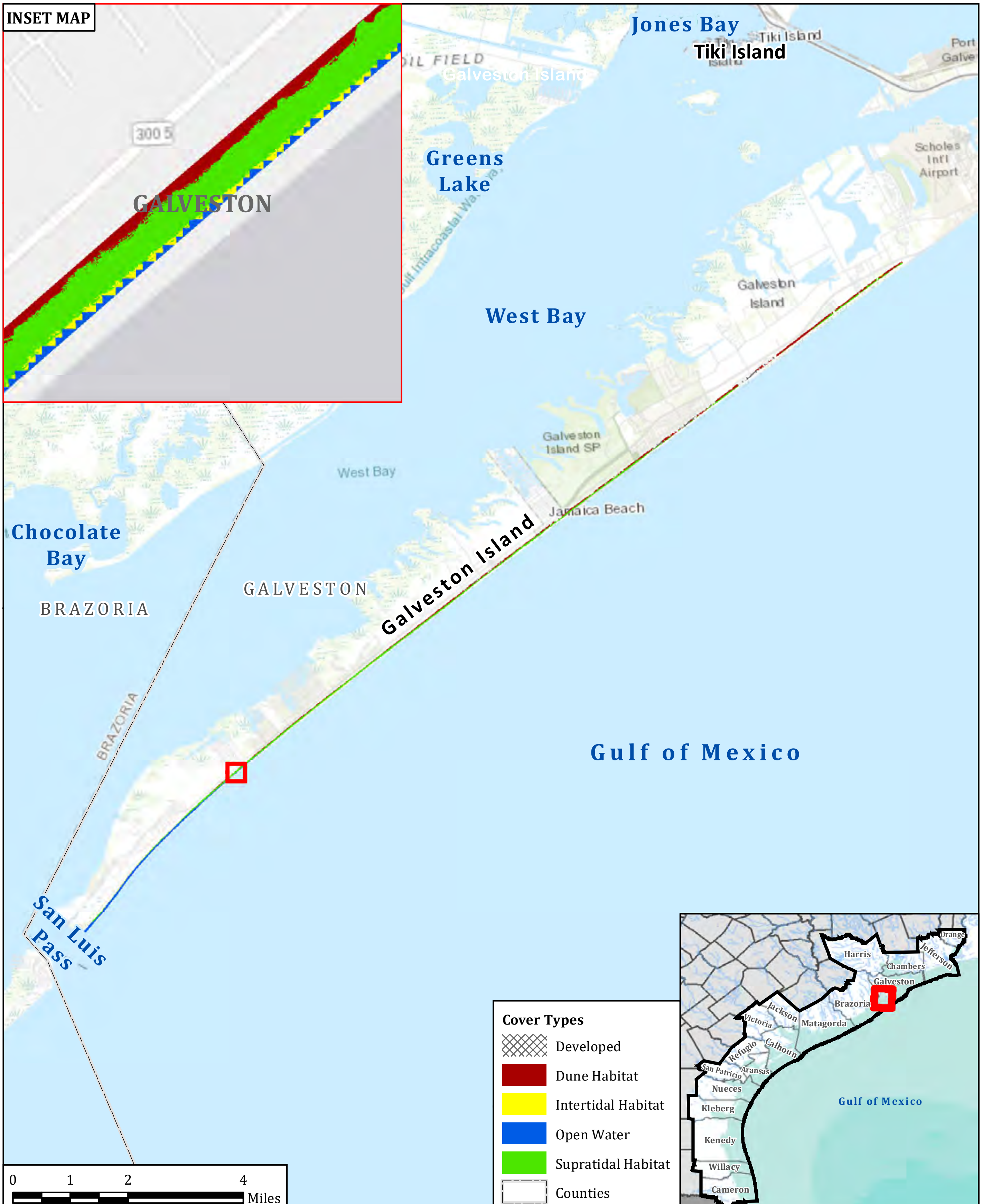
DESIGNED	KLC
DRAFTED	SSJ

FIGURE 1a

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

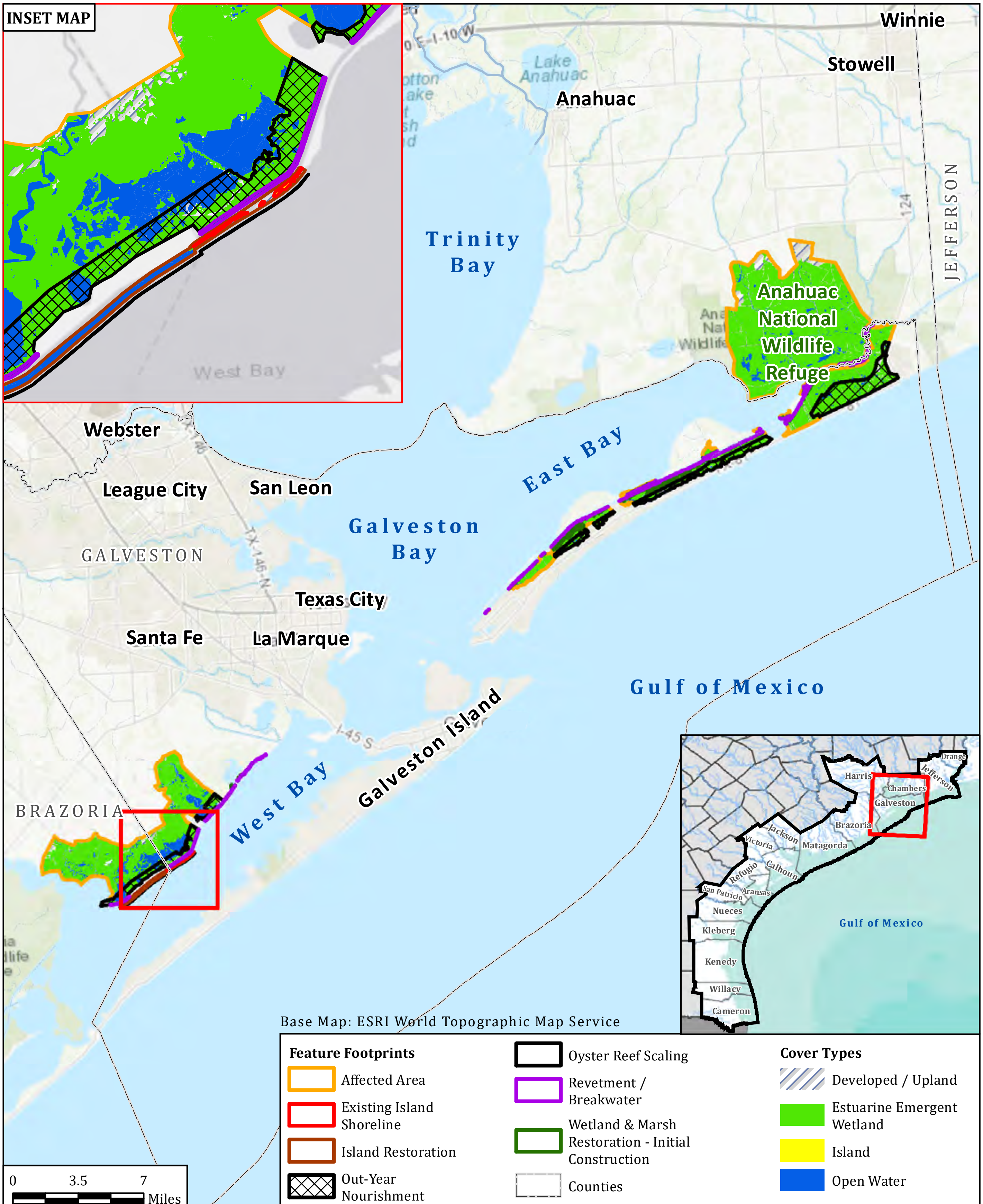
G-5 - Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration Baseline Cover Types

FN JOB NO	TGL18185
FILE NAME	1b_G5_Galveston.mxd
DATE	5/16/2018
SCALE	1:146,000
DESIGNED	KLC
DRAFTED	SSJ

1b

FIGURE

GCS North American 1927



USACE COASTAL TEXAS PROTECTION AND RESTORATION STUDY

G-28 - Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection Baseline Cover Types

FN JOB NO	TGL18185
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DATE	5/17/2018
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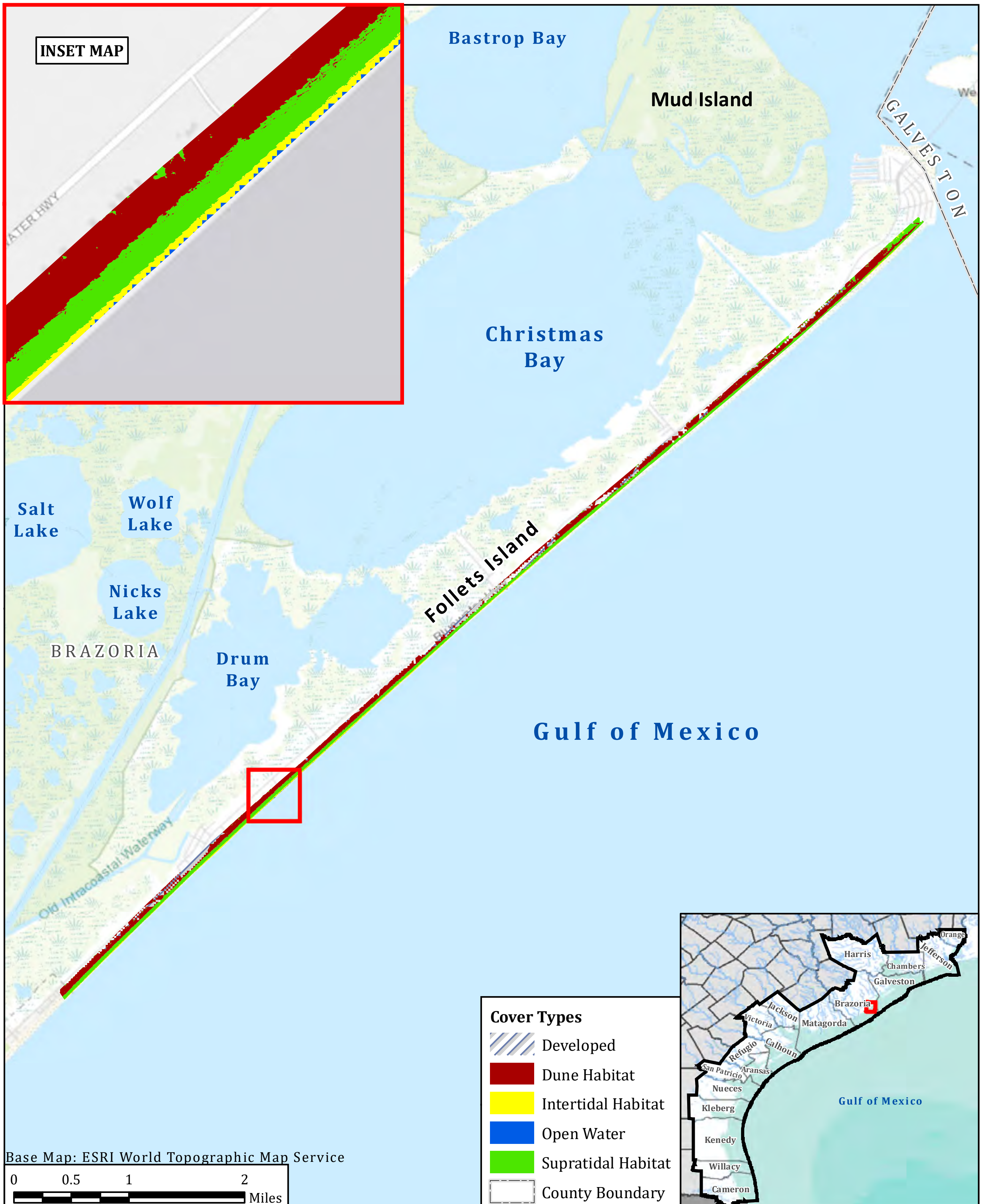
DESIGNED	KLC
DRAFTED	SSJ

