Coastal Texas Protection and Restoration Feasibility Study

Final Feasibility Report

Appendix A:

Plan Formulation

August 2021

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Acronyms and Abbreviations

AAHUs	Annual Average Habitat Units
ACE	annual chance exceedance
BEG	Bureau of Economic Geology
CAP	Continuing Authorities Programs
CE/ICA	Cost-effectiveness and Incremental Cost Analyses
CEPRA	Coastal Erosion Planning and Response Act
CIAP	Coastal Impact Assistance Program
CSRM	coastal storm risk management
cy	cubic yards
DIFR-EIS	Draft Integrated Feasibility Report and Environmental Impact Statement
EFH	essential fish habitat
ER	ecosystem restoration
FWOP	Future Without-Project
FWP	Future With-project
FY	fiscal year
GCCPRD	Gulf Coast Community Protection and Recovery District
GIWW	Gulf Intracoastal Waterway
GLO	Texas General Land Office
HEP	Habitat Evaluation Procedure
HFPS	Hurricane Flood Protection System
HIS	Habitat Suitability Index
HSDRRS	Hurricane and Storm Damage Risk Reduction System
msl	mean sea level
NAVD 88	North American Vertical Datum of 1988

Acronyms and Abbreviations	
NED	National Economic Development
NER	National Ecosystem Restoration
NOAA	National Oceanic and Atmospheric Administration
NRDA	Natural Resources Defense Act
NWR	National Wildlife Refuge
OMRR&R	operation, maintenance, repair, replacement, and rehabilitation
PDT	Project Development Team
RESTORE	Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States
RSLR	relative sea level rise
SAV	submerged aquatic vegetation
SLOSH	Sea, Lake and Overland Surges from Hurricanes
TSP	Tentatively Selected Plan
USACE	U.S. Army Corps of Engineers
WVA	Wetland Valuation Analysis

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1 Introduction

The Coastal Texas Ecosystem Protection and Restoration, Texas (Coastal Texas) study was authorized by Section 4091 of WRDA 2007, which directed the Secretary to "develop a comprehensive plan to determine the feasibility of carrying out projects for flood damage reduction, hurricane and storm damage reduction, and ecosystem restoration in the coastal areas of the State of Texas." Section 1205 of the Water Infrastructure Improvements for the Nation (WIIN) Act of 2016, further directed the Corp to consider and incorporate other past or current efforts to identify similar coastal protection and restoration needs and projects, such as GCCPRD Surge Suppression Study, which was a State-funded locally led effort to identify schemes to protect the upper Texas coast from hurricane storm surge. The Bipartisan Budget Act of 2018 (BBA 2018) authorized 100% federal funding to finish out the study.

The study effort focused on two core USACE missions, CSRM and ER. CSRM required development and evaluation of coastal storm risk from storm surges and erosion associated with tropical events. The ER mission focused upon formulation and evaluation of actions to increase the net quantity and quality of coastal ecosystem resources by maintaining or restoring critical or degraded coastal ecosystems and fish and wildlife habitat.

The Flood Risk Management (FRM) authority addresses inundation risk, typically in inland areas, distinct from storm surge induced flooding and erosion. FRM was also authorized for the study and was considered in the design of features and evaluation of performance proposed CSRM measures within the Coastal Texas Recommended Plan. This included the potentially detrimental impact of rainfall on the proposed CSRM measures, and the incidental benefits of the proposed measures on local drainage system performance. Several separate FRM studies are authorized in the Houston region, and will apply appropriate models and analysis to evaluate flood risks. The Coastal Texas study doesn't recommend independent FRM measures, but the Recommended Plan was developed to consider, harmonize with and support current and future FRM projects in the study area.

Given the study area's low elevation, flat terrain, and proximity to the Gulf, the people, economy, and unique environments in state's coastal communities are at risk of flooding from tidal surge and tropical storm waves. In addition, continued loss of natural ecosystems will contribute to the region's loss of biodiversity. Land subsidence, combined with rising sea levels, is expected to increase the potential for coastal flooding, shoreline erosion (in excess of 4 feet/year on the GIWW, for example), saltwater intrusion, and the loss of wetland and barrier island habitats across the landscape well into the future.

The main report summarizes the key points of the formulation and screening process that led to the selection of the recommended plan. This appendix presents supporting information about interim steps in the analysis and screening process that were omitted from the Main report in the interest of brevity.

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2 Planning Process Overview

The Corps planning process follows the principles, standards, and procedures established in the Principles and Guidelines that guide water resource development at the national level. Corps policy requires a consistent approach to identify and evaluate potential solutions to water resources problems to ensure that investment decisions reflect important benefits and consequences.

The planning process includes six major steps: (1) Specification of water and related land resources problems and opportunities; (2) Inventory, forecast and analysis of water and related land resources conditions within the study area; (3) Formulation of alternative plans; (4) Evaluation of the effects of the alternative plans; (5) Comparison of the alternative plans; and (6) Selection of the recommended plan based upon the comparison of the alternative plans. If additional information is developed during the screening process, the study team may repeat the steps to incorporate that information to balance the need for data and analysis with timely completion of the study.

Coastal problem statements presented in the introduction to the report describe the damaging impacts of coastal storms and the constant coastal processes on the physical features of the region. The area’s low elevation, flat terrain combined with long term changes such as land subsidence, and rising sea level create potential risk for coastal flooding, storm surge, erosion and habitat degradation. Erosive coastal forces impact the natural and built habitats. We lose shorelines, marshes retreat, and natural protective features are lost. Climate change worsens the impact of storm events when storm surge can push further past eroded shorelines and marshes.

Once the identification of problems and opportunities establishes the criteria for evaluation, plan development starts as small increments, or “features”, proposed for specific risks and subareas in the study area. The features are defined and evaluated, and the ones that effectively reduce the problems are combined into alternative plans. Alternative plans are assembled according to strategies to create a thorough set of possible solutions. These alternative plans are compared for performance, cost, and environmental impacts, until a cost-effective solution is identified.

The performance of features and alternatives are compared to a baseline condition, called the “Without-project Condition” (WOPC), to assess whether they achieve the planning objectives. The Team consulted storm history, local agencies, and reviewed the baseline condition to identify the nature, cause, location, dimensions, origin, time frame, and importance of the problem in each region.

Engineering and economic models are applied to characterize the performance of the plans in common measurement units. Engineering models estimate the risk in terms of erosion and the height and extent of flooding, described as water surface elevations. When that data is combined with the location of people, property, and critical infrastructure in the area, consequence models can estimate the risk to people and the potential damages in dollars from different storm events.

The same models measure the relative performance of alternatives by estimating the height and extent of the flooding if the alternative were in place, and the damages reduced as a result. The primary economic benefit is the avoided damage to property such as homes, businesses, roads, utilities, and industry.

Other benefit metrics include the reduced safety risks to the population, and avoided damage to critical systems, such as roads, ports, hospitals, and other similar infrastructure, that impact regional support systems, economic productivity and growth, and ongoing community support systems that maintain health and wellbeing.

Cost-effectiveness is measured by comparing benefits to costs. The Corps screening process defines specific categories of damages avoided, measured in dollars, as National Economic Development (NED) benefits, or contributions to the national economy. When NED benefits are shown to be larger than the costs of construction and operation of the alternative, it is considered to be cost-effective.

Engineering models can also be applied to estimate environmental impacts of the alternatives. If alternatives perform comparably, the ones that create fewer negative impacts are carried forward for further evaluation. If negative environmental impacts cannot be avoided, mitigation is required to compensate for negative impacts. The cost of mitigation also affects the cost-effectiveness of alternative plans, since plans that require extensive mitigation increase the cost of the alternative.

Screening of ecosystem restoration alternatives also compares baseline conditions to "with-project condition" performance measured with different tools. Biological models estimate plan performance as "habitat units". Comparing the incremental gain in habitat units as costs of plans increase assesses cost-effectiveness, since the benefits are not measured in dollars.

Federal Principles & Guidelines established four criteria for evaluation of water resources projects: effectiveness, efficiency, completeness, and acceptability. Benefits, costs, and social & environmental impacts are used to judge the degree to which an alternative plan meets these criteria.

Effectiveness is the extent to which the alternative plans achieve the planning objectives of the study. This is reflected in the benefits and positive effects of the plans.

Efficiency is the extent to which an alternative is cost-effective while meeting the planning objectives. This is reflected in the comparison of costs to the beneficial outcomes.

Completeness is the extent to which the alternative plans include all necessary actions and costs to achieve the planning objectives and the benefits that are claimed for each plan.

Acceptability is the extent to which the alternative plans comply with applicable laws, regulations and public policies. Environmental and social impacts are assessed, with the intent to avoid or minimize to the extent practicable, then utilize appropriate mitigation actions.

Alternatives considered in the study were evaluated to confirm that they meet minimum subjective standards of these criteria to qualify for further consideration and comparison with other plans.

Decisions to carry alternatives forward in the planning process can be made in steps. Initial comparisons can choose from conceptual descriptions based on professional judgment or available data about performance, comparisons of impacts or relative costs. As project features are refined or as more detailed information about performance, area conditions and impacts is developed, alternatives may be screened from further consideration. When additional detail is necessary to choose between alternatives, the Team will conduct additional analysis to generate necessary information to eliminate critical uncertainties.

This iterative process allows the Team to reduce duration and cost for studies by conducting the necessary technical analyses at each stage of the study. The risk informed decision making process is designed to speed the publication of the draft plan and seek agency and public comment on the proposed plan.

2.1 PLANNING FOR RESILIENCE

Resilience represents a comprehensive, systems-based approach to address acute hazards and chronic stressors over time. This study uses the concept of resilience to guide a broad-based, collaborative approach to finding integrated solutions to the erosion, storm, and sea level rise impacts summarized in Chapter 1.

Executive Order (EO) 13653, “Preparing the United States for the Impacts of Climate Change” (November 2013), describes resilience as “the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions." To help organize resilience activities and describe how resilience measures can be applied, the U.S. Army Corps of Engineers (USACE) has divided resilience into four key principles: prepare, absorb, recover, and adapt. These principles provide a lifecycle perspective for resilience-related actions in recognition of the fact that adverse events happen, and conditions change over time (EP1100-1-2).

To incorporate resilience concepts into the study, the team first sought to align the concepts with the familiar 6-step planning framework described above. The planning framework is a flexible problem-solving approach that adapts to all water resource studies. Application of the planning framework relies on a clear understanding of how successful outcomes are defined and achieved. Planning objectives were established in Chapter 1 to describe those successful outcomes. Under the P&G, USACE is required to formulate plans to contribute to the national economy and to identify the plan that maximizes net national economic development benefits, so this has traditionally served as the guide to success and primary decision rule in USACE planning studies.

This study used resilience as a guiding strategy for plan development, while still being mindful of the need to measure national economic effects. To assist the integration of resilience concepts into the traditional NED-focused process, the study team reviewed the City Resilience Framework (Rockefeller Foundation, 2015) developed to support the Rockefeller Foundation’s 100 Resilient Cities program. Figure A-1 displays the City Resilience Framework. The framework presents a broad, multi-dimensional perspective on the integrated conditions that support resilience within a community. The framework highlights four dimensions of resilience – Health & Wellbeing, Economy & Society; Infrastructure & Environment; and Leadership & Strategy. These dimensions align well with the 4 accounts that USACE uses in its standard planning process – Other Social Effects, National Economic Development, Regional Economic Development, Environmental Quality. Accordingly, the resilience framework offers an opportunity to consider how the effects of the alternative plans would support or hinder resilience in the study area, while still making use of many of the familiar metrics produced in USACE studies. The study team does not, however, claim that the framework was fully utilized as intended in the 100 Resilient Cities program.

A critical aspect of resilience is that it depends on integration of actions across a region by multiple actors or entities. Many of those actions are beyond the scope of this study, hence the limitation on fully utilizing the framework as described. However, the resilience implications of alternative plans can be evaluated despite this limitation.

In fact, a key part of the evaluation is this consideration of multiple dimensions, rather than an emphasis on one dimension (economic, societal, environmental, infrastructure) when choosing a recommended plan. Considering multiple dimensions also offers a cautionary note on the risks of single-dimension optimization of a risk management system.

This feasibility study was completed with three iterations:

Conceptual Plans: Evaluate potential measures and assess effectiveness of combined ER and CSRM measures to achieve study objectives.

TSP Selection: Quantify and compare benefits and impacts for identification of the TSP (NED and NER) and publication in the 1st Draft report

Integration and Refinement: Combine the NED and NER plan into the Recommended Plan that included integration of the two types of features, addressing public, agency and technical comments, and further technical refinement.

3 FORMULATION FRAMEWORK: PROBLEMS, OPPORTUNITIES AND CONSTRAINTS: CONCEPTUAL PLAN DEVELOPMENT

The initial plan formulation process considered four sub areas of the Texas coast study area to develop conceptual plans. The planning criteria and goals were further refined to reduce the complexity of the scope of the problems and opportunities, and planning objectives were developed to guide the development and screening of management measures to develop a comprehensive plan for the entire Texas coast.

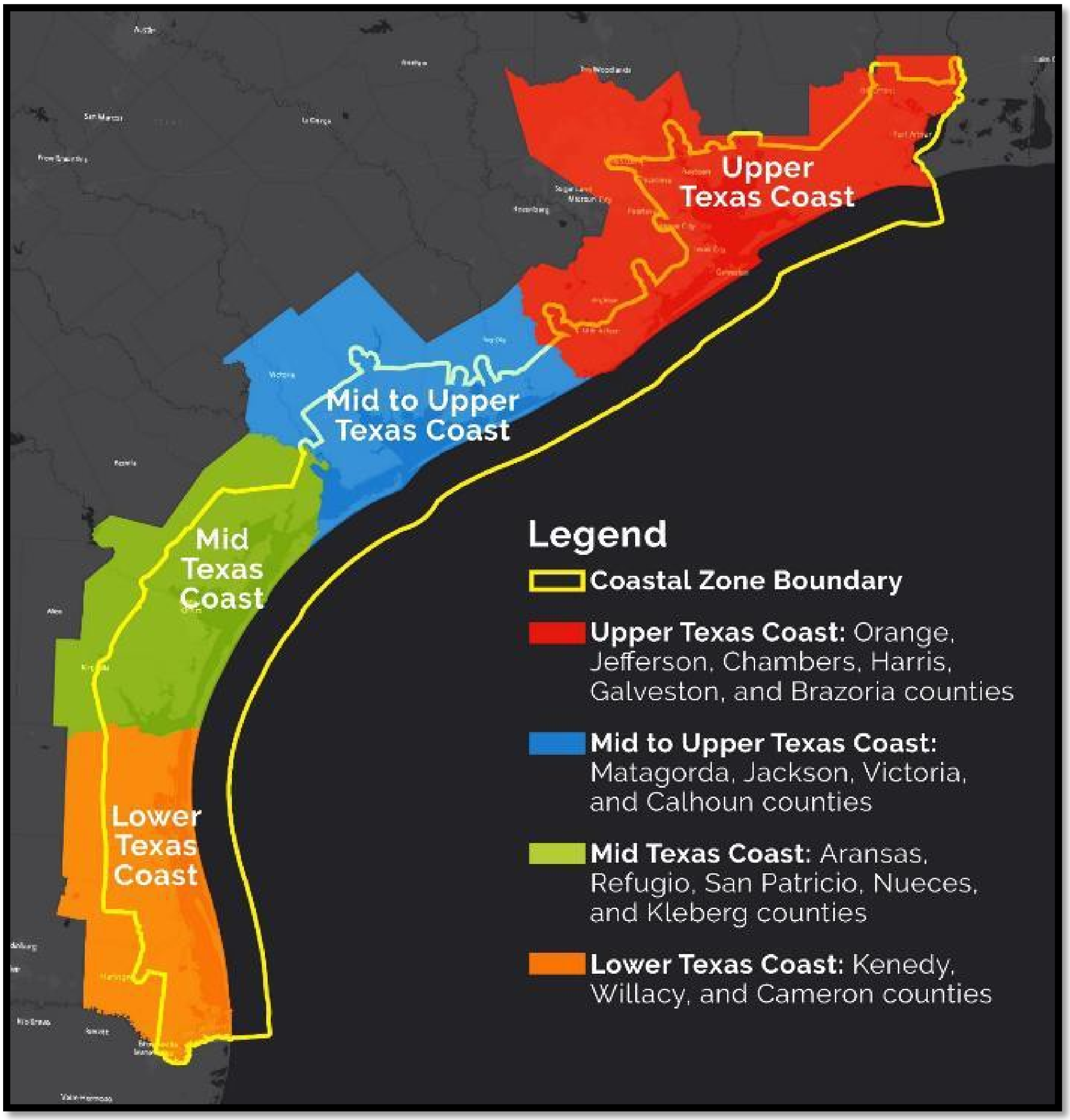

Figure 1 - Sub Regions

3.1 PROBLEMS AND OPPORTUNITIES

Due to the large scope of the study area, the problems, needs, opportunities, goals, and objectives were first reviewed based on the entire Texas coast from the Sabine River to the Rio Grande. The existing conditions and No-Action/future without-project (FWOP) conditions were used to guide the development of these key initial planning criteria and goals.

Characterization of the environmental settings and the initial plan formulation process focuses on the four areas of the Texas coast listed in the study area. As the planning process progressed, the planning criteria and goals were further refined along with the study area. Due to the complexity of the Texas Gulf coast, the four study areas were further developed into planning regions.

Problem Statement: Given the area's low elevation, flat terrain, and proximity to the Gulf, the people, economy, and unique environments are at risk due to tidal surge flooding and tropical storm waves. In addition, continued loss of natural surrounding ecosystems will contribute to the regions' loss of biodiversity. Land subsidence, combined with rising sea level, is expected to increase the potential for coastal flooding, shoreline erosion, saltwater intrusion, and loss of wetland and barrier island habitats in the future.

3.1.1 Region-Specific Problems and Opportunities

The initial plan formulation process focused on four areas of the Texas coast within the study area. As the planning process progressed, the planning criteria and goals were further refined to reflect the specific problems and opportunities within these four areas, and to develop specific planning objectives to guide the development and screening of management measures. The overall problems, opportunities, and objectives were to ensure that a comprehensive plan was being developed for the entire Texas coast. Figure 1 and the sections below explain this process and the rationale for this step of the planning process.

3.1.1.1 Region 1 – Specific Problems and Opportunities

Problems	Opportunities
Coastal Storm Risk Management (CRSM)	
• Populations are vulnerable to life safety from flooding due to their close proximity to the coast. This includes the fourth largest U.S. city (Houston), and other key metropolitan areas such as Beaumont/Port Arthur/Orange, Galveston/Texas City, and Freeport/ Surfside • Flood risk increase in the industrial section of upper Galveston Bay system due to coastal storm surges. The area at risk includes the nine of the largest oil refineries in the world, 40 percent of the nation's petrochemical industry, 25 percent of the Nation's petroleum- refining capacity, 60 percent of the U.S. jet fuel production and includes a two of the nation's strategic petroleum reserves • Local existing hurricane risk reduction systems are increasingly at risk from coastal storms due to Relative Sea Level Rise (RSLR). Majority do not meet current design standards for resiliency and redundancy • Infrastructure associated with nationally important deep-draft seaport and shallow-draft channels is susceptible to flood and hurricane storm damages, particularly the Port of Houston, which is #1 in importing fuel, and the Port of Beaumont, which is the #1 military outload port in the world.	• Reduce the susceptibility of residential, commercial, and public structures and infrastructure to hurricane-induced storm damages along Galveston Island, Bolivar Peninsula, and along the interior of the Galveston Bay system • Improve flood warnings for preparation and/or evacuation • Recommend future modifications to the roadway systems to maintain, as much as possible, emergency response vehicle access during and following hurricane and tropical storm events • Reduce region's population vulnerable to life safety issues from storm surge flooding

- Critical infrastructure throughout the region, including hurricane evacuation routes, nationally significant medical centers, government facilities, universities, and schools are at risk of damage due to storm events. Also, there is the potential for release of hazardous, toxic and radioactive waste to the sensitive environmental areas due to storm surge impacts on refineries and tank farms

Ecosystem Restoration (ER)

- Loss of fish and shellfish habitat in the Galveston Bay system due to navigation impacts and increased salinities
- Gulf shoreline erosion along the Texas- Louisiana Coastal Marshes due to loss of longshore sediment transportation particularly in areas near the Texas Point National Wildlife Refuge (NWR) and from the Clam Lake Road area to High Island in the McFaddin NWR area
- Gulf shoreline erosion along the Mid-Coast Barrier Islands and Coastal Marshes near the Brazos River due to the redirection of riverine flows
- Saltwater intrusion in the Galveston Bay estuary due to breaches in the Barrier Islands system resulting from coastal storms reduces the long-term sustainability of coastal wetland systems
- Loss of coastal wetlands along GIWW due to wind and barge traffic wave impacts
- Restoration of islands that protect navigation in the GIWW from wind fetch across large bay systems
- Increase resiliency of barrier island systems
- Benefit coastal and marine resources in the Galveston Bay system through marsh and oyster reef restoration
- Maintain sediment within the system and use beneficially where feasible, particularly when dredging in the Galveston Bay system
- Reduce saltwater intrusion associated with tropical systems within sensitive estuarine systems
- Assist in the restoration and long-term sustainability of coastal wetlands that support important fish and wildlife resources within areas of national significance
- Restore and protect endangered species habitat.

3.1.1.2 Region 2 - Specific Problems and Opportunities

Problems / Opportunities

Coastal Storm Risk Management

Problems

- Populations are vulnerable to life safety from flooding due to close proximity to the coast
- Critical infrastructure including hurricane evacuation routes at risk of damage and closure due to storm events
- Local existing hurricane risk reduction system systems are increasingly at risk from storm damages due to RSLR
- Anthropogenic hydrologic alterations have reduced riverine inflows and overland flows, or adversely altered tidal flows and circulation

Opportunities

- Reduce economic damages from storm surge flooding to business, residents, and infrastructure in Matagorda and Calhoun County system
- In the city of Matagorda, increase the resilience existing Hurricane Flood Protection System (HFPS) from sea level rise and storm surge impacts
- Improve and restore coastal geomorphology along Matagorda Island, Matagorda Peninsula, and the Sargent Beach Area that contributes to reducing the risk of storm surge damages
- Reduce the susceptibility of public health and safety from storm surge impacts in the areas Matagorda and Calhoun County system

Ecosystem Restoration (ER)

Problems

- Anthropogenic hydrologic alterations have resulted in a loss of connectivity in the Matagorda Bay system and the San Antonio Bay system
- Storm surge erosion is degrading nationally significant migratory waterfowl and fisheries habitats in the Matagorda Bay System
- The GIWW is creating shoreline erosion and impacts tidal flow entering interior marshes. Erosion of bay shorelines and islands caused by wind and wakes is destroying estuarine marsh habitat and rookery islands

Opportunities

- Restore hydrologic connectivity in the Matagorda Bay system and the San Antonio Bay system
- In area of Matagorda Bay System improve migratory bird habitat, and critical threatened and endangered habitat
- Along the GIWW reduce the magnitude shoreline erosion to marshes and also reduce the magnitude of tidal flow entering interior marshes to prevent continuing wetland loss

- Loss of coastal marshes and bay shorelines on Barrier Island system and estuarine systems. Oyster reefs are at risk due to increasing salinities, predation and disease in addition to the pressures of harvesting
- Loss of beaches and dunes to erosion

- Improve sustainability of coastal marshes and bay shorelines on Barrier Island system and estuarine systems
- Restore size and quality beaches and dunes focusing on areas with existing high erosion rates

3.1.1.3 Region 3 – Specific Problems and Opportunities

Problems	Opportunities
Coastal Storm Risk Management	
• Populations are vulnerable to life safety from flooding due to close proximity to the coast • Critical infrastructure including hurricane evacuation routes at risk of damage and closure due to storm events • Threat to energy security and economic impacts of petrochemical supply-related interruption due to storm surge impacts • Changes in coastal geomorphology contribute to risk of storm surge damages	• Reduce economic damage from storm surge flooding to business, residents and infrastructure in the Rockport/Fulton and surrounding area • Reduce risk to critical infrastructure and evacuation routes (e.g., Interstate Highway 37 (I-37), I-35, and US 361) from storm surge flooding the area of Corpus Christi; Rockport/ Fulton and surrounding area • Reduce risk to public health and safety from storm surge impacts in the Rockport/Fulton and surrounding area • In the surrounding areas of Corpus Christi, improve energy security and reduce economic impacts of petrochemical supply-related interruption due to storm surge impacts • Improve and restore coastal geomorphology along Mustang and North Padre Island that contributes to reducing the risk of storm surge damages
Ecosystem Restoration (ER)	
• Loss of hydraulic connectivity between rivers, deltas, and bays due to construction of roadways, diversion canals, ship channels, and other manmade features	• Maintain hydrologic connectivity in the Nueces Delta, Aransas Delta, and in the Mesquite Bay system • Region wide improvement of migratory bird habitat, and critical T&E habitat

- Loss of migratory bird and other T&E species habitat due to storm surge and erosion
- Loss of ecosystem function within coastal bays and estuaries
- Loss of coastal marshes and bay shorelines on Barrier Island system and estuarine systems. Oyster reefs are at risk due to increasing salinities, predation and disease in addition to the pressures of harvesting
- The GIWW is causing shoreline erosion and impacting tidal flow entering interior marshes. Erosion of bay shorelines and islands caused by wind and wakes is destroying estuarine marsh habitat and rookery islands

- Improve coastal bays and estuaries with restoration of marshes and oyster reefs
- Improve/sustain coastal marshes and bay shorelines on Barrier Island system and estuarine systems
- Along the GIWW, reduce the magnitude of shoreline erosion to marshes and also reduce the magnitude of tidal flow entering interior marshes to prevent continuing wetland loss

3.1.1.4 Region 4 – Specific Problems and Opportunities

Problems	Opportunities
Coastal Storm Risk Management	
• Populations are vulnerable to life safety from flooding due their close proximity to the coast • Critical infrastructure including hurricane evacuation routes at risk of damage and closure due to storm events • Public health and safety risks due to storm surge impacts • Loss of natural regional sediment movement contributes to increased storm surge risk • Loss of natural coastal geomorphology, such as dune systems, contributes to the risk of storm surge damages	• Reduce economic damage from storm surge flooding to business, residents, and infrastructure in Port Isabel, Port Mansfield, and South Padre and surrounding areas • Reduce risk to critical infrastructure and evacuation routes from storm surge flooding in Port Isabel, Port Mansfield, and South Padre and surrounding areas • Reduce risk to public health and safety from storm surge impacts in the areas of Port Isabel, Port Mansfield, and South Padre and surrounding areas • Manage regional sediment so that it contributes to storm surge attenuation where feasible • Improve and restore coastal beach and dune systems along South Padre Island to reduce the risk of storm surge damages

Texas has some of the highest erosion rates in the Nation. Shores are retreating an average of 4 feet per year, with some areas experiencing losses greater than 30 feet per year. With million (2010 census data) people living in the 18 Texas coastal counties, nearly one- quarter of the State's population, coastal erosion is quickly placing communities, business, and infrastructure at an increased risk from coastal storm surges. Disrupted sediment supply, coastal development, and relative sea level rise (RSLR) also amplify shoreline retreat (Bureau of Economic Geology [BEG], n.d.).

Systemwide problems were first used to identify overall problems and opportunities. The specific coastwide problems identified for the Coastal Texas Study include problems related to:

- Coastal communities, including residential populations and the petrochemical industry, becoming increasingly vulnerable to life safety and economic risks due to coastal storm events
- Critical infrastructure throughout the region, including hurricane evacuation

routes, nationally significant medical centers, government facilities, universities, and schools becoming more at risk of damage from coastal storm events

- Existing HFPSs, including systems at Port Arthur, Texas City, and Freeport that do not meet current design standards for resiliency and redundancy will be increasingly at risk from storm damages due to RSLR and climate change
- Degradation of nationally significant migratory waterfowl and fisheries habitats, oyster reefs, and bird rookery islands within the study area occurring and increasing due to storm surge erosion, and
- Water supply shortages due to increasing conflicts between municipal and industrial water supply and the ecological needs of coastal estuaries and ecosystems

The specific coastwide opportunities identified for the Coastal Texas Study include the opportunity to:

- Provide CSRM alternatives to reduce the risks to public, commercial, and residential property, real estate, infrastructure, and human life
- Reduce the susceptibility of residential, commercial, and public structures and infrastructure to hurricane-induced storm damages
- Increase the reliability of the Nation's energy supply by providing alternatives that will potentially lessen damages to refinery infrastructure caused by coastal storm events
- Improve public education and awareness to coastal storm risk
- Restore the long-term sustainability of coastal and forested wetlands that support important fish and wildlife resources within the study area
- Restore the barrier island environments to promote long-term sustainability of the fish and wildlife resources that rely upon those ecosystems
- Improve the water quality in coastal waters through marsh and oyster reef restoration
- Use available sediment within the system beneficially
- Support programs that promote long-term erosion reduction of the Gulf coast and bay shorelines and limit erosion potential during future coastal storm events
- Protect threatened and endangered species habitat, and
- Improve ecotourism and recreational opportunities

3.2 PLANNING GOALS AND OBJECTIVES

The CSRM planning goals promote a sustainable economy by reducing the risk of storm damage to residential structures, industries, and businesses critical to the Nation's economy. The CSRM measures and alternatives were formulated to achieve National Economic Development (NED) principles and objectives.

The planning goals for ER sustainably reduce coastal erosion; restore fish and wildlife habitat, such as coastal wetlands, oyster reefs, beaches, and dunes; and evaluate a range of coastal restoration components to address a multitude of ecosystem problems. ER measures and alternatives were formulated to achieve National Ecosystem Restoration (NER) principles and objectives. Contributions to NER are increases in the net quantity and/or quality of desired ecosystem resources and are measured in the study area and nationwide.

The PDT developed planning objectives to apply to the entire study area over the 50-year planning horizon (2035–2085) (Table 1). Seven overall CSRM and five ER objectives were identified for meeting those planning goals.

Table 1 - Overall Coastal Texas Study Goals, Objectives and Metrics

Goals	Objectives	Metrics
COASTAL STORM DAMAGE RISK REDUCTION	1. Reduce economic damage from coastal storm surge to business, residents, and infrastructure along coastal Texas	Dollar damages reduced
Promote a sustainable economy by reducing the risk of storm damage to residential structures, industries, and businesses critical to the Nation's economy	2. Reduce risk to human life from storm surge impacts along coastal Texas	Population at Risk
	3. Improve energy security and reduce economic impacts of petrochemical supply-related interruption due to storm surge impacts	REMI dollar denominated economic losses reduced
	4. Reduce risks to critical infrastructure (e.g., medical centers, ship channels, schools, transportation, etc.) from storm surge impact	Number/proportion of critical infrastructure removed from risk
	5. Manage regional sediment, including beneficial use of dredged material from navigation and other operations so it contributes to storm surge attenuation where feasible	Yes / No – Achieves RSM / No

Goals	Objectives	Metrics
	6. Increase the resilience of existing hurricane risk reduction systems from sea level rise (SLR) and storm surge impacts; and	Yes / No – Increases resilience of existing hurricane risk reduction systems
	7. Improve and restore coastal geomorphic landforms that contribute to storm surge attenuation where feasible.	Yes / No - Improves & restores coastal geomorphic landforms
ECOSYSTEM RESTORATION	1. Restore size and quality of fish and wildlife habitats such as coastal wetlands, forested wetlands, rookery, oyster reefs, and beaches and dunes;	Net AAHUs
Promote a sustainable coastal ecosystem by minimizing future land loss, enhancing wetland productivity, and providing and sustaining diverse fish and wildlife habitats	2. Improve hydrologic connectivity into sensitive estuarine systems;	Yes / No - Improves hydrologic connectivity
	3. Reduce erosion to barrier island, mainland, interior bay, and channel shorelines;	Yes / No – Reduces erosion
	4. Create, restore, and nourish oyster reefs to benefit coastal and marine resources; and	Net AAHUs
	5. Manage regional sediment so it contributes to improving and sustaining diverse fish and wildlife habitat.	Yes / No – Achieves RSM / No

3.3 PLANNING CONSTRAINTS

Planning constraints limit plan formulation. Planning constraints in this project pertain to causing negative impacts to existing ecosystem resources and existing Federal projects. The planning constraints in this study are:

- Avoid or minimize negative impacts to threatened and endangered species and protected species.
- Induce no impact to authorized navigation projects. Avoid actions that negatively affect the ability of authorized navigation projects to continue to fulfill their purpose.
- No loss of risk reduction from existing coastal storm damage risk reduction projects.
- Avoid or minimize impacts to critical habitat, e.g., essential fish habitat (EFH).
- Minimize impacts to commercial fisheries.
- Avoid or minimize contributions to poor water quality.
- Minimize impacts to local hydrology. Hydrology regimes in the study area are sensitive to changes in flows and drainage patterns. The measures and alternatives will consider local hydrology impacts. Careful consideration should also be given to actions that could induce flooding inside and outside of systems.
- Avoid induced development, to the maximum extent practicable, that contributes to increased life safety risk. Public comments in scoping meetings reflected a concern that potential enclosed wetland areas would be opened in the future to urban development
- The Recommended Plan must consider the guidelines of the Coastal Barrier Resources System Act.

3.4 CRITICAL ASSUMPTIONS

Several critical assumptions were made characterize the FWOP and to develop model boundary conditions to compare and evaluate FWOP conditions:

- Storms will occur in a manner and frequency similar to those that have historically occurred. The FWOP anticipates that although the consequence of storms will increase under higher rates of RSLC, that the frequency and intensity of future storms will not change in the FWOP and that the wave climate will be similar to historic patterns.
- Relative sea level rise will continue and increase the impact of the storms. A range of RSLC is expected in the future, and it is the timing of the increase that is uncertain.
- Future development will continue in the study area, consistent with existing regulations. Once structure damage exceeds 50 percent of the structure value

(substantially damaged) the building will be rebuilt above regulated Base Flood Elevation (BFE).

- Maintenance of the navigation channels through the existing inlets (Bolivar Roads, Galveston Entrance Channel, and Gulf Intracoastal Water Way, Brazos Island Harbor) and in the back bay will continue, consistent with past practices to maintain navigation capabilities and that these ongoing efforts will not measurably alter the existing hydrodynamics of the inlets and bays. Past practices of beach and intertidal placement associated with dredging will continue.
- San Luis Pass will remain a natural inlet.
- Local interests will continue to maintain the beach and dune through the use of acceptable coastal management actions, subject to approval by permitting agencies. Beach and dune conditions will fluctuate over the next 50 years largely dependent upon the timing and intensity of storms, the regional sediment framework, and localized erosion hot spots.
- The breach at Rollover Pass on Bolivar Peninsula will be closed and remain closed over the 50-year period of analysis.
- Natural coastal landforms will continue to be lost in response to natural coastal processes. Study area habitats will change in the FWOP in response to numerous factors including ongoing natural succession (natural change in the vegetative communities), RSLC, coastal erosion and related erosion control
- activities, periodic over wash and breaching, as well as land and infrastructure development.
- It is expected that some non-Federal coastal risk management efforts will likely continue without federal participation.
- Disinvestment in areas in response to SLC and increased risk to life safety will be driven by regulatory measures and economic disincentives. Any structures in risk areas will be repurposed for short term uses to reap any economic return during low risk time frames, such as recreational uses and short-term rentals.

4 CONCEPTUAL PLAN DEVELOPMENT

A management measure is a feature or an activity that can be implemented at a specific geographic site to address one or more planning objectives. They can be used individually or combined with other management measures to form alternative plans. Measures were developed to address problems and to capitalize upon opportunities. The objective of the ecosystem restoration (ER) measures was to restore degraded ecosystem structure, function, and dynamic processes to a less degraded, more natural condition, while coastal storm risk management (CSRM) measures are proposed to reduce flood damage to property and infrastructure, and increase the resilience of coastal populations from storm surge damage. Measures were selected from a variety of sources including prior studies, the public scoping process, and professional judgment of the Project Development Team (PDT) and resource agencies. Some measures were investigated but screened from other recent study efforts such as the Sabine Pass to Galveston Bay Study. The initial list included 92 different measures across all 4 planning regions.

The conceptual plan development phase culminated in the Alternatives Milestone, where the Division and Headquarters Review Teams confirmed that a viable suite of measures and alternatives have been identified. The conceptual phase included qualitative evaluation and screening of measures against project objectives, study constraints, or the likelihood that the measure would duplicate effort of other agencies proposing restoration at that site.

Table 2 - Region 1 Initial Measures List

Count	Map ID	Type	**REGION 1 INITIAL MEASURES LIST**	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
1	B-1	CSRM (NED)	Ring Bayou, Chocolate Bayou Plants (S2G Measure 3-10.6), Brazoria County	Brazoria County and Local Industry	
2	B-2	ER (NER)	Gulf Beach and Dune Restoration – Follets Island (S2G Measure 5-11), Brazoria County	✓	✓
3	B-3	NED with NER (Qualitative impacts)	Gulf Beach and Dune B22 Restoration – Surfside Island (S2G Measure 5-12)	CEPRA and GOMESA	
4	B-4	ER (NER)	Gulf Beach and Dune Restoration – Quintana (S2G Measure 5-13)	CEPRA and GOMESA	
5	B-5	ER (NER)	Bastrop Bay Shoreline Protection	✓	✓

Count	Map ID	Type	REGION 1 INITIAL MEASURES LIST	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
			(S2G Measure 7-2), Brazoria County		
6	B-6	ER (NER)	GIWW Breakwaters (S2G Measure 6-6.1), Brazoria County	✓	✓
7	B-7	ER (NER)	GIWW Island Restoration (S2G Measure 6-6.2), Brazoria County	O&M	
8	B-8	NED with NER (Qualitative impacts)	Follets Island Road Raising (S2G Measure 4-2.3), Brazoria County	TxDOT and FHWA	
9	B-9	ER (NER)	Galveston Bay Estuary Program	RESTORE, NRDA	
10	B-10	ER (NER)	Oyster Reef Restoration, Galveston County	RESTORE, NRDA	
11	C-1 East Galveston	ER (NER)	Bay Shoreline Restoration (S2G Measure 7-1), Chambers County	CEPRA, GOMESA, and RESTORE	
12	G-1	NER with NED (Qualitative impacts)	Closure of Rollover Pass (S2G Measure 5-10), Galveston County	Specific State appropriations	
13	G-2	CSRM (NED)	Galveston Ring Levee (S2G Measure 3-9), Galveston County	✓	✓
14	G-3	CSRM (NED)	Risk Reduction Measure for West Galveston Bay Area (S2G Measure 4-1), Galveston and Harris counties	✓	✓
15	G-3-SSPEED	CSRM (NED)	Risk Reduction Measure for West Galveston Bay Area SSPEED Center H-GAPS proposal Galveston and Harris counties		
16	G-4	CSRM (NED)	Texas City Hurricane Flood Protection (HFP) System (S2G Measure 3-2),	✓	✓

Count	Map ID	Type	**REGION 1** **INITIAL MEASURES LIST**	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
			Galveston County		
17	G-5 East	NER with NED (Qualitative impacts)	Galveston County Gulf Beach and Dune Restoration (S2G Measures 5-6 and 5-8), Galveston County	✓	✓
18	G-5 West	NER with NED (Qualitative impacts)	Galveston County Gulf Beach and Dune Restoration (S2G Measures 5-6 and 5-8), Galveston County	✓	✓
19	G-6	NER with NED (Qualitative impacts)	Galveston Seawall Dune-Beach Restoration (S2G Measure 5-7), Galveston County	✓	✓
20	G-7	CSRM (NED)	Galveston Bay Coastal Barrier (S2G Measure 1), Galveston County	✓	✓
21	G-7- 1979-USACE-1-B	CSRM (NED)	Galveston Bay Coastal Barrier (S2G Measure 1), Galveston County	✓	✓
22	G-8	CSRM (NED)	Surge Gate and Barrier at Hartman Bridge (S2G Measure 2), Harris County (part of a greater Galveston Bay/Galveston County risk reduction system)	✓	✓
23	G-9	ER (NER)	Bolivar Island Marsh Restoration (S2G Measures 8-4.1 and 8-4.2), Galveston County	ER grants, O&M, CAP	
24	G-10	ER (NER)	Galveston Island Marsh Restoration (S2G Measures 8-7.1, 8-7.2, 8-7.3, 8-7.4, 8-7.5, 8-7.6, 8-7.7), Galveston County	RESTORE, NRDA	

Count	Map ID	Type	REGION 1 INITIAL MEASURES LIST	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
25	G-11	ER (NER)	West Bay Marsh Restoration (S2G Measures 8-6.1, 8-6.2, 8-6.3), Galveston County	RESTORE, NRDA	
26	G-12 East	ER (NER)	GIWW Breakwaters (S2G Measures 6-4.1, 6-5.1), Galveston County	✓	✓
27	G-12 West	ER (NER)	GIWW Breakwaters (S2G Measures 6-4.1, 6-5.1), Galveston County	✓	✓
28	G-13 East	ER (NER)	GIWW Island Restoration (S2G Measures 6-4.2, 6-5.2, 6-5.3), Galveston County	RESTORE, NRDA, CEPRA	
29	G-13 West	ER (NER)	GIWW Island Restoration (S2G Measures 6-4.2, 6-5.2, 6-5.3), Galveston County	RESTORE, NRDA, CEPRA	
30	G-14	ER (NER)	Oyster Reef Restoration, Galveston County	RESTORE, NRDA	
31	G-15	CSRM (NED)	Texas City Nonstructural Improvements	✓	✓
32	G-16	CSRM (NED)	Galveston Island (Developed Area) Nonstructural Improvements	✓	✓
33	G-17	CSRM (NED)	Galveston Island (Rural Area) Nonstructural Improvements		
34	G-18	CSRM (NED)	Bolivar Peninsula (Rural Area) Nonstructural Improvements		
35	G-19	CSRM (NED)	San Leon Nonstructural Improvements	✓	✓
36	G-20	CSRM (NED)	Bacliff/Bayview Nonstructural Improvements	✓	✓
37	G-20	CSRM (NED)	Kemah Nonstructural Improvements	✓	✓
38	G-22	CSRM (NED)	Seabrook Nonstructural Improvements	✓	✓

Count	Map ID	Type	**REGION 1** **INITIAL MEASURES LIST**	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
39	G-22	CSRM (NED)	La Porte Nonstructural Improvements	✓	✓
40	O-1	ER (NER)	GIWW Breakwaters (S2G Measure 6-1.1), Orange County	✓	✓
41	O-2	ER (NER)	GIWW Island Restoration (S2G Measure 6-1.2), Orange County	✓	✓
42	O-3	ER (NER)	Neches River Marsh Restoration (S2G Measures 8-1, 8-2, and 8-3), Orange County	RESTORE, NRDA	
43	J-1	ER (NER)	Gulf Shoreline Ridge Restoration (S2G Measure 5-3), Jefferson County	✓	✓
44	J-2	ER (NER)	Marsh Restoration, Jefferson County, Jefferson County	RESTORE, NRDA	
45	J-3	ER (NER)	GIWW Siphons (S2G Measure 9.2), Jefferson County	RESTORE, NRDA, Jefferson County	
46	RI-1	ER (NER)	Smith Point Island Rookery Island Restoration	RESTORE, NRDA, CEPRA	
47	RI-2	ER (NER)	Vingt et un Islands Rookery Island Restoration	RESTORE, NRDA, CEPRA	
48	RI-3	ER (NER)	Rollover Pass Rookery Island Restoration	RESTORE, NRDA, CEPRA	
49	RI-4	ER (NER)	Alligator Point Rookery Island Restoration	RESTORE, NRDA, CEPRA	
50	RI-5	ER (NER)	West Bay Bird Island Old Rookery Island Restoration	RESTORE, NRDA, CEPRA	
51	RI-6	ER (NER)	Syndey Island Rookery Island Restoration	RESTORE, NRDA, CEPRA	