2

FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



N W E S

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

B-2 - Follets Island Gulf Beach and Dune Restoration
Baseline Cover Types

FN JOB NO	TGL18185
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DATE	5/17/2018
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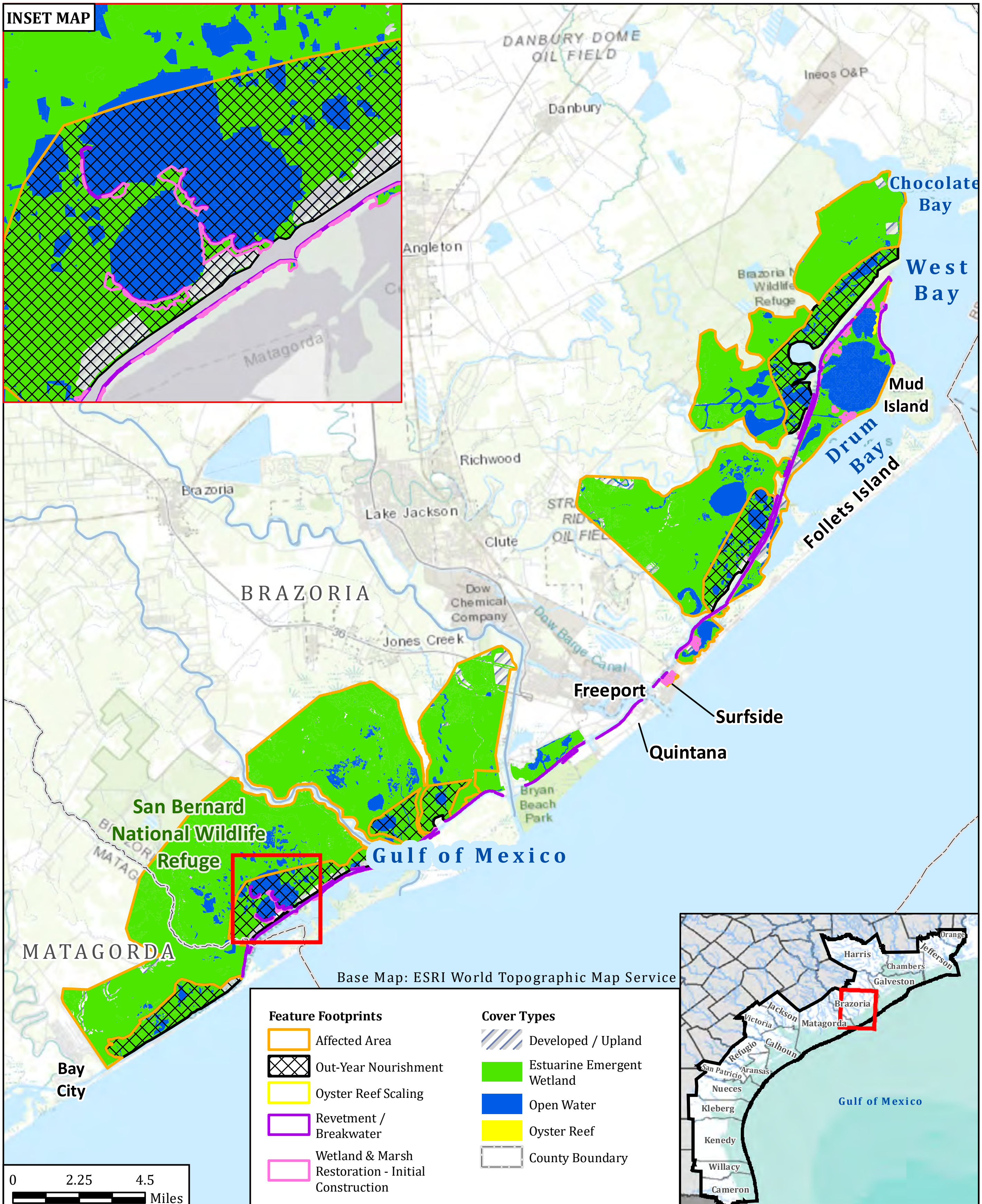
DESIGNED	KLC
DRAFTED	SSJ

3
FIGURE



N
W E
S

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

B-12 - West Bay and Brazoria GIWW Shoreline Protection Baseline Cover Types

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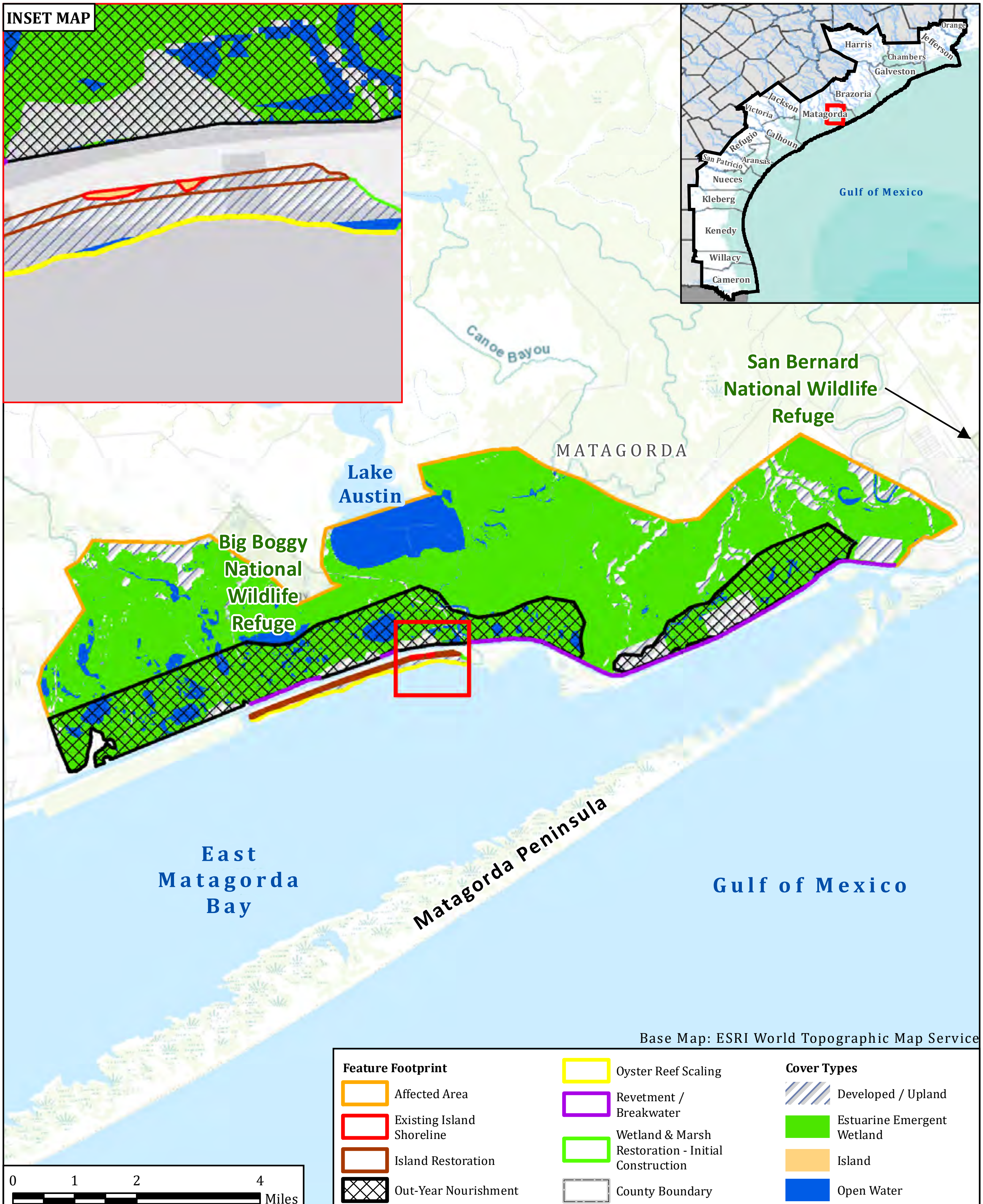
FILE NAME	4_B12.mxd
DATE	5/21/2018
SCALE	
DESIGNED	KLC
DRAFTED	SSJ