Count	Map ID	Type	**REGION 1** **INITIAL MEASURES LIST**	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
52	RI-7	ER (NER)	Dooms Island Rookery Island Restoration	RESTORE, NRDA, CEPRA	
53	RI-8	ER (NER)	Jigsaw Island Rookery Island Restoration	RESTORE, NRDA, CEPRA	
54	RI-9	ER (NER)	Dooms Island Rookery Island Restoration	RESTORE, NRDA, CEPRA	
55	RI-10	ER (NER)	North Deer Island Rookery Island Restoration	RESTORE, NRDA, CEPRA	
56	RI-11	ER (NER)	Point Hunt Island Rookery Island Restoration	RESTORE, NRDA, CEPRA	
57	RI-12	ER (NER)	HGNC Evia Island Rookery Island Restoration	RESTORE, NRDA, CEPRA	

Table 3 - Region 2 Initial Measures List

Count	Map ID	Type	**REGION 2 INITIAL MEASURES LIST**	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
58	CA-1	CSRM (NED)	Beach/Dune Restoration at Indianola Beach	CEPRA, GOMESA	
59	CA-2	CSRM (NED)	Beach/Dune Restoration at Port O'Connor	SWG-O&M	
60	CA-3	ER (NER)	Matagorda Island Hydrologic Restoration (Texas Advisory Committee Workbook Region 2, #R2-44, GLO 2012)	RESTORE, NRDA, CEPRA	
61	CA-4	ER (NER)	Redfish Lake Restoration (Texas Advisory Committee Workbook Region 2, #R2-23, GLO 2012)	✓	✓
62	CA-5	ER (NER)	Keller Bay Restoration	✓	✓
63	CA-6	NER with NED (Qualitative impacts)	Indianola/Magnolia/Powderhorn Lake Shoreline Protection	✓	✓
64	CA-7	ER (NER)	Guadalupe River Delta Hydrologic Restoration/Breakwaters (Texas Advisory Committee Workbook Region 2, #R2-37 and R2-39; 2012).	✓	✓
65	M-1	ER (NER)	Dune/Beach Restoration Sargent Beach	✓	✓
66	M-2	ER (NER)	Mouth of Colorado to 3-Mile Cut Beach/ Dune Restoration	Matagorda County	
67	M-3	ER (NER)	Additional Restoration at Half Moon Bay Oyster Reef	RESTORE, NRDA, CEPRA	
68	M-4	ER (NER)	Dressing Point Island Rookery Restoration	NRDA	

Count	Map ID	Type	**REGION 2** **INITIAL MEASURES LIST**	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
69	M-5 (A)	ER (NER)	East Matagorda Bay Hydrologic Restoration	RESTORE, NRDA, CEPRA	
70	M-5 (B)	ER (NER)	Matagorda Bay – Small Scale Hydrologic Restoration	RESTORE, NRDA, CEPRA	
71	M-6	ER (NER)	Oliver Point Reef/Coon Island Bay Restoration	RESTORE, NRDA, CEPRA	
72	M-7	ER (NER)	Chester (formerly Sundown) Island Restoration	RESTORE, NRDA, CEPRA	
73	M-8	NER with NED (Qualitative impacts)	GIWW Mainland Breakwaters at Chinquapin BU Site	✓	✓
74	M-9	CSRM (NED)	Matagorda HFPS	✓	✓
75	VA-1	NER with NED (Qualitative impacts)	Log-jam Removal, Lower Guadalupe and San Antonio Rivers	Local priority	

Table 4 - Region 3 Initial Measures List

Count	Map ID	Type	**REGION 3 INITIAL MEASURES LIST**	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Development
76	A-1	ER (NER)	Oyster Reef Restoration in Copano Bay (Texas Advisory Committee Workbook Region 3, #R3-15, GLO 2012)	RESTORE, NRDA, CEPRA	
77	A-2	CSRM (NED)	Rockport/Fulton Beach Road Protection (Texas Advisory Committee Workbook Region 3, #R3-3, 4, 5, 6 and 7, GLO 2012)	CEPRA, GOMESA	
78	A-3	ER (NER)	Cedar Bayou and Vinson Slough Hydrologic Restoration	GOMESA,	
79	N-1	CSRM (NED)	North Padre Island Beach and Dune Restoration (Texas Advisory Committee Workbook Region 3, #R3-34 and 36, GLO 2012)	CEPRA, GOMESA	
80	N-2	ER (NER)	North Beach Restoration (Texas Advisory Committee Workbook Region 3, #R3-19, GLO 2012)	CEPRA, GOMESA	
81	N-3	ER (NER)	Nueces Delta Restoration-Breakwaters	✓	✓
82	N-4	ER (NER)	Shamrock Island Rookery Breakwaters	CEPRA, GOMESA	
83	N-5	ER (NER)	Nueces Delta Hydrological Restoration	✓	✓
84	R-1	ER (NER)	Aransas River Delta Marsh Restoration (Texas Advisory Committee Workbook Region 3, #R3-16, GLO 2012)	RESTORE, NRDA, CEPRA	
85	R-2	CSRM (NED)	Copano Bay Shoreline Restoration (Texas Advisory Committee Workbook Region 3, #R3-17, GLO 2012)	CEPRA, GOMESA	
86	SP-1	ER (NER)	Dagger and Ransom Islands Breakwaters	✓	✓

Table 5 - Region 4 Initial Measures List

Count	Map ID	Type	**REGION 4 INITIAL MEASURES LIST**	Carried Comprehensive Plan (Funding)*	Carried Forward for Plan Develop-ment
87	CM-1	CSRM (NED)	Adolph Thomae, Jr. Park Shoreline Protection (Texas Advisory Committee Workbook Region 4, #R4-1, GLO 2012)	CEPRA, GOMESA	
88	CM-2	ER (NER)	Bahia Grande Hydrologic Restoration	RESTORE, NRDA, CEPRA	
89	CM-3	ER (NER)	Bird and Heron Islands Shoreline Stabilization (Texas Advisory Committee Workbook Region 4, #R4-7, GLO 2012)	RESTORE, NRDA, CEPRA	
90	CM-4	ER (NER)	Three Islands Rookery Restoration (Texas Advisory Committee Workbook Region 4, #R4-11, GLO 2012)	RESTORE, NRDA, CEPRA	
91	CM-5	CSRM (NED)	South Padre Island Beach Nourishment	✓	✓
92	W-1	ER (NER)	Mansfield Island Rookery Restoration (Texas Advisory Committee Workbook Region 4, #R4-12, GLO 2012)	✓	✓

4.1 SCREENING OF MEASURES

Some measures that were included in the initial list of measures were screened after confirming that the initial problem statements were not significant enough to be addressed by the goals of study. For example, an initial problem identified coastal storm vulnerability in the area of Corpus Christi in Region 3. A detailed review of the structure inventory for the region confirmed that many of the structures were outside of the areas of high risk from surges or were elevated above these surge impacts (Figure 2). The more frequent surges impacted the upper and lower Texas coast.

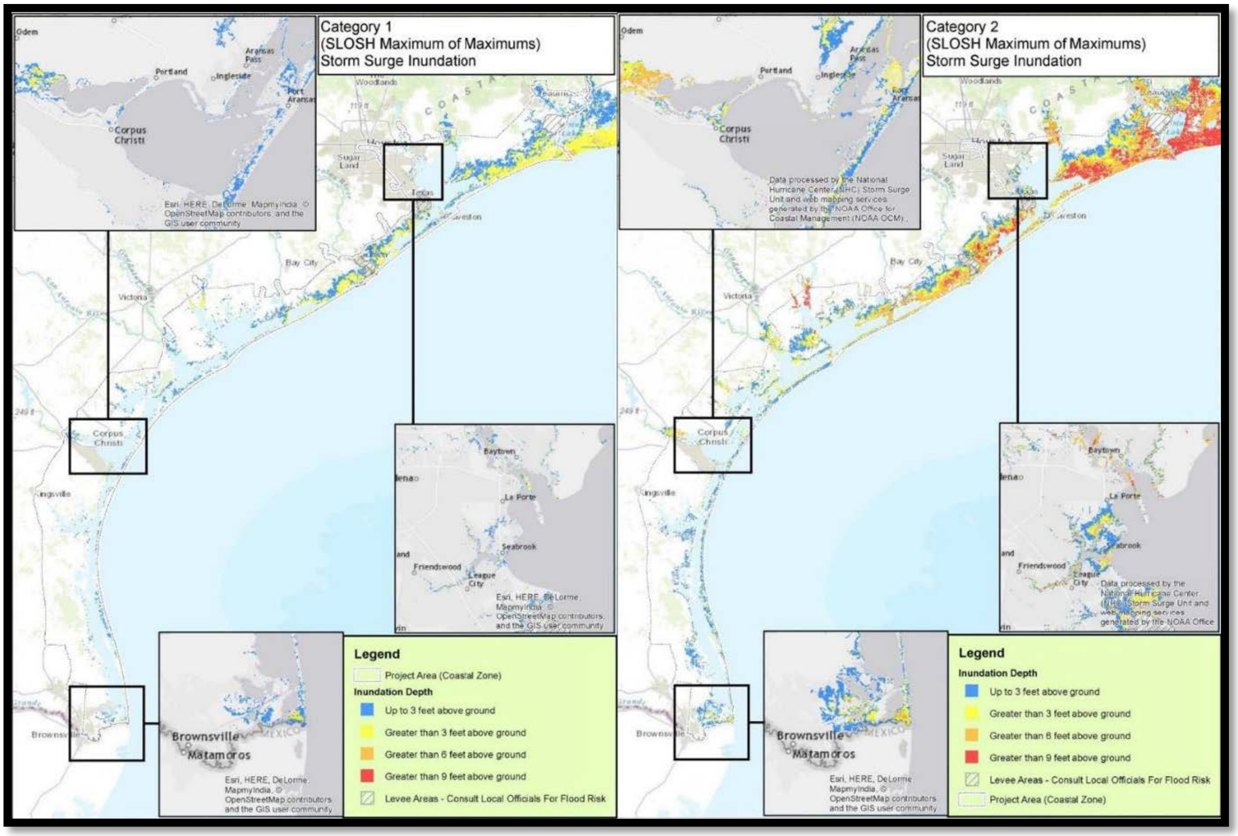

Figure 2 - Coastal Texas SLOSH Model Results

CSRM measures were revised after review of the current 100- and 500-year FEMA floodplains (Figure 3). The data showed some of the same results as the National Oceanic and Atmospheric Administration (NOAA) Sea, Lake and Overland Surges from Hurricanes (SLOSH) Models. Many structures in areas of Corpus Christi had limited risk from coastal storm surges due to their location in the coastal landscape or they had already been elevated above the frequent surge elevations. Ecosystem restoration problems objectives were revised after analysis of the historical shoreline erosion rates indicated that many areas are stable. Three primary areas with high erosion rates are evident (Figure 4 and Figure 5).

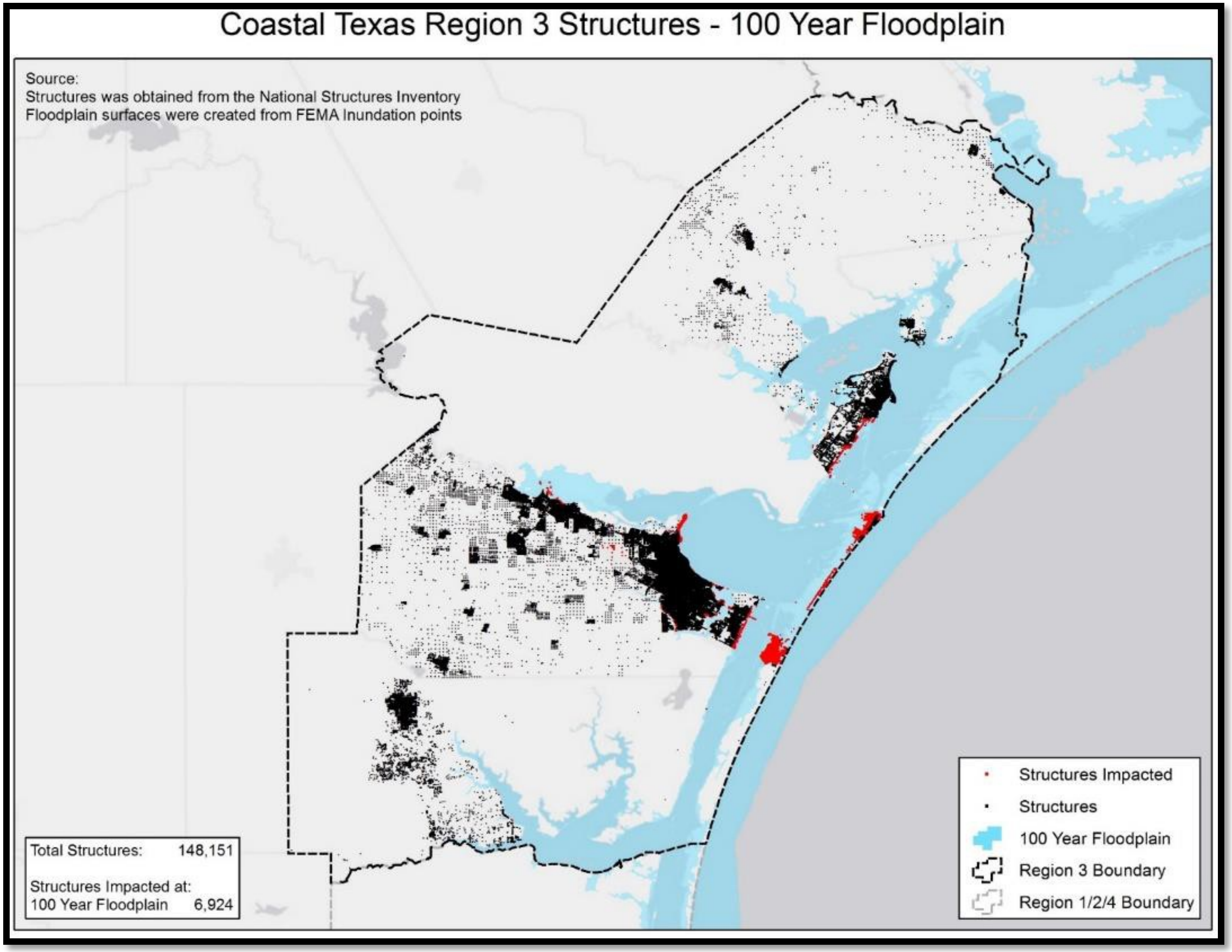

Figure 3 - Region 3 Structures and FEMA 100-year Floodplain

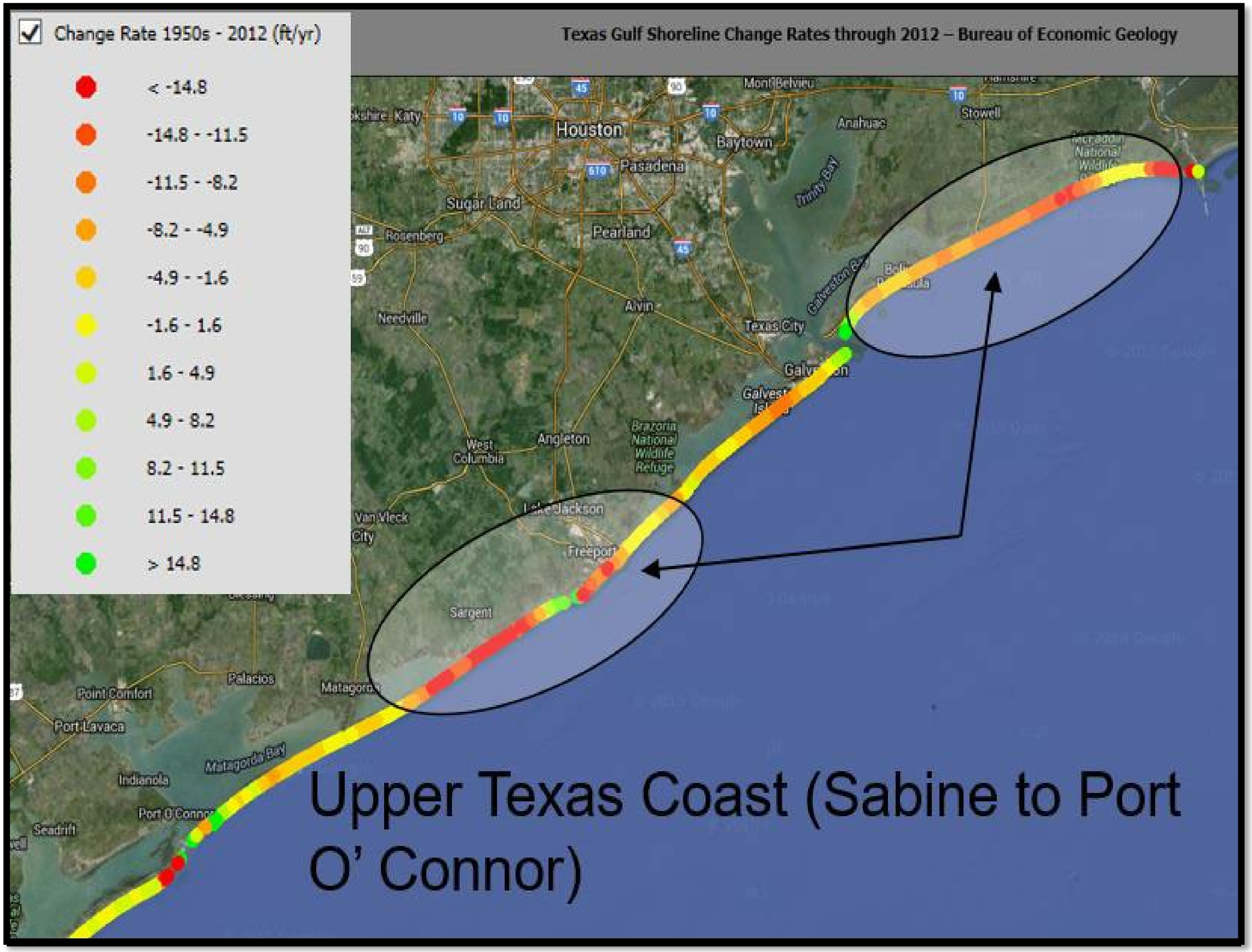

Figure 4 - Upper Texas Coast Shoreline Change Rates

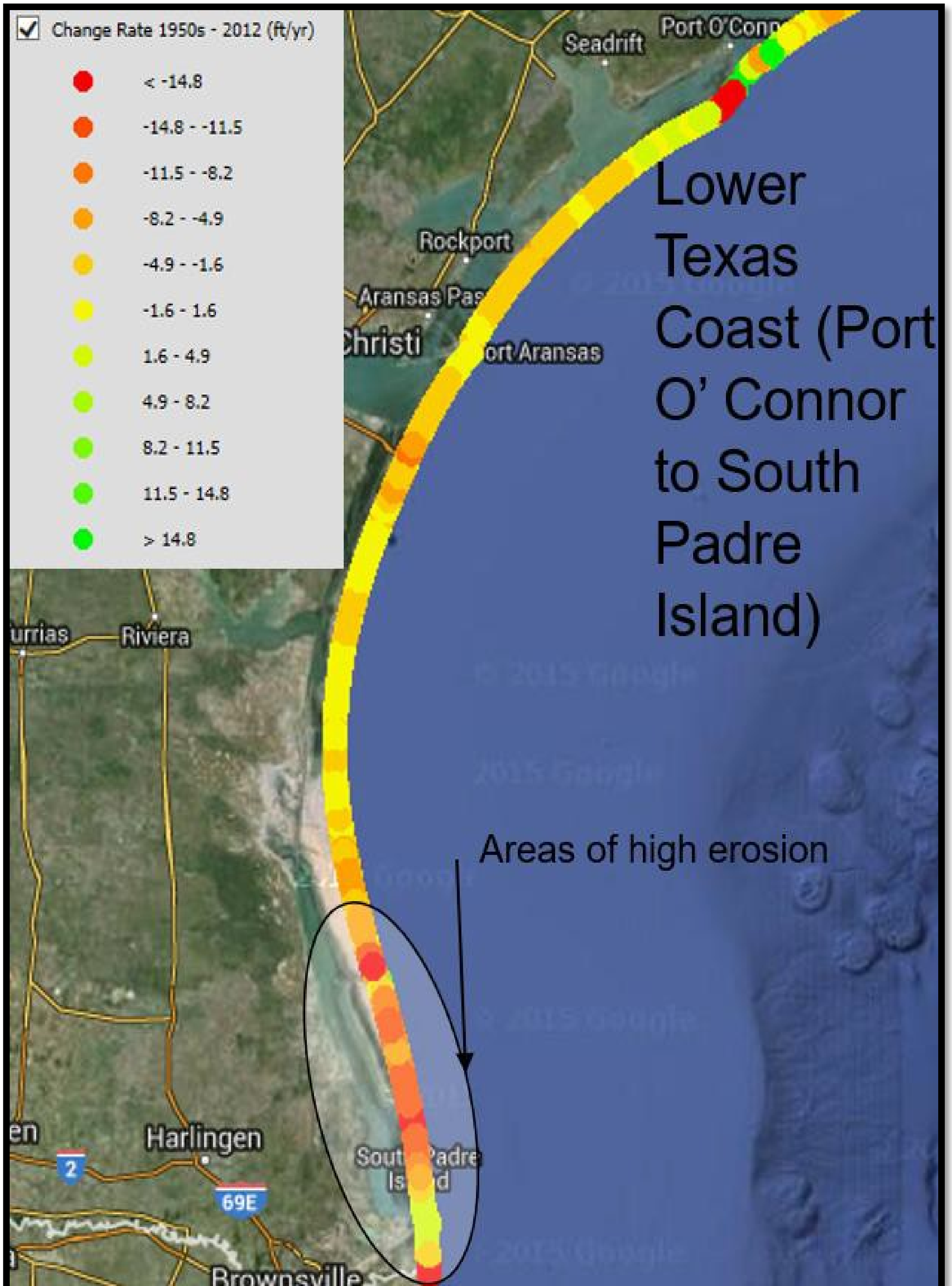

Figure 5 - Lower Texas Coast Shoreline Change Rates

Table 6 presents updates of the region-specific objectives based on information collected under the inventory and forecasting phase of the planning process.

Table 6 - Region 3 Specific Objectives

Title	Description	Changes to Description	Refinements
Objectives for CSRM (NED):			
Reduce Flood Damages	Reduce economic damage from storm surge flooding to business, residents and infrastructure in the area of Rockport/ Fulton and surrounding area	Reduce economic damage from storm surge flooding to business, residents and infrastructure in the area of Rockport/ Fulton and surrounding area	Limited Risk. Areas not included in final considerations
Life, Health, and Welfare (Facilities)	Reduce risk to critical infrastructure and evacuation routes (e.g., I- 37, Highway 35, and US 361) from storm surge flooding Corpus Christi; Rockport/ Fulton and surrounding areas	Reduce risk to critical infrastructure and evacuation routes (e.g. I- 37, Highway 35, and US 361) from storm surge flooding Corpus Christi; Rockport/ Fulton and surrounding areas	
Life, Health, and Welfare (Population)	Reduce risk to public health and safety from storm surge impacts in the area of Rockport/ Fulton and surrounding area	Reduce risk to public health and safety from storm surge impacts in the area of Rockport/Fulton and surrounding area	
Life, Health, and Welfare (Population/Facilities)	In the surrounding areas of Corpus Christi, improve energy security and reduce economic impacts of petrochemical supply-related interruption due to storm surge impacts	In the surrounding areas of Corpus Christi, improve energy security and reduce economic impacts of petrochemical supply-related interruption due to storm surge impacts	

Title	Description	Changes to Description	Refinements
Coastal Geomorphology	Improve and restore coastal landforms along Mustang and North Padre islands that contribute to reducing the risk of storm surge damages	Improve and restore coastal landforms along Mustang and North Padre islands that contribute to reducing the risk of storm surge damages	
Objectives for ER (NER):			
Hydraulic Connectivity	Restore hydrologic connectivity in the Nueces Delta, Aransas Delta, and in the Mesquite Bay system	Restore hydrologic connectivity in the Nueces Delta, Aransas Delta, and in the Mesquite Bay system	
Migratory Birds/ Rookery	Region-wide improvement to migratory bird habitat and critical T&E* habitat	Region-wide improvement to migratory bird habitat, and critical T&E habitat	
Estuary and Bay Habitat	Improve habitat quality in coastal bays and estuaries with restoration of marshes and oyster reefs	Improve habitat quality in coastal bays and estuaries with restoration of marshes and oyster reefs	
	Beaches and Dunes	Restore size and quality of beaches and dunes focusing on areas with existing high erosion rates	Restore size and quality of beaches and dunes focusing on areas with existing high erosion rates
	Sustainability of Barrier Islands and Estuaries	Improve/sustain sustainability coastal marshes and bay shorelines on barrier island system and estuarine systems	Improve/sustain sustainability coastal marshes and bay shorelines on barrier island system and estuarine systems

Title	Description	Changes to Description	Refinements
	Marshes	Along the GIWW, reduce the magnitude of shoreline erosion to marshes and also reduce the magnitude of tidal flow entering interior marshes to prevent continuing wetland loss	Along the GIWW, reduce the magnitude of shoreline erosion to marshes and also reduce the magnitude of tidal flow entering interior marshes to prevent continuing wetland loss

Figure 6 presents a flowchart overview of the process to refine the initial region-specific measures. A tiered decision process was applied to determine if measures would be carried forward.

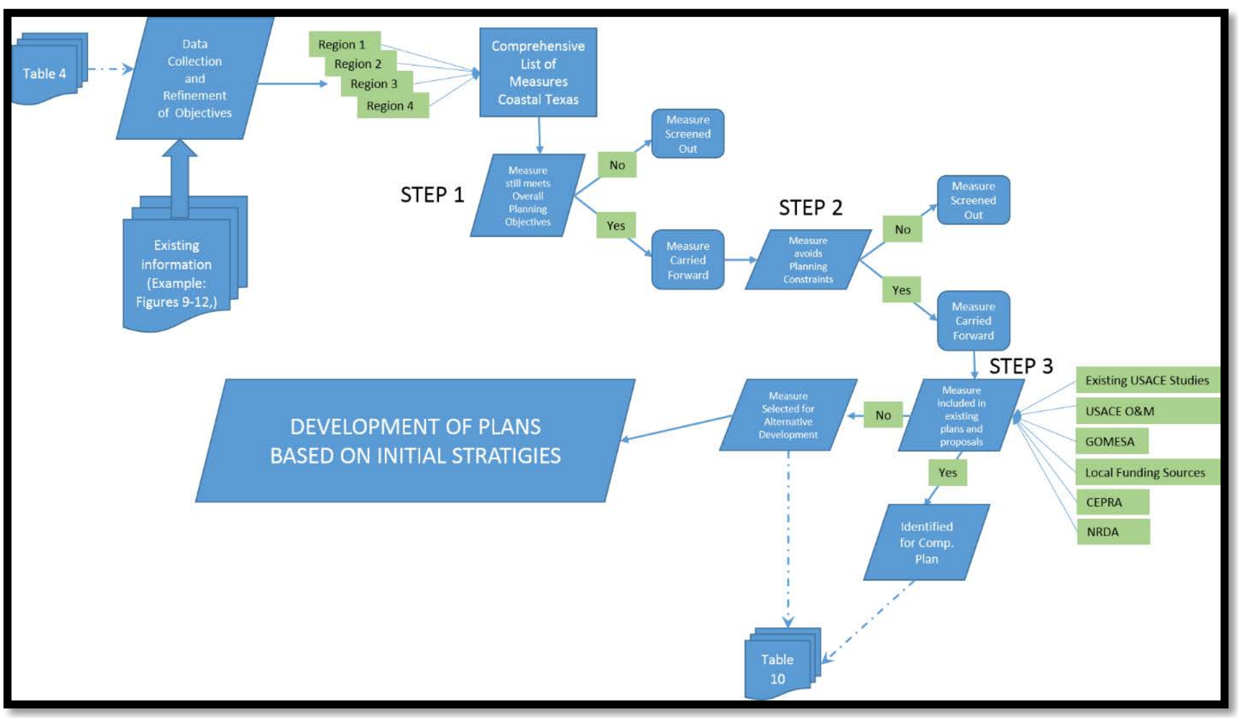

Figure 6 - Measure Screening Process

Table 7 through Table 10 indicate which measures were carried forward after the screening and provides a detailed list of the rationale used for the final screening. Several measures were screened out in the initial phases of formulation. Thirty-six measures remained to develop into alternative plans. Nine of the measures proposed non-structural actions to address flood prone properties.

Table 7 - Region 1 Remaining Coastal Texas Measures after Screening

Count	Map ID	Type	Description
1	B-2	ER (NER)	Gulf Beach and Dune Restoration – Follets Island (S2G Measure 5-11), Brazoria County
2	B-5	ER (NER)	Bastrop Bay Shoreline Protection (S2G Measure 7-2), Brazoria County
3	B-6	ER (NER)	GIWW Breakwaters (S2G Measure 6-6.1), Brazoria County
4	G-2	CSRM (NED)	Galveston Ring Levee (S2G Measure 3-9), Galveston County
5	G-3	CSRM (NED)	Risk Reduction Measure for West Galveston Bay Area (S2G Measure 4-1), Galveston and Harris Counties
6	G-4	CSRM (NED)	Texas City Hurricane Flood Protection (HFP) System (S2G Measure 3-2), Galveston County
7	G-5 East	NER with NED (Qualitative impacts)	Galveston County Gulf Beach and Dune Restoration (S2G Measures 5-6 and 5-8), Galveston County
8	G-5 West	NER with NED (Qualitative impacts)	Galveston County Gulf Beach and Dune Restoration (S2G Measures 5-6 and 5-8), Galveston County
9	G-6	NER with NED (Qualitative impacts)	Galveston Seawall Dune-Beach Restoration (S2G Measure 5-7), Galveston County
10	G-7	CSRM (NED)	Galveston Bay Coastal Barrier (S2G Measure 1), Galveston County
11	G-7- 1979-USACE-1-B	CSRM (NED)	Galveston Bay Coastal Barrier (S2G Measure 1), Galveston County
12	G-8	CSRM (NED)	Surge Gate and Barrier at Hartman Bridge (S2G Measure 2), Harris County (part of a greater Galveston Bay/Galveston County risk reduction system)

Count	Map ID	Type	Description
13	G-12 East	ER (NER)	GIWW Breakwaters (S2G Measures 6-4.1, 6-5.1), Galveston County
14	G-12 West	ER (NER)	GIWW Breakwaters (S2G Measures 6-4.1, 6-5.1), Galveston County
15	G-15	CSRM (NED)	Texas City Nonstructural Improvements
16	G-16	CSRM (NED)	Galveston Island (Developed Area) Nonstructural Improvements
17	G-19	CSRM (NED)	San Leon Nonstructural Improvements
18	G-20	CSRM (NED)	Bacliff/Bayview Nonstructural Improvements
19	G-20	CSRM (NED)	Kemah Nonstructural Improvements
20	G-22	CSRM (NED)	Seabrook Nonstructural Improvements
21	G-22	CSRM (NED)	La Porte Nonstructural Improvements
22	O-1	ER (NER)	GIWW Breakwaters (S2G Measure 6-1.1), Orange County
23	O-2	ER (NER)	GIWW Island Restoration (S2G Measure 6-1.2), Orange County
24	J-1	ER (NER)	Gulf Shoreline Ridge Restoration (S2G Measure 5-3), Jefferson County

Table 8 - Region 2 Remaining Coastal Texas Measures after Screening

Count	Map ID	Type	Description
25	CA-4	ER (NER)	Redfish Lake Restoration (Texas Advisory Committee Workbook Region 2, #R2-23, GLO 2012)
26	CA-5	ER (NER)	Keller Bay Restoration
27	CA-6	NER with NED (Qualitative impacts)	Indianola/Magnolia/Powderhorn Lake Shoreline Protection
28	CA-7	ER (NER)	Guadalupe River Delta Hydrologic Restoration/Breakwaters (Texas Advisory Committee Workbook Region 2, #R2-37 and R2-39; 2012)
29	M-1	ER (NER)	Dune/Beach Restoration Sargent Beach
30	M-8	NER with NED	

Table 9 - Region 3 Remaining Coastal Texas Measures after Screening

Count	Map ID	Type	Description
32	N-3	ER (NER)	Nueces Delta Restoration-Breakwaters
33	N-5	ER (NER)	Nueces Delta Hydrological Restoration
34	SP-1	ER (NER)	Dagger and Ransom Islands Breakwaters

Table 10 - Region 4 Remaining Coastal Texas Measures after Screening

Count	Map ID	Type	Description
35	CM-5	CSRM (NED)	South Padre Island Beach Nourishment
36	W-1	ER (NER)	Mansfield Island Rookery Restoration (Texas Advisory Committee Workbook Region 4, #R4-12, GLO 2012)

4.1.1 Assembly of Conceptual Alternative Plans

To assemble measures into alternatives, the PDT applied an overarching strategy similar to the North Atlantic Coast Comprehensive Study Coastal Storm Risk Management Framework. Increased coastal resilience and reduced vulnerability can be achieved by 1) instituting land use changes over time to adapt to impacts that increase risks; 2) accommodating potential changes such as climate variability, sea level change, etc. to preserve the natural and built environment over time; and 3) employing risk reduction measures to reduce flood damages to property and infrastructure. The development of alternative plans used the overall coastwide strategies to address the Texas coastal problems, however due to the scale of the Coastal Texas Study, not all of the strategies would work in all of the regions. Table 11 describes how the different strategies were used in different regions to begin to formulate plans based on the remaining measures listed in Table 7 through Table 10.

Table 11 - General Overview Proposed Formulation Strategies

Formulation Strategy Developed	Methodology for Strategy	Proposed Areas to Focus on
Multiple Lines of Defense	The strategy works on the well-founded premise that the Texas coast must be protected from hurricane surge by both man-made features, such as levees, and by the natural coastal wetland buffer along the Texas coast. Levees alone will not work. Together, a healthy coastal estuary and appropriately designed levees system can sustain Texas's ecology and economy of the coast.	Region 1 Region 3
Navigation Impacts	The strategy works on focusing ER measures on repairing or preventing future damages to the Texas coastal ecosystems from USACE navigation projects. The strategy focuses on areas of high land loss to wetlands from ship/barge wakes or from the disruption of freshwater or sediment flows.	All regions Focus on GIWW

Formulation Strategy Developed	Methodology for Strategy	Proposed Areas to Focus on
Resiliency	The strategy works on focusing ER measures that would provide resiliency to existing CSRM features or proposed CSRM features. The strategy also focuses on including nonstructural measures that would increase the resiliency of coastal communities.	All Regions, Galveston Island, Galveston Bay
Limited Impacts to Navigation	The strategy works on focusing on CSRM measures that would have limited impacts to existing navigation features.	Galveston Bay
Focus on Significant Resources	The strategy works on focusing on ER measures where they would restore protect key nationally significant migratory bird habitat, critical T&E species habitat, and critical EFH areas.	All Regions

The PDT combined the remaining management measures to develop a range of alternative plans based on the updated planning objectives, constraints, and ability to solve opportunities and problems. The following conceptual tiered approach shown in Figure 7 displays the process used to combine measures into plans.

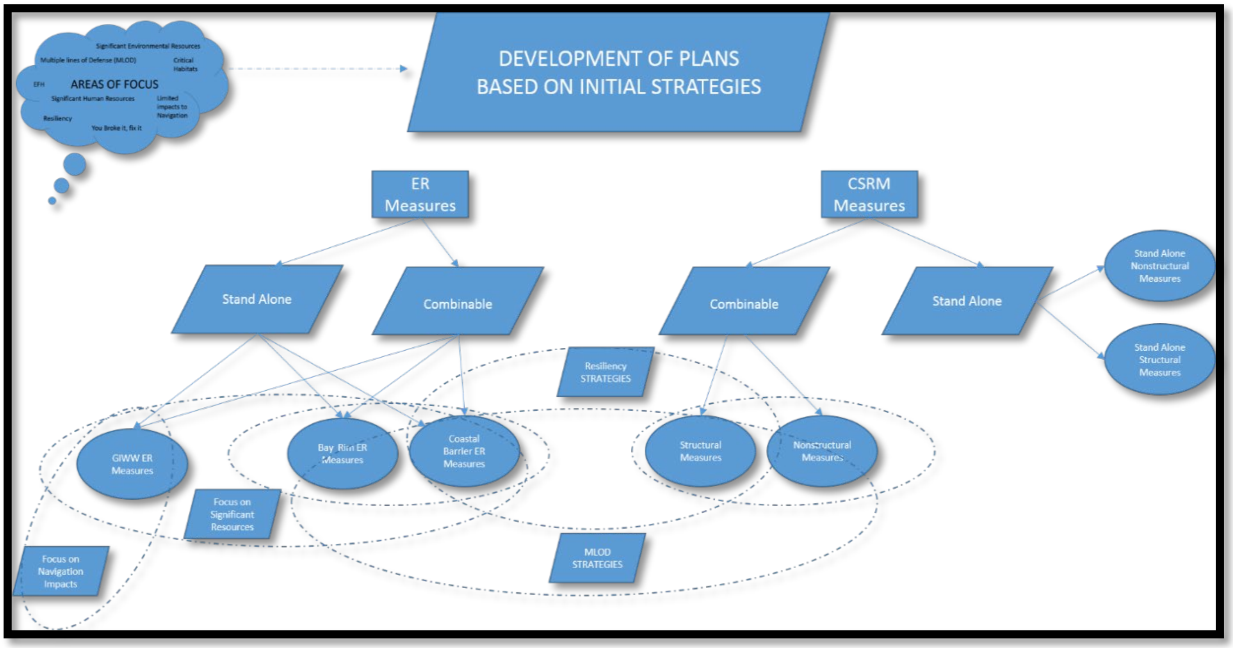

Figure 7 - Conceptual Approach for Developing Plans

4.1.1.1 Conceptual Alternative A – Coastal Barrier/Nonstructural System, and Maximize ER Benefits

A conceptual strategy was developed to focus on preventing storm surge from entering Galveston Bay with a barrier system across Bolivar Peninsula, a closure at Bolivar Roads, improvements to the Galveston seawall, and a barrier along the west end of Galveston Island. To address wind-driven surges in the bay, which could impact both Galveston Island and the upper reaches of the bay, nonstructural measures were added. The plan also addresses storm surge damages near South Padre Island and the city of Matagorda. This plan also includes all ER measures across the four regions to maximize ER benefits, regardless of cost. The plan provides some nexuses between ER and CSRM features by including beach and dune restoration between the Gulf and the Coastal Barrier CSRM, along Bolivar Peninsula and Galveston Island. The ER features should also increase the resiliency of the CSRM feature (Figure 8 through Figure 10).

Figure 8 - Conceptual Alternative A Region 1 Features

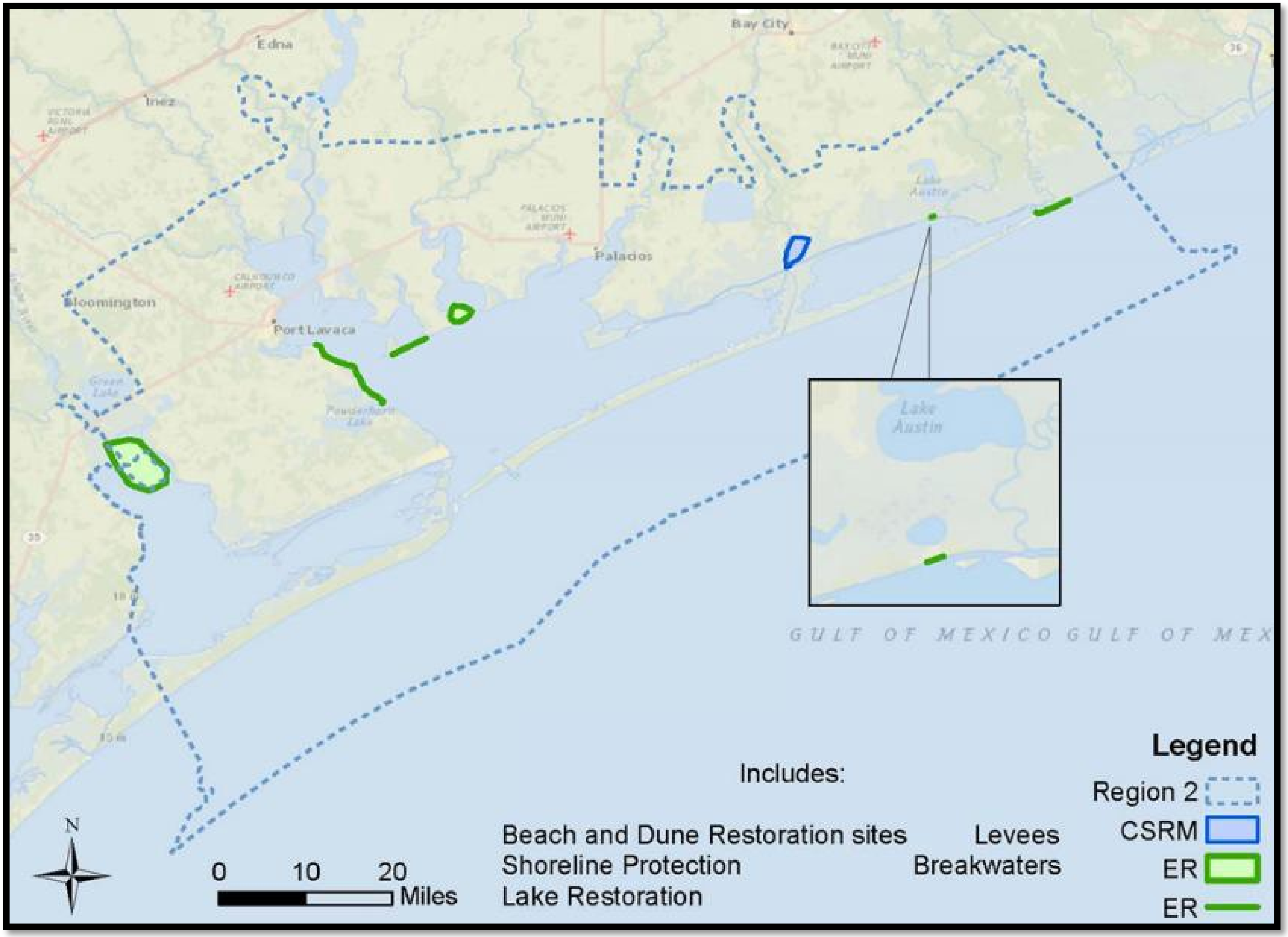

Figure 9 - Conceptual Alternative A Region 2 Features

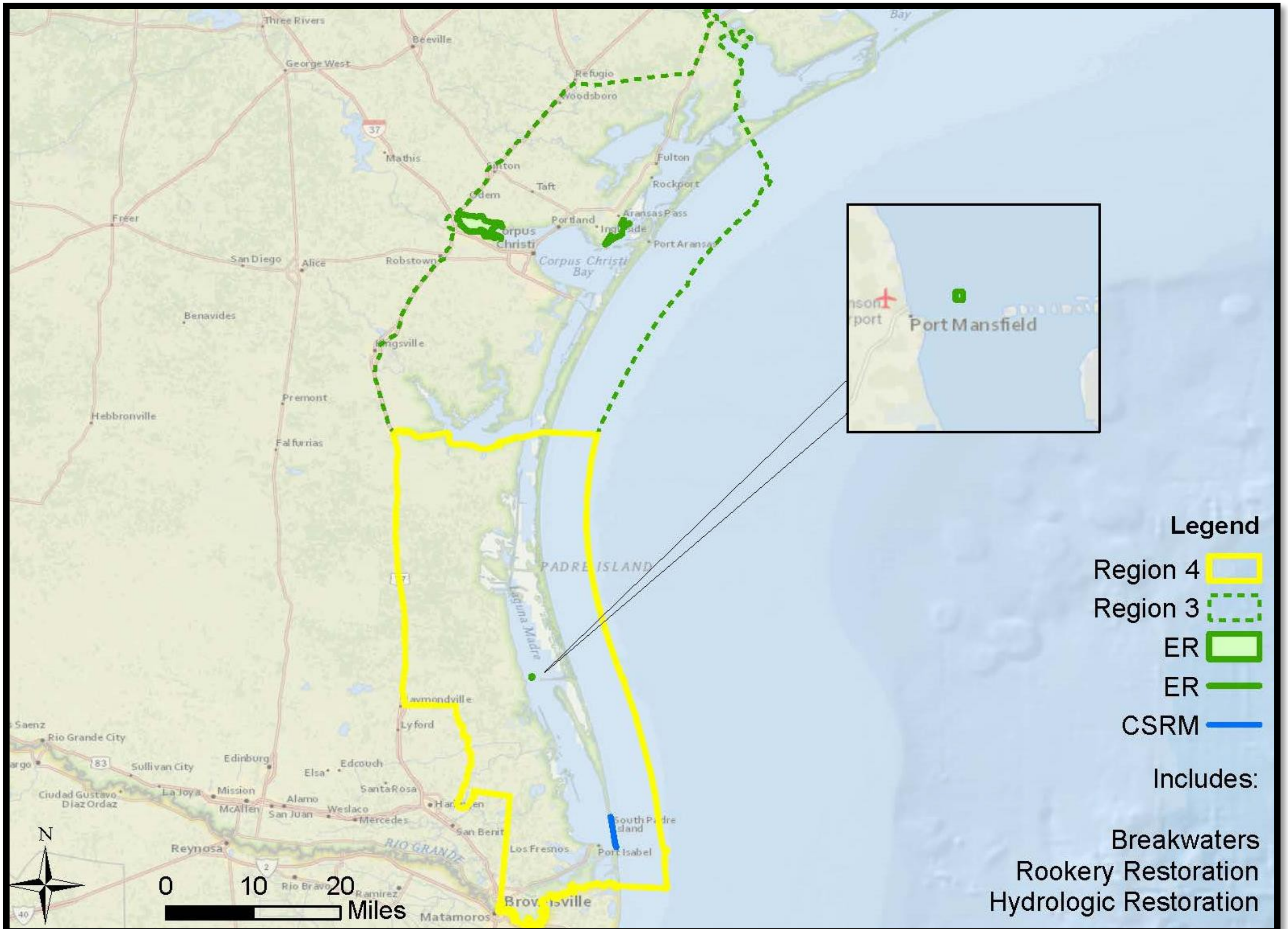

Figure 10 - Conceptual Alternative A Region 3 and 4 Features

4.1.1.2 Conceptual Alternative B – Coastal Barrier, and Maximize ER Benefits

For this conceptual alternative, a similar strategy was used as with Alternative A, but this plan only avoided the barrier islands and used existing landscape features such as the GIWW disposal dikes and the Texas City Dike as the coastal barrier (Figure 11). The plan addresses flooding on Galveston Island with a levee system or nonstructural improvement and addresses storm surge damages near South Padre Island and the city of Matagorda. Figures are not included for regions 2 through 4, since they included the same measures as Alternative A.