4
FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

M-8 - East Matagorda Bay Shoreline Protection
Baseline Cover Types

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DATE	5/17/2018
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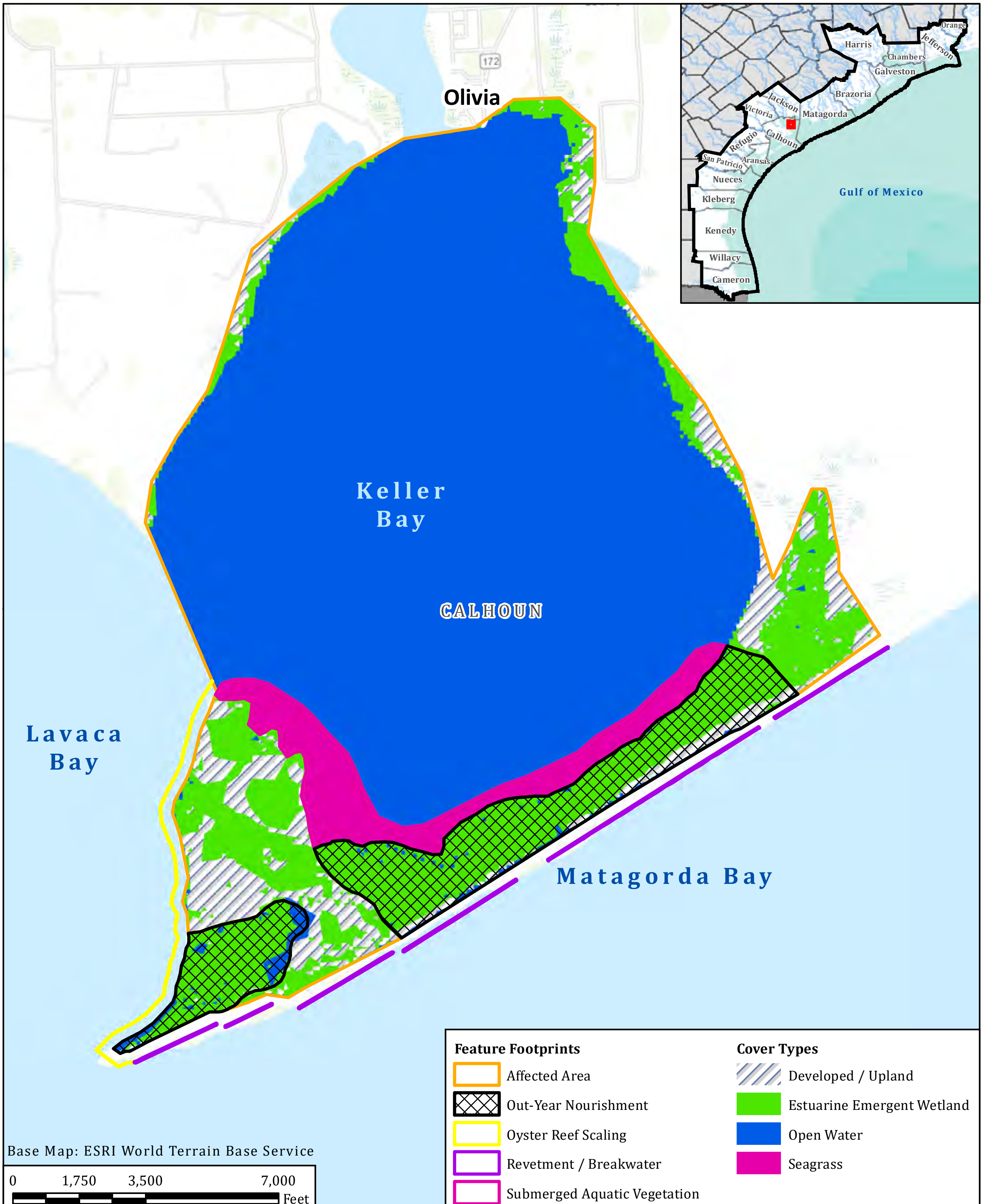
DESIGNED	KLC
DRAFTED	SSJ

5
FIGURE

GCS North American 1927



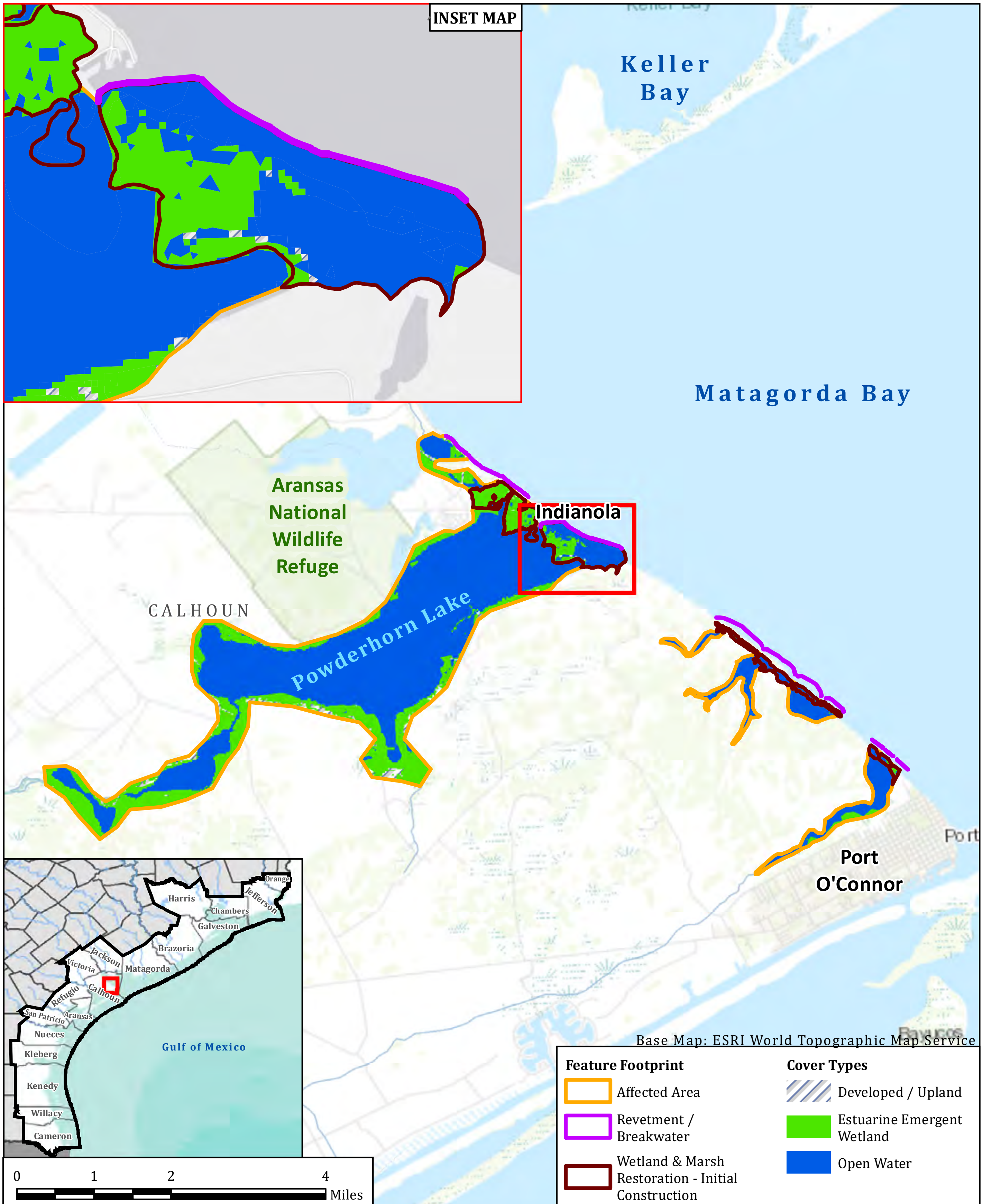
USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

CA-5 - Keller Bay Restoration
Baseline Cover Types

FN JOB NO	TGL18185
FILE NAME	6_CA5.mxd
DATE	5/16/2018
SCALE	1:42,000
DESIGNED	KLC
DRAFTED	SSJ

6
FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



N W E S

USACE COASTAL TEXAS PROTECTION AND RESTORATION STUDY

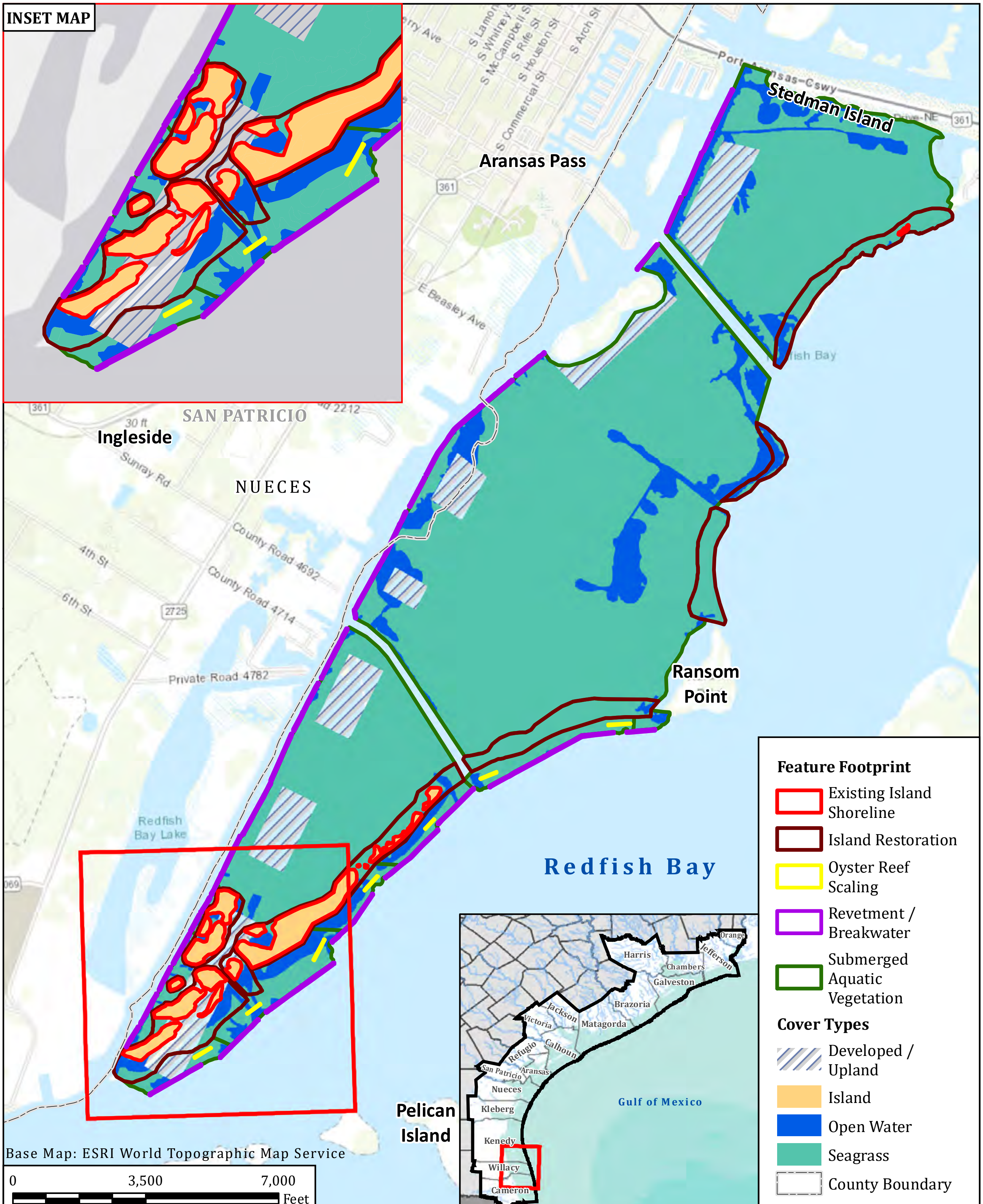
CA-6 - Powderhorn Shoreline Protection and Wetland Restoration Baseline Cover Types