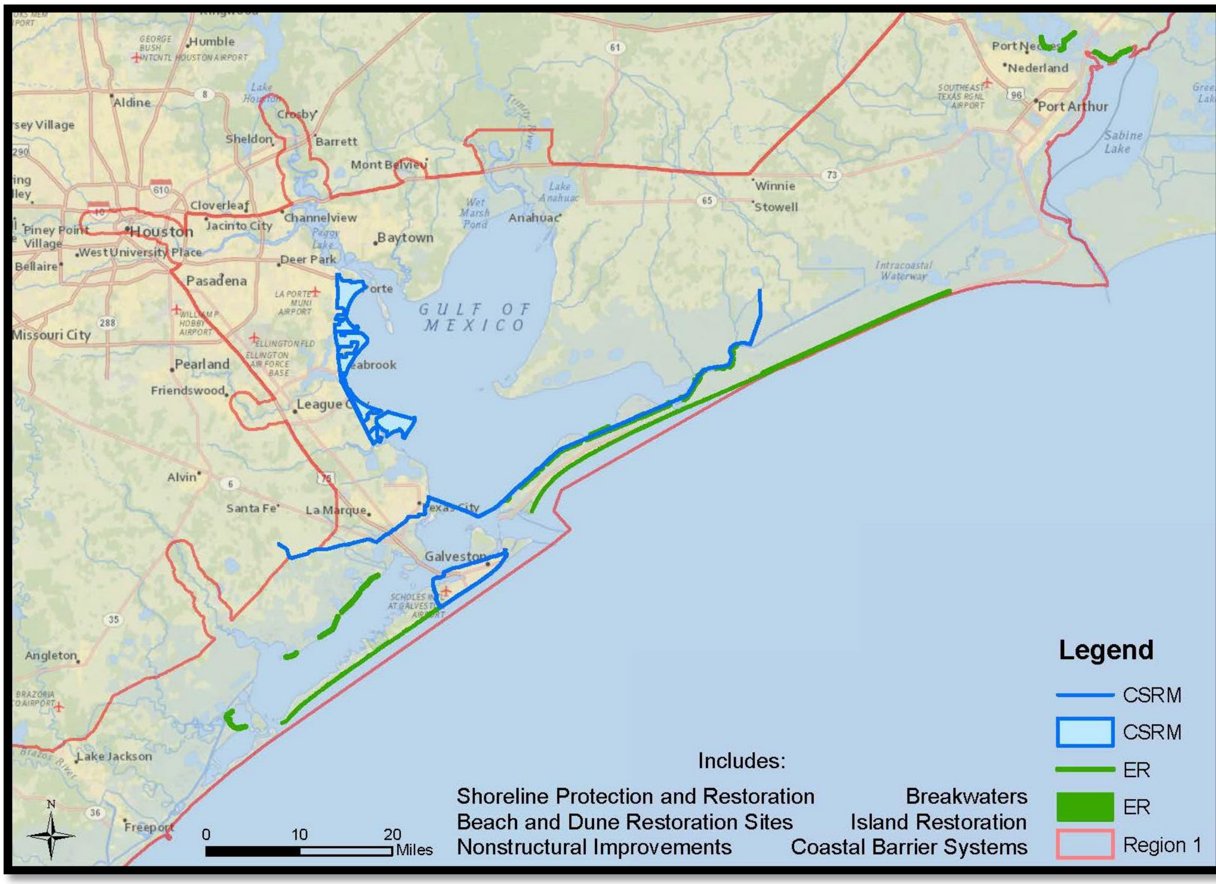

Figure 11 - Alternative B Region 1 Features

4.1.1.3 Conceptual Alternative C – Mid-Bay Barrier and Maximize ER Benefits

This conceptual strategy was developed to avoid some of the navigation impacts at Bolivar Roads by placing a surge barrier near the middle of Galveston Bay (Figure 12). The system would start on the east side of Galveston Bay near Smith Point, it would continue across the bay, crossing the ship channel, and tying into the existing Texas City Levee System. Improvements to this existing levee system would be included. The plan also addresses flooding on Galveston Island with a levee system. The plan does not address storm surge damages near South Padre Island and the city of Matagorda.

These portions are separable elements under conceptual alternatives A and B and could be added to this plan, if justified. This plan still focuses on including all ER measures across the regions to maximize ER benefits, regardless of cost. Figures for regions 2 through 4 are similar to Alternative A except that the South Padre Island and the city of Matagorda CSRM features have been removed.

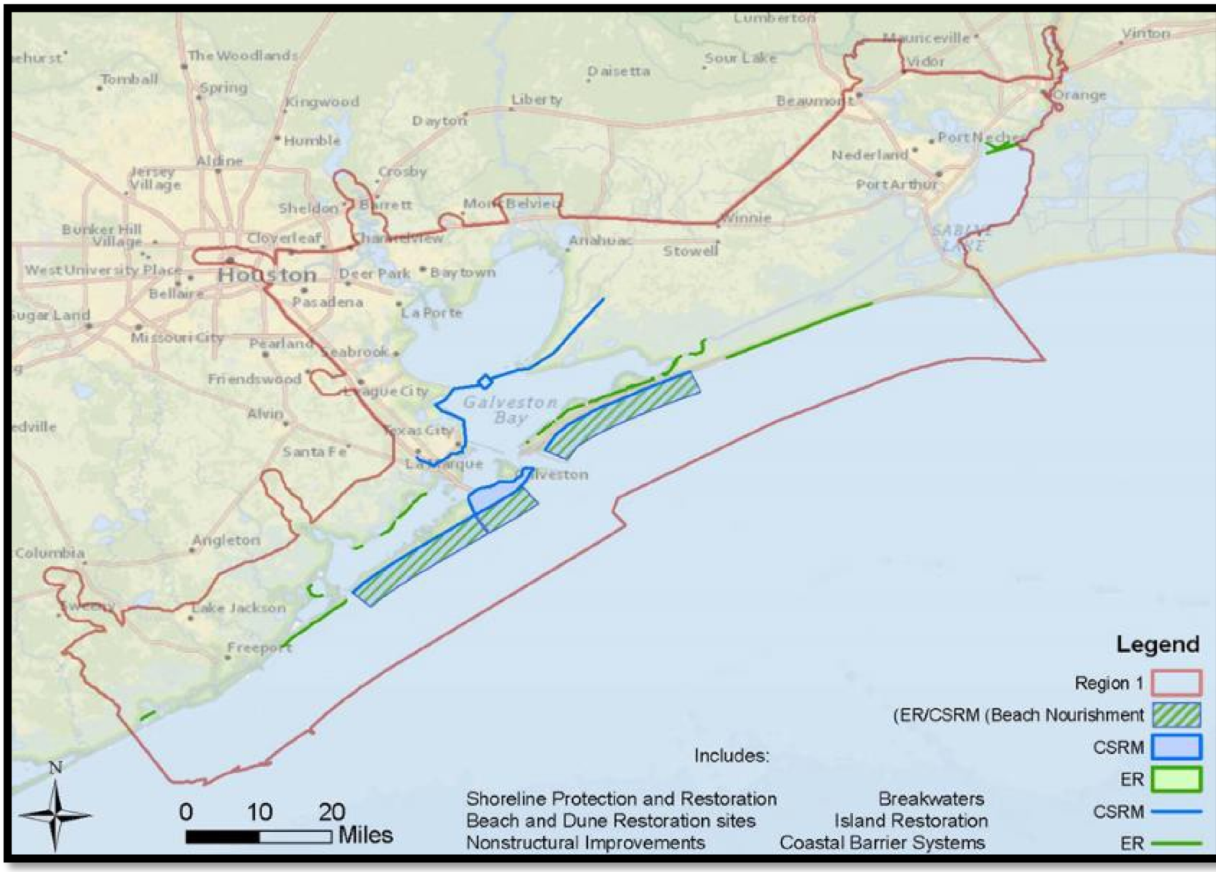

Figure 12 - Conceptual Alternative C Region 1 Features

4.1.1.4 Conceptual Alternative D – Upper Bay (SH 146) Nonstructural System and Maximize ER Benefits

This conceptual strategy was developed to potentially avoid all navigation impacts, by focusing on a levee system on the west side of Galveston Bay along SH 146 from Texas City to the Hartman Bridge (Figure 13). The levee system would be located such that there would be structures east of the levee outside of the system. Nonstructural measures have been formulated to address existing surges and any surges induced into the area by the levee system. The plan would eventually tie into the existing Texas City Levee System. Improvements to this existing levee system would also be included. The plan includes a surge gate and barrier at the Hartman Bridge; however, this is likely a separable element that will be evaluated for navigation impacts and benefit to the upper ship channel. The plan also addresses flooding on Galveston Island with a levee system, which rings the island. The plan does not address storm surge damages near South Padre Island and the city of Matagorda, but as with Alternative C, these portions are separable elements under conceptual alternatives A and B, and could be added to this plan, if justified. The plan still focuses on including all ER measures across the regions to maximize ER benefits, regardless of cost. Figures for regions 2 through 4 are similar to Alternative A except the CSRM features have been removed.

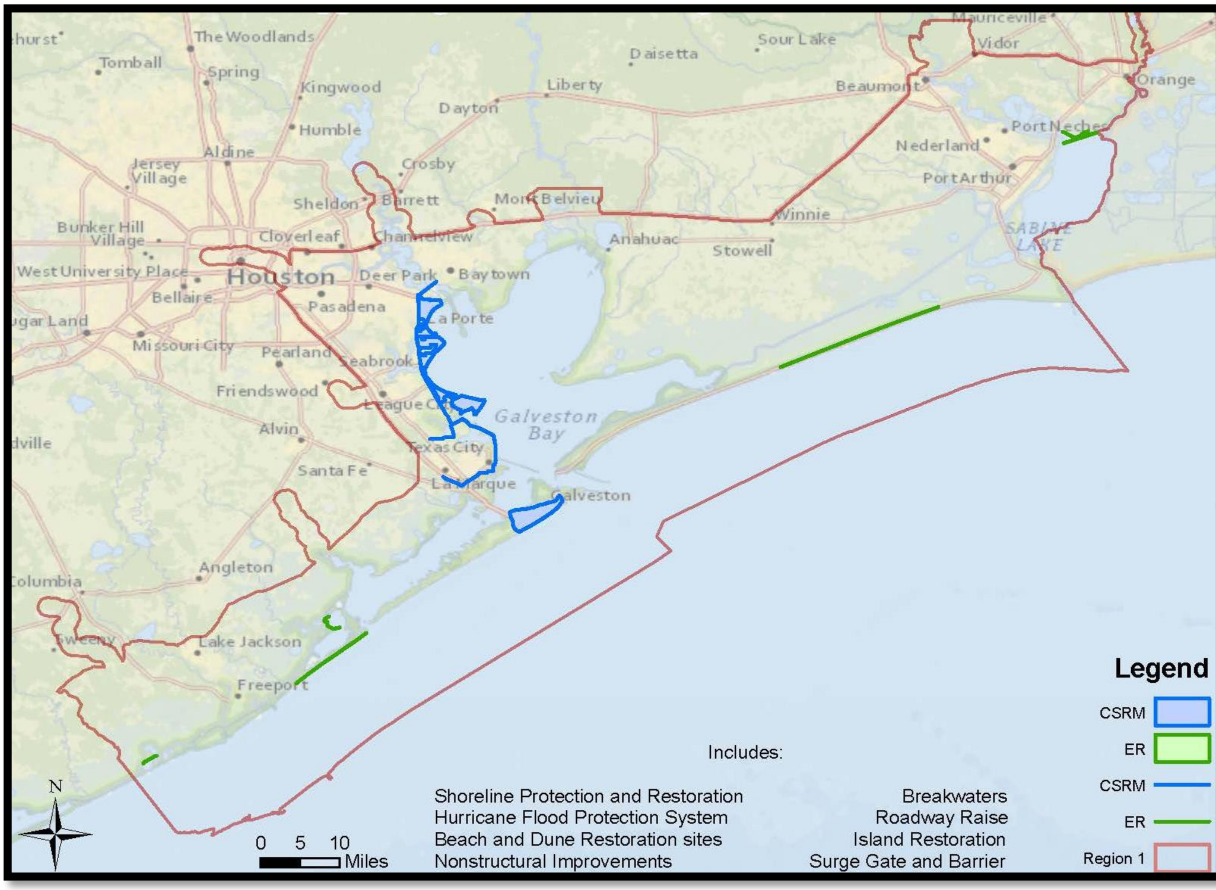

Figure 13 - Conceptual Alternative D Region 1 Feature

4.1.1.5 Conceptual Alternative E – Gulf Shoreline ER Focus

This conceptual plan focuses on maintaining the barrier island systems in regions 1, 2, and 4 (Figure 14 and Figure 15). This plan focuses on a beach and dune restoration measures to increase resiliency of barrier island systems and includes the CSRM feature in Region 4 associated with the incidental benefits for the South Padre Island Beach Nourishment measure.

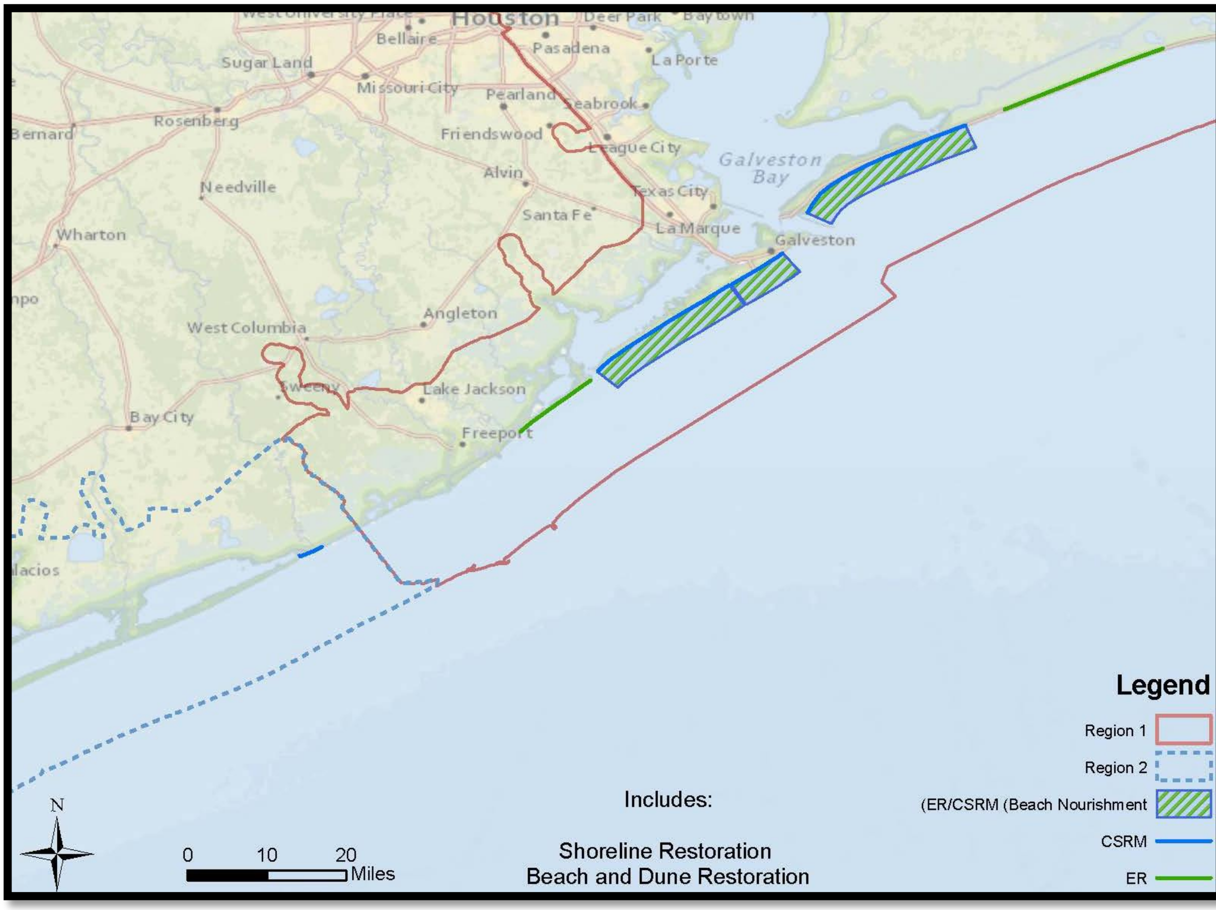

Figure 14 - Conceptual Alternative E Region 1 and 2 Features

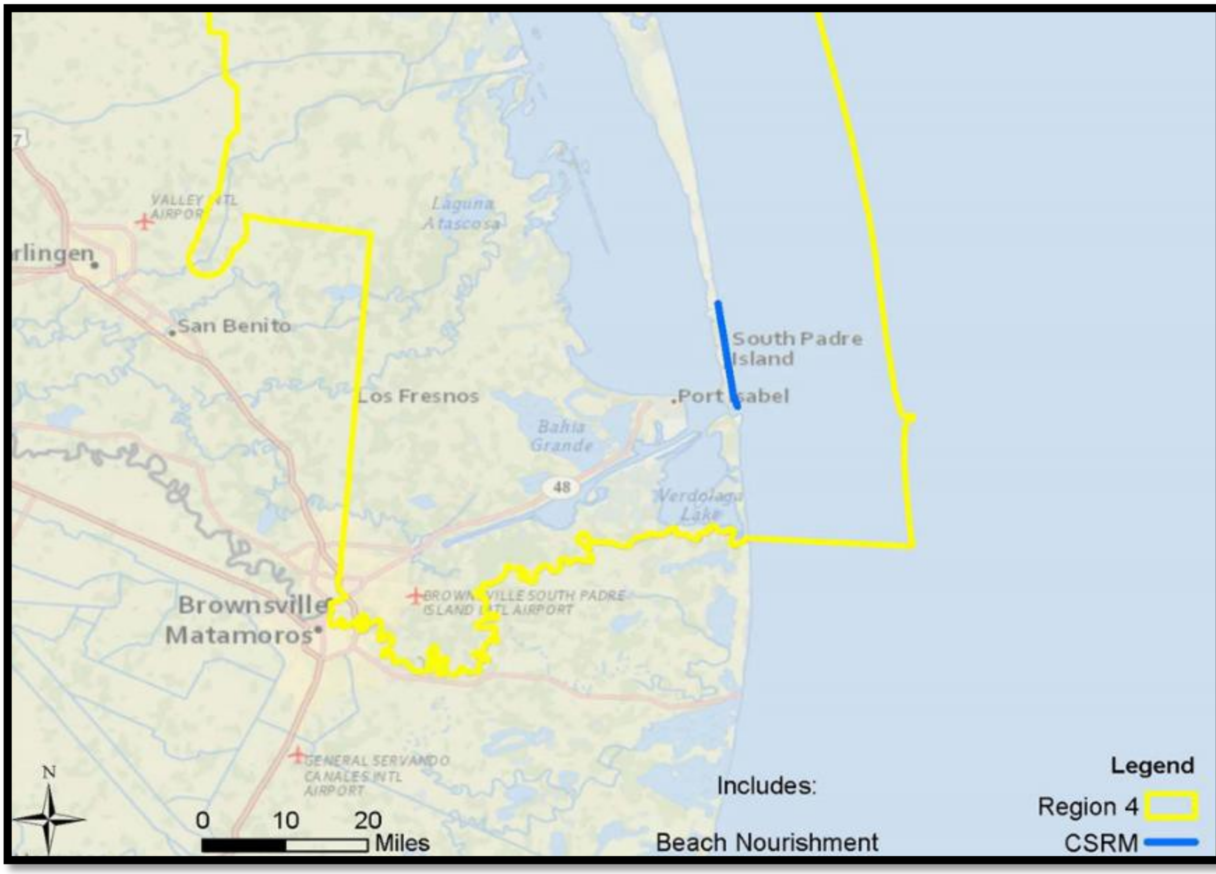

Figure 15 - Conceptual Alternative E Region 4 Features

4.1.1.6 Conceptual Alternative F – GIWW (Navigation Impacts) ER Focus

This conceptual plan focuses on addressing some of the historical navigation impacts across the Texas coast particularly along the GIWW (Figure 16 through Figure 18). The plan only includes measures along the GIWW to reduce the magnitude of shoreline erosion to marshes and tidal flow entering interior marshes.

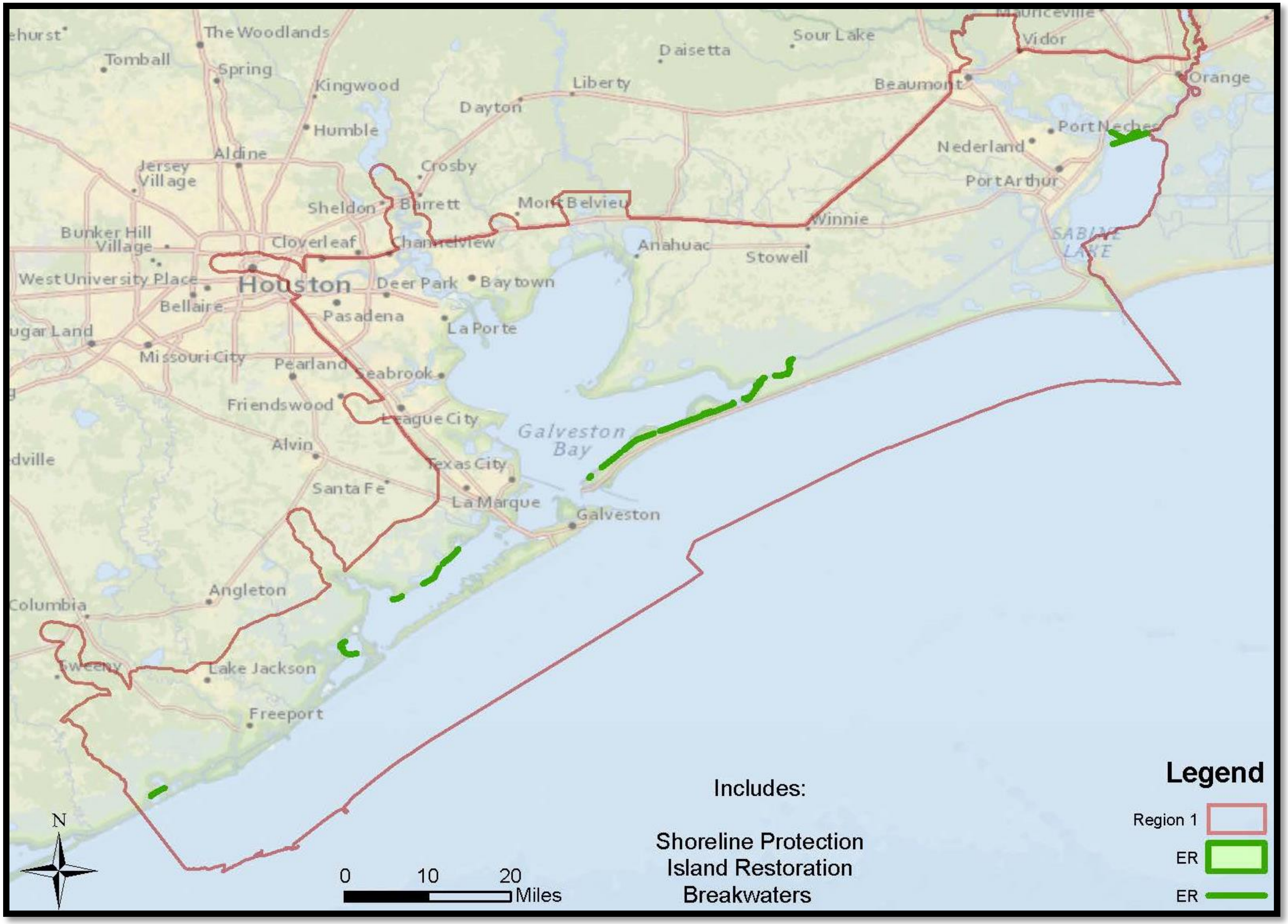

Figure 16 - Conceptual Alternative F Region 1 Features

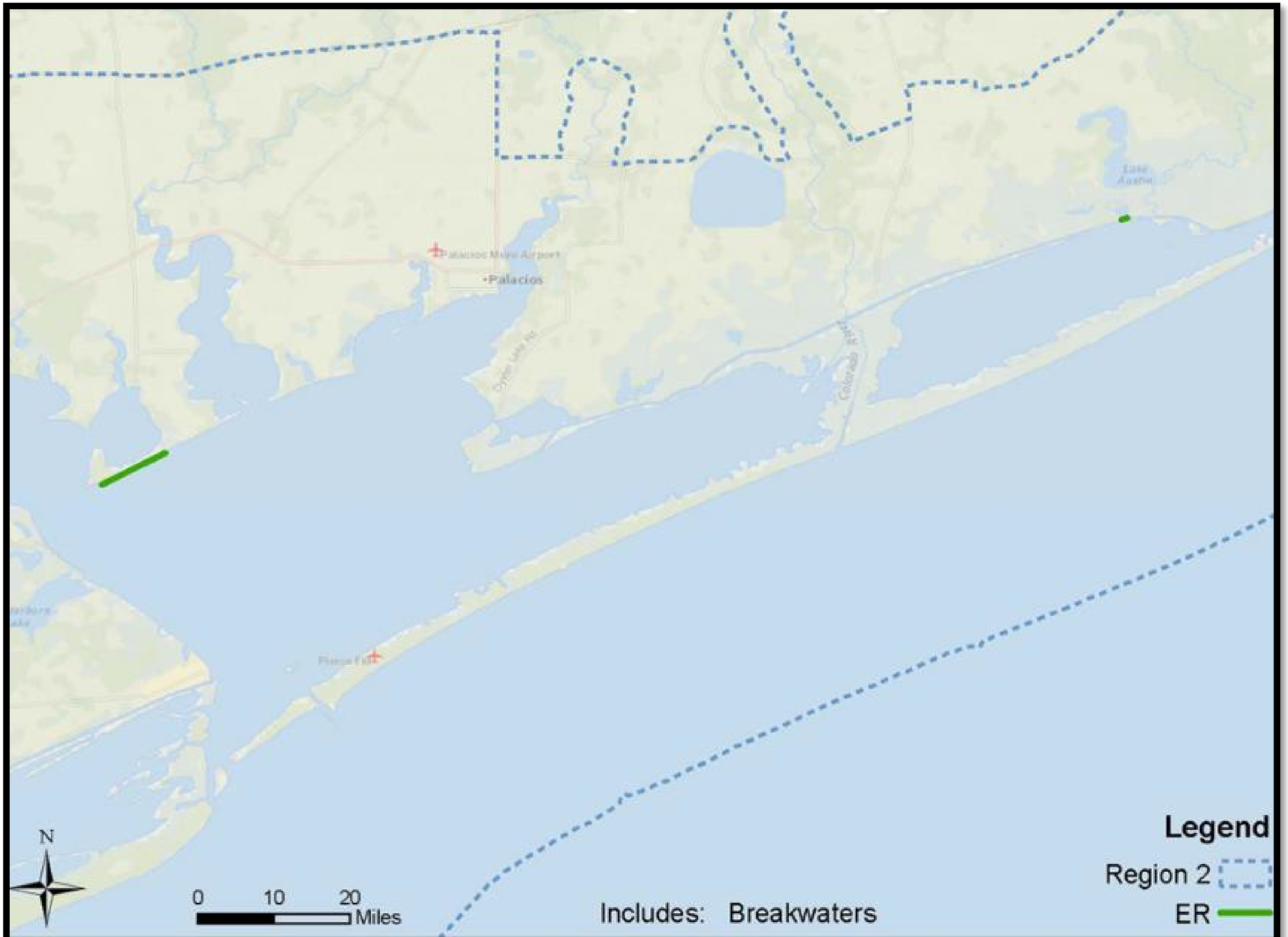

Figure 17 - Conceptual Alternative F Region 2 Features

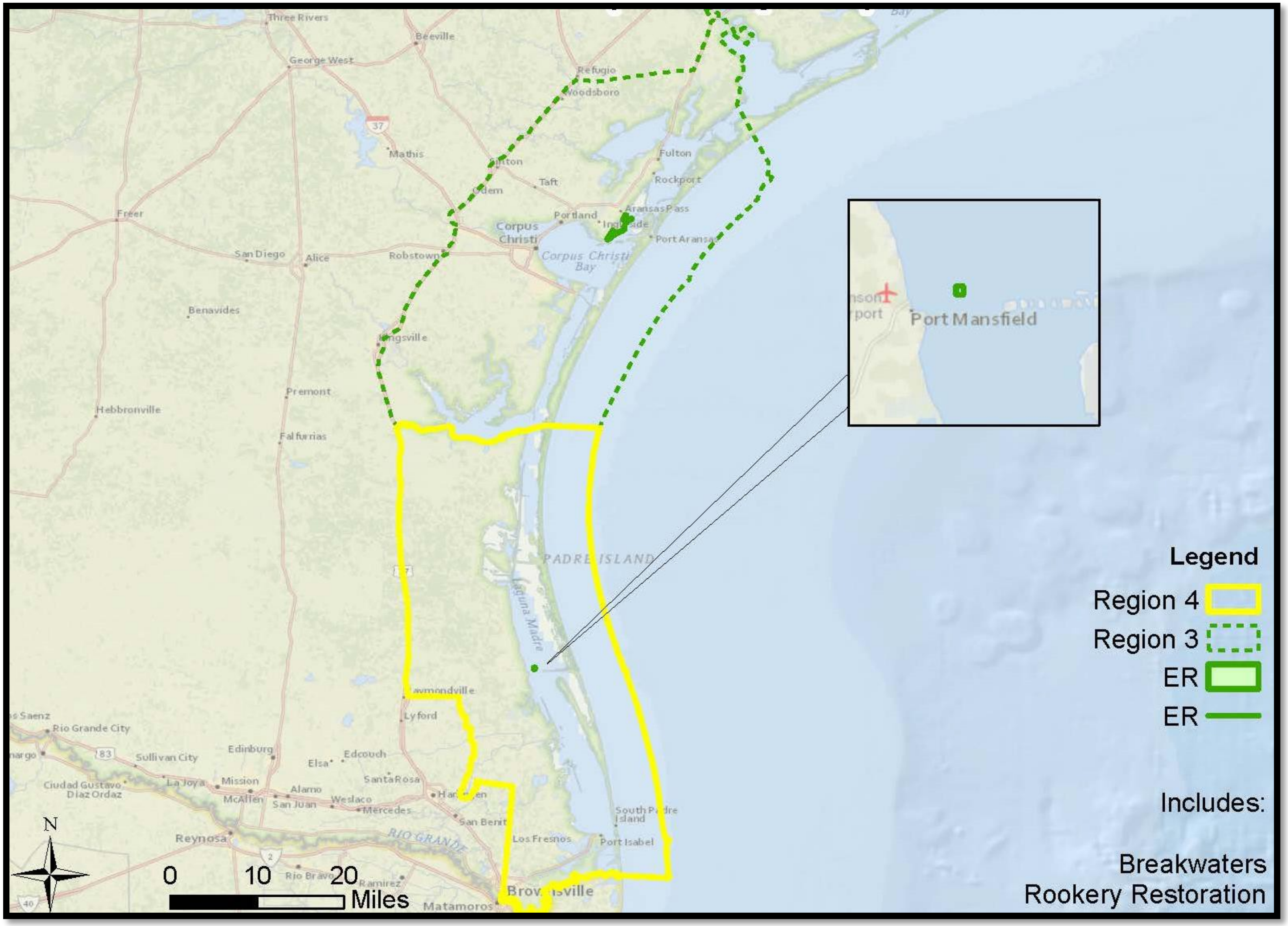

Figure 18 - Conceptual Alternative F Region 3 and 4 Features

4.1.1.7 Conceptual Alternative G – Upper Bays ER Focus

This conceptual plan focuses on addressing freshwater flows into the upper bay systems of the regions (Figure 19 and Figure 20). The plans intent is to improve hydrologic connectivity into sensitive estuarine systems around the upper bays. Galveston Bay and Coastal Bend Bays and Estuary are part of the U.S. Environmental Protection Agency's National Estuary Program and designated as an Estuary's of National Significance. Of all Texas bays, the Nueces Bay/Delta region is listed as "an unsound ecological environment" due to substantial alterations in freshwater reaching the bay and delta (Nueces River and Corpus Christi and Baffin Bays and Bay Expert Science Team [BBEST], 2011).

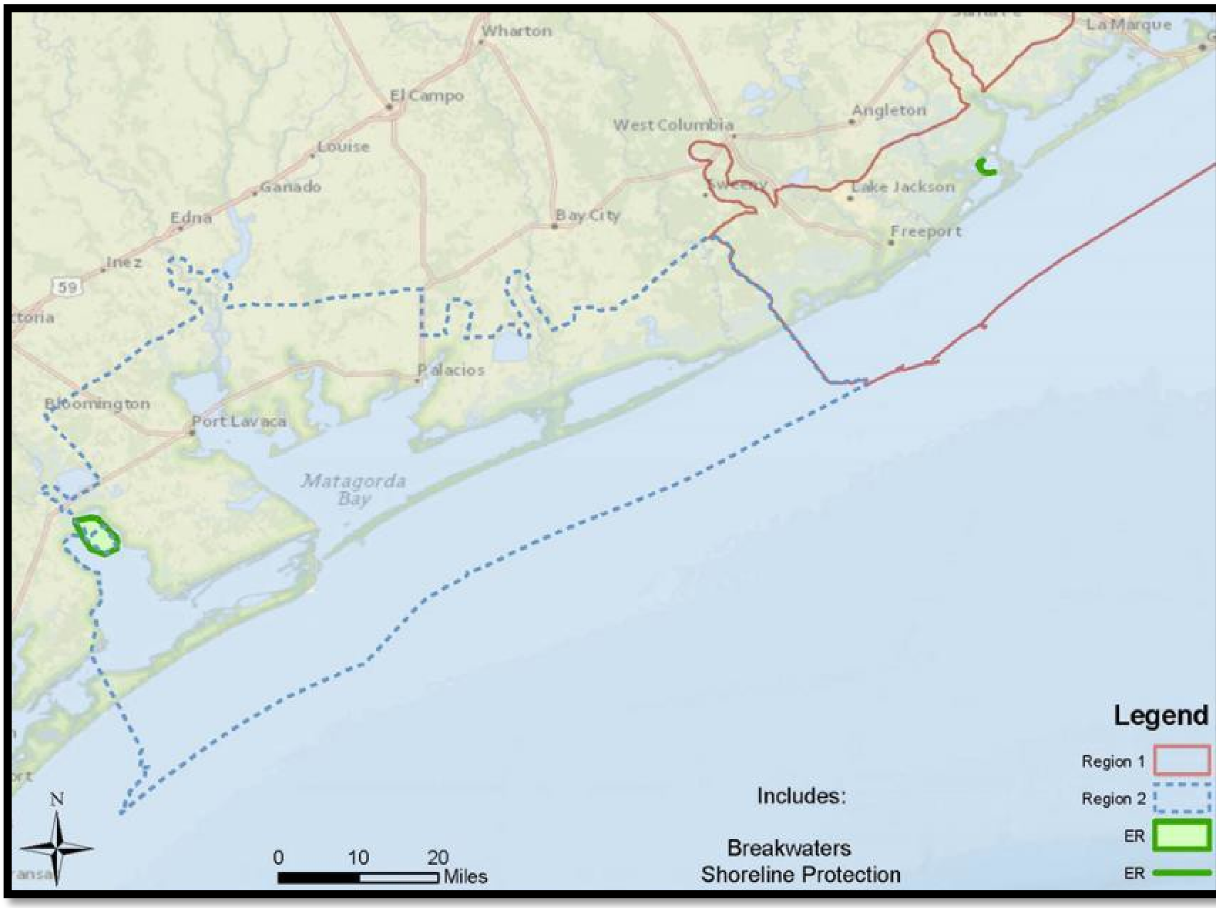

Figure 19 - Alternative G - Region 1 and 2 Features

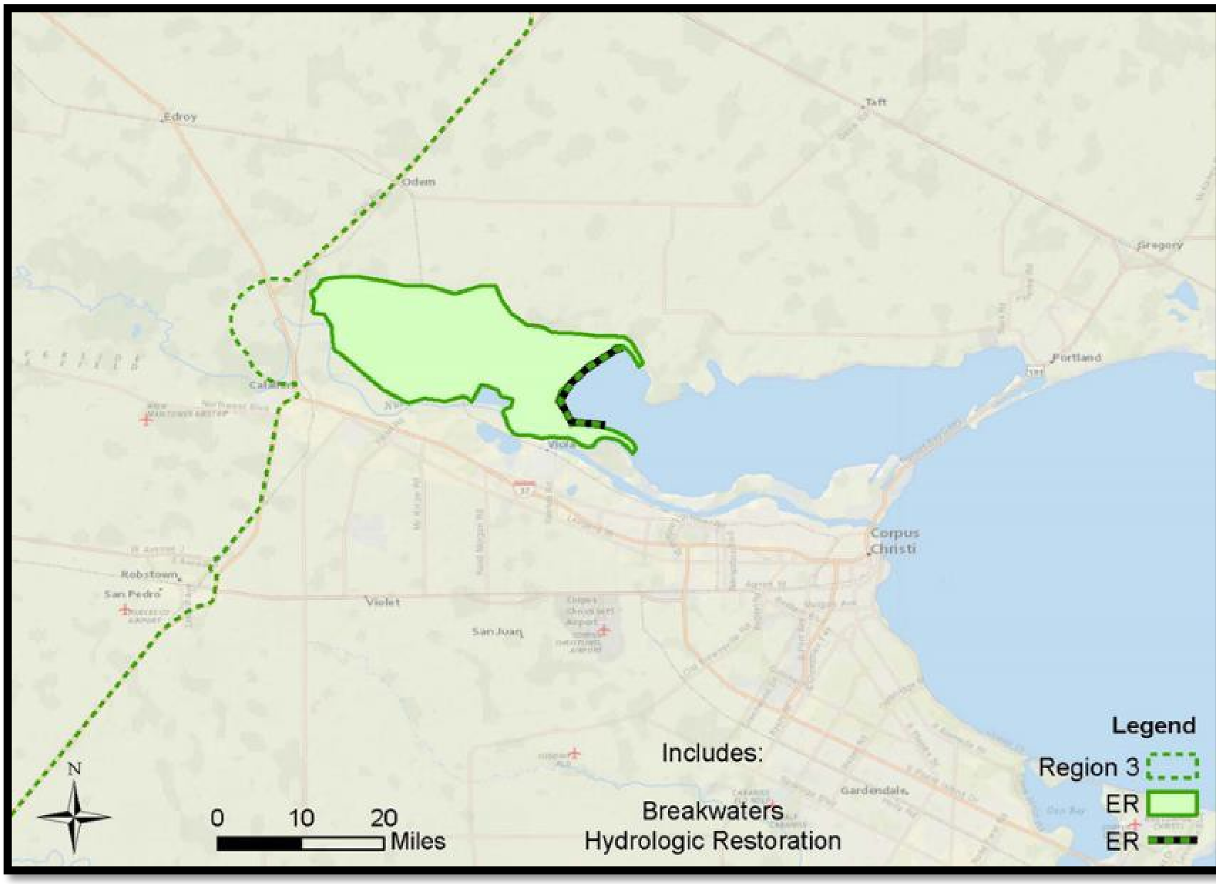

Figure 20 - Alternative G – Region 3 Features

4.2 TENTATIVELY SELECTED PLAN SELECTION PHASE

The second phase of plan formulation requires confirmation of cost-effectiveness and performance of each of the measures. Separate evaluation and comparison of the project features for storm risk management and ecosystem restoration is necessary. Quantitative comparisons require application of different metrics and models to characterize the without-project (baseline) condition and the performance of the with-project condition to identify the NED and NER Plans.