FN JOB NO	TGL18185
FILE NAME	7_CA6.mxd
DATE	5/17/2018
SCALE	1:24,000
DESIGNED	KLC
DRAFTED	SSJ

7

FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



N W E S

USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

SP-1 - Redfish Bay Protection and Enhancement
Baseline Cover Types

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FILE NAME	8_SP1.mxd
DATE	5/21/2018
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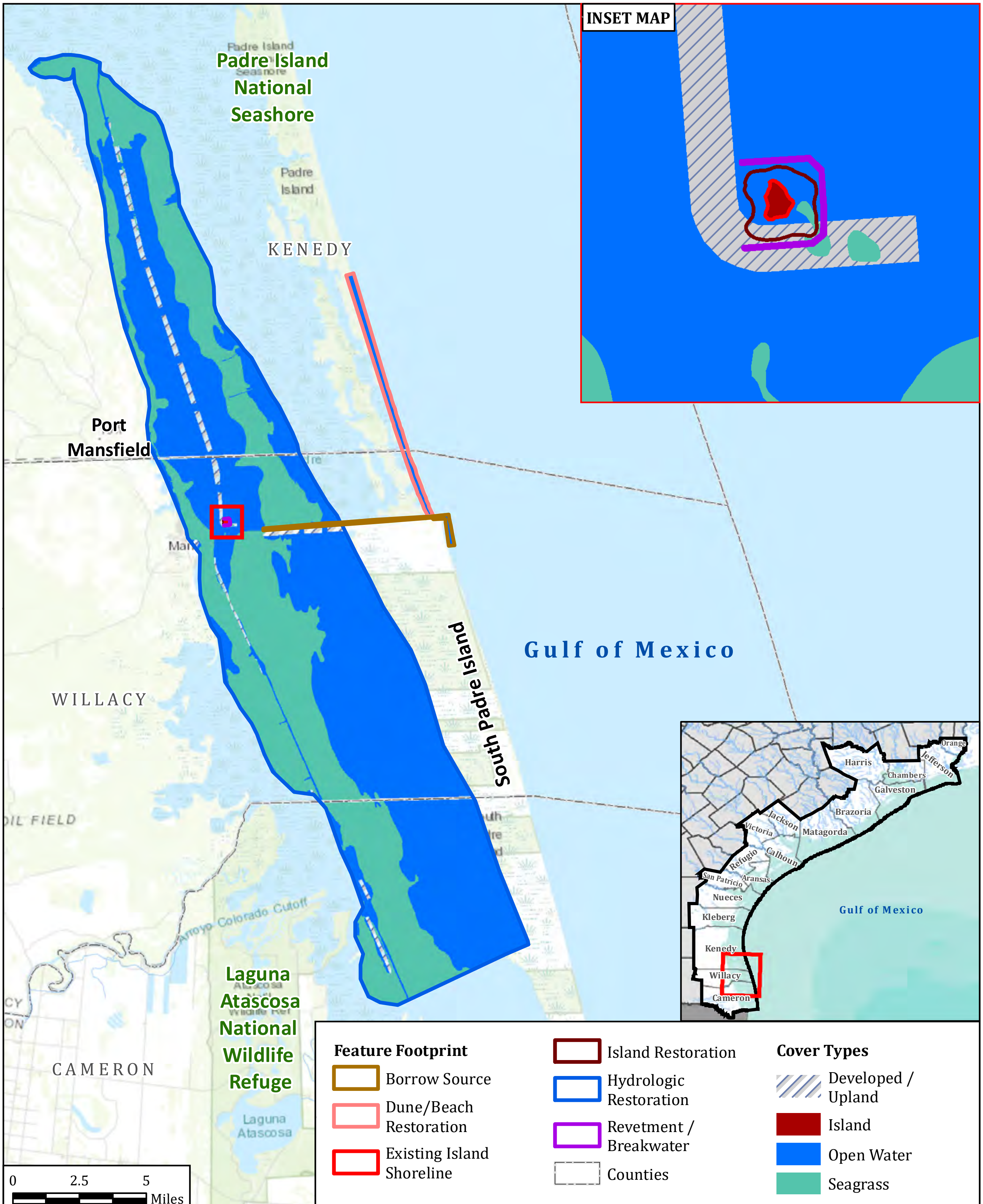
DRAFTED	SSJ

8
FIGURE

NAD 1983 StatePlane Texas Central FIPS 4203 Feet



USACE COASTAL TEXAS PROTECTION AND RESTORATION STUDY

W-3 - Port Mansfield Channel, Island Rookery, and Hydrologic Restoration Baseline Cover Types

FN JOB NO	TGL18185
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DATE	5/21/2018
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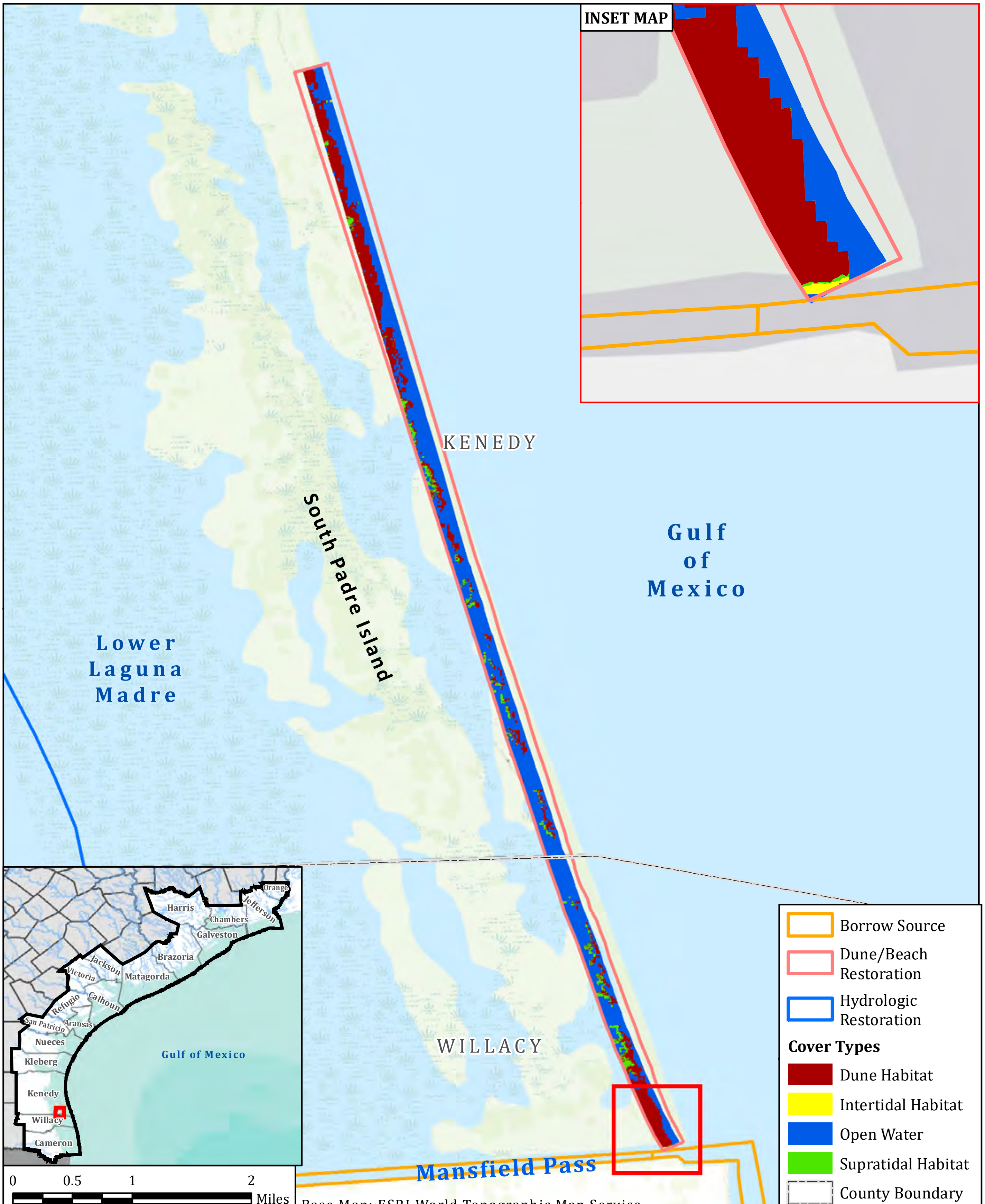
9

FIGURE



USACE COASTAL TEXAS
PROTECTION AND RESTORATION STUDY

W-3 - Port Mansfield Channel, Island Rookery, and Hydrologic Restoration Baseline Cover Types

FN JOB NO	TGL18185
FILE NAME	10_W3_WVA.mxd
DATE	5/17/2018
SCALE	1:70,416
DESIGNED	KLC
DRAFTED	SSJ

10

FIGURE

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7.0 REPORTING THE RESULTS

The screening process discussed in Section 3.0 identified an initial focused array of ER measures, which then underwent a second-level alternative screening process to formulate National Ecosystem Restoration alternative plans. The process of how the ER alternatives were formulated is described in detail in Section 4.1 of the DIFR-EIS. A final list of six ER alternatives was carried forward for further analysis, and these ER alternatives are described below.

Following completion of the HEP/WVA modeling for the ER measures, the net AAHU outputs were combined per ER alternative and were used to determine ecosystem restoration and mitigation requirements based on projected changes in habitat (i.e., Cost Effectiveness/Incremental Cost Analysis [CE/ICA] through Institute for Water Resources Planning Suite software) (see Section 4.3 of the DIFR-DEIS for more information on the CE/ICA process). Tables 3 through 8 present the combined net AAHU outputs and acres for all HSI and/or WVA models within each ER measure per ER alternative. Table 9 shows the final FWP Scale 1 and FWP Scale 2 totals, which were run through CE/ICA to evaluate the relationship between the cost and the environmental output (measured as AAHUs) associated with each alternative scale.

Table 3
ER Alternative 1 – Coastwide All-Inclusive Restoration
Alternative Net AAHU Outputs

ER Measure Description	Net AAHUs	Acres
G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration	1,820	3,395
G-28 – Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection		
Scale 1	1,083	1,148
Scale 2	9,213	31,088
B-2 – Follets Island Gulf Beach and Dune Restoration	391	850
B-12 – West Bay and Brazoria GIWW Shoreline Protection		
Scale 1	1,261	1,992
Scale 2	17,231	52,442
M-8 – East Matagorda Bay Shoreline Protection		
Scale 1	219	2,524
Scale 2	6,299	18,424
CA-5 – Keller Bay Restoration		
Scale 1	220	1,179
Scale 2	330	1,969
CA-6 – Powderhorn Shoreline Protection and Wetland Restoration	20	620
SP-1 – Redfish Bay Protection and Enhancement	3,501	3,679
W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration	30,535	47,812
FWP Scale 1 Total	39,050	63,199
FWP Scale 2 Total	69,340	160,279

Table 4
Alternative 2 – Coastwide Restoration of Critical Geomorphic or Landscape Features Alternatives Net AAHU Outputs

ER Measure Description	Net AAHUs	Acres
G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration	1,820	3,395
B-2 – Follets Island Gulf Beach and Dune Restoration	391	850
B-12 – West Bay and Brazoria GIWW Shoreline Protection		
Scale 1	1,261	1,992
Scale 2	17,231	52,442
CA-6 – Powderhorn Shoreline Protection and Wetland Restoration	20	620
W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration	30,535	47,812
FWP Scale 1 Total	34,028	54,669
FWP Scale 2 Total	49,998	105,119

Table 5
Alternative 3 – Coastwide Barrier System Restoration Alternative Net AAHU Outputs

ER Measure Description	Net AAHUs	Acres
G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration	1,820	3,395
G-28 – Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection		
Scale 1	1,083	1,148
Scale 2	9,213	31,088
B-2 – Follets Island Gulf Beach and Dune Restoration	391	850
W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration	30,535	47,812
FWP Scale 1 Total	33,829	53,205
FWP Scale 2 Total	41,959	83,145

Table 6
Alternative 4 – Coastwide Bay System Restoration
Alternative Net AAHU Outputs

ER Measure Description	Net AAHUs	Acres
G-28 – Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection		
Scale 1	1,083	1,148
Scale 2	9,213	31,088
B-12 – West Bay and Brazoria GIWW Shoreline Protection		
Scale 1	1,261	1,992
Scale 2	17,231	52,442
M-8 – East Matagorda Bay Shoreline Protection		
Scale 1	219	2,524
Scale 2	6,299	18,424
CA-5 – Keller Bay Restoration		
Scale 1	220	1,179
Scale 2	330	1,969
CA-6 – Powderhorn Shoreline Protection and Wetland Restoration	20	620
SP-1 – Redfish Bay Protection and Enhancement	3,501	3,679
FWP Scale 1 Total	6,304	11,142
FWP Scale 2 Total	36,594	108,222

Table 7
Alternative 5 – Coastwide ER Contributing to Infrastructure
Risk Reduction Alternative Net AAHU Outputs

ER Measure Description	Net AAHUs	Acres
G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration	1,820	3,395
G-28 – Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection		
Scale 1	1,083	1,148
Scale 2	9,213	31,088
B-2 – Follets Island Gulf Beach and Dune Restoration	391	850
B-12 – West Bay and Brazoria GIWW Shoreline Protection		
Scale 1	1,261	1,992
Scale 2	17,231	52,442
FWP Scale 1 Total	4,555	7,385
FWP Scale 2 Total	28,655	87,775

Table 8
Alternative 6 – Top Performers Net AAHU Outputs

ER Measure Description	Net AAHUs	Acres
G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration	1,820	3,395
G-28 – Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection		
Scale 1	1,083	1,148
Scale 2	9,213	31,088
B-2 – Follets Island Gulf Beach and Dune Restoration	391	850
B-12 – West Bay and Brazoria GIWW Shoreline Protection		
Scale 1	1,261	1,992
Scale 2	17,231	52,442
CA-6 – Powderhorn Shoreline Protection and Wetland Restoration	20	620
FWP Scale 1 Total	4,575	8,005
FWP Scale 2 Total	28,675	88,395

Table 9
ER Alternatives
FWP Scale 1 and FWP Scale 2 Net AAHU Outputs

ER Alternative	Net AAHUs	Acres
Alternative 1 (9 measures)		
FWP Scale 1	39,050	63,199
FWP Scale 2	69,340	160,279
Alternative 2 (5 measures)		
FWP Scale 1	34,028	54,669
FWP Scale 2	49,998	105,119
Alternative 3 (4 measures)		
FWP Scale 1	33,829	53,205
FWP Scale 2	41,959	83,145
Alternative 4 (6 measures)		
FWP Scale 1	6,304	11,142
FWP Scale 2	36,594	108,222
Alternative 5 (4 measures)		
FWP Scale 1	4,555	7,385
FWP Scale 2	28,655	87,775
Alternative 6 (5 measures)		
FWP Scale 1	4,575	8,005
FWP Scale 2	28,675	88,395

CE/ICA compared the annual costs and environmental outputs (AAHUs) of each ER alternative under consideration to identify the most cost-effective alternative plan for each possible level of environmental output. Subsequently, an incremental cost analysis (ICA) of the cost-effective ER alternative plans was conducted to reveal changes in costs as environmental output levels increased. The ICA identified best-buy plans from the cost-effective ER alternative plans and an "is it worth it" analysis was conducted to justify the incremental cost per unit of environmental output.

The CE/ICA outputs identified the following cost-effective plans:

- Alternative 2, Scale 2
- Alternative 3, Scale 2
- Alternative 4, Scale 1

The CE/ICA outputs identified the following best-buy plans:

- No-Action
- Alternative 4, Scale 2
- Alternative 1, Scale 2

Subsequently, the ER measures were run through CE/ICA unconstrained by the strategy described in Section 4.3.3 of the DIFR-DEIS for comparison to consider possible improvements to the best-buy plans that were initially identified by the model. The unconstrained analysis generated Alternative Z as a new alternative and as a new best-buy plan that provided the most environmental output for the least incremental cost per output. Alternative Z included the following ER measures: G-28 Scale 2, B-12 Scale 2, M-8 Scale 2, CA-5 Scale 2, CA-6, SP-1, and W-3.

As a result of the similarities between Alternative Z and Alternative 4-Scale 2, the PDT reformulated Alternative 4-Scale 2 to include ER measure W-3 and renamed the alternative to "Alternative 4 Revised-Scale 2". Thus, the final array of ER alternative plans included Alternative 1-Scale 2 and Alternative 4 Revised-Scale 2. The ecological benefits associated with both alternatives are described in more detail in Section 4.3.3 of the DIFR-EIS.

Following CE/ICA, the USACE Galveston District and its non-Federal sponsor the Texas GLO have recommended Alternative 1-Scale 2 as the Tentatively Selected Plan. The measures within this alternative would restore the natural features of the Texas coast, including beach and dune complexes, oyster reefs, bird rookery islands, and wetland and marsh complexes, that all work to support a diverse array of habitats and conditions necessary for coastal resiliency and mitigation of damages caused by coastal storms and SLR.

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Attachment

ER Measure Forecasting Assumptions

Table of Contents

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List of Tables

Acronyms and Abbreviations

AAHU	Average Annual Habitat Unit
C-CAP	Coastal Change Atlas Program
CSRM	Coastal Storm Risk Management
ER	Ecosystem Restoration
IFR-EIS	Integrated Feasibility Report and Environmental Impact Statement
FWOP	future without-project
FWP	future with project
GIS	Geographic Information Systems
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
HEAT	Habitat Evaluation and Assessment Tools
HEP	Habitat Evaluation Procedures
HSI	Habitat Suitability Index
HU	Habitat Unit
NOAA	National Oceanic and Atmospheric Administration
ppt	parts per thousand
SLR	sea level rise
SAV	submerged aquatic vegetation
TPWD	Texas Parks and Wildlife Department
TY	target year
USACE	U.S. Army Corps of Engineers
WVA	Wetland Value Assessment

1.0 INTRODUCTION

The Habitat Evaluation Procedures (HEP) methodology was incorporated into the Coastal Texas Protection and Restoration Study (Coastal Texas Study) via the Habitat Evaluation and Assessment Tool (HEAT) software and the Wetland Value Assessment (WVA) Barrier Island Community Model for evaluating project benefits and impacts. The HEAT software was developed to conduct HEP and allows the user to establish habitat units (HUs), the common form of currency when assessing project impacts and benefits, and to determine Average Annual Habitat Units (AAHUs) to capture future project changes for specific project timescales. In addition to estimating project impacts and benefits, the models were used to guide and optimize mitigation design and assist in development of mitigation recommendations for the Ecosystem Restoration (ER) and Coastal Storm Risk Management (CSRM) measures.