CSRM measures are quantified in dollar denominated metrics for performance, and ER measures are quantified in Average Annual Habitat Units (AAHUs), a metric that measures ecological lift in species-specific units. Both benefit streams require separate models for the distinct metrics, and due to the hydrologic separability of the CSRM features on the coast, they are also evaluated independently in different regions.

Nonstructural measures were also included in the evaluation. USACE policy requires that nonstructural measures be considered with other structural measures to create a comprehensive systems approach to risk reduction. Both a standalone nonstructural plan and nonstructural measures, which could function in combination with other risk-reducing structural measures to provide multiple lines of defense for the region were considered. While structural components of the system are intended to provide a reduction in damages from storm surges, a complementary system of nonstructural measures can also facilitate post-storm recovery in the event that the structural components are exceeded. Nonstructural measures could reduce the adverse consequences when storm flooding occurs. As a redundant feature, nonstructural measures contribute to management of the risk of interior flooding, whether from rainfall or from hurricane surge exceeding the channel capacity, levees, and floodwalls. An added benefit of this redundant system is found in the timing of implementation. Upon completion of the structural measures, the combined measures would provide redundancy to the risk reduction system.

Ecological modeling applies specific characteristics to measure improved performance for a representative species to quantify changes from the "without" to "with-project" condition as each feature is constructed and maintained.

The AAHUs allow Cost-effectiveness and Incremental Cost Analyses (CE/ICA) with a Corps approved model. Table 12 presents the transition from conceptual plans to individual CSRM and ER plans.

Table 12 - Overview of Evaluation Procedures for Alternative Plans

ID under Initial Formulation Process	Transformed Into	Carried Forward into Final Array* (NEPA)
No-Action Federal Action	No-Action Federal Action	✓
	Region 1: Standalone Nonstructural Plan	
Conceptual Alternative A	Region 1: Coastal Barrier with complementary system of nonstructural measures (Alternative A)	✓
	Region 2: City of Matagorda CSRM	
	Region 4: South Padre Island CSRM	✓
Conceptual Alternative B	Region 1: Coastal Barrier behind GIWW complementary system of nonstructural measures (Alternative B)	
Conceptual Alternative C	Region 1: Mid-bay Barrier Concept (Alternative C)	
Conceptual Alternative D	Region 1: SH 146 Barrier Alignment (Alternative D1)	
	Region 1: Bay Rim Barrier Alignment (Alternative D2)	✓
Conceptual	ER Measures evaluated under ecological	

ID under Initial Formulation Process	Transformed Into	Carried Forward into Final Array* (NEPA)
Alternatives E, F, and G	modeling and analysis followed by CE/ICA. This process led to 6 alternatives listed below: • Alternative 1: Coastwide All-Inclusive Restoration • Alternative 2: Coastwide Restoration of Critical Geomorphic Features • Alternative 3: Coastwide Barrier System Restoration • Alternative 4: Coastwide Bay System Restoration • Alternative 5: Coastwide ER Contributing to Infrastructure Protection • Alternative 6: Top Performers	✓

4.2.1 Development and Evaluation of Region 2 Alternative Plans – City of Matagorda CSRM

Matagorda flooding was included on the list of problems and opportunities within Region 2. The Matagorda Hurricane Flood Protection Project (HFPP) is a Federally authorized, non- Federally operated and maintained project located in Matagorda County. It is designed to protect the city of Matagorda from flooding on the Colorado River occurring concurrent with a minor hurricane approaching Matagorda from the Gulf. The system is 7.31 miles of levee embankment with nine drainage structures and two irrigation canal structures encircling the city of Matagorda, with its western portion of the levee system located along the Colorado River. Each drainage structure is equipped with a hand-operated slide gate located in the channel and a flap gate located on the unprotected end of the culvert. The irrigation structures are equipped with hand-operated slide gates located on the unprotected side of the culvert. The levee has a crest elevation of 17.3 feet North American Vertical Datum of 1988 (NAVD 88) through the southern portion of the alignment and slightly higher elevations along the northern portion. The Matagorda HFPP is designed to provide risk reduction up to a water surface elevation of 12.0 feet mean sea level (msl) at the Colorado River Locks and was the basis of design of the overall levee system. The design water surface elevation along the river side of the levee ranges from 12.0 feet above msl at the Colorado River locks to 15.8 feet above msl at the upstream end of the levee. Along the northern portion of the levee, the design water surface varies from 15.8 feet at the Colorado River to 15.0 feet above msl at the northeast corner. The eastern and southern portions of the system are designed to prevent damage from hurricane storm tides.

A series of periodic inspections gave the system an unacceptable rating due to the amount of damage recorded along the system's culvert and drainage system. This led to the installation of stability berms to increase the level of protection against failure due to long- and short-term loading, the placement of bedding and erosion protection around existing and repaired culvert and drainage systems, and placement of erosion protection along the slopes of the levee that are affected by river conditions. In 2015, an annual inspection noted that the majority of the concerns noted in the previous periodic inspection were addressed and repaired.

The PDT considered potential improvements to the system by reviewing external water surface elevations derived from a coast wide AdCirc modeling effort using a suite of synthetic storms. Table 13 through Table 15 show water surface elevations at the points identified on Figure 21 using water levels from 2017, 2035, and 2085, respectively. At 2017 water levels, the system provides risk reduction up to a 500-year exceedance event. With future sea level rise, the system provides risk reduction greater than a 100-year exceedance event.

Table 13 - Water Surface Elevations as a Function of Return Period Given 2017 Water Levels

		Water Surface Elevations (feet, NAVD 88)									
Station ID	Elevation (feet)	1-year	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year	1,000-year
10146	–4.98	1.11	1.77	2.48	3.31	4.57	6.88	9.71	12.47	15.10	16.75
13411	–0.54	--	--	--	--	4.38	6.95	9.97	12.90	15.57	17.22
13894	–14.00	1.09	1.77	2.53	3.39	4.63	6.59	8.60	10.32	12.31	13.54
17568	5.71	--	--	--	--	--	--	8.36	10.07	12.46	13.99
17569	–16.43	1.12	1.78	2.56	3.47	4.72	6.53	8.49	10.25	12.71	14.30
17576	8.37	--	--	--	--	--	--	--	9.81	12.49	14.04

Table 14 - Water Surface Elevations as a Function of Return Period Given 2035 Water Levels

		Water Surface Elevations (feet, NAVD 88)									
Station ID	Elevation (feet)	1-year	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year	1,000-year
10146	–4.98	1.74	2.46	3.26	4.13	5.40	7.82	10.54	13.17	15.71	17.31
13411	–0.54	0.77	0.91	1.09	1.25	5.26	7.91	10.81	13.59	16.17	17.77
13894	–14.00	1.71	2.44	3.26	4.13	5.36	7.33	9.29	10.98	12.97	14.22
17568	5.71	--	0.88	1.03	1.16	1.29	1.52	9.05	10.77	13.15	14.68
17569	–16.43	1.74	2.44	3.27	4.19	5.43	7.24	9.19	10.95	13.41	14.99
17576	8.37	--	--	--	1.14	1.29	1.52	1.74	10.54	13.18	14.73

Table 15 - Surface Elevations as a Function of Return Period Given 2085 Water Levels

		Water Surface Elevations (feet, NAVD 88)									
Station ID	Elevation (feet)	1-year	2-year	5-year	10-year	20-year	50-year	100-year	200-year	500-year	1,000-year
10146	–4.98	3.62	4.51	5.58	6.58	7.89	10.63	13.04	15.26	17.53	18.97
13411	–0.54	3.07	3.64	4.38	4.99	7.91	10.81	13.33	15.65	17.96	19.42
13894	–14.00	3.59	4.44	5.44	6.36	7.53	9.55	11.35	12.95	14.95	16.26
17568	5.71	--	3.54	4.12	4.62	5.16	6.08	11.14	12.85	15.22	16.75
17569	–16.43	3.61	4.43	5.40	6.37	7.56	9.38	11.28	13.05	15.49	17.06
17576	8.37	--	--	--	4.58	5.16	6.07	6.96	12.73	15.26	16.80

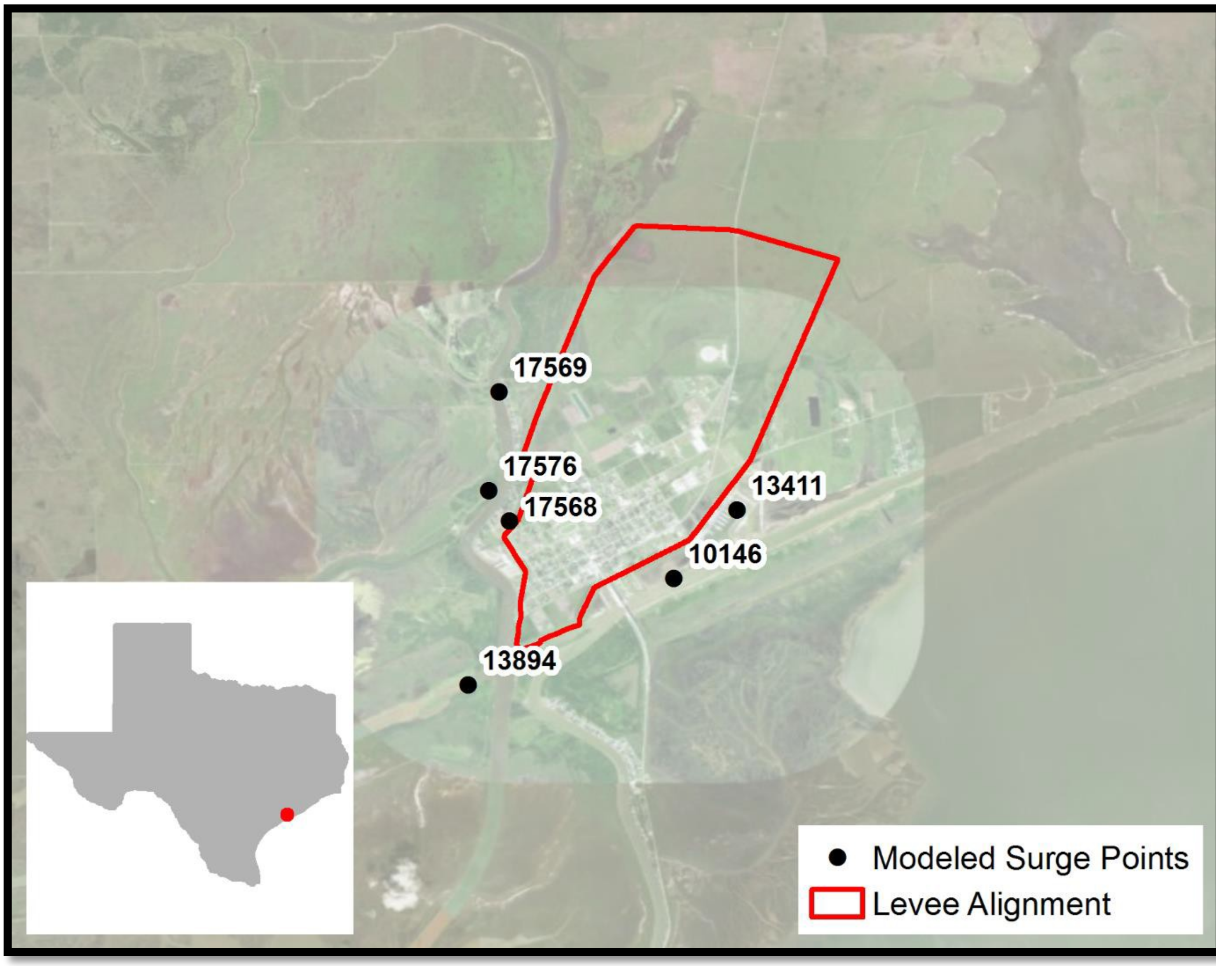

Figure 21 - Locations of Reported Storm Surge Modeling

After reviewing the recent levee inspection, and the external water surface elevations, it was determined that the Matagorda HFPP already meets many of the goals and objectives of the Coastal Texas Study. Under most storm conditions, the existing levee system performs well above a 100-year exceedance event. Many of the problems in the system are

related to interior drainage issues. There is a specific need in the area for an improvement of the culvert and drainage components of the levee system, focusing on the use of a medium sized pumping station and the installation of lift stations to address internal flooding; however, the PDT determined such an effort is more appropriate for a shorter duration study and authority than the scale of the Coastal Texas Study.

4.2.2 Development and Evaluation Region 4 Alternative Plans – South Padre Island

Erosion along South Padre Island was included on the list of problems and opportunities within Region 4. A dense concentration of structures is located along the gulf shore of

City of South Padre Island which has experienced a period of erosion that varied from 2 to 25 feet per year from 1800 to 1935. Jetty construction in 1935 led to erosion immediately north of the jetty. Erosion since the 1980s has been between 5 and 25 feet per year in the northern portion, and 18 feet per year when storm impacts are included.

The city of South Padre Island has conducted beneficial use placements intermittently since 1988 in conjunction with the Texas General Land Office (GLO) under a cooperative agreement with the USACE. These periodic projects used material from Brazos Santiago Pass to nourish the Gulf beach have maintained sediment within the coastal zone to counter the ongoing erosion along this heavily used stretch of coast. These periodic efforts require repeated coordination among multiple agencies to obtain funds and execute contracts. If time and funds are limited, or if bids vary significantly from actual placement cost estimates for non-market reasons, the BU opportunity is lost, and the structures and population are left at risk between storm events. The Future Without Project Condition, therefore, is that dredging will continue, but there is no certainty that beneficial use placements will be implemented, and the modeling does not include future BU placements in the FWOPC.

The planning process overview in Section 2.0 of this appendix describes the iterative process of USACE planning studies. The three screening iterations conducted within this study compared future without-project conditions to performance, impacts and relative costs of proposed features. As project features are refined or as more detailed information about performance, area conditions and impacts is developed, alternatives may be screened from further consideration. When additional detail is necessary to choose between alternatives, the Team will conduct additional analysis to generate necessary information to eliminate critical uncertainties.

The South Padre Island beach nourishment and sediment management measure was carried forward in each of the three evaluation phases:

- Conceptual Plans:

  South Padre Island was identified as vulnerable to coastal storm damage in the initial problem identification phase and shown as measure # CM-5 in Table 2 through Table 5 once it was confirmed to achieve study objectives.

- TSP Selection:

  BeachFX modeling demonstrated that net benefits are maximized at a specific scale of beach nourishment when compared to the FWOPC and the measure is included as a component of the CSRM portion of the TSP in the 1st Draft report.

- Integration and Refinement:

  Refined characterization of the physical conditions and background erosion rate were applied within BeachFX analysis to reassess the performance and costs of the beach nourishment measure during the overall plan refinement to integrate the ER and CSEM features, address public, agency and technical comments, and increase cost-effectiveness.

The planning evaluation considered only beach and dune measures because revetments, seawalls, rock groins, or offshore breakwaters would negatively impact the longshore and cross-shore sediment transport processes. Nonstructural measures were initially considered but not carried forward since flood proofing of structures, implementing flood warning systems, flood preparedness planning, establishment of land use regulations, development restrictions within the greatest flood hazard areas, and elevated development are already being implemented, and any larger scale nonstructural effort would be less cost-effective than a soft structural beach nourishment measure.

The life cycle nourishment costs and benefits of varying scales of dune and berm features were estimated with the BeachFX model. The area was divided into seven reaches to reflect similar physical beach conditions and structure inventory behind the beach to support the model application (Figure 22) to identify whether a cost-effective plan exists.

The initial model results suggested that the annual benefits exceed the annual project costs within reaches 3 and 4 for all scales of beach fill, since these 2 miles are the most erosive reaches. BeachFX estimates benefits in the form of reduced damages to structure and contents that are achieved with the beach fill measure in place. Recreation benefits can also be used to justify a beach fill project but cannot factor into measure selection. Therefore, the model results were the primary factor in the identification of the most cost-effective scale.

Based on the nourishment volumes and intervals , the scale that produced the maximum net benefits was a profile with a 12.5-foot dune and 100-foot-wide berm within reaches 3 and 4. A 10-year renourishment cycle produced slightly higher net benefits than a 15 year renourishment cycle of the same profile. Appendix E- 2, SPI Economic Analysis presents the intermediate range of potential benefits based on varying profiles that identified the TSP.

Figure 22 - South Padre Island Reaches

Beach nourishment measures proposed for CSRM purposes can also include recreation benefits if the alternative improves the recreation experience. Corps regulations prescribe specific computation approaches to capture recreation benefits. Rather than conducting an in -depth computation of recreation benefits through the willingness to pay method, the PDT applied a placeholder value of recreation benefits from the unit day value procedure to capture the applicable benefit. With Vertical Team concurrence, the team capped visitation at 750,000 per year and estimated a range of an applicable unit day value.

When the TSP was identified as beach nourishment for reaches 3 and 4, the GLO expressed interest in exploring a larger extent of beach fill along South Padre Island. A Locally Preferred Plan could be applicable if a larger extent was proven to be cost-effective. Section 4.2.2 presents the final refinement of the beach nourishment proposal that was undertaken in the third formulation phase, when the NER and NED plans published in the 1st Draft Feasibility Report were integrated to create a cost-effective, comprehensive and efficient Recommended Plan and to address technical, policy, public and agency review of the draft plan. Technical comments requested further comparison of performance across berm widths, renourishment cycles, and all rates of sea level change. Public comment expressed concern that Reach 5 was as erosive as Reaches 3 and 4. In response, the BeachFX model was reviewed to confirm the planform rates accurately compared the with- and without-project condition, and to confirm the appropriate scale and nourishment cycles were identified.

The model results indicated that erosion occurs over a longer extent, including Reach 5. The comparison of with and without-project condition confirmed that the NED scale of the beach nourishment is 2.9 miles from Reach 3 through 5, with the same dune and berm dimensions as before, but on a 10-year periodic renourishment cycle for the 50-year period of analysis. Although beach-fill typically includes construction of an initial profile and periodic renourishment, the recent practice of beneficial use of dredge material from the Brazos Island Harbor (nearby deep-draft navigation channel) has offset erosion and established a fairly healthy starting condition. No initial construction is required, and nourishment is not proposed, until the beach profile erodes in approximately Year 10 to reestablish the beach width. Future nourishment volumes may vary as storm or natural coastal processes influence portions of the beach. The project feature cost estimate was based on a larger, offshore borrow area to ensure adequate volumes of compatible sediment are available over the period of analysis. Smaller increments of sediment may be evaluated from closer sources to maintain the beach profile over time to reduce feature cost.

4.2.3 Development and Evaluation Ecosystem Restoration (ER) Alternative Plans

The planning process overview in Section 2.0 of this appendix describes the iterative process of USACE planning studies. The three screening iterations conducted within this study compared future without-project conditions to performance, impacts and relative costs of proposed features. As project features are refined or as more detailed information about performance, area conditions and impacts is developed, alternatives may be screened from further consideration. When additional detail is necessary to choose between alternatives, the Team conducted additional analysis to generate to reduce critical uncertainties.

The Ecosystem Restoration measures carried forward were screened in each of the three evaluation phases:

- Conceptual Plans:

  An initial array of 92 measures were identified to address region specific goals and objectives in the initial problem identification phase (Table 2 through Table 5). Sixty- four of those were ER measures, which conceived and evaluated by resource agency representatives for their ability to meet study goals and objectives.

- TSP Selection:

  Strategic combinations of the ER measures formed alternative ER plans. Habitat Suitability modeling was applied to estimate ecological lift of each measure and the alternative plans. Cost Effectiveness and Incremental Cost Analysis identified the Best Buy plans, and the lowest cost comprehensive alternative was included as the NER portion of the TSP in the 1st Draft report.

- Integration and Refinement:

  Features within the NER plan were refined to address public, agency and technical comments, and increase cost-effectiveness.

Ecosystem restoration measures were included in the conceptual formulation phase to explore the joint application of ER and CSRM measures to address storm risk to human, built and natural regions in the study area. Conceptual alternatives A through D, described in sections 4.1.1.1 through 4.1.1.4, combined different CSRM features with the maximum ER alternatives to demonstrate the compatibility of CSRM and ER to address coastal storm risk in the region. Conceptual alternatives E through G described in sections 4.1.1.5-7 combined subsets of the ER measures with the CSRM measures.

The underlying problems and opportunities are presented in greater detail in this section to support the evaluation and refinement of the measures as building blocks for larger ER alternatives, and comparing ecological lift achieved through the measure. The ER measures were reviewed to ensure that the array developed for the conceptual formulation and screening phase was sufficient to achieve the study goals and objectives and identify the lowest cost comprehensive plan. A comprehensive plan would address a variety of habitats across the study area.

The Texas coast is a complex and dynamic system that serves to protect the mainland as well as nourish a rich diversity of aquatic, bird, and land-based species — including the human population. Through years of anthropogenic alterations along the coast (including industrial uses, residential development, etc.), delicate ecosystems are degrading and losing their structure and function. At the base of this loss are changes in the geomorphological and hydrological dynamics of the region.

Of the 367 miles of shoreline, more than 60 percent has been identified as subject to high rates of erosion. Wetlands, barrier islands, beaches and dunes protect the Texas coast and inland areas from hurricanes and storm surge. These natural defenses are threatened by alarming erosion rates, demands of a rapidly growing population and rising sea levels which will continue to expose inland communities to increasing risks.

The marshes, prairies, and tidal flats over the entire coastal zone are a major wintering area for waterfowl of the Central Flyway, while primary routes for both the Central and Mississippi Flyways converge in the Sabine River area. Coastal scrub/shrub habitat and forests are critically important for the nation's neotropical migratory songbirds as many utilize this habitat during their trans- and circum-Gulf migrations.

Loss of transitional estuarine marsh and coastal prairie habitats would directly reduce habitat for T&E species. As interior marshes are lost, shoreline retreat rates increase. The continued erosion of the Gulf coast shoreline would reduce nesting sea-nesting habitat and lead to additional saltwater intrusion into the interior wetlands resulting in additional marsh loss. Without action, degradation and loss of emergent wetland habitats used by many different fish and wildlife species for shelter, nesting, feeding, roosting, cover, nursery, and other life requirements would continue.

4.2.3.1 Revisiting ER Goals

The Coastal Texas Study ER and management goals include:

- Goal #1: Promote a resilient and sustainable coastal ecosystem by reducing future land loss and restoring, creating, and enhancing coastal wetlands to achieve and sustain a coastal ecosystem that can support and protect the environment, economy, and culture of the Texas coast.
- Goal #2: Restore natural landscape features and hydrologic processes that are critical to sustainable ecosystem structure and function and that provide diverse fish and wildlife habitats.

4.2.3.2 Revisiting ER Objectives

The Coastal Texas Study ER overall objective to achieve sustainable coastal ecosystem through a comprehensive plan that minimizes future land loss, improves wetland productivity and diverse fish and wildlife habitats consistent with these specific sub- objectives:

- Objective 1: Shoreline Protection (SP) – Reduce/prevent shoreline erosion of barrier system shorelines, estuarine bay shorelines, and channel shorelines.
- Objective 2: Hydrologic Connectivity (HC) – restore and/or create hydrologic connectivity of sensitive estuarine systems.
- Objective 3: Estuarine Bay Systems Restoration (EB) – Restore, create, and/or protect critical estuarine wetlands, tidal flats, etc.
- Objective 4: Barrier Beach, Dune and Back Marsh Restoration (BD) – Nourish and protect barrier beach, dune, and back mar
- Objective 5: Oyster Reef Restoration (OR) – Restore and/or create important oyster reefs.

- Objective 6: Neotropical Migratory Bird Habitat Restoration (MB) – Restore and/or create important habitat used by migratory birds
- Objective 7: Bird Island Rookeries Restoration (BI) – Restore and/or create important islands used as bird rookeries.
- Objective 8: Restore Habitat Used by Species of Concern – Restore and/or create habitat (important, critical, essential, and other habitat types) used by species of concern, such as Federally listed species, shorebirds, Federally managed aquatic species (e.g., EFH), and others.

4.2.3.3 Ecosystem Restoration Strategy

Several key themes were applied in the ecosystem restoration strategy over the formulation process. An interagency team applied a fundamental understanding of the baseline physical conditions along the coast to develop and screen the alternatives in each iteration.

The conceptual development phase considered measures that reestablish coastal habitat for ecological functions, maintain physical landform buffers and establish lines of defense. Several sites were proposed for restoration actions because they would improve sustainability of regionally and nationally significant resources by maintaining physical landform buffers. The areas proposed for restoration connect habitat along the coast and improve the efforts of the GLO and other agencies. The restoration actions at specific areas applied combined actions to sustain comprehensive habitats over the period of analysis and to sustain active and passive benefits. The detailed formulation process is described in more detail in the following paragraphs.

The existing coastal barrier systems (barrier islands, shorelines, and headlands) and estuarine bay shorelines and marsh across the Texas coast, while still relatively intact, are critical geomorphic or key landscape features that are experiencing substantial land loss. According to Paine et al. (2014), the Texas coast shoreline has averaged 4.1 feet per year of retreat from 1930 through 2012 with net shoreline retreat along 80 percent of the shoreline. The annual rate of land loss along the Texas Gulf shoreline (through 2007) is 178 acres per year. Average rates of retreat are higher (5.5 feet per year) along the upper Texas coast than on the central and lower coast (3.2 feet per year).

Similarly, critical bayhead deltas, such as the Nueces and the Guadalupe deltas, provide important, essential, and critical fish and wildlife habitat, migratory bird habitat, and nursery habitat necessary for a healthy and functioning coastal bayhead deltaic system. However, the long-term prognosis for these critical bayhead deltas under present conditions is poor and the vulnerability of the delta systems is high. For example, Hodges et al. (2012) Nueces Delta Restoration Study for the Coastal Bend Bays and Estuaries Program determined freshwater inundation over the past 30 years has been insufficient in volume and distribution to maintain a healthy marsh, so the delta front is eroding into Nueces Bay, the marsh plants are under stress, and the connectivity of aquatic habitat is threatened.

Targeted ER and management actions now, can help prevent widespread Texas coastal barrier system degradation, fragmentation, and eventual loss (which in turn would expose interior bay shorelines and marshes to Gulf forces resulting in land loss on scales comparable to losses experienced in coastal Louisiana). The strategy described in this document outlines ER which supports the long-term functional geomorphic and ecosystem integrity of the entire Texas coast.

4.2.3.3.1 Conceptual Lines of Defense

This portion of the strategy is based on the concept that the primary threat to estuarine ecosystems is increased exchange with and exposure to Gulf waters and forces. Increased

exchange and exposure with the Gulf will change the tidal prism and salinity regime, impacting marsh vegetation and erosion. The concept of lines of defense relates to protection of coastal ecosystems and human infrastructure from storm damage caused by hurricanes and tropical storms coming ashore from the Gulf. The lines of defense provided first by the barrier islands, then by living shorelines, and finally coastal marshes, can reduce the physical impacts of storm surges and winds which enter the bays. This combination of lines of defense and ER is intended to provide redundant and resilient levels of protection and restoration for both humans and Texas coastal ecosystems. Each of these lines of defense and restoration will be individually discussed below:

- 1st Line of Defense and Ecosystem Restoration – Barrier Systems (includes barrier shorelines, islands, and headlands as well as barrier beach, dune, and back marsh. Restoration of this line of defense includes consideration of barrier system ecological and geomorphic functions.
- 2nd Line of Defense and Ecosystem Restoration – Estuarine Bay System (includes geomorphic bay features and estuarine habitats including bay shorelines and estuarine marsh, bird rookery islands, oyster reefs, and seagrass beds). Restoration of this line of defense includes consideration of estuarine and bay ecological and geomorphic functions.
- 3rd Line of Defense and Ecosystem Restoration – Bayhead Deltas (includes bayhead deltaic features and associated habitats including adjacent bird rookery islands, reefs, subaquatic vegetation, and marsh). Restoration of this line of defense includes consideration of bayhead delta ecological and geomorphic functions.

4.2.3.3.2 1st Line of Defense and Ecosystem Restoration – Barrier Systems

Barrier islands, shorelines and headlands, as well as tidal inlets form the 1st line of defense for the major estuarine bays and the residential, industrial and recreational structures therein. Barrier systems are the boundary between the Gulf and estuarine and the terrestrial ecosystems. These features include barrier beach, dune, back marsh, and shallow open water areas along the inland side of barrier islands. Natural and man-influenced tidal passes (including navigation channels and associated structures e.g., jetties, etc.), influence exchange of Gulf and riverine waters and sediments providing important habitats for many estuaries.

Coastal barriers also provide habitat for various marine, estuarine and terrestrial organisms as well as stopover habitat for migrating neotropic birds. Coastal barrier systems provide protection to the wetlands, bays, and estuaries located behind the barrier systems. These features influence tidal prism, limit storm surge heights, retard saltwater intrusion, and limit mechanical erosion by reducing wave energy at the margins of coastal wetlands. Coastal barrier systems and other features of the coastal landscape (e.g., shoals, marshes, and forested wetlands) can provide a significant and potentially sustainable buffer from wind-wave action and storm surge generated by tropical storms and hurricanes.

Associated with barrier systems are adjacent bird rookery islands, marsh complexes, oyster reefs, and submerged aquatic vegetation. Each of these habitat features can be limited in size and have intrinsic ecological functionality, as in the case of bird rookery islands. However, when considered from a cumulative perspective, the combination of these features along a barrier system can have significant local, regional, and national ecological implications; especially important to the NER requirements for the Coastal Texas Study. In addition, strategic placement and numbers of bird rookery islands, oyster reefs, marsh complexes, submerged aquatic vegetation, and other various living shorelines can also attenuate waves and erosion, reduce fetch, and create EFH.

4.2.3.3.3 2nd Line of Defense and Ecosystem Restoration – Estuarine Bay System

Bay shorelines, inlets, and bordering estuarine marshes form the 2nd line of defense. Like barrier systems, these features buffer wind and wave attack and help maintain hydrology within bays. These features protect coastal ecosystems and human communities further inland. In addition to forming a secondary storm buffer, estuaries provide habitat for ecologically, commercially, and recreationally important fish and wildlife. Estuaries are particularly important nursery habitat for many organisms with early life stages dependent on salinities below Gulf salinities. Shrub and woody habitat along estuarine shorelines provide important habitat for neotropical migrating birds.

Associated with estuarine bay systems are bird rookery islands, marsh complexes, oyster reefs, and submerged aquatic vegetation. Each of these habitat features can be limited in size and have intrinsic ecological functionality, as in the case of bird rookery islands. However, when considered from a cumulative perspective, the combination of these features along a barrier system can have significant local, regional, and national ecological implications; especially important to the NER requirements for the Coastal Texas Study. In addition, strategic placement and numbers of bird rookery islands, oyster reefs, marsh complexes, submerged aquatic vegetation, and other various living shorelines can also function as wave and sediment attenuation, reduce fetch, and create EFH.

4.2.3.3.4 3rd Line of Defense and Ecosystem Restoration – Bayhead Deltas

The 3rd line of defense and ER involves restoring, enhancing, and protecting bayhead deltas. Managing freshwater inflows to optimize salinity, sediment, and nutrient regimes helps sustain deltas and their associated habitats. Opportunities to manage hydrologic connectivity, and development of sediment management strategies would maximize delta accretion and sustain important wetland habitats dependent on deltaic eco-geomorphic function. Deltas function as the 3rd line of defense that further protects human infrastructure and estuarine ecosystems. Similar to barrier and estuarine bay systems, there are adjacent bird rookery islands, reef s, marsh complexes, and submerged aquatic vegetation which provide benefits similar to those previously described for barrier systems and bay systems.

4.2.3.4 Final Refinement of ER Measures

Interagency representatives met on a monthly basis throughout the project and collaborated to refine the remaining ER measures from Table 7 through Table 10. This final refinement reduced the array of ER measures from 21 to 9. The PDT and interagency team updated the current without- project conditions and screened out two measures because alternative efforts were in place to address the perceived problem and opportunity. It was also determined that several measures should be combined and presented as a single measure because of their similar function and location, complementarity, or dependency.

4.2.3.4.1 Adaptability Over Time

The refinement of ER measures included an assessment of current and future condition of wetland inundation images under the relative sea level change (RSLC) curves for each proposed footprint and surrounding area.

The PDT identified vulnerable areas at different points in time for the low, intermediate, and high rates of RSLC to evaluate the performance and cost-effectiveness across different sea level change scenarios. The comparison confirmed that RSLC threatens critical geomorphic ecosystem features and habitat along the Texas coast under all RSLC scenarios, with variation across the curves only in how quickly the water level reaches that height. A “tipping point”/break point, where the rate at which estuarine environments in Texas evolve into open water or unconsolidated shoreline, is evident when the water level increases by 2.7 feet.

Given the significant scale of the intervention necessary to restore marsh and estuarine environments in Texas, the PDT considered that underestimating the quantities, time of intervention, or cost of the measures could negate the value of the effort. The GLO expressed concern that the planning effort and the budget decisions should not underestimate the scale and the budget implications of a meaningful action to restore the coastal environment. As a result, several measures were formulated to include a second scale of the measure, with an out-year nourishment component on an adjacent parcel to adapt the overall habitat over changing physical conditions in the study area. These scales were presented in the 1st Draft Report, and Alternative 1 Scale 2 was proposed as the NER plan within the report. Following public, technical and policy review, the outyear nourishment was determined to be inconsistent with Corps policy and would not be a cost shared expense. The Integration of NED and NER summary during the final planning phase included only the Scale 1, initial placement features and proposed no outyear nourishment. The restoration design incorporated “lessons learned” from recent projects in the region and no OMRR&R has been scoped during the period of analysis.

Outyear nourishment is a viable future action if RSLR rates threaten the sustainability of the habitat on the lands adjacent to the ER measures, and may be pursued through subsequent studies or as BU efforts, which are consistent with the Corps policy encouraging regional sediment management (RSM) implementation.

4.2.3.4.2 Summary of Measures

The types of restoration actions included in the original 9 site specific ER measures are:

- Marsh Restoration

  Restore coastal marshes to similar ecological processes and functions of natural marshes to the maximum extent practicable in order maintain or provide valuable ecosystem services and functions. Breakwaters are proposed to sustain the marsh by impeding erosion from navigation in adjacent GIWW.

- Island Restoration/Creation

  Restore and/or create coastal islands to prevent shoreline erosion, inundation of inland areas from relative sea level rise, and maintain valuable ecosystem services and functions

- Dune and Beach Restoration

  Restore and/or improve beaches and dunes along the Gulf of Mexico shoreline to prevent breaches and erosion caused by storm surge and relative sea level rise and to protect coastal wetlands

- Oyster Reef Restoration/Creation

  Restore and/or create oyster reefs to prevent shoreline erosion, improve water quality, create estuarine habitat, and maintain valuable ecosystem services and functions

- Hydrologic Restoration

  Reduce the hypersaline conditions and improve the water quality of 112,864.1 acres of the Lower Laguna Madre by dredging the Mansfield Channel to increase tidal inflows into the lagoon.

A description of the final array of ER measures, their anticipated benefits, and the expected Future Without-Project (FWOP) conditions for each are described below. The benefits from enhancing and sustaining coastal habitats and landforms have been quantified with the Habitat Evaluation Procedure (HEP) and Wetland Valuation Analysis (WVA) models and in later phases, a turtle model, to characterize the improvement in habitat suitability modeling. Additional benefits to recreation, navigation, regional economies are anticipated but have not been explicitly quantified in the study. Navigation benefits include reduced maintenance needs from reduced shoaling and improved safety once channel widening is reduced.

The plan recognizes that the out-year nourishment on adjacent parcels could be a future action undertaken by the NFS in response to RSLC. Breakwaters were included in the initial formulation of restoration features to stop sediment loss over time.

Measure G-5 – Bolivar Peninsula/Galveston Island Gulf Beach and Dune Restoration

Project Description: Restore, create, and/or improve approximately 26 miles of Gulf shoreline from High Island on Bolivar Peninsula to the Galveston East Jetty about 18 miles of Galveston Island shoreline west of the Galveston seawall. Sediment sources have been identified to maintain the design profile over the period of analysis.

Project Benefits: The project would decrease the likelihood of erosion and breaches to beaches, dunes and wetlands caused by storm surge and sea level rise. It would protect the wildlife in these habitats and protect SH 87 and Farm-to-Market Road 3005, both of which are the only evacuation routes for Bolivar Peninsula and to the west end of Galveston Island, respectively. Several coastal communities, including Pirate's Beach, Jamaica Beach, the Silverleaf Seaside Resort, Vista Del Mar, Terramar, and Baywater would gain the benefits of the project.

Future Without-Project: The Gulf shoreline is eroding at a rate of up to 5.7 feet per year along this area of the Bolivar Peninsula and at 8.2 feet/year on the identified section of Galveston Island (Bureau of Economic Geology [BEG], 2016). If this project does not occur, much of the existing 5,000 acres of Gulf beach, dunes, and wetlands in this area would be lost in 50 years. Loss of these ecosystems would increase susceptibility of inland habitat and infrastructure to damage during storms.

Measure G-28, Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection

Project Description: Install breakwaters and restore marsh habitat to protect 27 miles of marsh habitat along the GIWW on Bolivar Peninsula and 9 miles of shoreline along the north shore of West Bay. Use sediment to restore, create, and/or improve islands adjacent to the GIWW to protect 5 miles of shoreline habitat along the north shore of West Bay, which is eroding. Subsequently in the future, based on relative sea level rise (RSLR), renourish 6,891 acres of marsh identified as "unconsolidated shore" using the NOAA (2017) marsh migration layer. G-12 East and G-12 West were combined with G-13 East and G-13 West to create measure G-28.

Project Benefits: Breakwaters are a proven method to greatly reduce, and sometimes reverse, the loss of marsh habitat that erodes along the GIWW due to barge wakes. The shoreline and marshes in these areas would be restored and protected from storm surge and erosion and from the effects of sea level rise. Beyond the ecological lift just described, this project also would reduce maintenance dredging of the GIWW.

Future Without-Project: If the habitat along the shoreline is not protected, approximately 18,000 acres of existing intertidal to high marsh along the south shore of the GIWW through Bolivar Peninsula and the north shore of West Bay would be inundated at a sea level rise of 3 feet (NOAA, 2017). This marsh habitat also serves as a buffer from some storm impacts to area infrastructure.

Ancillary benefits can be expected when the ecological habitat is restored in this way. Aside from the ecological loss when sediment is lost from the marsh, the accumulation in the GIWW increases shoaling and maintenance dredging frequency. The increased width of open water in the GIWW due to the loss of marsh and the erosion of the islands adjacent to the GIWW can change the waves and currents and accelerate erosion. These factors can negatively impact navigation.

Protecting the shoreline of Bolivar Peninsula reduces the likelihood it will breach to the Gulf since, at 3 feet of sea level rise, portions of the peninsula may narrow to less than 2,000 feet wide. Breaching could increase salinities in East Bay, which would impact bay habitat.

Measure B-2 – Follets Island Gulf Beach and Dune Restoration

Project Description: Restore, protect, and/or improve beach and dune complex on approximately 10 miles of Gulf shoreline on Follets Island in Brazoria County.

Project Benefits: A restored shoreline on Follets Island would guard against beach and dune breaches caused by erosion, storm surge and sea level rise. This would protect inland wetlands, seagrass meadows and other habitats. All of which shield SH 257 from the effects of storm surge, the only road accessing and providing evacuation capability to the east towards Galveston Island and to the west towards Freeport.

The beach, dune, wetland, and seagrass meadow ecosystems along Follets Island are the first line of defense for Bastrop, Christmas, and Drum bays, and the Brazoria NWR and various residential developments on the mainland. Christmas Bay is a designated Gulf Ecological Management Site because of its relatively undeveloped shorelines, high water quality, and unique mix of seagrass meadows, oyster reefs, and smooth cordgrass marsh; it is also a Texas Parks and Wildlife Department Coastal Preserve.

Future Without-Project: The Gulf shoreline in this area is eroding at a rate of 13 feet/year (BEG, 2016). Over the next 50 years, more than 200 acres of existing beaches and dunes that protect homes, infrastructure, and habitat may be washed away due to erosion and severe storms. The critical evacuation route of SH 257 would be substantially threatened because of its proximity to the shoreline. Currently, some sections of the highway are within 180 feet of the shoreline. Also, a Gulf-water breach of Follets Island into Christmas Bay would substantially affect its unique ecological features.

Measure B-12 – West Bay and Brazoria GIWW Shoreline Protection

Project Description: Restore, create, and/or improve critical areas of shoreline in the bay complex of Bastrop Bay, Oyster Lake, Cowtrap Lake, and the western side of West Bay. This would be accomplished through several methods. Use breakwaters along the GIWW and along the land that separates Oyster Lake from West Bay. In Oyster Lake, add 0.7 mile of oyster cultch near the shoreline that is expected to breach into West Bay. Measure B-5 (Bastrop Bay, Oyster Lake, and West Bay Shoreline Protection) was combined with measure B-6 (Brazoria County GIWW Shoreline Protection), because they are not considered separable elements and cannot stand alone, these combined measures were renamed to B-12.

Project Benefits: This restoration would protect this by complex from being breached by West Bay. This would safeguard the critical shoreline in this bay complex from erosion, and the effects of storm events, vessel wakes, and sea level rise. This also would preserve the marsh, oysters, colonial waterbird rookeries, and other habitats in this bay complex.

Future Without-Project: If this measure is not constructed, 10 miles of shoreline in this bay complex and more than 6,000 acres of intertidal marsh and freshwater wetland along the north side of the GIWW would be inundated with 3 feet of sea level rise. The Brazoria NWR will lose valuable wetland habitat. Patterns of sedimentation flow would change, which would negatively affect the oyster reefs in Bastrop Bay and Oyster Lake. The conversion of large expanses of wetlands to open water may also adversely affect navigation in the GIWW.

Measure M-8 – East Matagorda Bay Shoreline Protection

Project Description: This project would use living shorelines and/or breakwaters to restore, protect, create, and/or improve approximately 12 miles of shoreline and associated marsh along the Big Boggy NWR shoreline and eastward to the end of East Matagorda Bay. About 3.5 miles of shoreline directly in front of Big Boggy NWR also would be improved by adding a breakwater on the south side of the GIWW. In addition, the islands adjacent to the GIWW and the oyster reefs behind the adjacent islands on the bayside would be restored.

Project Benefits: This project would mitigate the effects of breaches, erosion, sea level rise, storm events, and vessel wakes to protect the GIWW shoreline and marshes in this area.

Future Without-Project: If this project does not occur, the following areas may convert to open water at 3-foot sea level rise: 1) more than 2,000 acres of intertidal marsh and wetlands around the Pelton, Kilbride, and Boggy lakes complex in the Big Boggy NWR along the north shore of the GIWW and west of the Chinquapin community; and 2) over 7,000 acres of intertidal marsh and wetlands to the east of Big Boggy NWR towards Bay City at the east end of Matagorda Bay. This will increase wave erosion along the north shore and on marsh, reefs, and islands in East Matagorda Bay and south of the GIWW.

Measure CA-5 – Keller Bay Restoration

Project Description: Use breakwaters and/or living shorelines to restore, protect, create, and/or improve approximately 5 miles of shore along Matagorda Bay between Matagorda and Keller bays. Add oyster reef balls to protect and improve about 2.3 miles of western shoreline along Sand Point, which separates the two bays.

Project Benefits: This project would prevent the breaching of the Matagorda and Keller bays shoreline into Keller Bay. This would reduce erosion to preserve and improve the intertidal marsh and oysters in Keller Bay.

Future Without-Project: If a breach into Keller Bay occurs, erosion would accelerate, and currents could be modified. This would lead to the degradation and loss of oysters and over 250 acres of intertidal marsh in Keller Bay along the Matagorda Bay and Keller Bay shoreline.

Measure CA-6 – Powderhorn Shoreline Protection and Wetland Restoration

Project Description: Restore and reduce erosion to approximately 6.7 miles of Matagorda Bay shoreline with breakwaters and marsh restoration. This area fronts the communities of Indianola, Magnolia Beach, and Alamo Beach, and the Powderhorn Lake Estuary.

Project Benefits: This shoreline is primarily used for recreation. The restoration would improve the economic value of this area and protect the intertidal marsh and ecological integrity of Powderhorn Lake Estuary.

Future Without-Project: More than 300 acres of intertidal marsh/open water complex would erode and submerge at a 3-foot sea level rise if the shoreline breaches. Another effect of not implementing this project is the significant widening of the mouth of Powderhorn Lake. This type of transformation would change the lake's salinity regime and increase wave generated erosion and lead to a decline or loss of marsh.

Measure SP-1 – Redfish Bay Protection and Improvement

Project Description: Use breakwaters and/or living shorelines, beneficial use material, and oyster reef balls to restore, create, and/or improve the island complex of Dagger, Ransom, and Stedman islands in Redfish Bay. Breakwater and islands would protect submerged aquatic vegetation (SAV) within Redfish Bay, and it is assumed about 200 acres of additional SAV will form between the breakwaters and islands.

Project Benefits: This measure would prevent loss of islands to protect extensive seagrass meadows and support coastal waterbirds and fisheries.

Future Without-Project: Not restoring this island complex would result in continued erosion and expose the area to greater wave action from the deep draft navigation in the Corpus Christi Ship Channel. This could threaten approximately 2,000 acres of seagrass meadows and damage the habitat for coastal waterbirds and fisheries.

Measure W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration

Project Description: This measure would restore the Port Mansfield Channel area by implementing the following: 1) use beach and dune restoration to improve and maintain the geomorphic function of the Gulf shoreline north of the Port Mansfield Channel through the barrier island; 2) protect and restore Mansfield Island with 3,696 feet of rock breakwater and rookery island restoration; and 3) restore and maintain the hydrologic connection between the Laguna Madre and the Gulf with dedicated dredging of a portion of the Port Mansfield Channel. W-1 and W-2 were combined to create one measure, W-3, in which the material dredged from the channel would be used beneficially for beach nourishment and for additional restoration of Mansfield Island.

Project Benefits: Currently, jetties block the prevailing south to north longshore current. This project would restore sediment transport north of the Port Mansfield Channel jetties. This would prevent the eminent breach of the barrier island and maintain access to visitors and National Park Service staff. Restoration of sediment transport would support dune development and help control erosion along the Gulf shore. This would help protect the critical habitat for wintering piping plovers and the primary U.S. nesting beach for the endangered Kemp's Ridley sea turtles.

Restoring Mansfield Island would increase the size and elevation of the island to mitigate erosion due to sea level rise, storms, and vessel wakes. Lastly, the hyper-salinity in the Laguna Madre would be reduced, improving the habitat.

Future Without-Project: If this project does not occur, erosion on the north side of the pass would continue at a rate of 14 feet per year (BEG, 2016). The beach and dune system would erode toward wash overs, which can increase the likelihood of system breaches. Increased water exchange with the Gulf would result in salinity, circulation, and habitat changes in the Laguna Madre.

Without this effort, the area would be vulnerable to the effects of sea level rise. With an expected 2-foot RSLR by 2085, dune areas could transition to brackish intertidal wetlands on the back side of South Padre Island and increase the possibility of breaches in the barrier island. RSLR of 2 feet combined with ongoing erosion would completely convert the 3-acre Mansfield Island used by colonial waterbirds to unconsolidated tidal flats.

4.2.3.4.3 National Significance

The ER alternatives will address significant habitats and natural resources in the region, and notable resources that are in the region and benefit from the restoration are the Central and Mississippi Flyways. The U.S. Fish & Wildlife Service and its partners manage migratory birds based largely on routes the birds follow as they migrate between nesting and wintering areas. Based on those routes, four administrative Flyways (Atlantic, Mississippi, Central and Pacific) were established in North America to facilitate management of migratory birds and their habitats.

The ER features proposed in the Coastal Texas Recommended Plan will add and sustain habitats within the Central Flyway. Extreme northern portions of the restoration features will also overlap with the Mississippi Flyway. The ER measures will sustain the coastal habitats that provide nesting, feeding and overwintering areas for migratory species. Central Flyway is massive, covering more than one million square miles across North America's interior from Canada's boreal forest and parklands across the Great Plains down to the Texas Gulf Coast. They are especially significant because the habitats in Texas are important stops on the migration and provide critical habitat before or after the trip across the Gulf of Mexico.

The study area encompasses:

- Critical coastal ecosystems including wetlands, seagrass beds, oyster reefs, and sea turtle nesting habitat
- Habitat for many threatened and endangered species, including Piping Plovers, Red Knot, Whooping Crane, Attwater’s Greater Prairie Chicken, West Indian Manatee, and sea turtles
- Critical Habitat for Piping Plover and Whooping Crane
- Mississippi and Central Flyway Migration Corridor
- Nesting habitat for Audubon’s priority species of the central flyway, including Red Knot and Brown Pelican, occur in the study area shorelines and bird islands
- Padre Island National Seashore
- Galveston Bay and Corpus Christi Bay are 2 of 28 National Estuary Programs in the U.S.

- The Laguna Madre, a rare hypersaline lagoon, is 1 of 6 in the world. It is a rich and biologically diverse ecosystem that accounts for ~80% of all of Texas' seagrass beds
- 12 National Wildlife Refuges
- Significant commercial fisheries for oysters, shrimp, and finfish
- Nursery habitat within estuaries for commercially and recreationally important aquatic species

Table 16 - Significance of Measures

Measure	Significance
G-28 Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection	• Restoration of a bird 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 • Strengthens first line of defense as buffer between coastal forces and developed areas
B2 Follet's Island Gulf Beach and Dune Restoration	• The Texas coast has 367 miles of Gulf shoreline, which have been shown to be eroding rapidly, with some areas experiencing more than 24 feet of erosion per year. (Paine, J. G., T. Caudle, and J. Andrews. 2014. "Shoreline Movement along the Texas Gulf Coast, 1930's to 2012." Final Report to the Texas General Land Office, Bureau of Economic Geology, The University of Texas at Austin.) • Follets Island protects Bastrop, Christmas, and Drum bays, and the Brazoria NWR on the mainland behind this bay system. It also protects seagrasses in Christmas Bay, extensive marshes throughout the bay complex, and scattered residential developments. Christmas Bay is a designated Gulf Ecological Management Site because of its relatively undeveloped shorelines, high water quality, and unique mix of seagrass meadows, oyster reefs, and smooth cordgrass marsh; it is also a TPWD Coastal Preserve.

Measure	Significance
B12 West Bay and Brazoria GIWW Shoreline Protection	• Marsh, oysters and colonial waterbird in this complex provide nationally significant habitats. Tidal marsh complexes that are prevalent along Texas Bays are threatened by erosion, developmental encroachment and sea level change. • Bird rookeries provide nesting and feeding opportunities for birds. These are often a first stop for migratory birds as they travel across the vast Gulf of Mexico • Estuarine marsh support recreational and commercially important finfish and invertebrates such as crabs and shrimp that use the tidal marshes as nursery areas. The marshes are also feeding and nesting areas for birds, including migratory waterfowl that nest in Texas and spend other life stages in other parts of the country or world. The measure reduces erosion and changes in circulation that would impact the marsh habitat.
M8 East Matagorda Bay Shoreline Protection	• Estuarine marsh are tidal nursery areas where juvenile fish, crabs, and shrimp feed and grow within the protection the marsh plants. • Restoring the island shoreline directly in front of Big Boggy NWR and placing oyster cultch on the bayside of the island • The Big Boggy National Wildlife Refuge serves as a salt marsh sanctuary. Dressing Point Island is one of the most prominent bird rookeries on the Texas Coast where Roseate spoonbills, white Ibis, snowy and reddish egrets and brown pelicans' nest. • Big Boggy Refuge conserves key coastal wetlands for neotropical migratory birds and shorebirds in spring and fall, and wintering waterfowl and year-round wildlife
CA5 Keller Bay Restoration	• Sea turtles, a critically endangered species, feed in and on seagrass beds. The Keller Bay shoreline intertidal marsh and SAV beds support the survival of this species.
CA6 Powderhorn Shoreline Protection and Wetland Restoration	• Powderhorn Lake is a saltwater lake and a western extension of Matagorda Bay. This restoration of intertidal marsh preserves the ecological integrity of Powderhorn Lake estuary and several minor estuaries occurring along the Powderhorn Ranch shoreline which have been rapidly eroding.

Measure	Significance
	• The region is biologically unique due to the ecological integrity and historical significance of the water body and adjacent coastal prairie as a food source for native Americans and settlers.
SP1 Redfish Bay Protection and Improvement	• Redfish Bay was designated a state scientific area by the Texas Parks and Wildlife Commission to protect and study native seagrasses. It contains the northernmost extensive stands of seagrass on the Texas coast. This includes 14,000 acres of submerged seagrass beds, with all five species of seagrass found in Texas.
W3 Port Mansfield Channel, Island Rookery, and Hydrologic Restoration	• Bird rookeries provide nesting and feeding opportunities for birds. These are regionally significant as an important stop for migratory birds as they travel across the vast Gulf of Mexico. • The Laguna Madre is one of only six other hypersaline lagoons in the world. It is one of the most important and unspoiled lagoon ecosystems in Texas and one of the most protected in the United States: 75% of its shores are protected by the Laguna Atascosa National Wildlife Refuge to the west and the Padre Island National Seashore on the east. The laguna's salt-tolerant sea grasses and algae support equally hardy crabs, shrimp and fish and is highly productive in terms of seagrasses and fisheries.

4.2.3.5 Construction Cost Estimates of ER Measures

Cost estimates to support the TSP phase screening were derived by applying unit costs from comparable restoration measures from adjacent projects in the district. The costs included real estate acquisition, mobilization and demobilization, and transportation costs from specific borrow areas to the feature locations.

The PDT identified multiple sediment sources for each measure to ensure adequate sediment is available to construct all measures. In several instances, a portion of the necessary sediment would be available from nearer sources, but the cost estimate reflects the cost of dredging and transporting from the largest and possibly farthest source. This approach recognized that certain cost savings may be achieved at the time of construction by using closer sources but ensured that the cost estimate adequately reflected the highest cost source.

The costs were presented in high and low range by considering the highest and lowest acceptable contingencies for each action. The costs were also estimated for each scale of the measure, with initial construction as a separate alternative, and as the initial and out- year construction undertaken at an assumed year in the future under an intermediate rate of RSLC.

Table 17 - Construction Cost Estimates of ER Measures, FY 18

Measure*	Initial			Continuing			Total of Average Estimates
	Low Estimate	High Estimate	Average Estimate	Low Estimate	High Estimate	Average Estimate	
G-5	2,974,454	3,711,107	3,342,781	946,809	1,325,533	1,136,171	4,478,952
G-28-1	757,074	989,345	873,210	0	0	0	873,210
G-28-2	757,074	989,345	873,210	474,513	664,318	569,416	1,442,626
B-2	433,386	600,155	516,771	517,313	724,238	620,776	1,137,547
B-12-1	517,262	717,713	617,488	0	0	0	617,488
B-12-2	517,262	717,713	617,488	2,925,131	4,095,183	3,510,157	4,127,645
M-8-1	149,971	209,720	179,846	0	0	0	179,846
M-8-2	149,971	209,720	179,846	298,825	418,355	358,590	538,436
CA-5-1	46,692	65,369	56,031	0	0	0	56,031
CA-5-2	46,692	65,369	56,031	15,685	21,959	18,822	74,853
CA-6	64,078	88,280	76,179	0	0	0	76,179
SP-1	274,405	384,164	329,285	0	0	0	329,285
W-3	36,098	50,039	43,069	433,173	606,442	519,808	562,877

* Measures with “-1” do not include the one-time out-year nourishment in 2065. Measures with “-2” include the one- time out-year nourishments in 2065.

4.2.3.6 ER Alternative Development Strategy

The ER measures were assembled into alternatives with a systematic combination of management measures based upon specific planning objectives to narrow the possible solutions

4.2.3.6.1 Identification of Lines of Defense and Ecosystem Restoration

The formulation strategy is based on the concept that natural landforms provide lines of defense against coastal storms. The concept of lines of defense is also related to protection of coastal ecosystems and human infrastructure from storm damage caused by hurricanes and tropical storms coming ashore from the Gulf. The series of barriers provided first by the barrier islands, then by living shorelines, and finally coastal marshes can reduce the physical impacts of storm surges and winds which enter the bays. This combination of lines of defense and ER is intended to provide redundant levels of protection and restoration for both humans and Texas coastal ecosystems.

1st Line of Defense and Ecosystem Restoration – Barrier Systems

Barrier islands, shorelines and headlands, as well as tidal inlets form the first line of defense for the nine major estuarine bays and the residential, industrial, and recreational structures therein. They are the boundary between the Gulf and estuarine and the terrestrial ecosystems. These features include barrier beach, dune, back marsh, and shallow open- water areas along the inland side of barrier islands. Coastal barriers also provide habitat for various marine, estuarine, and terrestrial organisms as well as stopover habitat for migrating neotropic birds. Coastal barrier systems provide protection to the wetlands, bays, and estuaries located behind the barrier systems. These features influence tidal prism, limit storm surge heights, retard saltwater intrusion, and limit mechanical erosion by reducing wave energy at the margins of coastal wetlands. Coastal barrier systems and other features of the coastal landscape (e.g., shoals, marshes, and forested wetlands) can provide a significant and potentially sustainable buffer from wind-wave action and storm surge generated by tropical storms and hurricanes.

2nd Line of Defense and Ecosystem Restoration – Estuarine Bay System

Bay shorelines, inlets, and bordering estuarine marshes form the second line of defense and ER. As the barrier systems are eroded, fragmented, and lost, the tidal prism seeks to re- establish dynamic equilibrium between the higher energy Gulf forces moving tidal waters faster and higher into the upper parts of the estuary thereby subjecting bay shorelines and estuarine wetlands to greater Gulf forces of wind and wave erosion and higher salinities. These cumulative changes can cause estuarine marsh loss and shoreline erosion. Estuaries provide habitat for ecologically, commercially and recreationally important fish and wildlife. Estuaries are particularly important nursery habitat for many organisms with early life stages depending on salinities below Gulf salinities. Estuarine shorelines also provide important habitat for migrating neotropic birds.

Associated with estuarine bay systems are adjacent bird rookery islands, oyster reefs, and submerged vegetation beds. Each of these habitat features are typically isolated and relatively small features, as in the case of bird rookery islands. Despite this, when considered from a cumulative perspective, the combination of these features within an estuarine bay system can have significant local, regional, and especially important to the NER requirements for the study, national importance. In addition, strategic placement and numbers of bird rookery islands, oyster reefs, submerged vegetation beds and living shorelines can also function as terraces to slow down waves and sediments, reduce fetch and create EFH.

3rd Line of Defense and Ecosystem Restoration – Bayhead Deltas

The third line of defense and ER involves conserving, restoring, and protecting bayhead deltas. Managing freshwater inflows to optimize salinity, sediment, and nutrient regimes helps sustain deltas and their associated habitats. Developing sediment management strategies would maximize delta accretion and sustain important wetland habitats provided by healthy deltas. Opportunities to manage hydrologic connectivity could also help benefit delta wetlands. The land and wetland habitat provided by deltas further protects human infrastructure and estuarine ecosystems.

Similar to barrier and estuarine bay systems, there are adjacent bird rookery islands, reefs, and SAV which provide benefits similar to those previously described for barrier systems and bay systems.

Six ER alternatives were developed using the formulation strategies. Initial formulation considered two scales for the measures to reduce impacts of RSLR scenarios. Following policy review, the Scale 2 measures that proposed out-year construction for measures G- 28, B-12, CA-5, and M-8 were found to be policy non-compliant and removed from the Recommended Plan. Table 18 provides a summary of the measures in the alternatives. Table 19 presents the list and title of the alternatives. Figure 23 through Figure 28 illustrate the alternatives as a combination of the features.

Table 18 - ER Measures by Alternative

Alt.	G5	G28-1	G28-2	B2	B12-1	B12-2	CA5-1	CA5-2	CA6	M8-1	M8-2	SP1	W3
1-1	•	•		•	•		•		•	•		•	•
1-2	•		•	•		•		•	•		•	•	•
2-1	•			•	•				•				•
2-2	•			•		•			•				•
3-1	•	•		•									•
3-2	•		•	•									•
4-1		•			•		•		•	•		•	
4-2			•			•		•	•		•	•	
5-1	•	•		•	•								
5-2	•		•	•		•							
6-1	•	•		•	•				•				
6-2	•		•	•		•			•				

Table 19 - List of Fully Formed ER Alternatives

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

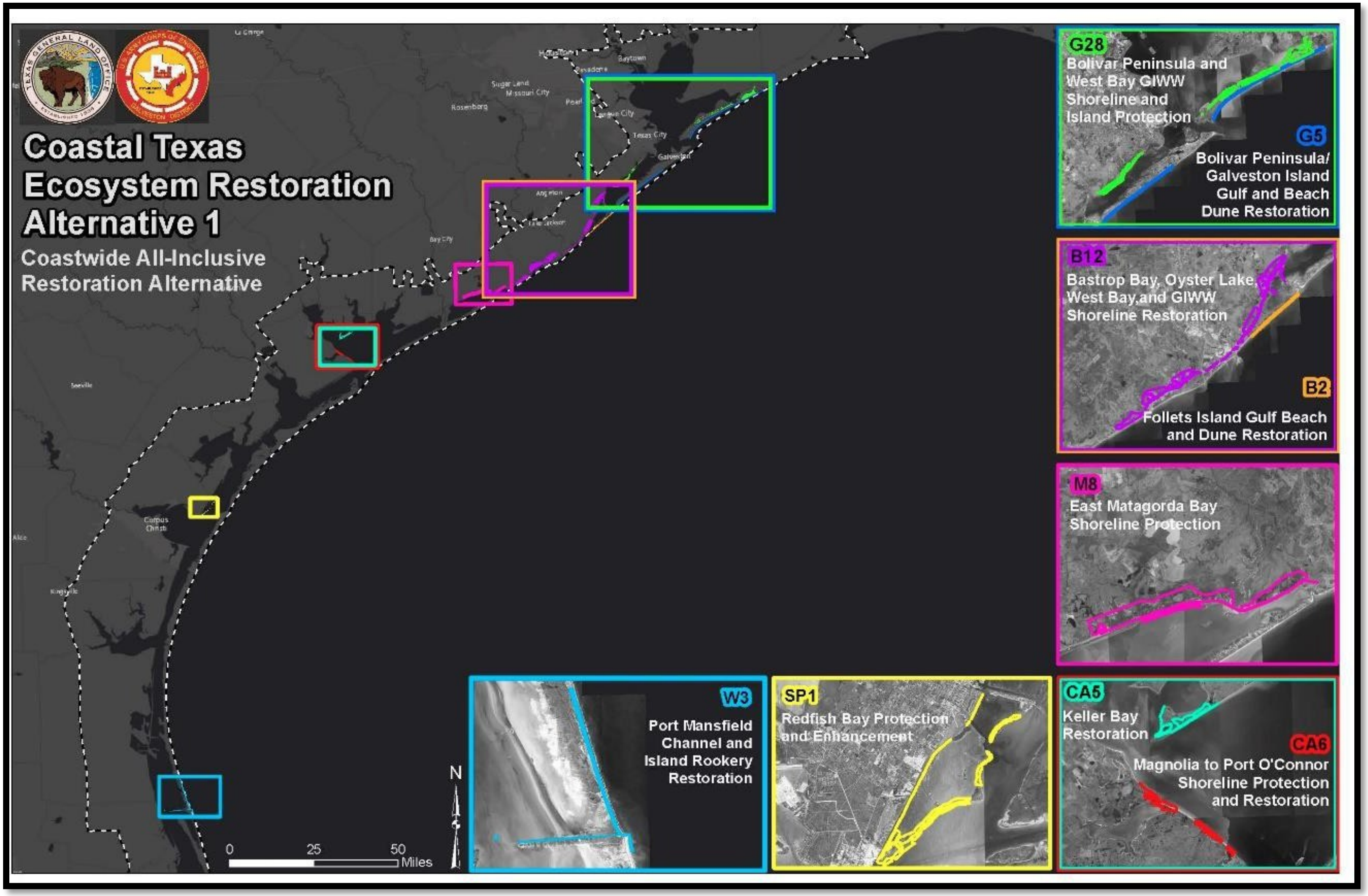

Figure 23 - ER Alternative 1, Scale 2

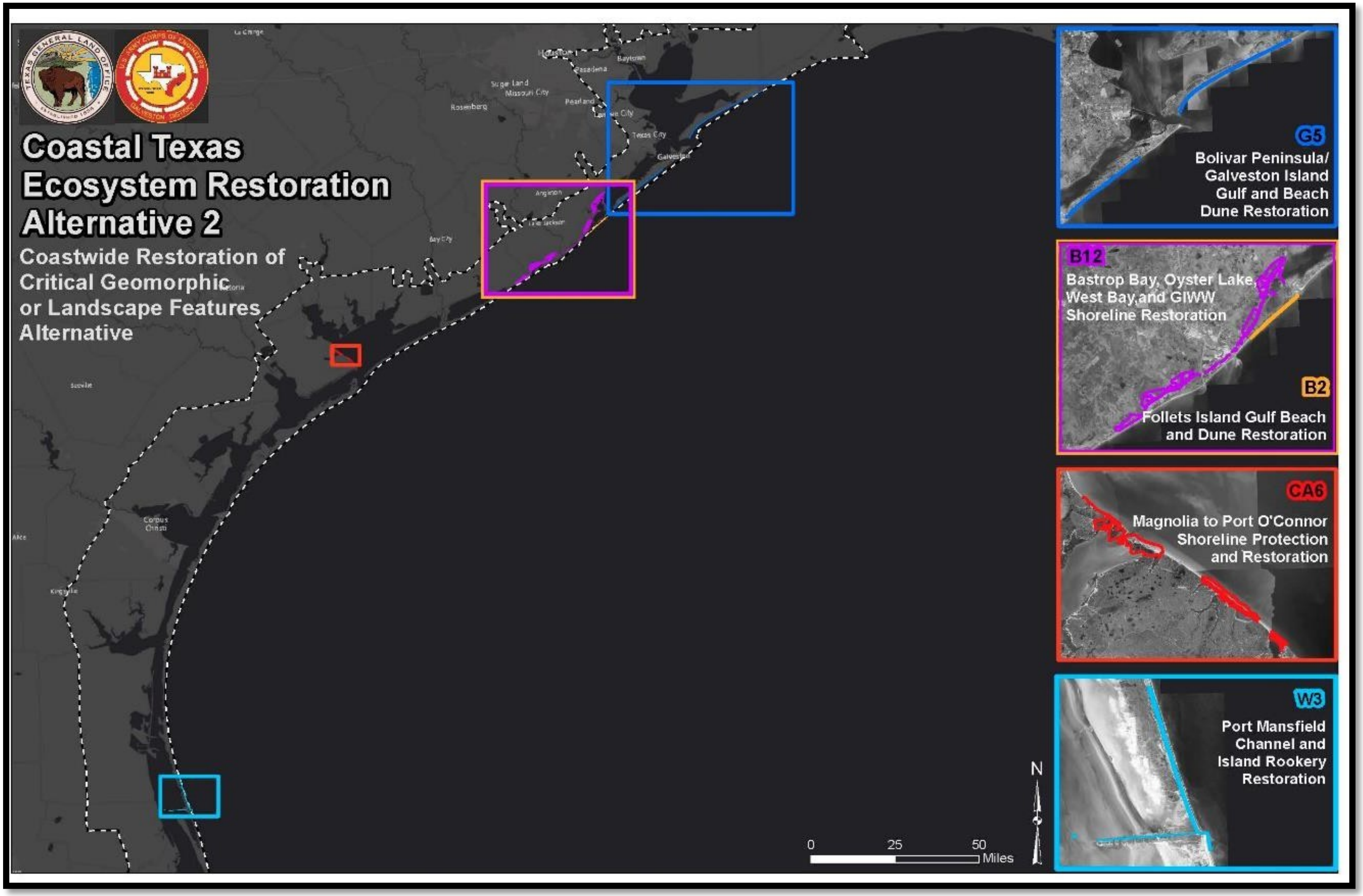

Figure 24 - ER Alternative 2, Scale 2

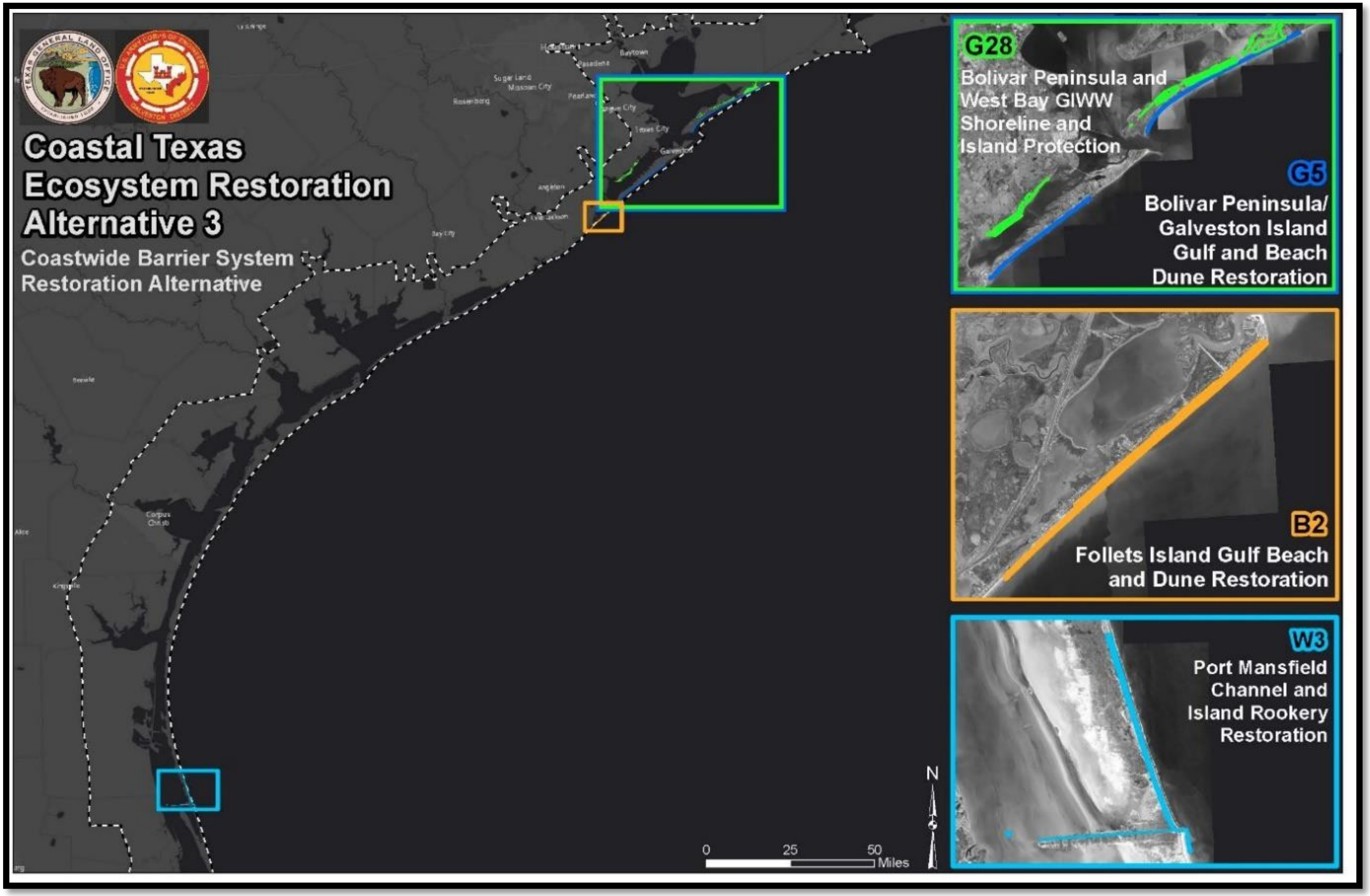

Figure 25 - ER Alternative 3, Scale 2

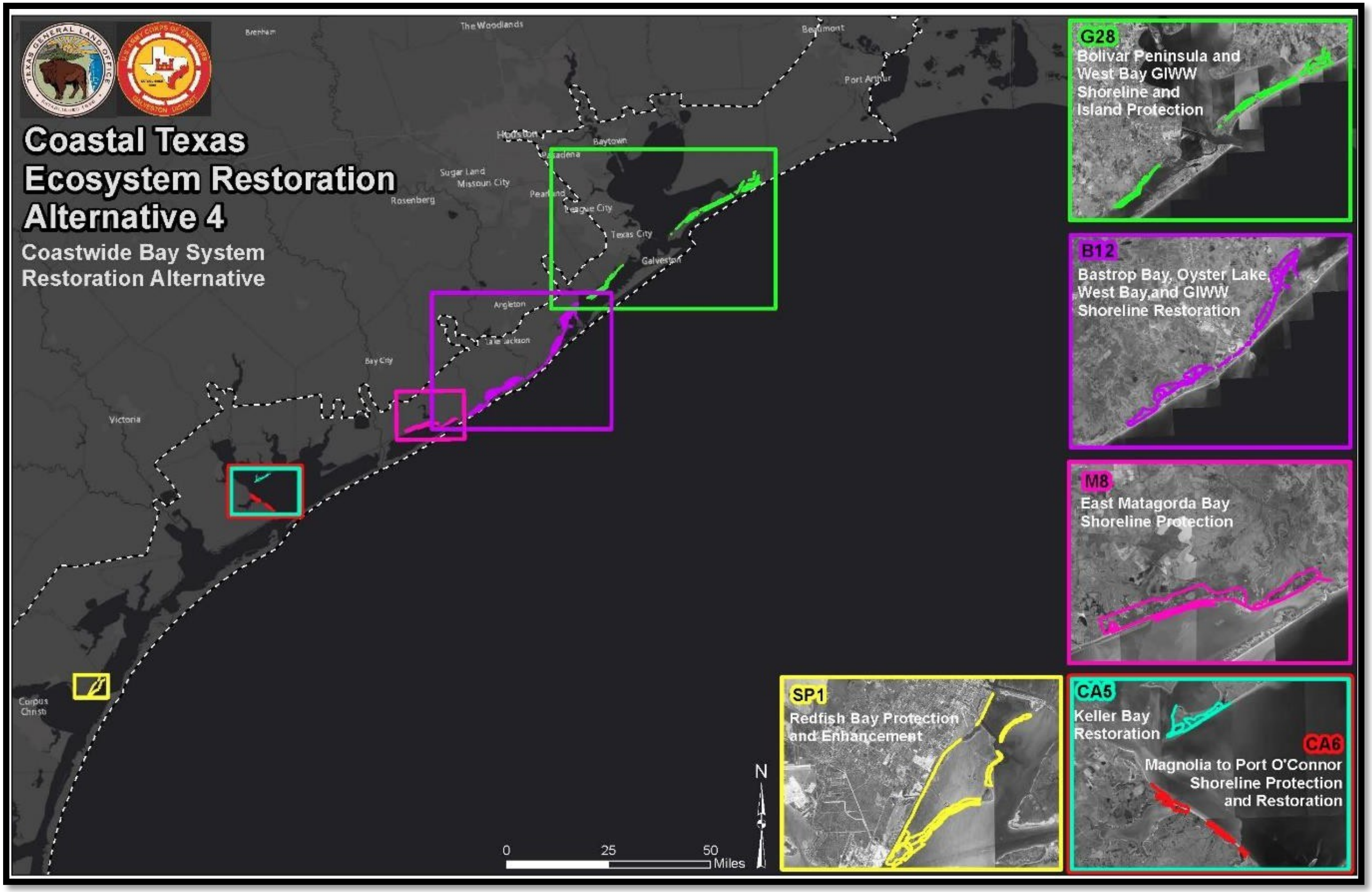

Figure 26 – ER Alternative 4, Scale 2

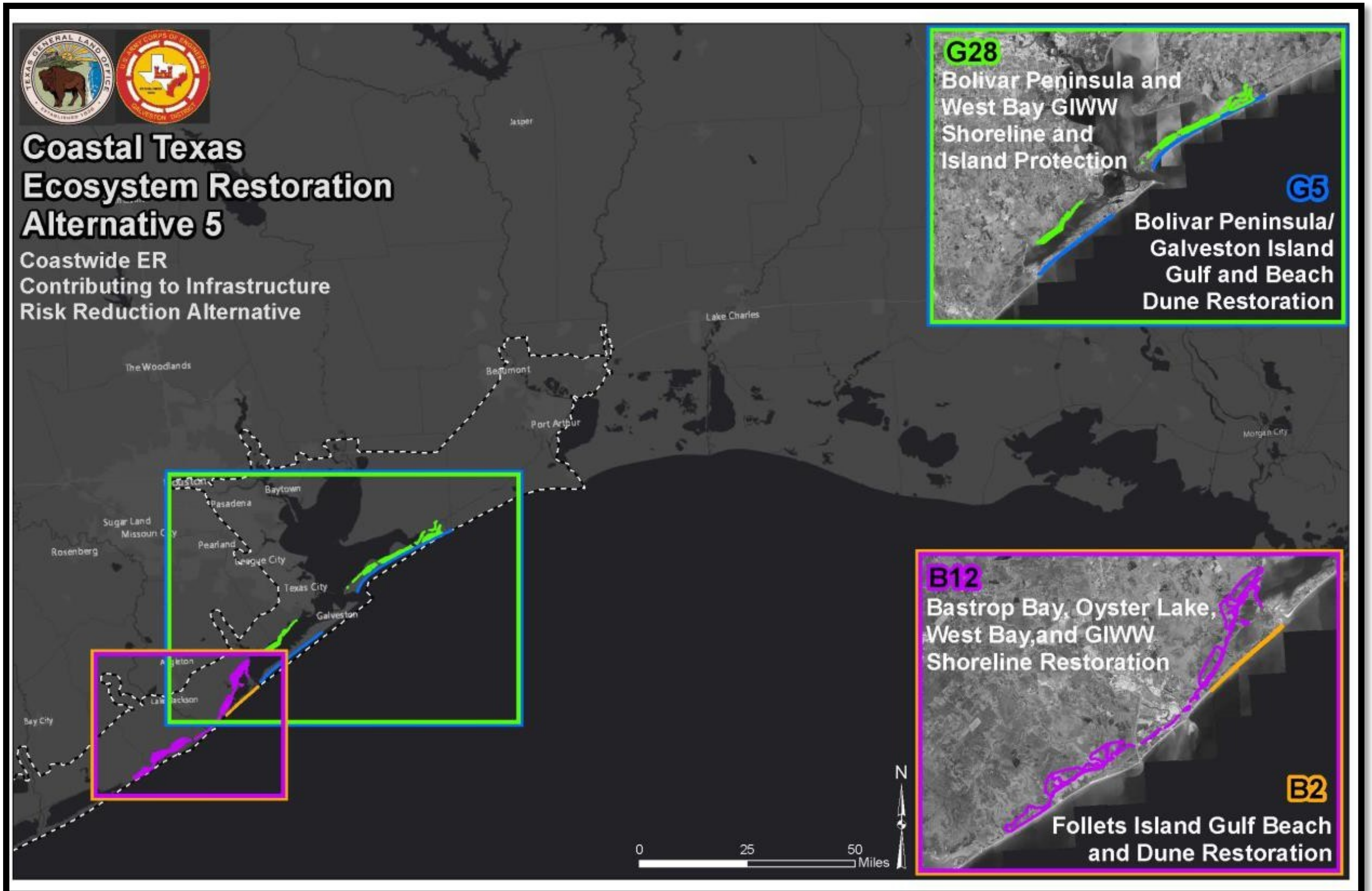

Figure 27 – ER Alternative 5, Scale 2

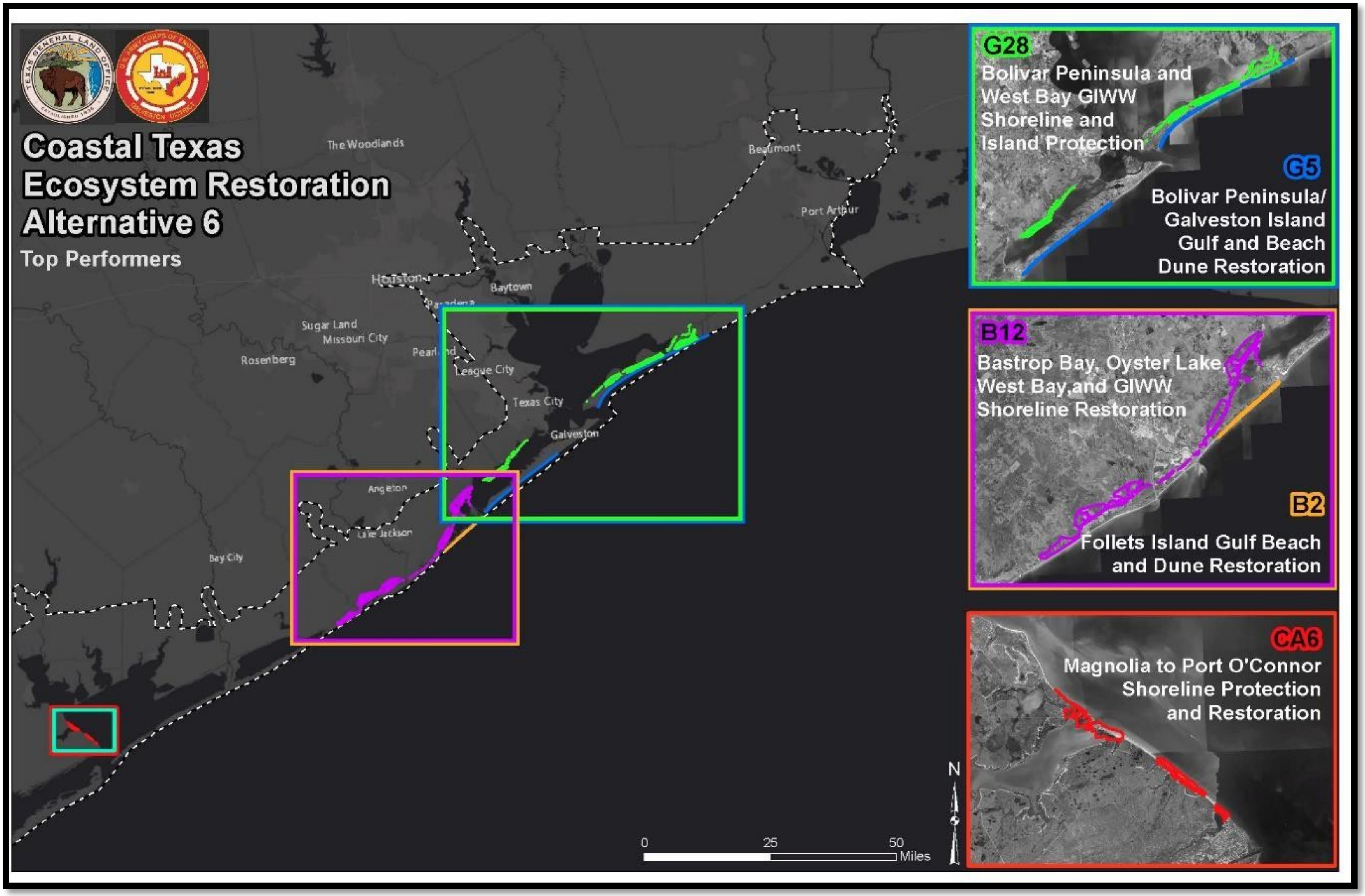

Figure 28 - ER Alternative 6, Scale 2

4.2.3.7 ER Benefit Quantification

Analysis of ER alternatives requires quantification of ecological lift in the form of net Annual Average Habitat Units (AAHUs) and comparison of the future-without (FWOP) and future with-project (FWP) condition. The TSP selection phase completed for the initial Draft Integrated Feasibility Study in 2018 applied the Habitat Evaluation Procedure (HEP) and Wetland Valuation Analysis (WVA) models to quantify the improvement in habitat suitability. HEP is a widely accepted approach for quantitative evaluation of measures or management activities that cause environmental changes and to predict ecological impact of measures. The WVA methodology quantifies changes in habitat quality and quantity that are predicted to result from management activities. HEP uses a species-oriented approach and is based on approved Habitat Suitability Index (HSI) models, while WVA uses a community approach.

Four of the nine management measures were initially developed with two scales, initial construction and out-year construction. Therefore, the analysis considered this array to be 13 management measures in total, although Scales 1 and 2 for a single measure were not combinable. Scale 1 proposed initial construction of each measure, and Scale 2 assumed one or more out-year nourishment would occur after initial construction and within the 50-year period of analysis. Environmental benefits and project first costs were developed separately for each measure and are fully additive when measures are combined to form alternatives. Note that Scale 2 features were removed from the plan following the TSP phase, but they are presented in this analysis, which supported identification of the TSP, and preceded their removal. Table 21 and Table 22 display Initial scales of measures, and benefits measured in AAHUs for the measures and alternatives,

Table 20 - ER HSI Models per Cover Type and ER Measure

Model	Cover Type	Measure
Brown Shrimp	Estuarine Wetland and Marsh	G-28, B-12, M-8, CA-5, CA-6
Spotted Seatrout	SAV	CA-5, SP-1, W-3
Brown Pelican	Bird Rookery Islands	G-28, M-8, SP-1, W-3
American Oyster	Oyster Reefs	G-28, B-12, M-8, CA-5, SP-1, W-3
Kemp's ridley sea turtle	Beach/Dune	B-2, W-3

Table 21 - AAHUs by ER Measure and Scale

Measure	FWOP	FWP	Net AAHUs
G-5	804	2,624	1,820
G-28-1	20,327	21,414	1,087
G-28-2	20,327	29,537	9,210
B-2	222	613	391
B-12-1	30,357	31,618	1,261
B-12-2	30,357	47,591	17,234
M-8-1	10,769	10,992	223
M-8-2	10,769	17,072	6,303
CA-5-1	559	781	222
CA-5-2	559	890	331
CA-6	901	919	18
SP-1	20	3,521	3,501
W-3	8,279	38,815	30,536

Table 22 - Future With-Project AAHUs and Acres by ER Alternative and Scale

ER Alternative	Net AAHUs	Target Year 51* Acres
Alternative 1 (9 measures)		
Scale 1	39,050	63,199
Scale 2	69,340	160,279
Alternative 2 (5 measures)		
Scale 1	34,028	54,669
Scale 2	49,998	105,119
Alternative 3 (4 measures)		
Scale 1	33,829	53,205
Scale 2	41,959	83,145
Alternative 4 (6 measures)		
Scale 1	6,304	11,142
Scale 2	36,594	108,222
Alternative 5 (4 measures)		
Scale 1	4,555	7,385
Scale 2	28,655	87,775
Alternative 6 (5 measures)		
Scale 1	4,575	8,005
Scale 2	28,675	88,395

Target Year 51 is the end of the period of analysis.