The U.S. Army Corps of Engineers (USACE) Civil Works policy requires that only standard habitat models previously certified by the USACE Ecosystem Planning Center of Excellence be used to determine ecological benefits and/or impacts and mitigation. A final list of five HEP models (using the HEAT software) and one WVA model were approved by the USACE to conduct the future-without project (FWOP) and future-with project (FWP) analyses. Additional information regarding the model selection process is described in Section 5.0 of Appendix C-8.

The following provides an overview of the data sources, methods, and assumptions in the development of the variables within each model, as applied to the final list of ER measures (Table 1). Following the Agency Decision Milestone, HEP analyses will be conducted for proposed CSRM measures carried forward and the results will be incorporated into the HEP and WVA Modeling Report for the Final Integrated Feasibility Report and Environmental Impact Statement (IFR-EIS).

Table 1
Habitat Suitability Index (HSI) Model Evaluations by ER Measure

HSI Model	G-28	B-12	M-8	CA-5	CA-6	SP-1	W-3
Brown Shrimp	X	X	X	X	X		
Spotted Seatrout				X		X	X
Brown Pelican	X		X			X	X
American Oyster	X	X	X	X		X	

The WVA Barrier Island Community Model was used to quantify barrier island system benefits from the proposed beach and dune restoration efforts for the Coastal Texas Study. Specifically, the WVA model was applied to the following ER measures at the project footprint scale:

- G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration
- B-2 – Follet’s Island Gulf and Beach Dune Restoration
- W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration

The steps to determine the final AAHUs for each ER measure included the following: defining the project area, calculating baseline conditions, and forecasting FWOP and FWP conditions. Additional information regarding the assumptions and methods used in the development of the WVA model variables is described in Section 6.3 of Appendix C-8.

1.1 VARIABLE DATA SOURCES

Some of the selected HSI models share similar variables, and in most cases, the variable data are derived from the same sources. The following provides a summary of the variable assumptions and data common among the HSI models. Other variable data were derived specifically for certain model variables. Those descriptions and any exceptions to data use are described in tables 2–5.

1.1.1 Area

The area for each ER measure was calculated from within the project footprint using Geographic Information Systems (GIS) or Google Earth and is reported in acres. Project footprints for each ER measure for FWP conditions are assumed to remain the same over the life of the project (a project purpose is to preserve those areas). For FWOP conditions, many areas are assumed to decrease in size due to erosion or sea level rise (SLR). Assumptions specific to each ER measure are described in tables 2–5.

1.1.2 Cover Types

Cover types for each ER measure were calculated from the project or feature footprint using GIS and are reported in acres.

1.1.2.1 Brown Shrimp

Cover types for the brown shrimp model were mapped using the National Oceanographic and Atmospheric Administration (NOAA) Coastal Change Atlas Program (C-CAP) 2010 land cover dataset for baseline conditions and the NOAA Marsh Migration land cover datasets for FWOP and FWP conditions that involved the calculation of estuary or estuarine emergent wetland at the project footprint scale. For the FWOP condition, an annual erosion rate was applied to capture the area lost because of no project action (i.e., no breakwaters). The erosion rate was calculated for unprotected segments of shoreline along the Gulf Intracoastal Waterway (GIWW) and was performed by the USACE Galveston District using Google Earth aerial imagery. For the FWP condition, two scales were considered. Under the Scale 1 scenario, it is assumed that construction would end in 2035, and that all wetlands within the initial construction footprints are restored. Marsh areas immediately adjacent to the GIWW are assumed to be maintained with maintenance dredging material from the GIWW or other adjacent navigation channels through 2085. Under the Scale 2 scenario, the out-year marsh nourishments represent areas that were identified by the NOAA SLR viewer as unconsolidated shoreline or open water by 2065. It is assumed that these areas are fully restored in 2065 and are maintained through 2085.

1.1.2.2 American Oyster

Baseline oyster reef area was mapped using the Texas Parks and Wildlife Department (TPWD) oyster locations datafile provided by the Texas General Land Office (GLO). The oyster reef restoration features are a component of the initial construction features to be completed in 2035 and maintained through the end of the project life (2085). Oyster reef area was assumed to represent the total feature footprint in the FWP condition. For the FWOP condition, 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 was eliminated with no project action due to SLR, increased bay energy, and changes in freshwater inflow and salinity.

1.1.2.3 Brown Pelican

Island area was digitized using GIS or Google Earth for baseline conditions. The island restoration features are a component of the initial construction features to be completed in 2035 and maintained through the end of the project life (2085). Island area was assumed to represent the total feature footprint in the FWP condition. For the FWOP condition, some areas were recalculated for each target year to account for erosion of islands located along unprotected segments of the GIWW. Erosion rates for those areas were provided by the USACE.

1.1.2.4 Spotted Seatrout

Cover types for the spotted seatrout model were mapped using data from the Galveston Bay Estuary's Status and Trends Atlas for seagrass locations and through consensus among the interagency team on the location of submerged aquatic vegetation (SAV). FWP conditions assumed the project actions would protect SAV habitat within the project footprint and it would remain unchanged. Optimal conditions would occur at the end of construction (2035) and remain through the project life (2085). Under FWOP conditions, it was assumed the SAV within the project footprint would be eliminated due to increased energy, turbidity, and water depth associated with SLR.

1.1.3 Salinity

Salinity data were obtained from TPWD water quality data (2007–2016). This dataset consists of 20 years of salinity measurements taken along the Texas coast. Data applied to the model analyses for each ER measure included all salinity measurements that intersected the boundary or were within the project footprint. Salinity calculations followed the respective model criteria, which are summarized in tables 2–5. The number of data points used for calculating various salinity variables ranged from 200 to more than 3,000. Data to forecast and evaluate changes in salinity for FWOP were not readily available; as a result, the interagency team determined that a 20 percent increase to baseline salinities should be applied to the FWOP and FWP conditions to capture the potential change in salinities over the period of analysis. Over the project life (2017–2085), the annual rate of salinity increase was estimated at 0.3 percent, which was used to calculate the target year salinities.

1.1.4 Temperature

Water temperature data were obtained from TPWD water quality data (2007–2016). This dataset consists of 20 years of water temperature measurements taken along the Texas coast. Data applied to the model analyses for each ER measure included all water temperature measurements that intersected the boundary or were within the project footprint. Water temperature calculations followed the respective model criteria, which are summarized in tables 2–5. The number of data points used for calculating water temperature variables ranged from 200 to more than 3,000. Although climate change indicates water temperatures would rise in the future, it is not believed that the temperature rise would raise water temperatures above optimal conditions, at which point the HSI value would be negatively impacted. Therefore, temperature was held constant for future conditions.

1.1.5 Distance

For HSI model variables that required spatial estimates at the landscape level, distances were measured along a straight path using GIS or Google Earth and were reported in miles.

Table 2
American Oyster Model for all ER Measures Methodologies and Assumptions

Variable	Variable Description	TY 0 (2017)	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
Area (acres)	Oyster reef	Total oyster reef acres at baseline conditions were determined using the TPWD oyster locations datafile provided by the GLO.	Oyster reef restoration features are a component of the FWP initial construction features to be completed in 2035 and maintained through the end of the project life (2085). With no action, the oyster reef acres are assumed to be eliminated.	Same assumptions	Same assumptions
V_1	Percent cultch	If no oyster reef existed within the project footprint, then the percent cultch was suboptimal (HSI = 0). Alternatively, any amount of oyster reef existing within the project footprint was assumed to provide optimal bottom substrate (HSI = 1.0).	Under the FWP condition, percent cultch is optimal (HSI = 1.0) because the oyster reef restoration feature is assumed to be complete in 2035 and maintained through the end of the project life (2085). Under the FWOP condition, percent cultch is suboptimal (HSI = 0) because it is assumed all oyster reef has been eliminated.	Same assumptions	Same assumptions
V_2	Mean salinity May–September (ppt)	Variable was calculated by averaging monthly salinity values from May 1 through September 30.	Assumed 20 percent increase from baseline salinity applied over the period of analysis	Same assumptions	Same assumptions
V_3	Minimum annual salinity (ppt)	Variable was calculated by averaging monthly salinity values from 2007–2016 to determine the minimum annual salinity.	Assumed 20 percent increase from baseline salinity applied over the period of analysis	Same assumptions	Same assumptions
V_4	Annual mean salinity (ppt)	Variable was calculated by averaging monthly salinity values from 2007–2016 to determine the annual mean salinity.	Assumed 20 percent increase from baseline salinity applied over the period of analysis	Same assumptions	Same assumptions

TY = target year; ppt = parts per thousand

Table 3
Brown Pelican Model for all ER Measures Methodologies and Assumptions

Variable	Variable Description	TY 0 (2017)	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
Area (acres)	Island	Total baseline area	Island acres calculated from the island restoration footprint. An erosion rate was applied to capture acres lost in FWOP condition due to erosion (i.e., no breakwaters or oyster cultch). For the FWP condition, the island is assumed to be restored in 2035 and maintained through the end of the project life (2085).	Same assumptions. For the FWP condition, loss around the island was accounted for as a result of increased SLR (according to the USACE intermediate SLR curve and the USACE typical island cross sections and dimensions).	Same assumptions
V_1	Island surface area (categorical response)	Categorical response within model based on island size	Categorical response based on island size	Categorical response based on island size	Categorical response based on island size
V_2	Distance from mainland (miles)	Distance from the center of the island to the mainland	Restoration would not change distance from the mainland. Therefore, this variable was held constant through the end of the project life (2085).	Same assumptions	Same assumptions
V_3	Distance from human activity (miles)	Closest urban development on the mainland was considered a "human activity center." The distance from human activity was the distance from the center of the island to the nearest human activity.	Variable held constant through the end of the project life for FWOP and FWP conditions because predictions regarding future urban development in proximity to the project area was not considered.	Same assumptions	Same assumptions
V_4	Nesting coverage/island elevation (percent)	Current and historical aerial imagery was evaluated to calculate the ratio of the island greater than 2 feet in elevation and vegetated to the total island area.	Nesting coverage held constant in the FWOP condition, unless the island was completely lost to SLR. For FWP condition, the proportion of nesting cover derived from USACE island cross sections with assumed 100 percent vegetation coverage.	Same assumptions	Same assumptions