4.2.3.8 Cost-effectiveness/Incremental Cost Analysis

Environmental restoration benefits can be measured in habitat units or some other physical unit, while costs are measured in dollars. Therefore, benefits and costs cannot be directly compared. Two analyses are conducted to help planners and decisionmakers identify plans for implementation, though the analyses themselves do not identify a single, ideal plan. These two analyses are cost-effectiveness and incremental cost analysis (CE/ICA). Application of CE/ICA is required for ER formulation, and the process is described in the Economic and Environmental Principles and Guidelines for Water and Related Land Resource Implementation Studies (U.S. Water Resources Council, 1983).

Cost-effectiveness analysis compares the annual costs and benefits of plans under consideration. It identifies the least cost plan alternative for each possible level of environmental output, and the maximum level of output for any level of investment.

Incremental cost analysis of the plans that are identified as cost-effective reveals changes in costs as output levels are increased. Results from both analyses are presented graphically to help planners and decision makers select plans. For each of the Best Buy plans identified through incremental cost analysis, an “is it worth it?” analysis is then conducted for each incremental measure or plan to justify the incremental cost per unit of output to arrive at a recommended plan.

For this study, multiple CE/ICA runs were informative, and supported reformulation of alternative plans to ensure the maximum ecological lift was achieved for incremental costs. CE/ICA was run initially to defend the NER plan proposed within the TSP and published in the Draft Integrated Feasibility Report and EIS. It was rerun with the final ER plan to confirm the revisions made in response to public, agency, technical and policy comments generated an ER plan that is cost-effective and incrementally justified.

The measures within Alternative 1-2 were refined through multiple screenings of their effectiveness specific to the needs and opportunities within the study area and the diversity of the habitat they preserve, and Alternative 1-2 was recommended for inclusion in the TSP and published in the first draft integrated feasibility report.

Figure 29 illustrates the screening process for ER measures to identify the NER component of the TSP. Refinements were made to the ER Plan following publication of the DIFR-EIS in 2018 and receipt of public, agency, technical and policy comment. The changes are described in Section 4.3.7 of this Appendix, the most significant being the removal of the outyear nourishment noted as Scale 2 measures.

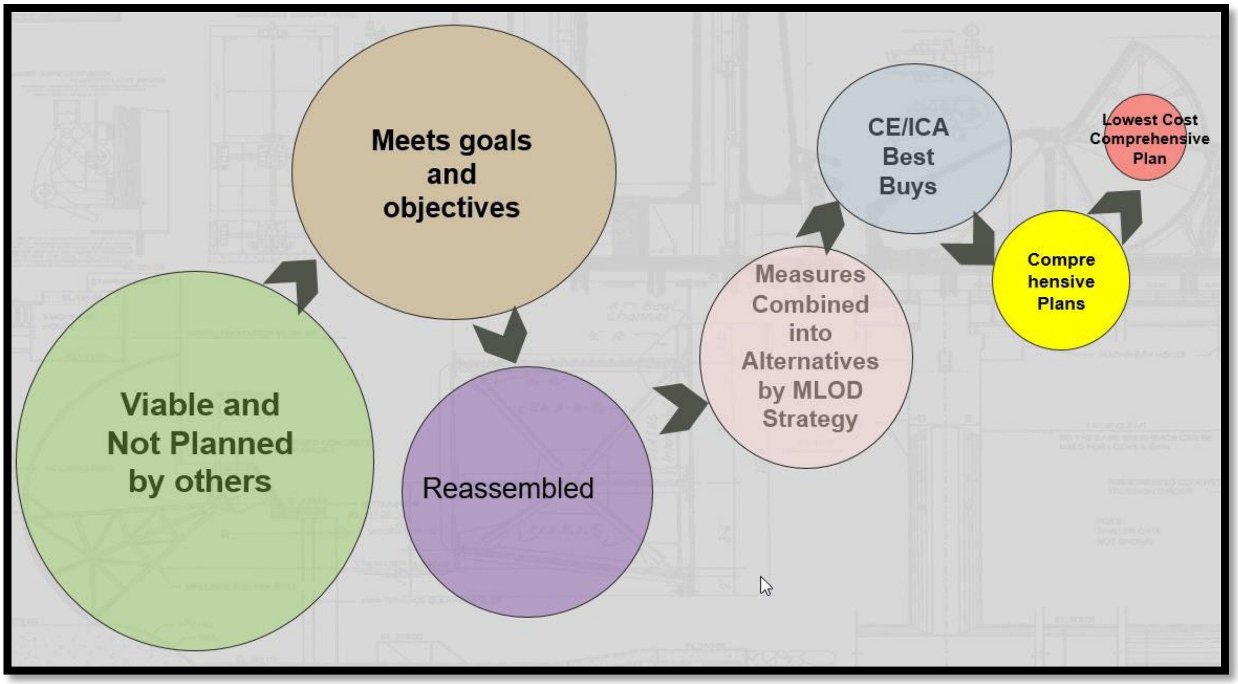

Figure 29 - Screening Steps to Identify Lowest Cost Comprehensive ER Alternative

4.2.4 Development and Initial Screening Evaluation Region 1 Alternative Plans – 1 CSRM

After the initial screening was completed, the remaining CSRM measures in Table 7 through Table 10 and the conceptual plans were reformulated into an array of six CSRM alternative plans for Region 1, in addition to the No-Action Alternative. As plans were developed, they were assumed to have similar level of risk reduction to the sum of the existing risk reduction systems in Region 1. For example, plans that had a levee system tying into the Galveston seawall were designed and evaluated based on similar heights of the existing seawall, which is at an elevation of approximately 17 feet NAVD. The same assumption was used for plans tying into the Texas City HFPS. The PDT made this simplifying assumption to ensure that the analysis focused on an initial comparison of distinctly different plans rather than different scales of plans. This was consistent with the conceptual formulation strategy, which explored different strategies (Gulf Shoreline Focus, Back/Mid Bays Focus, Upper Bay Focus). Once a strategy for risk reduction was selected, the study team focused on the scale of the level of risk reduction for the TSP in the second planning iteration phase.

4.2.4.1 Nonstructural Plans and Managed Retreat

4.2.4.1.1 Managed Retreat

A coastal storm risk management alternative that allows the shoreline to move inland, rather than addressing storm surge, inundation and erosion through structural alternatives is “managed retreat”. It moves human development away from risk, invests in a more landward line of defense, and allows natural coastal forces and flooding to impact the coastal area.

Properties in areas that are too risk prone to cost-effectively enclose within a structural system are acquired and residents and businesses relocate to less vulnerable locations. Successful implementation has been achieved when the program is implemented shortly after a disaster event and before storm damage is repaired.

Managed retreat experiences from locations in different countries and with different economic and developmental characteristics have identified challenges to implementation. Social and livelihood losses, jurisdictional conflicts, and lack of political will inhibit the effectiveness of impactful retreat. Residents of all income levels can feel economic and social loss from relocation. Regional governments resist the loss of tax base from relocations, or support residents who recognize and accept the risk and resist relocation.

In the Coastal Texas study area, managed retreat was considered impractical and cost prohibitive as a primary alternative in the base year. Risk prone areas are broad and densely populated, and acquisition would include many high value coastal properties. The acquisition would likely face legal challenges, which would have cost and schedule implications that do not achieve the study goals and objectives to reduce risk of life to populations and reduce damage to structure and contents in the period of analysis.

Managed retreat was considered more appropriate as an adaptive measure in areas where the coastal storm risk and sea level change impacts make structural solutions cost prohibitive in future years.

4.2.4.1.2 Nonstructural Plans

Section 73 of the Water Resources Development Act of 1974 requires consideration of nonstructural alternatives in flood damage reduction studies. They can be considered independently or in combination with structural measures. Nonstructural measures reduce flood damages without significantly altering the nature or extent of flooding. Damage reduction from nonstructural measures is accomplished by changing the use made of the floodplains, or by accommodating existing uses to the flood hazard. Examples are flood proofing, relocation of structures, flood warning and preparedness systems (including associated emergency measures), and regulation of floodplain uses.

- **Dry Flood Proofing:** Dry Flood Proofing measures allow flood waters to reach the structure but diminish the flood threat by preventing the water from getting inside the structure walls. Dry Flood Proofing measures considered in this screening make the portion of a building that is below the flood level watertight through attaching watertight closures to the structure in doorway and window openings. Detached levees and floodwalls were not considered due to the density of structures in the floodplains.
- **Wet Flood Proofing:** Allowing flood water to enter lower, non-living space areas of the structure via vents and openings to reduce hydrostatic pressure and in turn reducing flood-related damages to the structure's foundation. This technique can be used along with the protection of utilities and other critical equipment, which

can include permanently raising machinery, critical equipment, heating and cooling units, electrical outlets, switches, and panels and merchandise/stock above the estimated flood water height. It can also involve construction of interior or exterior floodwalls, utility rooms, or additional living space to compensate for space subject to flooding, and the use of flood resistant materials.

- **Elevation:** Raising the lowest finished floor of a building to a height above the design flood level. This option was considered both as a stand-alone measure and in conjunction with additional construction. In some cases, the structure is lifted in place, and foundation walls are extended up to the new level of the lowest floor. In other cases, the structure is elevated on piers, posts, or piles.
- **Acquisition:** Removal of the structure from the floodplain through demolition. Lands are then preserved for open space uses.
- **Relocation:** Moving the structure out of the floodplain, either within the existing property boundary (if sufficient space is available) or to another property.
- **Rebuild:** Demolishing a flood-prone structure and replacing it with a new structure built to comply with local regulations regarding new construction and substantial improvements in a floodplain and therefore is at a lower risk. The rebuild option would be considered only where the costs were found to be less than those associated with an otherwise recommended treatment.

The team initially evaluated a nonstructural raising or a buyout program in the entire area of Region 1. The nonstructural assumption was based on 100 percent participation rate and would have included removing or modifying over 64,000 residential and nonresidential structures receiving flood damage by the stage associated with the 0.01 (100-year) annual chance exceedance (ACE) event in 2035 and 2085 under without-project conditions. The PDT determined that a nonstructural treatment as a stand-alone plan does not achieve the project goals and objectives for several reasons. Initial stakeholder and study sponsor discussions suggest it is highly likely a voluntary program would receive very little participation due to the number of structures potentially removed from the community. Residents may not want to volunteer for buyouts because of the economic cost of relocation and the social costs of breaking up a community or uprooting a family. Also, it is important to note that, as seen with Hurricane Harvey impacts, relocating residents away from the coastal surge doesn’t necessarily remove all flooding risk from residents.

Significant community cohesion and environmental justice concerns also arise in minority and low-income populations in some communities along the west side of the Galveston Bay. A large-scale nonstructural plan creates challenges since the final detailed evaluations for raising or buyout proposals include a Benefit-Cost Analysis (BCA) defending that the estimated cost of future flood damage exceeds the cost of purchasing and demolishing a structure. Significant equity concerns have come up around the BCA method when reviewing the Social Vulnerability Index in the communities of La Porte, Santa Fe, La Marque, and in portions of the city of Galveston (Figure 30). For instance, because the cost of repeated flooding must be greater than the cost of acquisition and demolition to justify the effort, neighborhoods with low land values and lower value homes may not qualify. Residents of these low-lying, affordable neighborhoods are more likely to be low-income, elderly, or people of color.

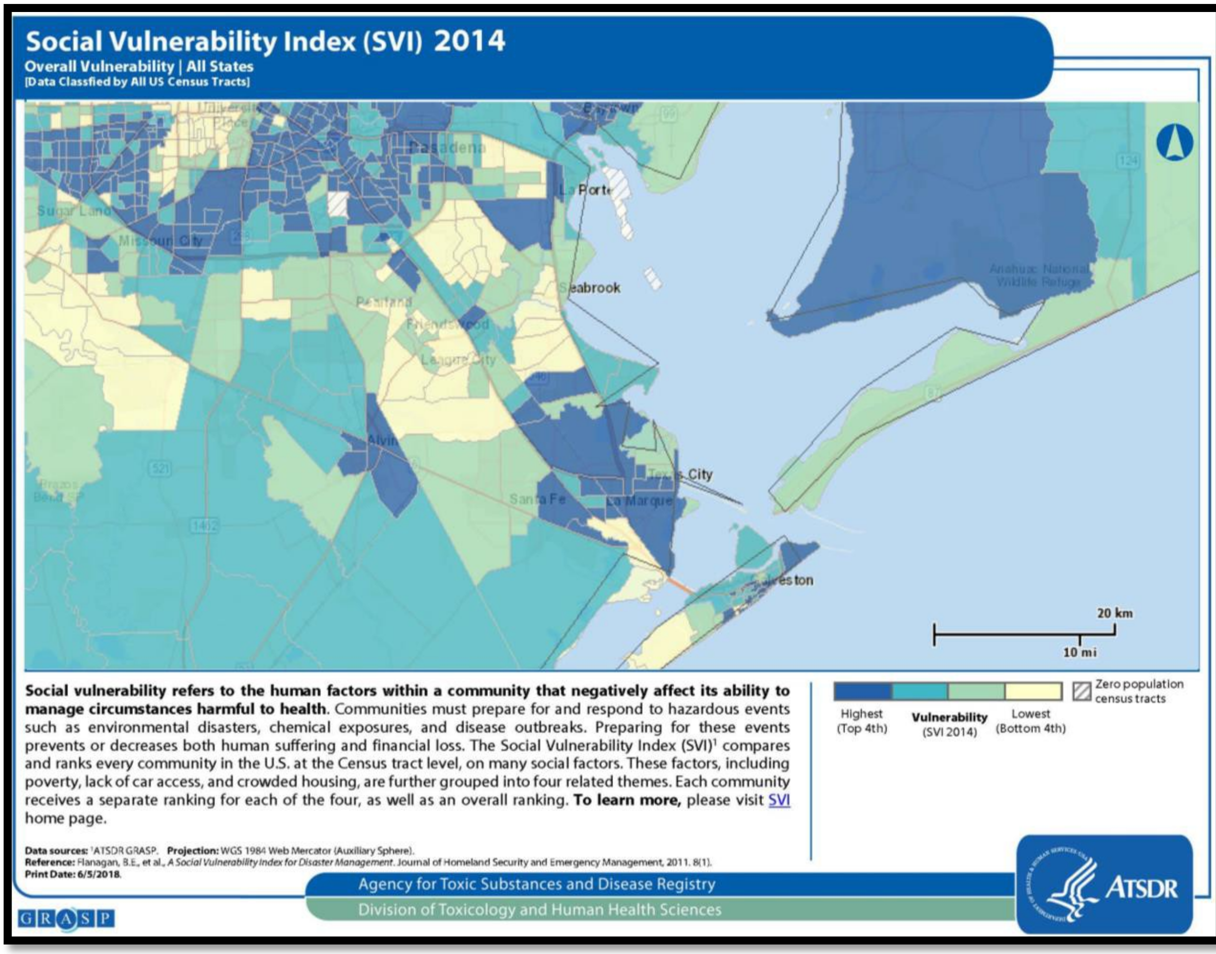

Figure 30 - Galveston Bay Region Social Vulnerability Index

Elevation is a common approach already undertaken by residents and businesses in the study area. Specific assumptions related to managed retreat were applied in scenario analysis when developing the without-project conditions. Adjustments were made to the structure inventory to reflect the most-likely FWOP more accurately and FWP conditions. Under FWOP and FWP conditions, residential and nonresidential structures that were identified as severely flooded structures (greater than 50 percent damage to the structural components) from the 0.10 (10-year) ACE event were set equal to the stage associated with 0.002 (500-year) plus 1 foot for the year 2085 under the high sea-level rise scenario. This adjustment is consistent with the FEMA floodplain regulations, which require residents to rebuild above the base flood elevation after a structure receives greater than 50 percent damage to the structural components as a result of a flood and would simulate a managed retreat on a small scale. The first-floor elevations of 21 structures in 2017, 68 structures in 2035, and 542 structures in 2085 were adjusted for severe flooding. The severe damage adjustment lowered equivalent annual without-project damages from $2.1 billion to $1.75 billion under the high sea-level rise scenario.

4.2.4.2 Behind the GIWW with Complementary System of Nonstructural Measures (Alternative B)

One of the first alternatives developed was a coastal barrier placed behind the GIWW. This alternative was developed to address storm surge flooding at the Gulf interface but also avoided some of the high and intense surges on a large navigation gate that would be needed to close off Galveston Bay to elevated water level experienced ahead of storms. The alignment also avoided some of the critical habitat along Bolivar Peninsula, Galveston Island, and west Galveston Bay. The strategy prevents storm surge from entering Galveston Bay by placing navigation gate across the Houston Ship Channel, north of Bolivar Roads. The system includes a barrier across Bolivar Peninsula, which would be placed north of the GIWW and would avoid the habitat along Bolivar Peninsula. The closure north of the pass at Bolivar Roads would tie into the existing Texas City Dike. The dike would require significant improvements to be able to address coastal storm surge. The system would then tie into the existing Texas City Levee system, with improvements to that system, and would include additional improvements further west into the communities of Hitchcock and Santa Fe. Due to the uncertainties associated with induced stages on the city of Galveston, the alternative would include a ring levee around the city. To address wind-driven surges in the bay's upper reaches, nonstructural measures, closures on key waterways, Dickinson Bayou, and Clear Lake were included. Figure 31 provides an overview of the features included with a Coastal Barrier behind the GIWW.

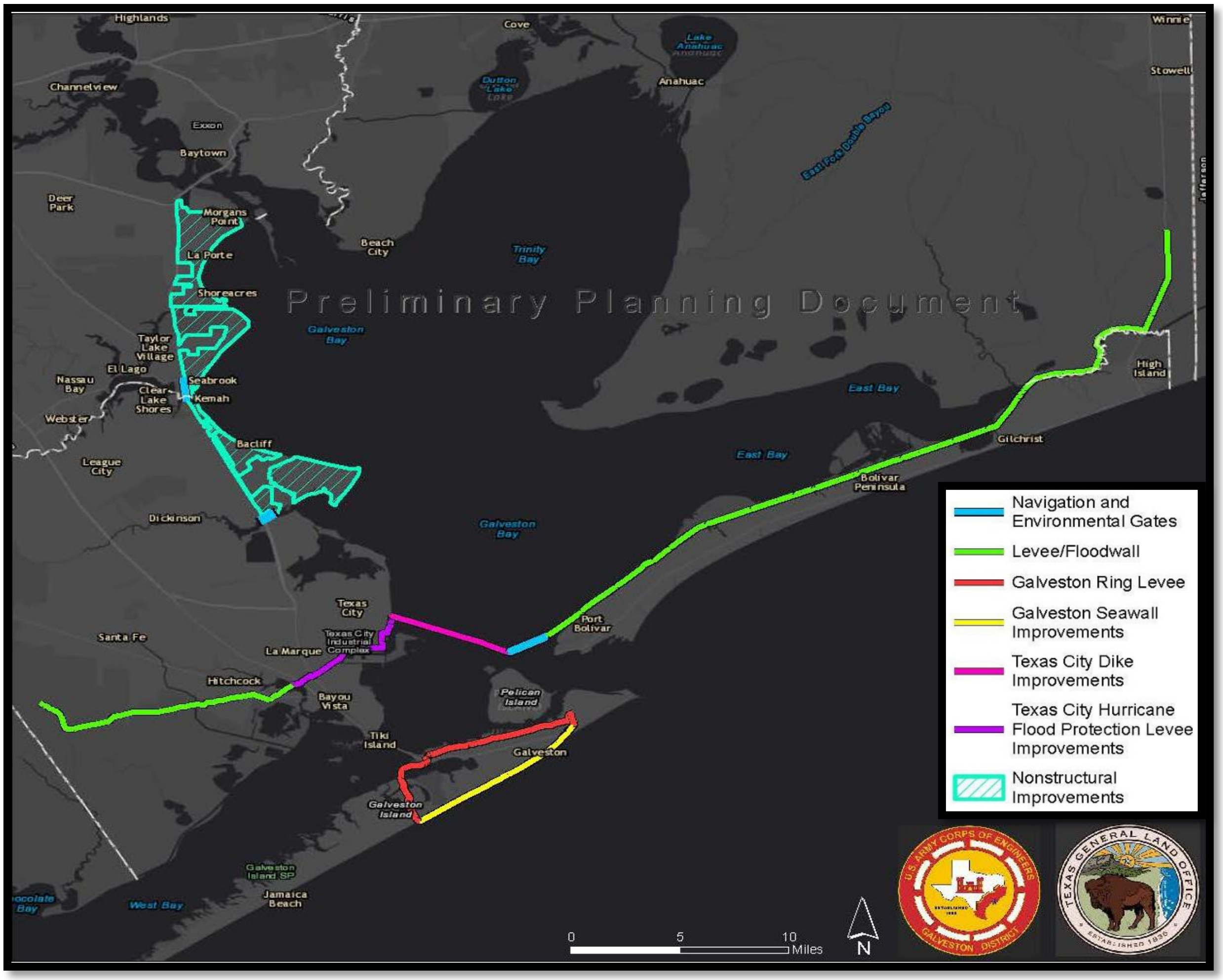

Figure 31 - Coastal Barrier Behind GIWW with Complementary System of Nonstructural Measures (Alternative B)

The alternative was compared to the FWOP conditions; it was determined that there were a few areas of concern that needed detailed review to determine if this was a viable alternative for further development.

4.2.4.2.1 Navigation Concerns

One of the first areas of concern was navigation impacts, particularly surrounding navigation safety. The concern is related to the number of deep draft ships (foreign traffic) and shallow draft tugs and barges (domestic traffic) that would have to transition through the gate. Using data from the USACE's Waterborne Commerce Statistics Center, the team determined that over 300,000 shallow draft tugs and barges would have pass through the large navigation gate at this location (Figure 32).

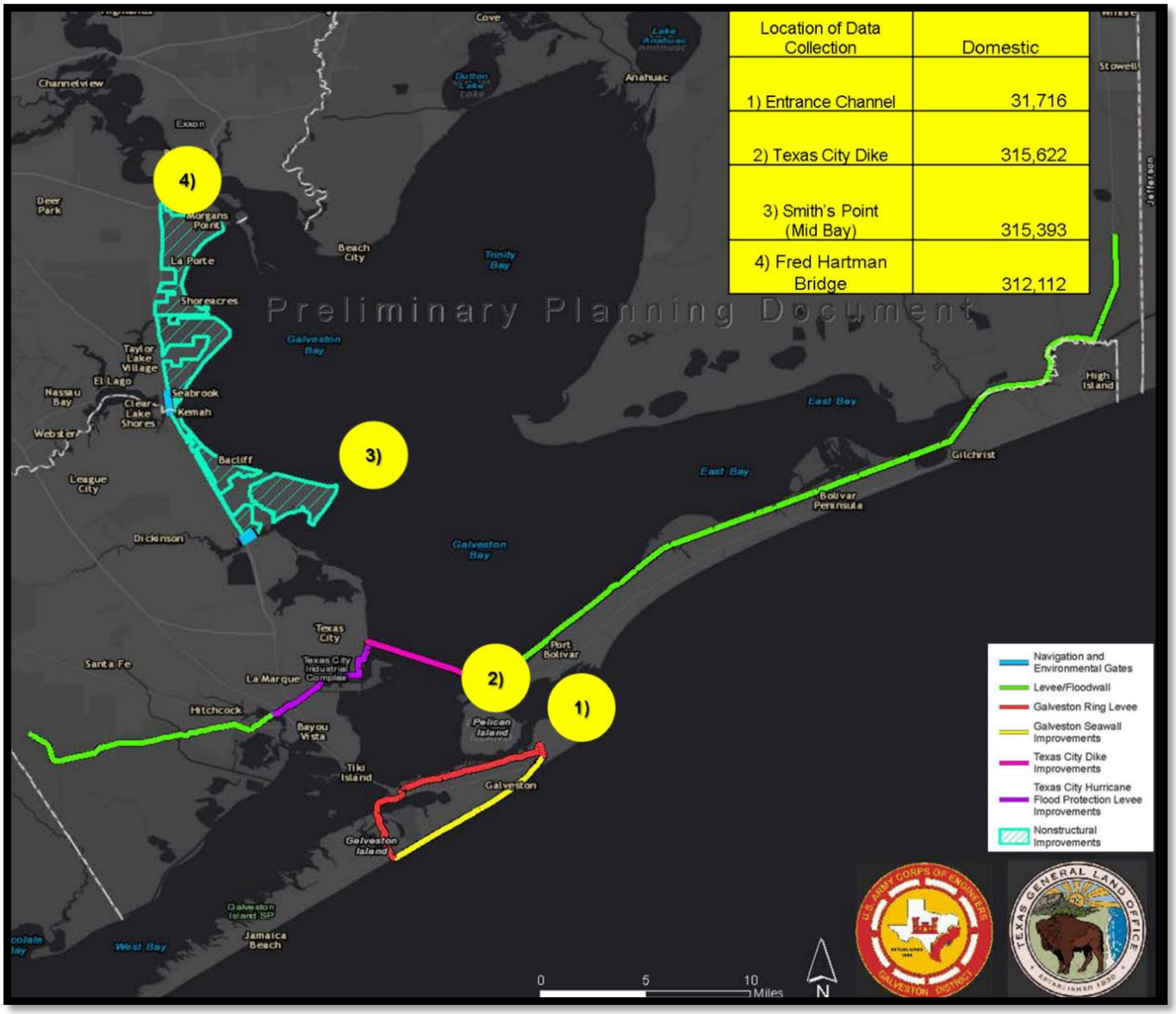

Figure 32 - Navigation Impacts – Domestic Traffic (Source: USACE Waterborne Commerce Statistics Center)

This alternative would also have impacts on interactions between deep draft ships (foreign traffic) and shallow draft tugs and barges (domestic traffic). The intersection with the Houston Ship Channel and the GIWW is very busy, and with additional traffic and larger vessels transiting every year, it is expected to become even more challenging. The Houston- Galveston Navigation Safety Advisory Committee has implemented an alternate route that allows mariners to avoid the Bolivar Roads/Houston Ship Channel intersection. Known as the Bolivar Roads Alternate Inbound Route (Figure 33). The passage acts much like a freeway on-ramp. Westbound traffic exiting Bolivar Roads may enter the ship channel via the Bolivar Roads Alternate Inbound Route and continue inbound, rather than navigating the difficult 105-degree turn at the intersection. The alternative would impact this route since barge traffic would be redirected to the large navigation gate, or the system would require addition navigation gates.

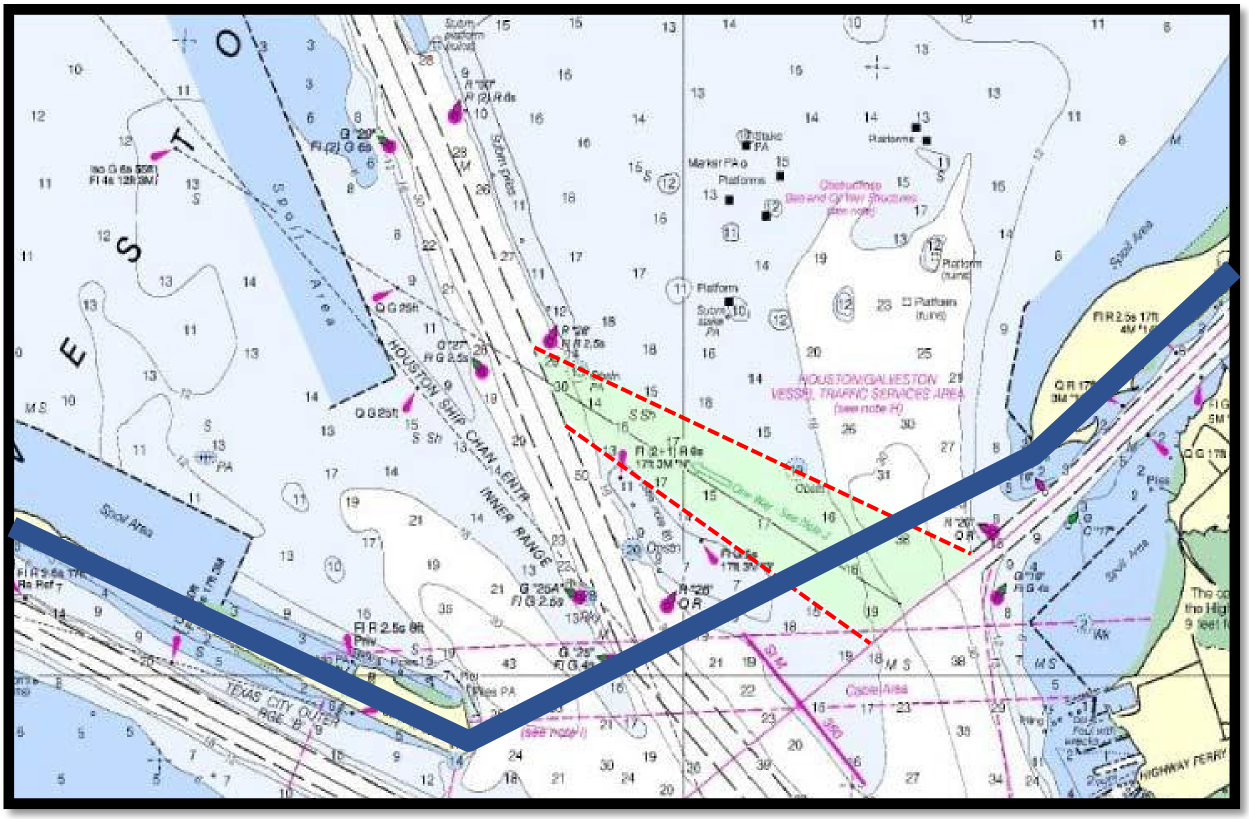

Figure 33 - Bolivar Roads Alternate Inbound Route with Coastal Barrier behind GIWW Alignment

4.2.4.2.2 Construction Concerns

Part of the construction activities for this alternative would be to raise the exiting Texas City Dike to provide risk reduction from Gulf storm surges. The dike's existing structure consists of a 28,200-foot-long (approximately 5.34 miles) pile dike paired with a rubble-mound dike that runs along the south edge of the pile dike (USACE, 2007). The Texas City Dike was built to protect the Texas City Channel from cross currents and excessive silting, but not necessarily storm surge. In discussions with the PDT, it was determined that the foundation of the existing structure would have to be improved to increase its existing height. This action would have significant impacts on the current recreation use on the dike. The dike includes recreation features such as asphalt and crushed gravel parking areas, roughly three-quarter miles of beaches, four boat ramps (two with running water for fish cleaning stations), ten concrete picnic shelters, and one wheelchair accessible pier. The Dike's Samson-Yarbrough boat ramp was the busiest on Galveston Bay, and the dike as a whole was the second-busiest boat launch site in the state (Aulds, 2010). Many of the features would be impacted during construction or would have to be relocated after construction.

Due to both the navigation and construction concerns the “Coastal Barrier behind the GIWW” alternative was removed from further consideration.

4.2.4.3 Mid-bay Barrier Concept (Alternative C)

This alternative was developed to avoid some of the navigation impacts at Bolivar Roads, by placing a surge barrier near the middle of Galveston Bay. This alignment is similar to the recommendation in a USACE Texas Coast Hurricane Study released in 1979. The system would start on the east side of Galveston Bay near Smith Point and would continue across the bay, crossing the ship channel. The barrier across Galveston Bay also include environmental control gates to maintain flows between the upper Galveston Bay and lower Galveston Bay and small gates to address small recreational vessels moving through the system. The system would tie into the existing Texas City Levee system. Improvements to this existing levee system would be included and require additional improvements farther west into the communities of Hitchcock and Santa Fe. The plan also addresses flooding on Galveston Island with a levee system. Due to the limited open-water area north of the system, wind-driven surges in the bay's upper reaches are not expected to be a concern, which is why the nonstructural measures, ring levees, and closures on key waterways were dropped from consideration.

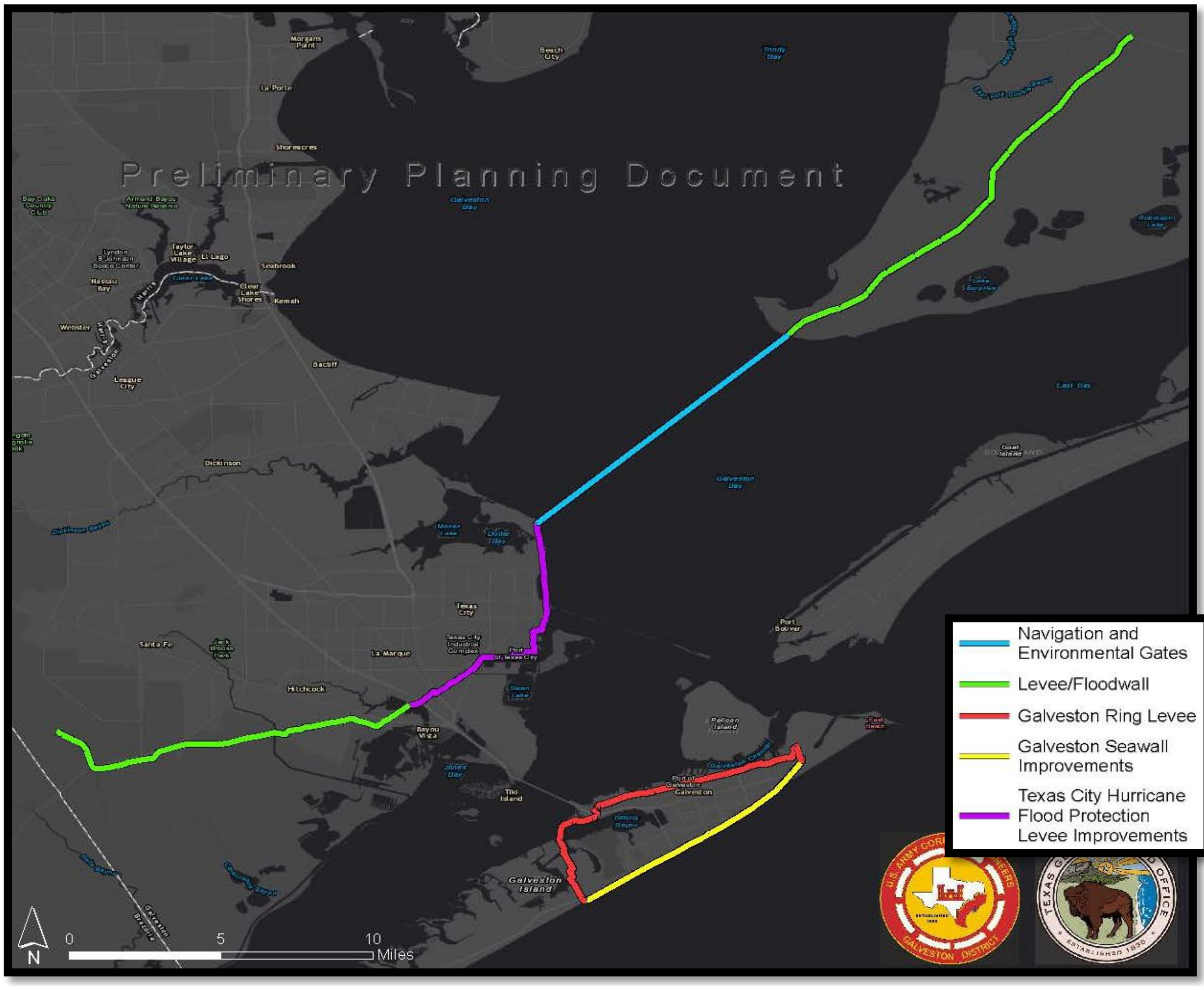

Figure 34 - Mid-bay Barrier Concept

When the alternative was compared to the FWOP conditions, several areas of concern required detailed review to determine if this was a viable alternative for further development.

4.2.4.3.1 Navigation Concerns

Similar to the previous alternative “Coastal Barrier behind the GIWW,” there was also a concern with navigation impacts, particularly surrounding navigation safety for recreational vessels. Deep draft ships (foreign traffic), shallow draft tugs and barges (domestic traffic), and large recreational vessels would all be forced to use one opening in the center of the bay. Small recreational vessels and small commercial vessels with limited draft, width, and vertical clearance could use some of the environmental gates and small sector gates similar to the gates used in the Greater New Orleans Hurricane and Storm Damage Risk Reduction System (HSDRRS) (Figure 33 and Figure 34); however, Galveston Bay includes one of the nation’s largest recreational sailing fleet, including multiple yacht clubs along the east side of the bay. Vertical clearances and keel clearances may force some of the recreational vessels through the large gate near the center of the system, adding to vessel congestion and safety concerns.

Figure 35 - Example Vertical Lift Gate (HSDRRS, Bayou Bienvenue Gate at Surge Barrier)

Figure 36 - Example Sector Gate (HSDRRS, Bayou Bienvenue Gate at Back Levee)

4.2.4.3.2 Operation, Maintenance, Repair, Replacement, and Rehabilitation Concerns

In order to maintain flows between the upper Galveston Bay and lower Galveston Bay, the structure would include environmental gates to maintain the natural water circulation in the bay when the system is open. The environmental gates would be similar to the vertical lift gate shown on Figure 36. Current modeling estimates that over 100 environmental gates would be needed to maintain existing circulation in the bay. In addition to the significant cost for constructing these gates, there would be significant operation, maintenance, repair, replacement, and rehabilitation (OMRR&R) cost associated with these gates. OMRR&R with environmental gates typically include:

- Monthly startup of backup generators/systems
- Yearly closure of gates pre-hurricane season
- Dive inspection
- Gate adjustments/greasing
- Gate rehab
- Gate replacement

4.2.4.3.3 Direct and Indirect Environmental Impacts

The location and size of the required underwater footprint for the mid-bay closure would significantly impact Galveston Bay's oyster reefs. Historically, the creation and widening of the Houston Ship Channel has increased the area of oyster productivity northward in the bay by allowing penetration of saline water into the upper estuary and increasing current velocities. Over 2,500 acres of reef have developed along this channel (Powell et al., 1994). The current alignment would have significant direct impacts to the historic "Redfish Oyster Reef" near the middle of Galveston Bay and the reefs along the Houston Ship Channel near the proposed navigation gate (Figure 37).

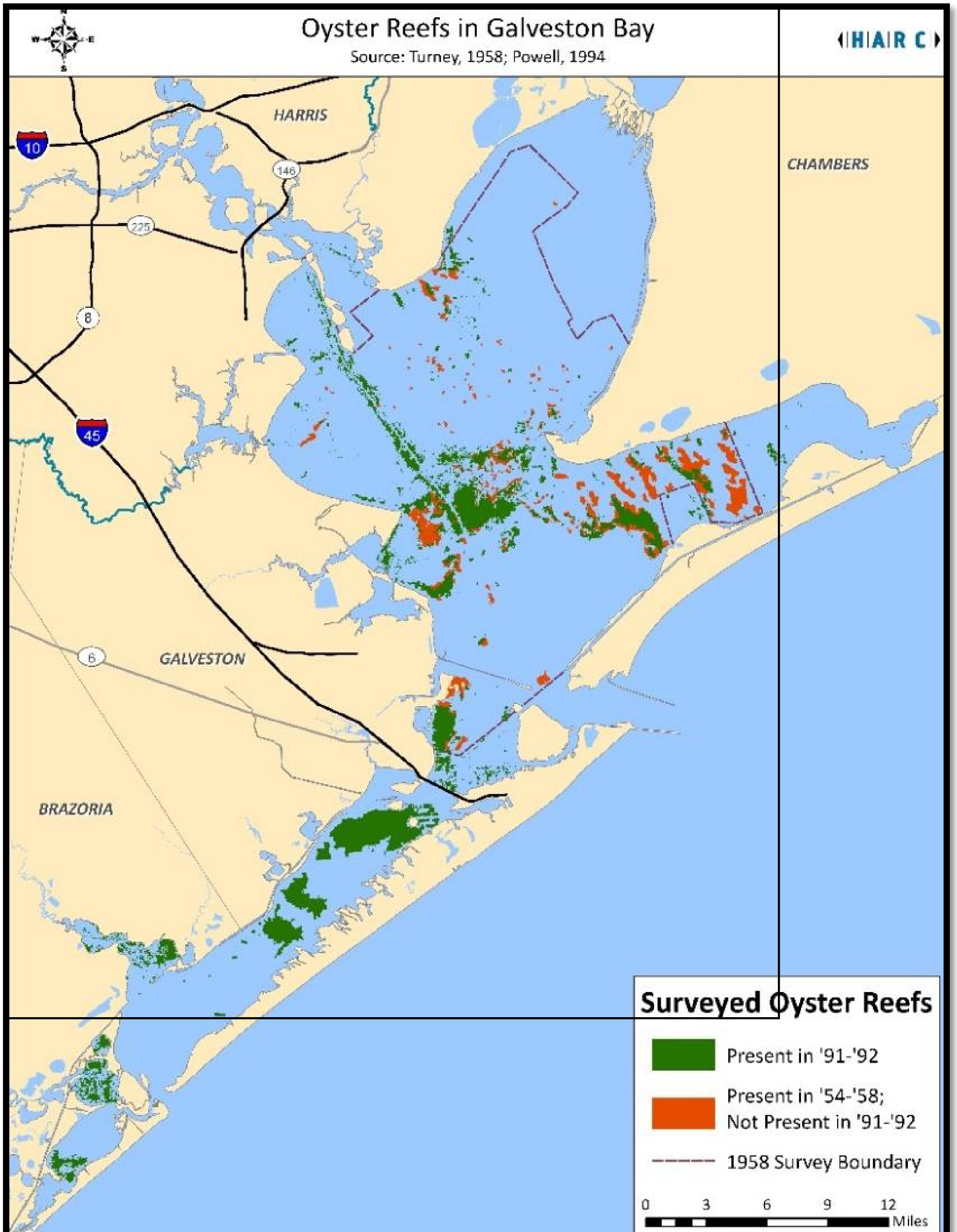

Figure 37 - Galveston Bay Oyster Reef Locations

Source: Galveston Bay Status and Trends

It was estimated that 240 acres of oyster reefs would be impacted with the Mid-bay Barrier Concept. Indirect impacts were not evaluated, but the location of the structure places the environmental gates in a complex location in the bay for circulation. Today, the bulk of the Trinity River flow exits Trinity Bay along the southern shore and wraps around Smith Point, and flows across Mattie B. Reef and Tom Tom Reef, reaching nearly to the Bolivar Peninsula before becoming entrained in the seaward flowing water at Bolivar Roads. This circulation pattern has likely existed for many decades, but its intensity has dramatically increased as the Houston Ship Channel became deeper and Redfish Reef ceased to function as a circulation barrier (Lester and Gonzalez, 2011). Even with the environmental structures in the open position, the support structures for the gate could function as a circulation barrier, changing the circulation pattern across local reefs.

Due to the concerns listed above the “Mid-bay Barrier Concept” alternative was removed from further consideration.

Note: The following two alternatives were included in the final array for the Region 1 CSRM and underwent additional evaluations. The planning discussion below provides general overview of the assumption that went in to the development of the alternatives and results of the comparison of the alternatives. It is important to note that the team focused on the general geographic location of the barriers and used the locations to make informed decisions on the environmental consequences of each system. The team used a conservative approach to document the widest possible impacts with each system.

4.2.4.4 Coastal Barrier with Complementary System of Nonstructural Measures (Alternative A)

This alternative was developed to address storm surge flooding at the Gulf interface and to include the highest number of structures and critical facilities within the risk reduction alignment. The alignment would also provide risk reduction to the critical GIWW by maintaining the existing geomorphic features along Bolivar Peninsula and Galveston Island. The strategy included preventing storm surge from entering the Galveston Bay with a barrier system across Bolivar Peninsula, a closure at the pass at Bolivar Roads, improvements to the Galveston seawall, and a barrier along the west end of Galveston Island. The barrier is similar to other proposals that have been released to the public, such as the Gulf Coast Community Protection and Recovery District’s (GCCPRD) Central Region Alternative (CR#1) – Coastal Spine and Texas A&M University at Galveston’s Ike Dike. For planning purposes for the draft report, the team had evaluated a levee/floodwall system across Bolivar Peninsula and Galveston Island; however, the team recognized that there are opportunities to optimize the design and alignment to minimize impacts to existing structures and the environment on the peninsula and island. Future design efforts focused on where engineered dune systems maybe appropriate versus levees and floodwalls.

To address wind-driven surges in the bay, which could impact both the back side of Galveston Island and the upper reaches of the bay, nonstructural measures, such as ring levees and closures on key waterways, have been included in the system. As discussed above, elevation is a common approach already being undertaken by residents and businesses in the study area. The area on the west side of Galveston, the hashed area shown on Figure 38, includes non-structural proposals for approximately 10,000 structures between the SH 146 and the bay rim.

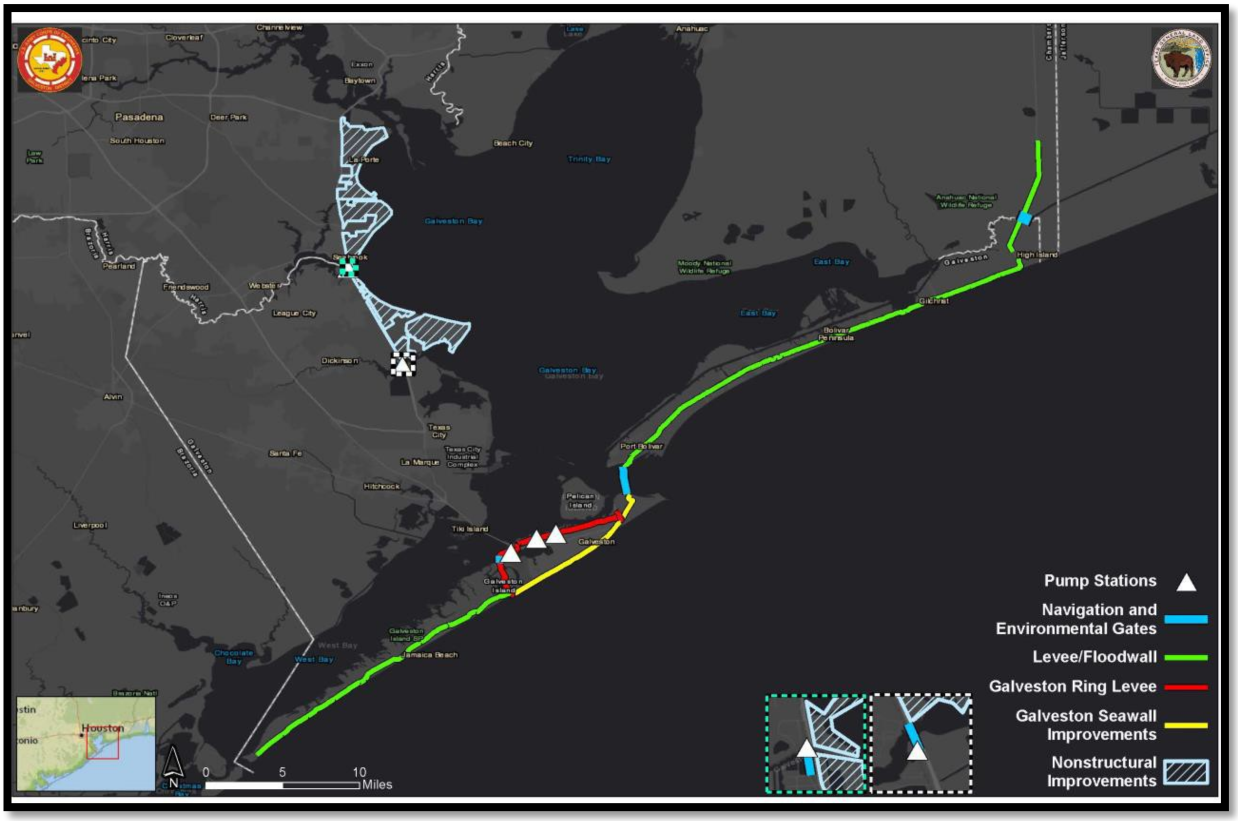

Figure 38 - Coastal Barrier with Complementary System of Nonstructural Measures

Although the ER and CSRM alternatives are evaluated for separate benefits, the different alternatives provide some nexuses between the features. By connecting the CSRM features to the beach and dune features along Bolivar Peninsula and Galveston Island, the ER features can increase the resiliency of the CSRM feature.

4.2.4.5 Upper Bay Barrier (Alternative D)

This alternative was developed to potentially avoid a majority of the navigation impacts by focusing on a levee system on the west side of Galveston from Texas City to the Fred Hartman Bridge. The alternative evolved into two options.

4.2.4.5.1 SH 146 Alignment (Alternative D1)

The first option was named D1. This alignment was similar to GCCPRD’s Reach 2, Texas City Extension North (SH 146) alignment, which included a levee system paralleling SH 146 from Texas City to the Fred Hartman Bridge (Figure 39). The levee system placed approximately 10,000 structures east of the levee outside of the system. In order to address this concern, nonstructural measures were initially included to address existing surges and any surges induced into the area by the levee system.

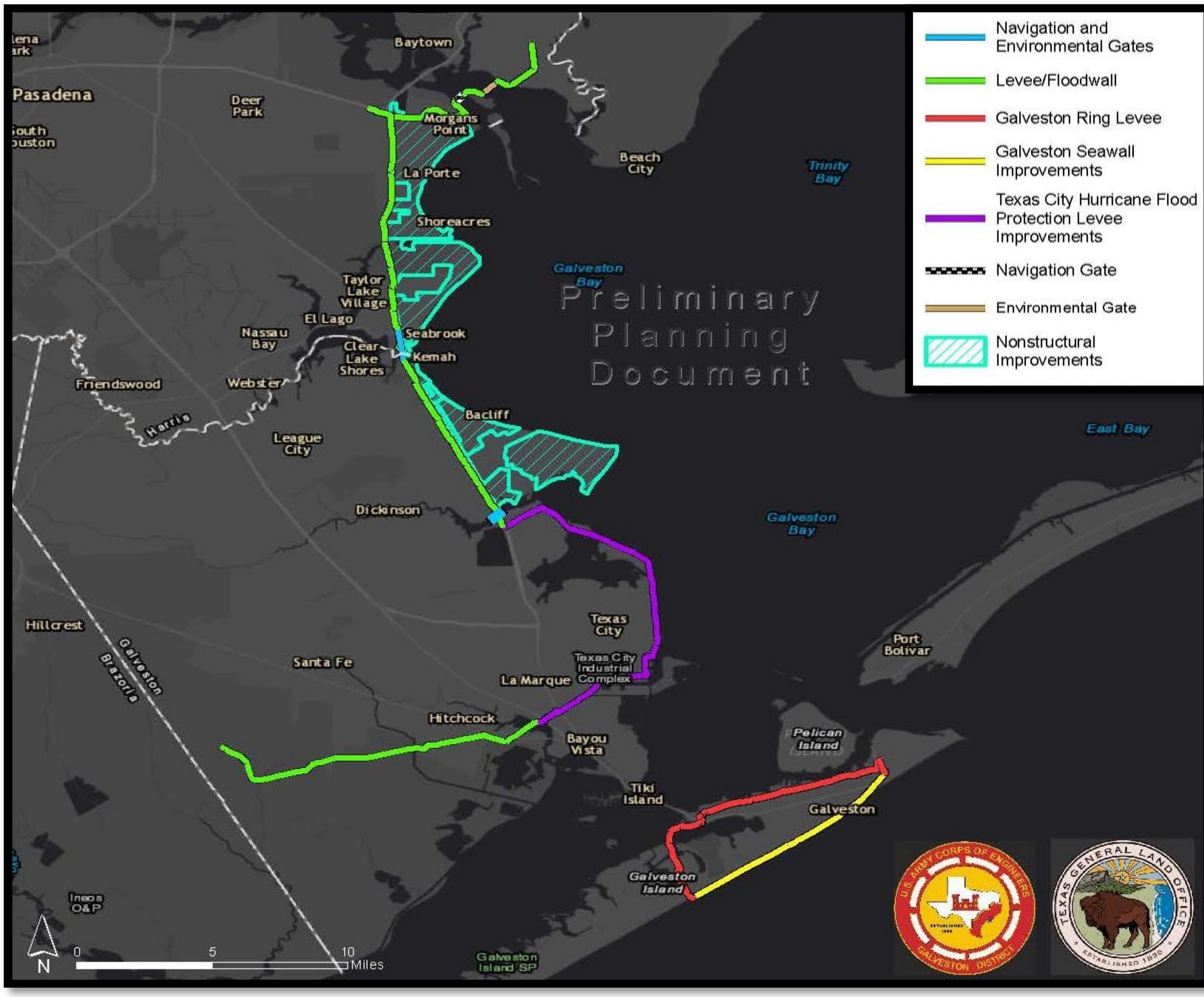

Figure 39 - SH 146 Alignment Barrier (Alternative D1)

A detailed evaluation revealed other significant concerns with this option. The first issue was related to the overall project objective of reducing risk to critical infrastructure (e.g., medical centers, government facilities, universities, and schools) from coastal storm surge flooding. An evaluation of the FWOP condition surges and economic damages determined that the area surrounding the system is one of the highest reaches for economic damages. Once a levee is constructed near SH 146, modeling showed that it would induce stages and damages in the area outside of the levee system (Figure 40). Economic modeling estimated that over $175 million in average annual damages would be included in the area without addressing the inducements.

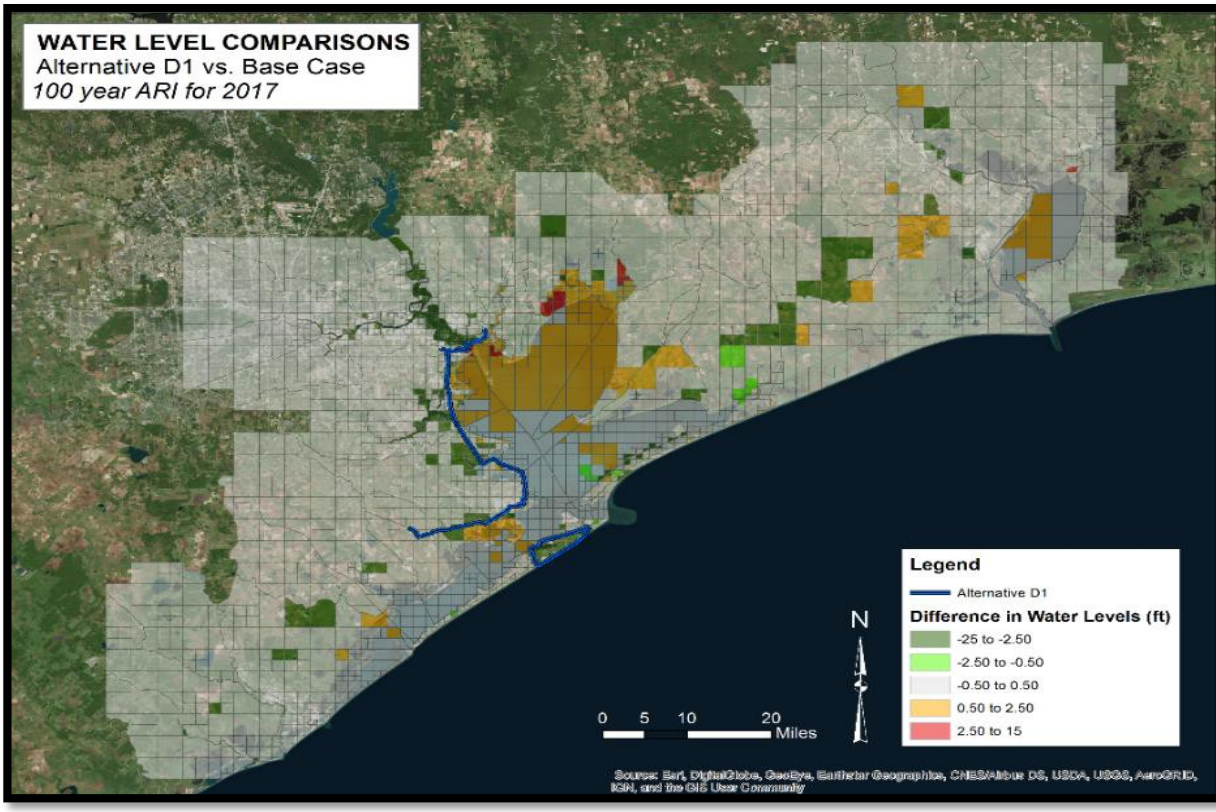

Figure 40 - FWOP vs FWP stages for SH 146 Alignment Barrier (Alternative D1)

A site visit to the SH 146 alignment also highlighted significant relocation and construction concerns. SH 146 is already a highly developed area, and the expansion of the highway to a 6- to 12- lane freeway is currently underway. Many of the existing right of ways or corridors necessary to build a levee system would be unavailable because of the expanded highway. Also, a significant number of vehicle and railroad gates would have to be added to the system to work with the existing infrastructure. Many of these concerns were documented at some of GCCPRD's public forums. Based on these concerns and because this alignment does not meet some of the project's key objectives, it was removed from further consideration.

4.2.4.5.2 Bay Rim (Alternative D2)

The second variation was named D2. The plan was modified to move the structure out to the bay rim instead of adjacent to SH 146 (Figure 5-40). This option would enclose the 10,000 structures in the system with a levee or floodwall system along the existing bay rim or would be designed similar to the New Orleans Lakefront, where the system is built out into the bay for some reaches (Figure 41). For planning purposes, the team assumed that the system would be built on the existing bay rim and not into the water and would require relocations to build the system. The system could be optimized to avoid relocations but would generate additional costs and environmental impacts if it were built in the bay instead.

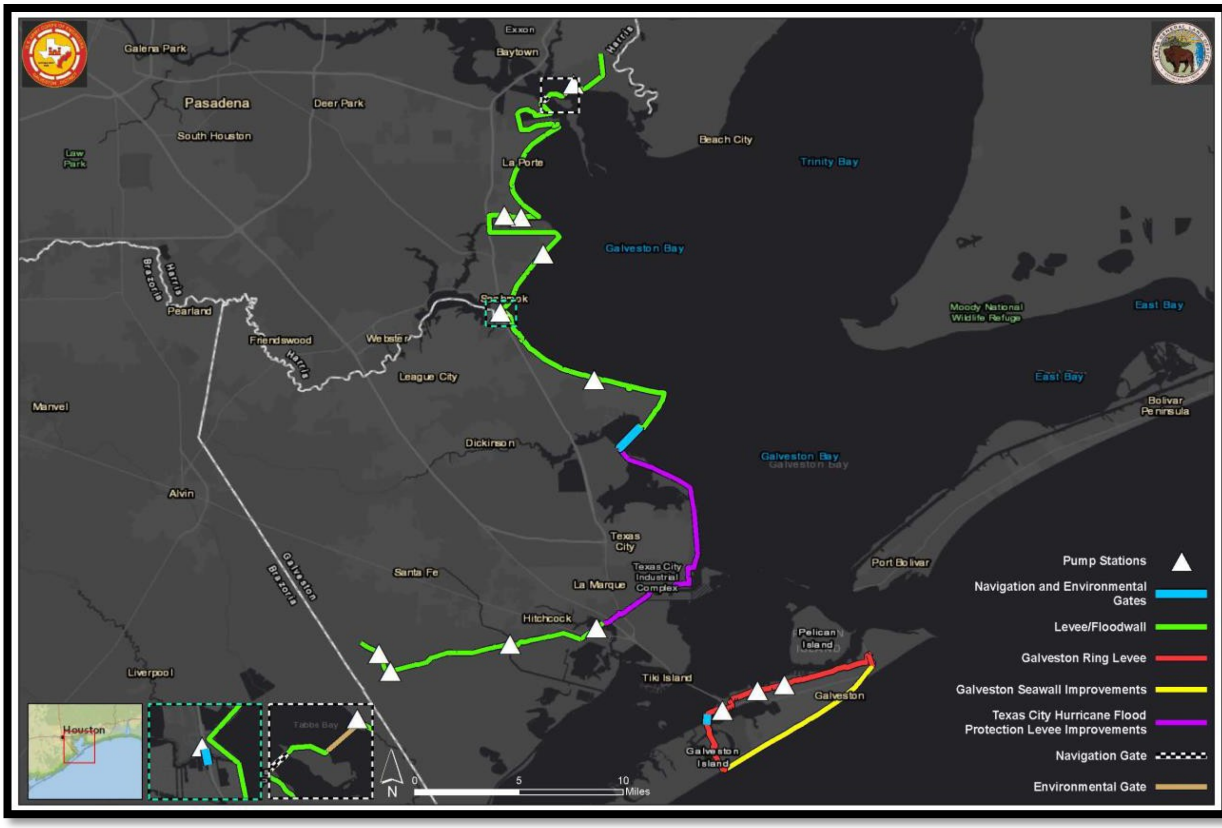

Figure 41 - Bay Rim Barrier (Alternative D2)

Figure 42 - Lakeshore Drive, New Orleans, with Seawall and Levee System (Michael

DeMocker/NOLA.com | The Times-Picayune)

The D2 alignment would eventually tie into the existing Texas City Levee system and includes improvements to that system. The plan includes additional improvements farther west into the communities of Hitchcock and Santa Fe. The plan includes a surge gate and barrier at the Fred Hartman Bridge; however, this is likely a separable element that would have to be evaluated for navigation impacts and benefit to the upper ship channel if the system was recommended. The plan also addresses flooding on Galveston Island with a levee system, which rings the island. As with the other plans, the team also investigated the opportunity to integrate ecosystem features and CSRM features by reviewing the beach and dune restoration along Bolivar Peninsula and Galveston Island. The ecosystem features should also increase the resiliency of the CSRM features.

4.2.4.6 Evaluation and Comparison Coastal Barrier with Complementary System of Nonstructural Measures (Alternative A) and Upper Bay Barrier-Bay Rim (Alternative D2)

Table 23 provides an overview of information used to compare the significant differences between the two alternatives that were carried forward. The sections below include the detailed discussion related to the topic in the table.

Table 23 - Comparison of Alternatives A and D2

Criteria	Alternative A	Alternative D2
Comparison of Design Details	Complex design only focused on large navigation structure	Complex design due to multiple tie- ins
Construction Schedule and Benefit Assumptions	Lower acquisition risk	High acquisition risk
Environmental Impacts	High indirect environmental risk (Galveston Bay)	Localized direct and indirect risk (smaller waterbodies)
Potential Induced Flooding	Localized manageable risk	Localized to levee tie in points
Navigation Impacts	Potential impacts to deep draft operation but reduces risk to navigation infrastructure from storm surges	Potential impacts to shallow draft operation and navigation infrastructure still at risk from impacts from storm surges
Critical Infrastructure	Highway and navigation infrastructure included in the system	Critical highway and navigation infrastructure left out of the system

Criteria	Alternative A	Alternative D2
RSLR Scenario	Limited cost for adaptation (Galveston Bay storage)	Significant cost for adaptation (floodwall modification)
Project Cost	Low cost range – high cost range $14.2 – $19.9 billion	Low cost range – high cost range $18.2 – $23.8 billion
Net Benefits ($ millions) and Benefit-Cost Ratios	Range: High RSLR and Low Cost - Low RSLR and High Cost (Without GDP Impacts) $571 – ($294) and 1.8 – 0.6 (With GDP Impacts) $1,192 – $14 and 2.7 – 1.0	Range: High RSLR and Low Cost – Low RSLR and High Cost (Without GDP Impacts) $255 – ($544) and 1.3 – 0.5 (With GDP Impacts) $923 – ($237) and 2.0 – 0.8
Residual Risk	Galveston Bay's storage capacity mitigates risk	Significant risk from exceedance surge events and rainfall events

4.2.4.7 Comparison of Design Details

Plans were developed and assumed to have similar levels of risk reduction to the existing risk reduction systems in Region 1. Storm surge modeling was used to estimate water levels and waves along the selected levee alignment in later phases of the study. Outputs of surge and wave information at various locations along the proposed levee alignment will be used to refine the level of risk reduction in PED phase consistent with the conditions with the Storm Surge Gate in place. However, there are some significant design differences between the Alternative A-Coastal Barrier and the Alternative D2-Upper Bay Barrier-Bay Rim. Table 24 provides an overview of these differences.

Table 24 - Differences Between Alternatives A and D2

Category	Alternative A	Alternative D2
Approximate Total Length (miles)	76	79
Total Floodwall and Levee (miles)	74	79
Total Floodwall (miles)	20	43
Total Levee (miles)	54	36

Category	Alternative A	Alternative D2
Estimated Quantities (cy) for Levees	10,000,000	15,500,000
Estimated Vehicle Gates Required	93	138
Estimated Railroad Gates Required	4	19
Estimated Drainage Structures Required	80	38
Estimated Pump Stations Required	5	14
Deep Draft Navigation Gates Required	1	1
Size of Deep Draft Navigation Gates	1200	1200
Shallow Draft Gates	4	3
Total Relocations (Pipelines)	30	55
Temporary Work Area Easements (acres)	545	656
Estimated Number Property Tracts Impacted	1,709	1,703
Estimated Number Owners	1,214	1,423

Below are some key differences between the designs of the system:

- **Galveston Ring Levee:** When compared to the Coastal Barrier with complementary system of nonstructural measures (Alternative A), the Galveston Ring Levee associated with the Upper Bay Barrier-Bay Rim (Alternative D2) would have to be constructed with a greater level of resiliency. The Galveston Ring Levee with Alternative A only has to address wind driven surges from the Galveston Bay system (north to south), while a Galveston Ring Levee with Alternative D2 must address surges originating from the Gulf and any surges deflected back onto the system (induced stages) from the system on the westside of Galveston Bay. Figure 43 shows the surge forces on the backside of Galveston Island. The yellow arrows depict potential surge directions.
- **Drainage Structures:** Although both systems would require drainage features on the Galveston Ring Levee, Alternative D2 would also require a significant number of drainage features along the westside of Galveston Bay. With Alternative A the only additional drainage structures needed are associated with the closures at Clear Lake and Dickinson Bayou.

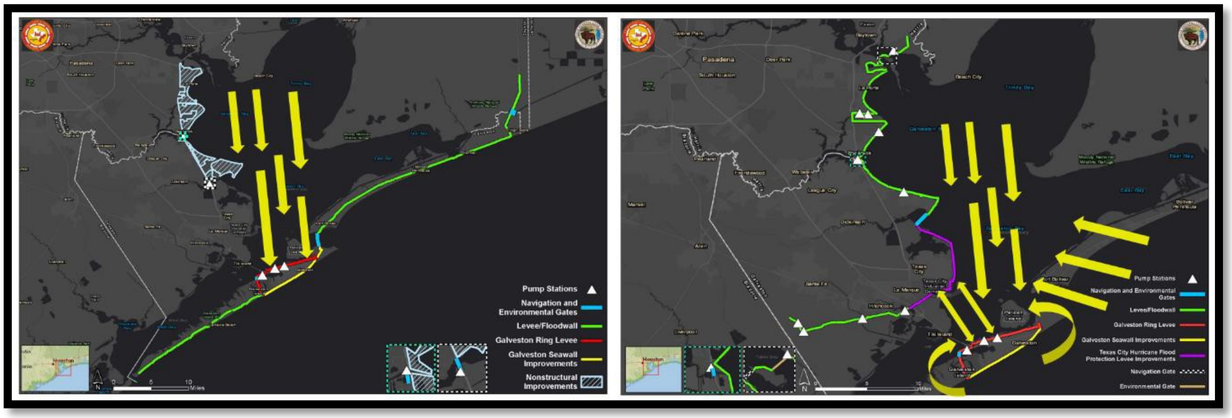

Figure 43 - Surge Forces on Galveston Ring Levee

- **Access Structures (Railroad/Vehicle):** With Alternative D2, the port facilities and smaller recreation water access facilities would still require access routes. For example, with Bayport, depending on the final alignment, the system may require multiple vehicle and railroad access gates (Figure 44).

Figure 44 - Example Bay Port Access Routes (Alternative D2)

4.2.4.8 Construction Schedule and Benefit Assumptions

Preliminary construction schedules for alternatives were needed to calculate annual cost streams and BCR. In most cases, project benefits cannot start accruing until a “closed” risk reduction system is in place, which would require, at a minimum, all structures and levees to be constructed. For planning purposes, the team assumed construction ending for both system in 2035 to compare benefits; however, there are some significant differences between the alternatives and potential construction options between alternatives.

- The footprint of Upper Bay Barrier-Bay Rim (Alternative D2) includes a significant number of properties with structures and piers that may have to be relocated or condemned. There is a significant real estate risk that could extend the construction completion schedule if lands need to be acquired through condemnation proceedings.
- It may be possible to construct only the large surge gate first for the Coastal Barrier with complementary system of nonstructural measures (Alternative A) to obtain an initial level of benefits. Currently, the existing landscapes of Bolivar Peninsula and Galveston Island provide a level of risk reduction from smaller storms. Building only the large surge gate with the beach and dune restoration features along Bolivar Peninsula and Galveston Island would obtain a certain level of interim risk reduction.
- Without tie-back levees into higher ground, the Upper Bay Barrier-Bay Rim (Alternative D2) will not give the region any level of risk reduction until the system is complete.

Table 25 - CSRM Alternatives Baseline Direct Cover Type Acreages

NOAA C-CAP Land Cover Classifications*	Total CSRM Footprint Acres	Developed / Upland[2]				Palustrine Emergent Wetland Freshwater Wetland & Marsh				Estuarine Emergent Wetland[3] Wetland & Marsh (Saline & Brackish)				Oyster Reef[4]	Open Water			
Land Ownership		Protected State	Protected Federal	Other[1]	Subtotal	Protected State	Protected Federal	Other[1]	Subtotal	Protected State	Protected Federal	Other[1]	Subtotal	Protected State	Protected State	Protected Federal	Other[1]	Subtotal
Alternative A - Coastal Barrier	4,525.3	43.3	218.3	1,259.3	1,520.9	19.3	15.6	477.6	512.5	5.7	52.5	279.7	338.0	--	4.3	7.0	2,142.7	2,154.0
Alternative D2 - Upper Bay Barrier–Bay Rim	2,334.3	28.8	--	1,342.4	1,371.2	2.6	--	224.6	227.1	14.5	--	157.5	172.0	0.0347	2.4	--	561.5	564.0

1 The "Other" category under Land Ownership consists of privately-owned tracts (including preserves owned and managed by NGOs) and GLO-state submerged lands. The "Other" category under Development/Uplands also includes USACE placement areas.
2 The "Developed / Upland" category consists of bare land, cultivated crops, deciduous forest, develop (low, medium, high, open space), evergreen forest, grassland/herbaceous, mixed forest, pasture/hay, and shrub/scrub.
3 Estuarine Emergent Wetland includes Estuarine Scrub/Shrub Wetland from the NOAA C-CAP 2010 landcover data.
4 Oyster Reef data was obtained from Texas General Land Office.
* Mitigation is planned for palustrine and estuarine marsh and oyster reef.

The environmental team and interagency team determined which HSI models would be used to evaluate the impacts presented above (Table 26). The models selected were all approved models and were coordinated with the Ecosystem Planning Center of Expertise and the vertical team. The models determine a HSI based on specific variables for each species. The species models are used to represent the habitat, not necessarily that specific species. Habitat evaluation for directly impacted areas measured the quality of each habitat category (the HSI value) multiplied by the quantity of each habitat category (acres) resulting in habitat unit measurements. Adding target years, or changes in habitat over time, allowed calculation of AAHUs. HEP allowed determination of mitigation requirements for loss of or degradation of habitat due to construction of CSRM features.

Table 26 - Habitats Impacted Based on NOAA C-CP Classification and the HSI Models Used to Calculate Mitigation Requirements for Each Habitat

Habitat Impacted	Model Used
Palustrine Emergent Wetland	American Alligator (Newsom et al., 1987)
Estuarine Emergent Wetland	Brown Shrimp (Turner and Brody, 1983)
American Oysters	Oyster Model (Swannack et al., 2014)

A systemwide model was used to make a preliminary estimate and comparison of the impacts of the proposed project on hydrology and salinity. Due to the limited enclosure of wetland with Alternative D2, indirect impacts were assumed to be negligible. Due to a partial closure at the Bolivar Roads from Alternative A's structure, reduced tidal flow and a change in the tidal amplitude may occur (McAlpin et al., 2018). The structure consists of a navigation gate and environmental gates. The navigation gate was proposed as a floating sector gate, which requires islands to be built to store the gates when not closed for storms. These islands, along with the structural base of the environmental lift gates, reduce the opening in Bolivar Roads. At the time of the TSP, the reduction of the opening at the pass was optimized to 27.5 percent closure with the barrier in the open position. This closure amount was found to be a priority refinement to achieve in subsequent phases of the study process to reduce impacts to the hydrology of Galveston Bay system. The final design includes less than a ten percent restriction.

During the initial assessment, the team developed a methodology to determine the potential impacts to estuarine marshes within the tidal influence areas of Bolivar Roads. ADH modeling was used to predict hydrological impacts, changes in tidal prism, and tidal amplitude that may occur from the proposed CSRM gates. A change in tidal amplitude was assumed to create a situation where the high tides are lower, and the low tides are high than in a FWOP condition (McAlpin et al., 2018). It was assumed that a change in tidal amplitude will affect tidal marsh since the potential would exist for marsh at the upper bound of the cover type to experience less inundation, while marsh at the lower bounds of the area would experience potentially constant inundation.

To generate an estimate of indirect tidal marsh impacts due to the presence of a CSRM structure across Bolivar Roads, a spatial analysis was developed using the NOAA Marsh Migration viewer outputs associated with a projected 1 foot of RSLR. It was assumed that 2035 would represent the condition to apply potential effects from the CSRM structure on tidal marsh, which corresponds to approximately 1 foot of sea level rise based on USACE RSLR curves. For the analysis, only tidally influenced cover types, which included estuarine and brackish wetlands were included.

Preliminary ADH modeling of Galveston Bay determined that 0.5 foot would be eliminated from the tidal amplitude if a CSRM structure were placed across Bolivar Roads (McAlpin et al., 2018). The reduction was assumed to be symmetric about the high and low tide. The reduction of 0.5 foot resulted in a FWP tidal range of 0.0 to +1.5 foot.

Using GIS, marsh acres were calculated. FWOP Tidal Marsh Acres were estimated to be 38,696 acres. FWP Tidal Marsh Acres were estimated at 35,321 acres. Subtracting the with- project acre estimate from the without-project acre estimate resulted in a total of 3,375 acres of tidal marsh indirectly impacted by a CSRM structure or storm surge barrier across Bolivar Roads. It is important to note that the exact number could vary depending on wetland loss prior to construction, which could be caused by sea level rise, subsidence, hurricanes, or other factors. Also, the indirect number is based on a conservative estimate related to the optimized to percent closure. The team will continue to further optimize the percent closure through feasibility design.

The HEP tool was again applied to calculate the AAHUs of impacted estuarine emergent marsh and the AAHUs and associated number of acres of mitigation that would be needed to address these impacts. Table 27 shows the mitigation requirements for the CSRM alternatives.

Table 27 – Preliminary Mitigation Requirements for Each CSRM Alternative

Impact/Mitigation	**Alternative A**		**Alternative D2 (Bay Rim)**	
	Acres	**AAHUs**	**Acres**	**AAHUs**
IMPACTS:				
Direct				
➡Palustrine Wetlands	512.5	–93.8	227.1	–41.6
➡Estuarine Wetlands	338.0	–185.7	172.0	–94.5
➡Oyster	0	0	0	0
Total Direct Impacts	850.5	–279.5	399.1	-136.1
Indirect				

Impact/Mitigation	Alternative A		Alternative D2 (Bay Rim)	
	Acres	AAHUs	Acres	AAHUs
Tidal Prism Change	38,696.0	–4,738.5		
MITIGATION:				
Direct Impacts				
➡Palustrine Wetlands	138.0	93.7	62.0	42.1
➡Estuarine Wetlands	270.0	185.8	138.0	95.0
➡Oyster	0		0	0
Mitigation Direct Subtotal	408.0	279.5	200.0	137.1
Mitigation Indirect Subtotal	6,887.0	4,739.0		
Total Mitigation	7,295.0	5,018.5	200.0	137.1

4.2.4.9 Potential Induced Flooding

Both alternatives have the potential to increase water level stages (stages) to the areas outside of the levee. With Alternative A, the potential of induced flooding is limited to the structures on Bolivar Peninsula and Galveston Island. Approximately 1,000 structures are outside of the 2018 TSP levee/floodwall alternative design. These structures could be subject to induced stages. The risk with Alternative D is mainly focused on the impacts to the levee tie-ins. There is a margin of error in both the economic model and the storm surge modeling (ADCIRC), which is recognized by team hydrologists and economists. Additional investigation would be needed in the densely populated communities of Baytown and Santa Fe to determine if the levee system induces stages.

4.2.4.10 Navigation Impacts

Similar to alternatives B and C, which were discussed in the previous sections, Alternative D2 would have impacts on interactions between deep draft ships (foreign traffic) and shallow draft tugs and barges (domestic traffic). Currently, Alternative D2 includes a navigation gate near the Fred Hartman Bridge. Under the FWOP conditions, the channel in this section includes a deep draft channel with a north- and south-bound shallow draft channel adjacent to the deep draft channel. If a gate is built at this location, the shallow draft traffic would likely be forced to use the deep draft channel to transition through the gate. Two adjacent shallow draft gates were considered but there is limited space in the upper reaches of the channel to place two additional gates.

Another significant difference between the two alternatives is that Alternative D2 leaves much of the navigation infrastructure at risk from storm surges since many of the ports and channels would be outside of the system. Storm surge can move large amounts of sediment into the navigation channel during an event, adding to the annual O&M cost of dredging.

There is significant risk to the GIWW under the FWOP conditions. Approximately 83 million tons of cargo with a commercial value estimated at $25 billion travels on the Texas GIWW annually. Existing openings on the peninsula already cause significant dredging impacts on the GIWW. Prior to 2020, the USACE spent over $500,000 per year to address shoaling from Rollover Pass (Figure 45).

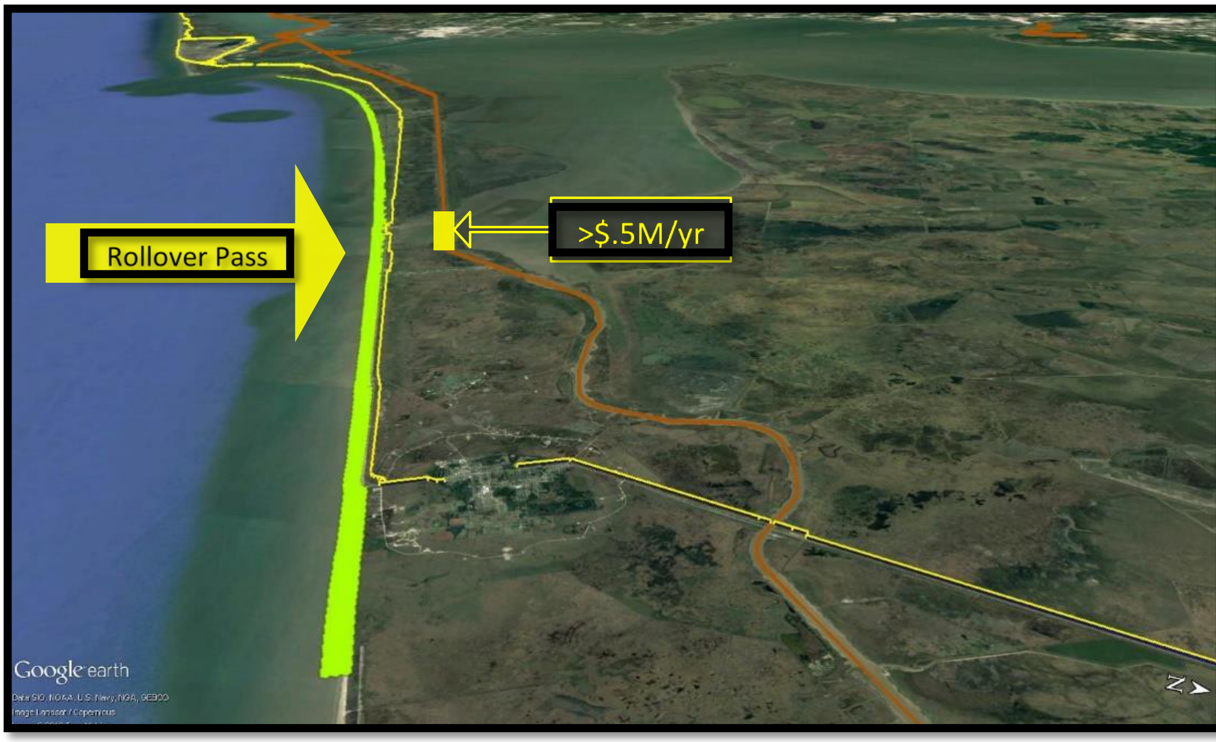

Figure 45 - Alternative A with Current GIWW Shoaling at Rollover Pass Highlighted

Dredging costs are expected to increase if breaches are allowed to develop under the FWOP conditions. Alternative A, with a levee/floodwall or even with an engineered dune system would help to maintain existing geomorphic features along Bolivar Peninsula.

4.2.4.11 Critical Infrastructure

In addition to the critical navigation infrastructure, Alternative D2 leaves many of the region's critical roadways at risk in the future. SH 124 is at immediate risk due to its proximity to the Gulf. This was one of the key highways that was destroyed after Hurricane Ike, leaving the communities of Bolivar Peninsula with only ferry access from Galveston. The loss of the highways can have significant impacts on the recovery times. Another area of concern is the future risk to the I-10 corridor (Figure 46). As RSLR occurs and more habitat is lost along Smith Point on the east side of Galveston Bay, the risk for surge inundating I-10 increases.

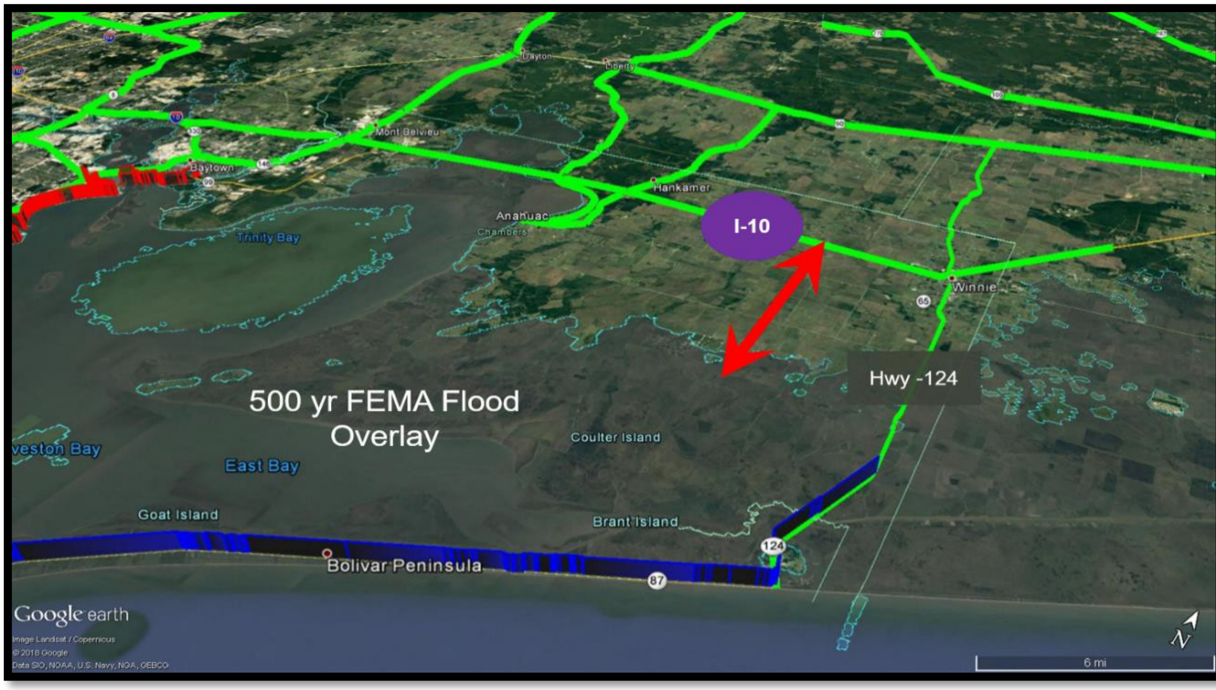

Figure 46 - Alternative A with I-10 and SH 124 Highlighted

4.2.4.12 Relative Sea Level Rise Scenario

Since both alternatives would be constructed over a significant number of years, there will be opportunities to reevaluate RSLR. For example, if over time it appears that the actual RSLR rate is higher than expected, additional lifts can be added to levees; however, in the case of Alternative D2 there would be significant cost risk for adaptation due to the significant number of floodwall section compared to Alternative A. If RSLR rates are lower than expected, then final levee lifts will not need to be constructed, although structures may remain overbuilt.

4.2.4.13 Comparison of Alternative Project Cost

The cost estimates for the alternatives proposed in the 2018 TSP were developed with input from the GCCPRD report. Since the cost in the GCCPRD report were from FY 15, they were escalated to FY 18 using the current Civil Works Construction Cost Index System tables; the 2015 costs were escalated by 6 percent. Costs for Alternative A were obtained from the GCCPRD report with modifications made to the large closure gate by the New Orleans District structural section to meet environmental requirements. Additional design and quantities were developed for the new reaches that did not exist in the GCCPRD report. The same report format and unit costs were used to bring consistency to the two alternatives. Mitigation quantities and costs for the both CSRM alternatives were also developed. Cost for the alternatives are presented as a range (Table 28). This was accomplished by identifying the critical cost drivers in each major feature of work in order to define ranges of potential cost for the feature/alternative. Additional information on the cost development can be found in the Engineering Appendix (Appendix D).