Table 4
Brown Shrimp Model for all ER Measures Methodologies and Assumptions

Variable	Variable Description	TY 0 (2017)	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
Area (acres)	Estuarine emergent wetland	Baseline included "estuarine emergent wetland" area within each "affected area," "out-year nourishment," and "wetland and marsh restoration – initial construction" footprint for each ER measure.	NOAA Marsh Migration 1.0-foot land cover dataset was used to determine estuarine emergent wetland area for the 2035 FWOP and FWP conditions.	NOAA Marsh Migration 2.0- and 1.75-foot land cover datasets were used to determine estuarine emergent wetland area for the upper Texas coast and mid Texas coast, respectively. Scale 1 and Scale 2 calculated accordingly.	NOAA Marsh Migration 3.0- and 2.5-foot land cover datasets were used to determine estuarine emergent wetland acres for the upper Texas coast and mid Texas coast, respectively. Scale 1 and Scale 2 calculated accordingly.
V_1	Percentage of estuary covered by vegetation	Ratio of estuarine emergent wetland to open water within the total ER measure footprint area.	NOAA Marsh Migration 1.0-foot land cover dataset used to determine the 2035 FWOP and FWP conditions.	NOAA Marsh Migration 2.0-foot land cover dataset used to determine conditions for upper Texas coast (G-28, B-12, and M-8). NOAA Marsh Migration 1.75-foot land cover dataset used to determine conditions for mid Texas coast (CA-5 and CA-6).	NOAA Marsh Migration 3.0-foot land cover dataset used to determine conditions for upper Texas coast (G-28, B-12, and M-8). NOAA Marsh Migration 2.5-foot land cover dataset used to determine conditions for mid Texas coast (CA-5 and CA-6).
V_2	Substrate composition	Class 1 (soft bottom) assumed for the upper Texas coast (G-28, B-12, and M-8) and Class 2 (muddy or fine sands) assumed for mid Texas coast (CA-5 and CA-6).	Same assumptions	Same assumptions	Same assumptions
V_3	Mean salinity during spring (ppt)	Variable calculated by averaging spring salinities for the months of March, April, and May.	Assumed 20 percent increase from baseline salinity applied over the period of analysis	Same assumptions	Same assumptions
V_4	Mean spring water temperature (degrees Fahrenheit [°F])	Variable calculated by averaging spring water temperatures for the months of March, April, and May.	Assumed temperature held constant	Same assumption	Same assumption

Table 5
Spotted Seatrout Model for all ER Measures Methodologies and Assumptions

Variable	Variable Description	TY 0 (2017)	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
Acres	SAV	Total baseline area	For the FWOP condition, SAV habitat assumed to be lost. For the FWP condition, SAV protected and remains same as baseline.	Same assumptions	Same assumptions
V_1	Lowest monthly average winter-spring salinity (ppt)	Variable represents the minimum value of the 4 monthly mean salinities determined for each year of data between the months of December and March.	Assumed 20 percent increase from baseline salinity applied over the period of analysis.	20 percent increase from baseline salinity applied over the period of analysis.	20 percent increase from baseline salinity applied over the period of analysis.
V_2	Highest monthly average summer salinity (ppt)	Variable represents the maximum value of the 4 monthly mean salinities determined for each year of data between the months of June and September.	Assumed 20 percent increase from baseline salinity applied over the period of analysis.	20 percent increase from baseline salinity applied over the period of analysis.	20 percent increase from baseline salinity applied over the period of analysis.
V_3	Lowest monthly average winter water temperature (°F)	Variable represents the minimum value of the 4 monthly mean water temperatures determined for each year of data between the months of December and March.	Assumed temperature held constant	Same assumptions	Same assumptions
V_4	Highest monthly average summer water temperature (°F)	Variable represents the maximum value of the 4 monthly mean water temperatures determined for each year of data between the months of June and September.	Assumed temperature held constant	Same assumptions	Same assumptions
V_5	Percentage of study area with optimal cover	Current and historical aerial imagery was evaluated using Google Earth.	For the FWOP condition, SAV assumed eliminated and suitability decreases to 0 percent. For the FWP condition, SAV habitat assumed protected and this variable remains same as baseline.	Same assumptions	Same assumptions

Attachment

ER Measure Forecasting Assumptions

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Acronyms and Abbreviations

AAHU	Average Annual Habitat Unit
C-CAP	Coastal Change Atlas Program
CSRM	Coastal Storm Risk Management
ER	Ecosystem Restoration
IFR-EIS	Integrated Feasibility Report and Environmental Impact Statement
FWOP	future without-project
FWP	future with project
GIS	Geographic Information Systems
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
HEAT	Habitat Evaluation and Assessment Tools
HEP	Habitat Evaluation Procedures
HSI	Habitat Suitability Index
HU	Habitat Unit
NOAA	National Oceanic and Atmospheric Administration
ppt	parts per thousand
SLR	sea level rise
SAV	submerged aquatic vegetation
TPWD	Texas Parks and Wildlife Department
TY	target year
USACE	U.S. Army Corps of Engineers
WVA	Wetland Value Assessment

1.0 INTRODUCTION

The Habitat Evaluation Procedures (HEP) methodology was incorporated into the Coastal Texas Protection and Restoration Study (Coastal Texas Study) via the Habitat Evaluation and Assessment Tool (HEAT) software and the Wetland Value Assessment (WVA) Barrier Island Community Model for evaluating project benefits and impacts. The HEAT software was developed to conduct HEP and allows the user to establish habitat units (HUs), the common form of currency when assessing project impacts and benefits, and to determine Average Annual Habitat Units (AAHUs) to capture future project changes for specific project timescales. In addition to estimating project impacts and benefits, the models were used to guide and optimize mitigation design and assist in development of mitigation recommendations for the Ecosystem Restoration (ER) and Coastal Storm Risk Management (CSRM) measures.

The U.S. Army Corps of Engineers (USACE) Civil Works policy requires that only standard habitat models previously certified by the USACE Ecosystem Planning Center of Excellence be used to determine ecological benefits and/or impacts and mitigation. A final list of five HEP models (using the HEAT software) and one WVA model were approved by the USACE to conduct the future-without project (FWOP) and future-with project (FWP) analyses. Additional information regarding the model selection process is described in Section 5.0 of Appendix C-8.

The following provides an overview of the data sources, methods, and assumptions in the development of the variables within each model, as applied to the final list of ER measures (Table 1). Following the Agency Decision Milestone, HEP analyses will be conducted for proposed CSRM measures carried forward and the results will be incorporated into the HEP and WVA Modeling Report for the Final Integrated Feasibility Report and Environmental Impact Statement (IFR-EIS).

Table 1
Habitat Suitability Index (HSI) Model Evaluations by ER Measure

HSI Model	G-28	B-12	M-8	CA-5	CA-6	SP-1	W-3
Brown Shrimp	X	X	X	X	X		
Spotted Seatrout				X		X	X
Brown Pelican	X		X			X	X
American Oyster	X	X	X	X		X	

The WVA Barrier Island Community Model was used to quantify barrier island system benefits from the proposed beach and dune restoration efforts for the Coastal Texas Study. Specifically, the WVA model was applied to the following ER measures at the project footprint scale:

- G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration
- B-2 – Follet’s Island Gulf and Beach Dune Restoration
- W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration

The steps to determine the final AAHUs for each ER measure included the following: defining the project area, calculating baseline conditions, and forecasting FWOP and FWP conditions. Additional information regarding the assumptions and methods used in the development of the WVA model variables is described in Section 6.3 of Appendix C-8.

1.1 VARIABLE DATA SOURCES

Some of the selected HSI models share similar variables, and in most cases, the variable data are derived from the same sources. The following provides a summary of the variable assumptions and data common among the HSI models. Other variable data were derived specifically for certain model variables. Those descriptions and any exceptions to data use are described in tables 2–5.

1.1.1 Area

The area for each ER measure was calculated from within the project footprint using Geographic Information Systems (GIS) or Google Earth and is reported in acres. Project footprints for each ER measure for FWP conditions are assumed to remain the same over the life of the project (a project purpose is to preserve those areas). For FWOP conditions, many areas are assumed to decrease in size due to erosion or sea level rise (SLR). Assumptions specific to each ER measure are described in tables 2–5.

1.1.2 Cover Types

Cover types for each ER measure were calculated from the project or feature footprint using GIS and are reported in acres.

1.1.2.1 Brown Shrimp

Cover types for the brown shrimp model were mapped using the National Oceanographic and Atmospheric Administration (NOAA) Coastal Change Atlas Program (C-CAP) 2010 land cover dataset for baseline conditions and the NOAA Marsh Migration land cover datasets for FWOP and FWP conditions that involved the calculation of estuary or estuarine emergent wetland at the project footprint scale. For the FWOP condition, an annual erosion rate was applied to capture the area lost because of no project action (i.e., no breakwaters). The erosion rate was calculated for unprotected segments of shoreline along the Gulf Intracoastal Waterway (GIWW) and was performed by the USACE Galveston District using Google Earth aerial imagery. For the FWP condition, two scales were considered. Under the Scale 1 scenario, it is assumed that construction would end in 2035, and that all wetlands within the initial construction footprints are restored. Marsh areas immediately adjacent to the GIWW are assumed to be maintained with maintenance dredging material from the GIWW or other adjacent navigation channels through 2085. Under the Scale 2 scenario, the out-year marsh nourishments represent areas that were identified by the NOAA SLR viewer as unconsolidated shoreline or open water by 2065. It is assumed that these areas are fully restored in 2065 and are maintained through 2085.

1.1.2.2 American Oyster

Baseline oyster reef area was mapped using the Texas Parks and Wildlife Department (TPWD) oyster locations datafile provided by the Texas General Land Office (GLO). The oyster reef restoration features are a component of the initial construction features to be completed in 2035 and maintained through the end of the project life (2085). Oyster reef area was assumed to represent the total feature footprint in the FWP condition. For the FWOP condition, 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 was eliminated with no project action due to SLR, increased bay energy, and changes in freshwater inflow and salinity.

1.1.2.3 Brown Pelican

Island area was digitized using GIS or Google Earth for baseline conditions. The island restoration features are a component of the initial construction features to be completed in 2035 and maintained through the end of the project life (2085). Island area was assumed to represent the total feature footprint in the FWP condition. For the FWOP condition, some areas were recalculated for each target year to account for erosion of islands located along unprotected segments of the GIWW. Erosion rates for those areas were provided by the USACE.

1.1.2.4 Spotted Seatrout

Cover types for the spotted seatrout model were mapped using data from the Galveston Bay Estuary's Status and Trends Atlas for seagrass locations and through consensus among the interagency team on the location of submerged aquatic vegetation (SAV). FWP conditions assumed the project actions would protect SAV habitat within the project footprint and it would remain unchanged. Optimal conditions would occur at the end of construction (2035) and remain through the project life (2085). Under FWOP conditions, it was assumed the SAV within the project footprint would be eliminated due to increased energy, turbidity, and water depth associated with SLR.

1.1.3 Salinity

Salinity data were obtained from TPWD water quality data (2007–2016). This dataset consists of 20 years of salinity measurements taken along the Texas coast. Data applied to the model analyses for each ER measure included all salinity measurements that intersected the boundary or were within the project footprint. Salinity calculations followed the respective model criteria, which are summarized in tables 2–5. The number of data points used for calculating various salinity variables ranged from 200 to more than 3,000. Data to forecast and evaluate changes in salinity for FWOP were not readily available; as a result, the interagency team determined that a 20 percent increase to baseline salinities should be applied to the FWOP and FWP conditions to capture the potential change in salinities over the period of analysis. Over the project life (2017–2085), the annual rate of salinity increase was estimated at 0.3 percent, which was used to calculate the target year salinities.

1.1.4 Temperature

Water temperature data were obtained from TPWD water quality data (2007–2016). This dataset consists of 20 years of water temperature measurements taken along the Texas coast. Data applied to the model analyses for each ER measure included all water temperature measurements that intersected the boundary or were within the project footprint. Water temperature calculations followed the respective model criteria, which are summarized in tables 2–5. The number of data points used for calculating water temperature variables ranged from 200 to more than 3,000. Although climate change indicates water temperatures would rise in the future, it is not believed that the temperature rise would raise water temperatures above optimal conditions, at which point the HSI value would be negatively impacted. Therefore, temperature was held constant for future conditions.

1.1.5 Distance

For HSI model variables that required spatial estimates at the landscape level, distances were measured along a straight path using GIS or Google Earth and were reported in miles.

Table 2
American Oyster Model for all ER Measures Methodologies and Assumptions

Variable	Variable Description	TY 0 (2017)	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
Area (acres)	Oyster reef	Total oyster reef acres at baseline conditions were determined using the TPWD oyster locations datafile provided by the GLO.	Oyster reef restoration features are a component of the FWP initial construction features to be completed in 2035 and maintained through the end of the project life (2085). With no action, the oyster reef acres are assumed to be eliminated.	Same assumptions	Same assumptions
V_1	Percent cultch	If no oyster reef existed within the project footprint, then the percent cultch was suboptimal (HSI = 0). Alternatively, any amount of oyster reef existing within the project footprint was assumed to provide optimal bottom substrate (HSI = 1.0).	Under the FWP condition, percent cultch is optimal (HSI = 1.0) because the oyster reef restoration feature is assumed to be complete in 2035 and maintained through the end of the project life (2085). Under the FWOP condition, percent cultch is suboptimal (HSI = 0) because it is assumed all oyster reef has been eliminated.	Same assumptions	Same assumptions
V_2	Mean salinity May–September (ppt)	Variable was calculated by averaging monthly salinity values from May 1 through September 30.	Assumed 20 percent increase from baseline salinity applied over the period of analysis	Same assumptions	Same assumptions
V_3	Minimum annual salinity (ppt)	Variable was calculated by averaging monthly salinity values from 2007–2016 to determine the minimum annual salinity.	Assumed 20 percent increase from baseline salinity applied over the period of analysis	Same assumptions	Same assumptions
V_4	Annual mean salinity (ppt)	Variable was calculated by averaging monthly salinity values from 2007–2016 to determine the annual mean salinity.	Assumed 20 percent increase from baseline salinity applied over the period of analysis	Same assumptions	Same assumptions

TY = target year; ppt = parts per thousand

Table 3
Brown Pelican Model for all ER Measures Methodologies and Assumptions

Variable	Variable Description	TY 0 (2017)	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
Area (acres)	Island	Total baseline area	Island acres calculated from the island restoration footprint. An erosion rate was applied to capture acres lost in FWOP condition due to erosion (i.e., no breakwaters or oyster cultch). For the FWP condition, the island is assumed to be restored in 2035 and maintained through the end of the project life (2085).	Same assumptions. For the FWP condition, loss around the island was accounted for as a result of increased SLR (according to the USACE intermediate SLR curve and the USACE typical island cross sections and dimensions).	Same assumptions
V_1	Island surface area (categorical response)	Categorical response within model based on island size	Categorical response based on island size	Categorical response based on island size	Categorical response based on island size
V_2	Distance from mainland (miles)	Distance from the center of the island to the mainland	Restoration would not change distance from the mainland. Therefore, this variable was held constant through the end of the project life (2085).	Same assumptions	Same assumptions
V_3	Distance from human activity (miles)	Closest urban development on the mainland was considered a "human activity center." The distance from human activity was the distance from the center of the island to the nearest human activity.	Variable held constant through the end of the project life for FWOP and FWP conditions because predictions regarding future urban development in proximity to the project area was not considered.	Same assumptions	Same assumptions
V_4	Nesting coverage/island elevation (percent)	Current and historical aerial imagery was evaluated to calculate the ratio of the island greater than 2 feet in elevation and vegetated to the total island area.	Nesting coverage held constant in the FWOP condition, unless the island was completely lost to SLR. For FWP condition, the proportion of nesting cover derived from USACE island cross sections with assumed 100 percent vegetation coverage.	Same assumptions	Same assumptions

Table 4
Brown Shrimp Model for all ER Measures Methodologies and Assumptions

Variable	Variable Description	TY 0 (2017)	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
Area (acres)	Estuarine emergent wetland	Baseline included "estuarine emergent wetland" area within each "affected area," "out-year nourishment," and "wetland and marsh restoration – initial construction" footprint for each ER measure.	NOAA Marsh Migration 1.0-foot land cover dataset was used to determine estuarine emergent wetland area for the 2035 FWOP and FWP conditions.	NOAA Marsh Migration 2.0- and 1.75-foot land cover datasets were used to determine estuarine emergent wetland area for the upper Texas coast and mid Texas coast, respectively. Scale 1 and Scale 2 calculated accordingly.	NOAA Marsh Migration 3.0- and 2.5-foot land cover datasets were used to determine estuarine emergent wetland acres for the upper Texas coast and mid Texas coast, respectively. Scale 1 and Scale 2 calculated accordingly.
V_1	Percentage of estuary covered by vegetation	Ratio of estuarine emergent wetland to open water within the total ER measure footprint area.	NOAA Marsh Migration 1.0-foot land cover dataset used to determine the 2035 FWOP and FWP conditions.	NOAA Marsh Migration 2.0-foot land cover dataset used to determine conditions for upper Texas coast (G-28, B-12, and M-8). NOAA Marsh Migration 1.75-foot land cover dataset used to determine conditions for mid Texas coast (CA-5 and CA-6).	NOAA Marsh Migration 3.0-foot land cover dataset used to determine conditions for upper Texas coast (G-28, B-12, and M-8). NOAA Marsh Migration 2.5-foot land cover dataset used to determine conditions for mid Texas coast (CA-5 and CA-6).
V_2	Substrate composition	Class 1 (soft bottom) assumed for the upper Texas coast (G-28, B-12, and M-8) and Class 2 (muddy or fine sands) assumed for mid Texas coast (CA-5 and CA-6).	Same assumptions	Same assumptions	Same assumptions
V_3	Mean salinity during spring (ppt)	Variable calculated by averaging spring salinities for the months of March, April, and May.	Assumed 20 percent increase from baseline salinity applied over the period of analysis	Same assumptions	Same assumptions
V_4	Mean spring water temperature (degrees Fahrenheit [°F])	Variable calculated by averaging spring water temperatures for the months of March, April, and May.	Assumed temperature held constant	Same assumption	Same assumption

Table 5
Spotted Seatrout Model for all ER Measures Methodologies and Assumptions

Variable	Variable Description	TY 0 (2017)	TY 1 (2035)	TY 31 (2065)	TY 51 (2085)
Acres	SAV	Total baseline area	For the FWOP condition, SAV habitat assumed to be lost. For the FWP condition, SAV protected and remains same as baseline.	Same assumptions	Same assumptions
V_1	Lowest monthly average winter-spring salinity (ppt)	Variable represents the minimum value of the 4 monthly mean salinities determined for each year of data between the months of December and March.	Assumed 20 percent increase from baseline salinity applied over the period of analysis.	20 percent increase from baseline salinity applied over the period of analysis.	20 percent increase from baseline salinity applied over the period of analysis.
V_2	Highest monthly average summer salinity (ppt)	Variable represents the maximum value of the 4 monthly mean salinities determined for each year of data between the months of June and September.	Assumed 20 percent increase from baseline salinity applied over the period of analysis.	20 percent increase from baseline salinity applied over the period of analysis.	20 percent increase from baseline salinity applied over the period of analysis.
V_3	Lowest monthly average winter water temperature (°F)	Variable represents the minimum value of the 4 monthly mean water temperatures determined for each year of data between the months of December and March.	Assumed temperature held constant	Same assumptions	Same assumptions
V_4	Highest monthly average summer water temperature (°F)	Variable represents the maximum value of the 4 monthly mean water temperatures determined for each year of data between the months of June and September.	Assumed temperature held constant	Same assumptions	Same assumptions
V_5	Percentage of study area with optimal cover	Current and historical aerial imagery was evaluated using Google Earth.	For the FWOP condition, SAV assumed eliminated and suitability decreases to 0 percent. For the FWP condition, SAV habitat assumed protected and this variable remains same as baseline.	Same assumptions	Same assumptions