Table 28 - Costs for Alternatives A and D2

Description	Alternative A Low – High	Alternative D2 Low – High
NON-FEDERAL COST:		
01-Lands and Damages	$643,779,000–$736,112,000	$1,872,604,000–$2,322,029,000
02-Relocations	$60,939,000–$60,939,000	$114,717,000–$114,717,000
Total	$704,718,000–$797,051,000	$1,987,321,000–$2,436,746,000
FEDERAL COST:		
06-Fish and Wildlife	$652,939,000–$874,013,000	$15,240,000–$20,400,000
11-Levees and Floodwalls	$2,582,229,000–$5,005,970,000	$4,057,064,000–$7,230,854,000
13-Pumping Plants	$1,048,097,000–$1,220,583,000	$1,562,821,000–$2,027,619,000
13-Pumping Plants - Buffalo Bayou	--	$1,261,779,000–$1,298,805,000
15-Flood Control and Div Str	$297,627,000–$297,627,000	$496,106,000–$496,106,000
15-Flood Control and Div Str – "Big Gate"	$5,097,492,000–$6,304,361,000	$4,289,250,000–$4,314,226,000
Subtotal Federal Cost	$9,678,384,000–$13,702,554,000	$11,682,260,000–$15,388,010,000
30-Engineering and Design	$2,496,200,000–$3,540,435,000	$2,964,157,000–$3,921,439,000
31-Construction Management	$1,291,138,000–$1,831,260,000	$1,533,185,000–$2,028,330,000
Total Federal Cost	$13,465,722,000–$19,074,249,000	$16,179,602,000–$21,337,779,000
Total Project Cost (rounded)	$14,170,440,000–$19,871,300,000	$18,166,923,000–$23,774,525,000

4.2.4.14 Net Benefits and Benefit-Cost Ratios

The USACE NED procedure manuals for coastal and urban areas recognize four primary categories of benefits for flood risk management measures: inundation reduction, intensification, location, and employment benefits. The majority of the benefits attributable to a project alternative generally result from the reduction of actual or potential damages caused by inundation. Inundation reduction includes the reduction of physical damages to structures, contents, and vehicles and indirect losses to the national economy. The Economic Appendix (Appendix E) provides a detailed description of the methodology used to determine NED damages and benefits under existing and future conditions and the projects costs. The damages and costs were calculated using FY 18 (October 2017) price levels. Damages and benefits were converted to equivalent annual values using the FY 18 Federal discount rate of 2.75 percent and a period of analysis of 50 years with the year 2035 as the base year. The equivalent annual damage and benefit estimates were compared to the annual construction costs and the associated OMRR&R costs for each of the project alternatives. Table 29 and Table 30 provide an overview of the results of these evaluations for both CSRM alternatives under a range of RSLR scenarios and cost ranges.

Table 29 - Alternative A Net Benefits and BCRs ($ millions)

SLR and Cost Scenario	FWOP Damages[1]	Alt A FWP Damages[1]	Annual Damage Reductions	Annual Benefits (Damage Reduction plus GDP Impacts*)	Annual Costs	Equivalent Annual Net Benefits (includes GDP Impacts*)	Equivalent Annual Net Benefits (Without GDP Impacts)	BCR (includes GDP Impacts)	BCR (Without GDP Impacts)
High SLR & Low Cost	$3,106	$1,818	$1,288	$1,908	$717	$1,192	$571	2.7	1.8
High SLR & High Cost	$3,106	$1,818	$1,288	$1,908	$956	$952	$332	2	1.35
Intermediate & Low Cost	$2,243	$1,464	$779	$1,141	$717	$424	$62	1.6	1.09
Intermediate & High Cost	$2,243	$1,464	$779	$1,141	$956	$185	($177)	1.2	0.81
Low SLR & Low Cost	$2,044	$1,382	$662	$970	$717	$253	($55)	1.4	0.92
Low SLR & High Cost	$2,044	$1,382	$662	$970	$956	$14	($294)	1	0.69

1 Equivalent Annual Values, 2035-2085 period of analysis

* Regional Economic Models Inc. (REMI) was used to quantify the indirect impacts U.S. economy

Table 30 - Alternative D2 Net Benefits and BCRs ($ millions)

SLR and Cost Scenario	FWOP Damages[1]	Alt A FWP Damages[1]	Annual Damage Reductions	Annual Benefits (Damage Reduction plus GDP Impacts*)	Annual Costs	Equivalent Annual Net Benefits (includes GDP Impacts*)	Equivalent Annual Net Benefits (Without GDP Impacts)	BCR (includes GDP Impacts)	BCR (Without GDP Impacts)
High SLR & Low Cost	$3,106	$1,902	$1,204	$1,809	$887	$923	$255	2	1.29
High SLR & High Cost	$3,106	$1,902	$1,204	$1,809	$1,122	$687	$20	1.6	1.02
Intermediate & Low Cost	$2,243	$1,543	$700	$1,049	$887	$163	($193)	1.2	0.78
Intermediate & High Cost	$2,243	$1,543	$700	$1,049	$1,122	($73)	($429)	0.9	0.62
Low SLR & Low Cost	$2,044	$1,453	$591	$885	$887	($2)	($308)	1	0.65
Low SLR & High Cost	$2,044	$1,453	$591	$885	$1,122	($237)	($544)	0.8	0.52

1 Equivalent Annual Values, 2035-2085 period of analysis
* REMI model was used to quantify the indirect impacts US economy

In addition to the direct damages to residential and nonresidential structures, their contents and residential vehicles and the costs of debris removal, there can be indirect impacts to the local and national economy resulting from a storm event. These indirect impacts are related to disruptions in the production of goods and services by the industries affected by the storm. Businesses can be forced to curtail their normal operations because workers are displaced, facilities are inundated, and flooded roads limit access to the facilities. By implementing coastal storm risk reduction measures, the losses associated with indirect economic impacts can be reduced. The REMI model developed by Regional Economic Models Inc. was used to quantify the indirect impacts to in the region, the remaining counties of Texas and the rest of the U.S. economy. The model estimates the geographic redistribution of production and the net changes in national output associated with storm damage. The information was included in the above tables as separate values as a sensitivity to investigate the possible range of benefits between the alternatives when including indirect economic impacts. Additional information on the REMI model assumptions can be found in the Economic Appendix (Appendix E).

4.2.4.15 Residual Risk

While Alternative D2 is predicted to have fewer environmental impacts than Alternative A, Alternative D2 comes with significant residual flood and lift safety risk, such that it could be classified as a nonpractical alternative. An alternative can be defined as practicable if it is capable of being implemented. Using lessons learned from the Interagency Performance Evaluation Task Force, post event investigations of Hurricane Katrina and also from other USACE Dam and Levee Safety studies, Alternative D2 would be considered not to be a practicable alternative. The Interagency Performance Evaluation Task Force report illustrates an effective platform for developing better policy and planning decisions when recommending and designing hurricane risk reduction systems. One of the key lessons learned was to use a systems approach when assessing risk to make practicable, rational, and defensible decisions.

One of the key areas of assessing risk is accomplished through analyzing a system's performance for a given set of events. This performance is assessed by modeling how each structure and component of the system (levees, floodwalls, gates, etc.) would perform under the forces generated by surge and waves. Results from modeling of the Greater New Orleans HSDRRS illustrated that as components are added to the system, the risk for failure increases. Similar lessons have been assessed in reviews of the Dutch storm surge risk reduction system. Application of this principle helped lower risk and improve system performance for the greater New Orleans area.

If Alternative D2 were implemented, it would likely include a large number of different T-Wall sections for levee tie-in points. Alternative A tie-in points are mainly limited to the large navigation structure. Risk experts agree, and Interagency Performance Evaluation Task Force illustrated, that there will always be residual risk with any system; however, it is imperative that flooding vulnerability from extreme events is factored into planning decisions. These decisions may require designing a system to allow for more effective evacuations or emergency responses to extreme events (i.e., greater than the recommended 100-year level of risk reduction). In the case of Alternative D2, residual risk is high due to the proximity of the levee alignment to developed areas.

Alternative D2 has the greatest residual risk since overtopping of the levee by storm surge during extreme events would immediately inundate vulnerable populated areas and key emergency service routes. Alternative A is set farther away from the developed areas of the study area and therefore has a lower residual risk in the event of extreme overtopping events. The nonstructural measures in the developed area also reduce this residual risk. Galveston Bay's storage capacity also plays a key role in reducing residual risk. It not only provides a storage basin for exceedance surge events; it also avoids inducing damage under other events such as Hurricane Harvey. Alternative D2 includes multiple drainage and pump stations, which would likely be overwhelmed during a Hurricane Harvey event. This likely would add to the flooding seen under extreme rainfall events, since rainfall would have stacked up behind the levee system until it was pumped or drained out.

4.2.5 Summary of Alternatives Comparison

The two final CSRM alternatives were evaluated for performance against the criteria established by policy and the original study objectives

Federal Principles & Guidelines established four criteria for evaluation of water resources projects. These are completeness, effectiveness, efficiency, and acceptability. These criteria and their definitions are listed below. Alternatives considered in the study were evaluated to confirm that they meet minimum subjective standards of these criteria to qualify for further consideration and comparison with other plans.

Completeness

Completeness is defined as the "extent to which an alternative provides and accounts for all features, investments, and/or other actions necessary to realize the planned effects, including any necessary actions by others". It does not necessarily mean that alternative actions need to be large in scope or scale. Does the plan include all the necessary parts and actions to produce the desired results?

Effectiveness

Effectiveness is defined as the "extent to which an alternative alleviates the specified problems and achieves the specified opportunities." Does the plan meet the objectives? How does the plan address constraints?

Efficiency

Efficiency is the extent to which an alternative plan is a cost-effective means of alleviating the specified problems and realizing the specified opportunities. Does the plan minimize costs? Is it cost effective? Does it provide net benefits?

Acceptability

Acceptability is defined as “the viability and appropriateness of an alternative from the perspective of the Nation’s general public and consistency with existing Federal laws, authorities, and public policies. It does not include local or regional preferences for particular solutions or political expediency.” Is the plan acceptable and compatible with laws and policies?

Table 31 - Alternative A and D2 Evaluation Against Applicable Criteria

Criteria /Metric	Coastal Barrier Plan	Bay Rim Plan
	P&G	
Completeness Does the plan include all the necessary parts and actions to produce the desired results?	This plan includes layered features that address risk over a broad region and perform as a system.	This plan includes features that features that address risk in a more concentrated landward alignment adjacent to development and independent Galveston ring barrier
Effectiveness Does the plan meet the objectives?	This plan addresses coastal risk in the broadest region, enclosing the more coastal landforms within the system.	This plan addresses coastal risk in a smaller sub region of the study area.
Efficiency Is the plan cost-effective?	Both plans achieve net benefits	Both plans achieve net benefits
Acceptability Is the plan acceptable and compatible with laws and policies?	This plan includes broad communities rather than concede to SLC losses over time in coastal barrier communities. Primary feature, the storm surge barrier, can meet mitigation requirements for potential impacts, but generates concern among the public and agencies.	This plan concedes that coastal barrier communities may be sacrificed to SLC over time. Levee or wall along bay rim generates concern among the public and agencies about community disruption and impacts, and creates some unacceptable risk without redundancy in the case of design exceedance.
	NED	
	RISK REDUCTION	

Criteria /Metric	Coastal Barrier Plan	Bay Rim Plan
Redundancy	System provides redundant features, with coastal alignment and maintain the bay as a "release valve" to contain water if design is exceeded Redundancy increases reliability over time	This system places features within close proximity to assets and people, providing less redundancy.
Robustness		
RED		
Economic activity	Sustains coastal region for tourism, fisheries and related industries Sustains support infrastructure-childcare, shopping, services in areas that house regional workforce Preserves medical campus	Concedes coastal barrier region over time to SLC damages to natural and business resources
EQ		
Air	Temporary impacts from emissions during construction	Temporary impacts from emissions during construction
Noise	Temporary impacts from pile driving, construction equipment to species and humans for a longer duration than Bay Rim	Temporary impacts from pile driving, construction equipment to species and humans
Water Quality	Small changes to tidal amplitude from the storm surge barrier will impact salinity in Galveston Bay	Avoids salinity impacts of gate closure, does not avoid impacts of storm surge over land and into bay
Species or Habitat	More mitigation for in-water construction from Storm Surge Gate construction and operation	Less potential impact to species from in-water construction

Criteria /Metric	Coastal Barrier Plan	Bay Rim Plan
Cultural and Historic Resources	Preserves historical architecture on Galveston Island Sustains culturally significant recreation	Concedes coastal barrier lands to eventual SLC risks, risking loss of cultural resources
Community Cohesion	Maintains viability for broader region of communities facing storm risk or SLC	Concedes to SLC and storm damage for outer communities which will face disinvestment over time May alter community identity and cohesion with bay area structures creating subregions that are “in” or “out” of the system.
Recreation	Maintains bay and Gulf as separate habitats over time Renourishes and maintains beach resources along coastal barrier system	System may sacrifice exterior regions under RSLC.
Life Safety		
PAR losses	Smaller population exposed to flood risk and displaced following storms	Larger population exposed to flood risk and displaced following storm events and eventually retreated from barrier island system
Life Safety	System reduces surge risks while not exacerbating risks during high-precipitation events Larger community afforded risk reduction by placing system at the broadest extent	System places features adjacent to communities which may not reduce all risks when coastal storms coincide with high-precipitation events

Several broad performance comparisons can be made:

Higher net benefits: Under all RSLR Scenarios and cost ranges, Alternative A still obtains the highest net benefits.

Lower residual risk: Alternative A is set farther away from the developed areas of the study area and therefore has a lower residual risk in the event of extreme overtopping events.

Greater flexibility and greater focus on critical infrastructure: Alternative A takes a systems approach when reviewing the regions larger system context. Similar to the Multiple Lines of Defense approach it builds upon existing projects and other proposed recommendation yet to be built (Figure 47).

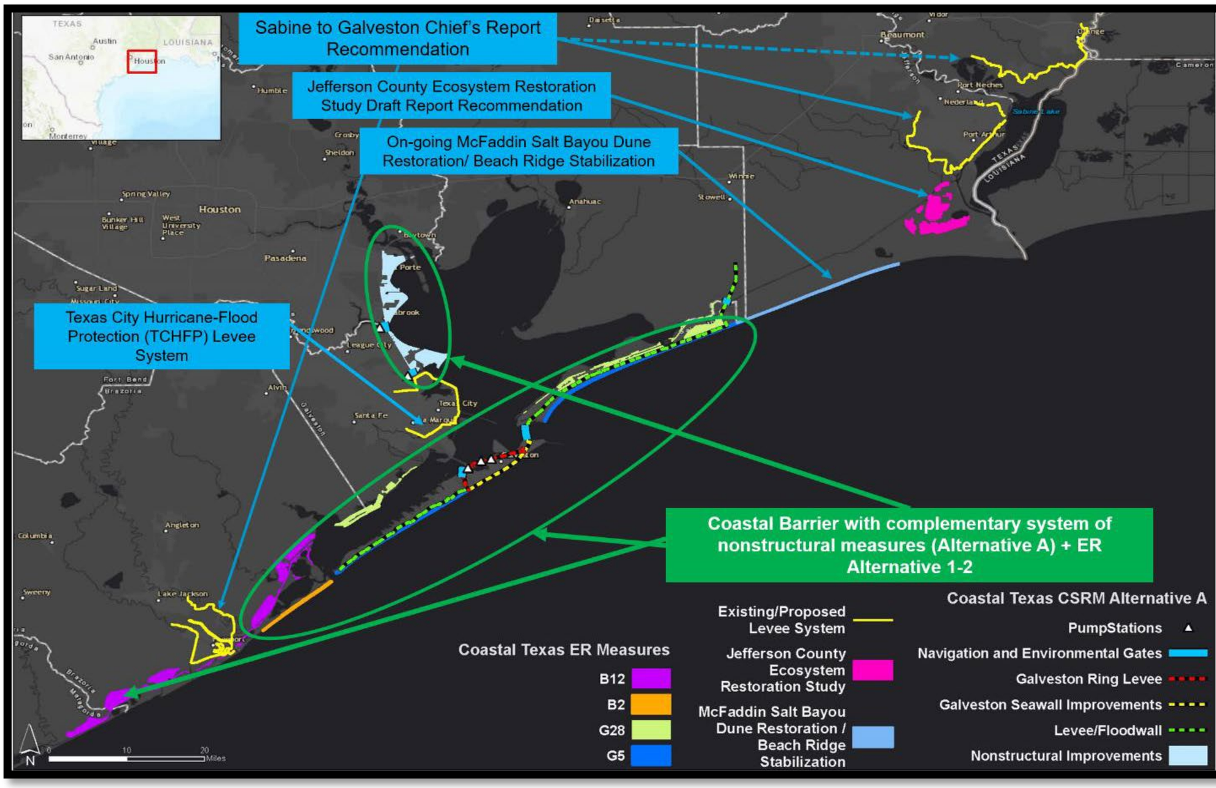

Figure 47 - Linked ER and CSRM in the Upper Coast with existing and large scale projects

4.2.6 Selection of Region 1 CSRM TSP

The “Coastal Barrier with complementary system of nonstructural measures (Alternative A)” was identified as the TSP and the NED plan as determined by the evaluation criteria for the upper coast of Texas. It fulfilled the focused CSRM planning objectives for Region 1, and it reasonably maximized net benefits, consistent with protecting the Nation’s environment in accordance with national environmental statutes, applicable Executive Orders, and other Federal planning requirements.

The recommendation builds redundancy into the system for Gulf Storm Surge Barrier and Galveston Bay Defense System – the NED Plan to address the variability in storm tracks. The action of layering of critical components or functions of a system with the intent of increasing the reliability of the system, either in the form of a backup features, or to improve actual system performance, equates to varying levels of risk reduction across the system. The Hurricane and Storm Damage Risk Reduction System

(HSDRRS) design guidelines (USACE 2012) criteria established the basis of design and were applied to determine the crest elevations for the most critical components of the recommended features. The criteria used for design of the systems and crest elevations was based on overtopping limit state with an annual exceedance probability of 1%. This was consistent with the present USACE practice and other recent Region 1 projects such as Sabine to Galveston Project. The flood risk reduction potential for the recommended plan is based on damages that would be prevented considering RSLC, wave set-up, and run-up under average still-water levels (SWL), and that some of the project features will remain in service much longer than the economic period of analyses (50-year) planning horizon. Consequently, an adaptation strategy was developed for up to 100 years, consistent with ER 1110-2-8159, and ER 1100-2-8162. The engineering and conceptual design conducted during this study support the project alignment, type of structure and top of system elevation; but do not finalize design criteria or detail project features. Further investigation, engineering, and design analysis will be needed in future phases. The features were developed to incorporate uncertainty by including redundancy and robustness so they are adaptable to future conditions, including relative sea level change (RSLC).

4.3 REFINEMENTS AND INTEGRATION FOLLOWING DRAFT REPORT

A first draft of the Coastal Texas Study’s Draft Integrated Feasibility Report and EIS (DIFR-EIS) was released in October 2018. The DIFR-EIS was provided to all known Federal, state, and local agencies, and interested organizations and individuals were sent a notice of availability. In addition to the official public comment period, seven Public Meetings, covering all of the different regions which comprise the Texas coast, were held in 2018 to provide the public with updated information about the study scope and schedule and to solicit public comments for consideration on the DIFR-EIS and the proposed TSP. This public comment period occurred at the same time as USACE technical/policy review and resource agency review. All comments received and USACE responses have been included in Chapter 7 of the Environmental Impact Statement (EIS).

Based on public and resource agency comments, and supported by continued engineering design and optimization efforts, multiple changes to the TSP were considered and evaluated to improve the performance of the ER and CSRM measures and to further minimize environmental and social impacts. The following sections summarize some of the major changes to the TSP which occurred after publication of the 2018 DIFR-EIS.

4.3.1 Levee along West Galveston and Bolivar

The levee proposed along West Galveston and Bolivar peninsula provided an engineered barrier to prevent storm surge from entering the Bay over land. Public comment indicated that the roadway access issues were unfavorable, the real estate impacts were disruptive, and the views would be unacceptably changed. Many expressed dissatisfaction that the impacts would be borne by the residents and businesses on the island and peninsula without reducing their storm surge risk. Many commenters also expressed that they are aware of the risks of development on a barrier island or peninsula and accept the risk of storm damage over creating the levee. In response, the Team found that the levee was unimplementable and it was removed from the recommendation.

4.3.2 Beach and Dune Restoration (G5)

The beach and dune restoration feature proposed along the Gulf on West Galveston and Bolivar Peninsula was justified for inclusion within the ER purpose. It restored the coastal habitat that had lost sediment to years of coastal forces on the Gulf side and to hardened features, yards, structures and roadways. Once the levee was found to be unacceptable, the beach and dune restoration was refined to include a second dune, taller dune height and wider berms to increase the risk reduction it provides. The beach feature does not provide a comparable scale of risk reduction as compared to the levee, but is placed gulfward of all structures, and creates fewer community impacts. The larger beach feature also sustains the barrier features and supports the function of the Bolivar Roads Gate System. The refinement of the beach and dune feature as a CSRM and a necessary component of the NED plan was confirmed through vertical team engagement. The feature sustains the coastal barrier system and supports the function of the storm surge gate over time and is not considered a Locally Preferred Plan.

4.3.3 Beach Nourishment – South Padre Island

The beach nourishment of South Padre Island was revisited in response to technical comments on the analysis. The lifecycle modeling of the beach fill that identified the cost-effective reaches and scales was rerun to confirm that smaller scales were not more cost-effective. The modeling confirmed that the central reaches of the barrier island warrant nourishment over time, and that the efficiency of that action can be improved through continued beneficial use placement in the nearshore area to extend the time between required nourishment cycles.

Several refinements to the BeachFX model were made following public, agency and technical review. Technical comments requested further comparison of performance across berm widths, renourishment cycles, and all rates of sea level change. Public comment expressed concern that reach 5 was as erosive as reaches 3 and 4. The BeachFX model was reviewed to confirm the planform rates accurately compare the with- and without-project condition, and to confirm the appropriate scale and nourishment cycle were identified.

The model results indicated that erosion occurs over a longer extent, including Reach 5. The comparison of with and without-project condition confirmed that the NED scale of the beach nourishment is 2.9 miles from Reach 3 through 5, with the same dune and berm dimensions as before, but on a 10-year periodic renourishment cycle for the authorized project life of 50 years. Initial construction will occur in 2034, and nourishment is proposed on a ten year cycle to maintain the beach width.

Table 32 presents the costs of the revised SPI proposal. Table 33 presents the costs and benefits when considering damages avoided only. Table 34 summarizes the two sources of applicable benefits, recreation and CSRM damages avoided as annual benefits and costs expressed in October 2020 prices. The model assumptions and output and the derivation of recreation benefits underlying these tables are provided in Appendix E-2 provides the model assumptions and output, and the derivation of recreation benefits. Under the assumption of 750,000 annual visitors, the net benefits are $2.6 million and a benefit-to-cost ratio of 2.3. With an assumption of 5.2 million visitors, the net benefits are $18 million, with a benefit-to-cost ratio of 10.3.

Table 32 - Costs of Revised South Padre Island CSRM Measure* (Final)

Year	Nourishment	PED	Construction Management	Cultural	Lands and Damages	In House Real Estate	IDC	Total Construction Cost	Present Value of Costs
2034	$8,793	$1,319	$528	$182	$18,328	$648	$203	$30,001	$30,001
2044	8,793	1,319	528				72	$10,712	8,368
2054	8,793	1,319	528				72	$10,712	6,537
2064	8,793	1,319	528				72	$10,974	5,107
2074	8,793	1,319	528				72	$10,712	3,989
						Totals		$73,111	$54,002
					Average Annual Cost				$1,904

$1,000, October 2020 Prices, 2.5% Interest Rate

Table 33 - Costs and Damages Avoided Benefits of Revised South Padre Island CSRM Measure* (Final)

Cost Terms	Without-project Damages	With-project Damages	Damages Avoided	Costs	Net Benefits	Benefit-to-Cost Ratio
Average Annual Values	$5,569	$4,375	$1,294	$1,904	-$610	0.68

$1,000, October 2020 Prices, 2.5% Interest Rate

Table 34 - Costs and Total Benefits of Revised South Padre Island CSRM Measure* (Final)

Recreation Benefits	CSRM Net Benefits	Recreation Benefit	Total Average Annual Benefits	Average Annual Costs	Net Benefits	Benefit-to-Cost Ratio
Assuming 750,000 visitors	$1,294	$2,565	3,894	$1,904	$1,955	2.03
Assuming 5.2 million visitors	$1,294	$17,784	$19,078	$1,904	$17,174	10.02

$1,000, October 2020 Prices, 2.5% Interest Rate

4.3.4 Bolivar Roads Gate System

The Bolivar Roads Gate System was refined to reduce the constriction of the flow in the channel. The refinement was undertaken in response to potential environmental impacts that were identified during the screening process. Operators of storm surge structures offered technical recommendations for design refinements to maintain function while reducing environmental impacts. Thee refinement includes the replacement of a single larger gate with two smaller gates. Public comments addressing the storm surge gate are included in Chapter 7 of the DEIS.

4.3.5 Galveston Ring Barrier System

The Galveston Ring Barrier System was realigned to include additional areas and to avoid other impacts. Residents of Lindale Park opposed the partial enclosure of the neighborhood within the barrier, and the alignment that overlaid existing homes. Other alignment changes were made to reduce waterfront business and infrastructure impacts, and to reduce environmental impacts from crossing wetlands. Additional comments opposed the disruption of traffic and access, the potential to exacerbate drainage problems, and the potential environmental impacts. The revised alignment is presented in greater detail in the Main Report summary of the Recommended Plan.

4.3.6 Galveston Seawall Improvements

The Seawall height increase was proposed as a future adaptation to address sea level change. Following publication of the initial draft report, the height increase was proposed for the north side of Seawall Boulevard to avoid view impacts and to avoid impacting the existing Seawall stability.

4.3.7 Ecosystem Restoration

Several revisions were made to the NER plan in response to technical, public, agency and policy comments.

4.3.7.1 Scale 2 Features Removed

The ER features initially included outyear nourishment for adjacent areas that would be subject to sea level change over the study period. Policy review clarified that those actions would not be considered policy compliant. Therefore, continuing construction would not be a cost shared action in the Recommended Plan. Those nourishments, which were reflected in the original draft as Scale 2 of several alternatives, are now recommended future considerations, instead of plan components. AAHUs were recalculated to reflect the ecological lift from the features without additional placement on adjacent parcels to offset SLC impacts.

CE/ICA was rerun to confirm that the plan ordering would not be changed as a result of the removal of Scale 2 features, or the removal of the West Galveston and Bolivar beach nourishment.

4.3.7.2 Federal Lands Identified

The restoration measures included in the Recommended Plan evolved through the three planning stages described earlier: initial conceptual measures, refinement to identify the NER plan as part of the TSP, and the final adjustments to combine the NER and NED features, following public, agency, technical and policy comment. The initial restoration sites were selected through a collaborative process with resource agency representatives and the PDT to identify habitats that are degrading as a result of coastal forces and storms. The final subset of restoration proposals in the region were selected for their relative contribution to the state and regional restoration vision established within the GLO Coastal Resiliency Master Plan and efforts of several other resources agencies. The ER features were conceived at a scale consistent with the Federal capability to achieve overall restoration, consistent with the multiple lines of defense strategy in combination with the structural CSRM measures in the NED plan. Public land ownership was a consideration in the initial formulation process to minimize costs and avoid obstacles to implementation. As a result, restoration proposals overlay some federally managed parks and refuges. Although the proposed restoration is consistent with the mission of the federal agencies and adjacent areas, it is Corps Policy to separate the costs of the restoration proposed for lands owned and managed by other federal agencies. Agency representatives have expressed that the restoration mission is compatible with the agency mission but cannot commit future funding at this time. The cost apportionment in the Main Report shows the federal lands as a separable cost element within the Recommended Plan.

4.3.7.3 ER Benefit Refinement

Technical and policy review highlighted several areas where additional qualitative benefits of the breakwaters could be captured beyond those quantified by the ecological modeling of the specific footprints of the restoration actions. Breakwaters along the GIWW would reduce erosive impacts to adjacent coastal marsh, seagrasses, coastal barriers, and shorelines. The breakwaters support habitat sustainability by reducing turbidity and wave energy, moderating salinity changes in interior marsh, and stabilizing the interface between the bay and marsh habitats. The ER measures that contain breakwaters are in close proximity to the following protected areas: the McFaddin NWR, the Anahuac NWR, the Brazoria NWR, the San Bernard NWR, the Big Boggy NWR, the Aransas NWR, the Candy Cain Abshier WMA, the Justin Hurst WMA, and the Powderhorn WMA. Those NWRs and WMAs are adjacent to or nearby the GIWW and total approximately 342,000 acres which is comprised of restored, scarce, or highly valuable habitats that support numerous resident species, migratory avian species, and endangered species. These benefits were captured in refined modeling because of their contribution to the overall health of these ecosystems. Although some of the benefits are quantified in the HSI modeling described above, details are provided in the ER Modeling Appendix and the “Is It Worth It Analysis” later in this document.

The 2018 DIFR-EIS also assessed impacts to beach and dune communities using a Wetland Valuation Assessment (WVA) Barrier Island Community Model, a community-based HEP model. The final phase of measure refinement applied a turtle species habitat suitability model instead of WVA to quantify ecological lift of the beach restoration measures. In the interagency group meetings that followed the 2018 Draft Report, members expressed dissatisfaction with the performance of the WVA model in predicting ecological benefits for beach and dune system in Texas. To improve the quality of the ecological modeling, the team developed the Kemp’s Ridley sea turtle nesting model to calculate benefits and impacts from proposed beach and dune ER and CSRM measures. The model was developed in consultation with the resource agencies and has been certified for use by the USACE Ecosystem Planning Center Community of Practice. Further detail is provided in the ER Modeling Appendix.

The turtle model captures habitat improvements for the Texas coast more specifically than the WVA model, and also was an effective tool in the refinement of the beach restoration measures during the final phase of integration of the ER and CSRM measures to formalize the Recommended Plan. The model also embedded Texas specific considerations into the evaluation. Since vehicles are allowed on most beaches, the turtle model incorporated those impacts into the suitability assessment and scoring.

Table 35 - Final AAHU Summary by Measures

Measure	Net Change in AAHUs	FWP 2035 Acres
G-28	1295.4	1653
B-2	240.1	691
B-12	1297.5	1121
M-8	481.5	766
CA-5	240.1	300
CA-6	18.4	2416
SP-1	3500.5	3453
W-3	13,936.6	56,858

4.3.8 Final CE/ICA Results

A summary of the final array of ER alternative plans measures, as refined through the three formulation phases is shown in Table 36. The Alternative first costs and CEICA inputs are shown in Table 37. Project first costs range from $1.03 billion for Alternative 2 to $2.7 billion for Alternative 1. The net AAHUs range from 2,853 for Alternative 6 to 15,494 to 21,013 for Alternative 4. Average annual project first costs were computed for each alternative in the manner previously described in this appendix, with updated costs expressed in October 2020 prices, a 2.5% discount rate and a 50-year period of analysis.

Table 36 - Final Matrix of Measures by Alternative

Alternative	G28	B2	B12	CA5	CA6	M8	SP1	W3
1	•	•	•	•	•	•	•	•
2		•	•		•			•
3	•	•						•
4	•		•	•	•	•	•	•
5	•	•	•					
6	•	•	•		•			

Table 37 - Summary of CEICA Inputs

Alternative	First Cost	Average Annual Project Cost	Net AAHUs	Acres
Alternative 1	$2,672,733	$102,032	21,013	67,258
Alternative 2	1,034,920	$39,666	15,494	61,086
Alternative 3	1,060,282	$40,745	15,474	59,202
Alternative 4	2,613,675	$99,670	20,772	66,567
Alternative 5	1,797,009	$69,257	2,834	3,465
Alternative 6	1,657,069	$73,285	2,853	5,881

$1,000, October 2020 Prices, 2.5% Discount Rate, 50 Year Period of Analysis

The cost-effective analysis identified four cost-effective plans, No Action, and Alternatives 1, 2 and 4. Three of the plans, No Action, Alternative 1 and Alternative 2 were identified as best buy plans, their costs are presented in Table 38. Alternatives 3, 5 and 6 were not cost-effective plans. A graphical summary of the incremental cost analysis is shown in Figure 48.

Table 38 - Summary of Best Buy Plan Costs and Benefits

Alternative	Output (AAHU)	Cost ($1,000)	Average Cost ($1,000/ AAHU)	Incremental Cost ($1,000)	Incremental Output	Incremental Cost per Output ($1,000)	First Cost ($1,000)
No Action	0	0					
2	15,494	$39,666	$2.56	$39,666	15,494	$2.56	$1,034,920
1	21,013	$102,032	$4.86	$62,366	5,519	$11.30	$2,672,733

$1,000, October 2020 Prices, 2.5% Discount Rate, 50 Year Period of Analysis

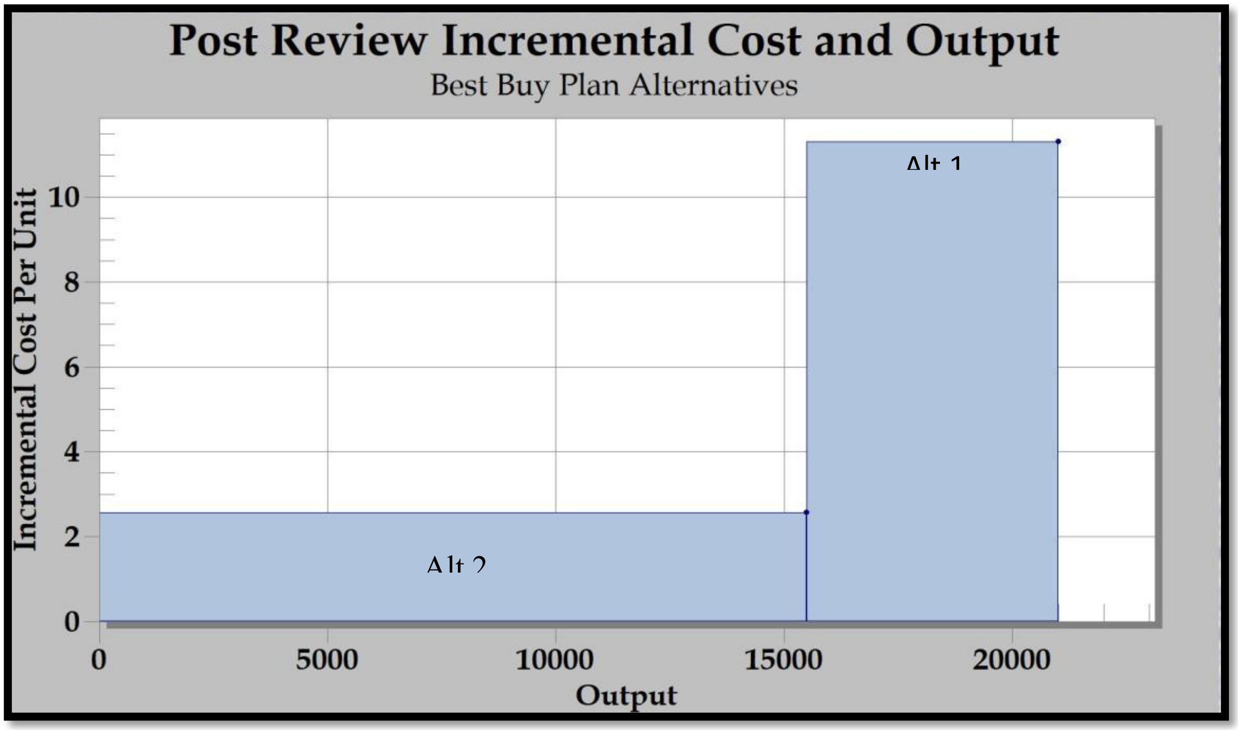

Figure 48 - Incremental Cost of Post Review Best Buy Plans

Alternative 2 provides the least incremental cost per incremental output over the no action plan with an increase of 15,499 AAHUs. The incremental cost per incremental AAHU is $2,560 and a total project cost of $1.03 billion.

Alternative 1 provides 21,023 AAHUs, an incremental increase of 5,519 AAHUs over Alternative 2. The incremental cost per additional unit of output is $11,300. The project first cost is $2.7 billion.

In order to arrive at the recommended NER plan, an “Is It Worth It” analysis is carried out on the incremental plans as presented, making the case why that plan is worth the higher incremental cost per incremental output. The final array of ER plans included Alternative 2, Alternative 4 (Revised), and Alternative 1.

Alternative 2, Coastwide Restoration of Critical Geomorphic or Landscape Features includesmeasures B-2, B-12, CA-6 and W-3.This alternative is a subset of the array of ER measures that was formulated to sustain specific geomorphic features and protect bay shorelines in the coastal region. This emphasis on coastal landforms excludes the measures that restore interior marshes. Without restoration, interior marshes are left vulnerable to coastal forces, and continue to degrade, transitioning to open water.

Alternative 2 does not include measures G28, CA 5, M8 or SP1. Selection of Alternative 2 would significantly limit the areas along the Texas Coast that would be restored and would not satisfy the goal of achieving a comprehensive restoration plan. Alternative 2 would not address the historic, existing or future problems to mitigate the degraded/degrading ecosystem in three of the counties along the coast, or several of the region-specific problems and opportunities scoped in plan formulation. Although the incremental cost for the last added habitat unit is only $2,560, the alternative is not considered comprehensive since it does not restore a variety of habitats, and it would not be considered by the PDT, NFS, and resource agencies as only a partial intervention andresponse to the study authority.

Alternative 1: Coastwide All-Inclusive Restoration was the largest alternative and included all ER measures: G-28, B-2, B-12, M-8, CA-5, CA-6, SP-1,W-3. This alternative would restore natural features, which provide diverse habitat within the coastal ecology and support natural conditions to withstand coastal storm conditions that cause land and habitat loss. This alternative includes B-2, Follets Island and Gulf Beach and Dune restoration, which adds diversity of habitats and restores sediment to the coastal region. B-2 protects against barrier island breach, which would threaten valuable habitat further inland. The quantified benefits do not reflect the protection of the interior resources. Alternative 1 also adds G28 and M8, which are critical for their indirect protection of interior marsh behind GIWW revetments.

Comprehensive restoration is a significant commitment to a regional effort of the State of Texas and federal resource agencies to maintain meaningful habitats along the Texas Coast. The ER alternatives were generated by an interagency team who identified vulnerable habitats and scoped restoration alternatives that complement the efforts of government and non-government agencies. The Corps has been actively modifying the Texas Coastline for 100 years through the construction of navigable ports and the GIWW. These navigation improvements have resulted in unintended consequences that decrease the delivery of sediments to the coastline for littoral transport, increase erosion along the GIWW, and change salinity conditions to bays and lagoons along the coastline.

Corps participation is critical because the scale of intervention needed to offset years of coastal erosion is large, and because the Corps has critical resources in the region that are interdependent upon sustainability of the coastal systems. Corps participation at this time is critical because of the concurrent efforts in the region to address the years of impacts to coastal habitat, and to address the vulnerable areas, many which are of national significance, before restoration needs are infeasible. A detailed summary of National Significance is attached in Appendix A-1.

Table 39 - Justification for Incremental Cost within ER Plan

Features in Alternative 1	Is It Worth it?
G-28 Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection	• Only restoration in Galveston County • Nourishes eroding and degrading marshes, sustains a significant habitat on the coastal barrier system • Addresses navigation impacts to marsh survival • Strengthens first line of defense as buffer between coastal forces and developed areas, not captured in AAHUs
B2 Follet's Island Gulf Beach and Dune Restoration	• The Texas coast has 367 miles of Gulf shoreline, which have been shown to be eroding rapidly, with some areas experiencing more than 24 feet of erosion per year. (Paine, J. G., T. Caudle, and J. Andrews. 2014. "Shoreline Movement along the Texas Gulf Coast, 1930's to 2012." Final Report to the Texas General Land Office, Bureau of Economic Geology, The University of Texas at Austin.) • Enhancing the beach/dune of Follets Island protects Bastrop, Christmas, and Drum bays, and the Brazoria NWR on the mainland behind this bay system. It also protects seagrasses in Christmas Bay, extensive marshes throughout the bay complex and scattered residential developments. • Christmas Bay is a designated Gulf Ecological Management Site because the Christmas Bay Estuarine System and its tributaries is the most pristine bay system of the upper Texas coast, and a vital part of the ecology of the Galveston Bay system, with hatcheries and nurseries for marine life and bird sanctuaries

Features in Alternative 1	Is It Worth it?
M8 East Matagorda Bay Shoreline Protection	• Only restoration in Matagorda County • Addresses navigation impacts to marsh survival • Has indirect benefit (unquantified benefit) of protecting interior marsh located in State and Federal parks and wildlife refuges. • AAHUs measure habitat but are not weighted to reflect that Dressing Point Island is one of the most prominent bird rookeries on the Texas Coast where Roseate spoonbills, white Ibis, snowy and reddish egrets and brown pelicans' nest.
CA5 Keller Bay Restoration	• Sea turtles, a critically endangered species, feed in and on seagrass beds. The Keller Bay shoreline intertidal marsh and SAV beds support the survival of this species.
SP1 Redfish Bay Protection and Improvement	• Restores a designated state scientific area to protect and study native seagrasses. AAHUs do not capture the unique value to the Texas Coast of the concentration and variety of stands of seagrass here.

4.3.9 San Luis Pass

Public comments questioned the effectiveness of the structures at stopping storm surge without a closure at San Luis Pass. Engineering models were revisited to confirm the contribution of a closure at San Luis Pass. The study team conferred with the SSPEED Center to compare engineering models and confirm the areas most likely to see increased water surface elevations with surge entering through San Luis Pass. The evaluation confirmed that the relatively low development areas to the east of Galveston Bay would not justify the environmental impacts of constructing a barrier in the pass.

4.4 DEVELOPMENT OF THE RECOMMENDED PLAN

Standard damage procedures (NED) for CSRM measures, habitat criteria (AAHU) for ER measures, and critical infrastructure evaluations were used to compare alternatives. In addition, the alternatives were evaluated with regard to their contribution to the broader resiliency of the Texas coast, which assesses the region's ability to prepare, withstand, recover, and adapt from coastal storms and maintain the region's critical social, economic and support systems. Multiple CSRM alignments and ER measures were evaluated to identify and assemble a Recommended Plan that met the intent of the authority to develop a comprehensive plan to protect, restore and maintain a diverse coastal ecosystem and reduce the risks of storm damage to homes and businesses across Texas' coastal regions. The Galveston Bay Storm Surge Barrier System is the NED plan, when evaluated at a system scale. The Gulf defense includes three components that cannot be evaluated as separable elements, because the Bolivar Roads Gate System is dependent upon stabilized barrier islands. Under the intermediate relative sea level change scenario, the barriers are expected to breach during the 50-year period of analysis. Breaches would allow Gulf surge to reach the Bay, undermining the effectiveness of the system. The recommended beach and dune segments would assist in stabilizing Bolivar Peninsula and Galveston Island, providing an integrated line of defense along the Gulf. The Bay defenses are needed to provide redundancy and robustness for the system, considering Bay-surge risks, and to increase resiliency of bayside communities. Economic resiliency y depends on getting the critical refinery and petrochemical facilities back to normal operations, which, in turn, depends on keeping people in their homes with access to food, power, shelter, and care for their families.

The structural components of the Recommended Plan were evaluated through a simplified incremental analysis in December 2019. The analysis was undertaken to confirm the selection of Alternative A as the NED plan, quantify increasing effectiveness of the structural components and to inform the implementation strategy. The analysis assessed the storm surge gate initially. A second increment assessed the storm surge gate and the dune and berm segments and raised seawall, and the final increment added the ring levee with pump stations.

The incremental analysis was conducted with available data. The water surface elevations (WSEs) were derived from a smaller probabilistic storm suite to characterize performance with reasonable modeling effort, and do not reflect the refinements that were made to the H&H datum in April 2020. The analysis did not compute benefit cost ratios of individual features.

The HEC-FDA model was used to calculate the without-project damages and the with-project damages and benefits attributable to the storm surge gate by itself and then in conjunction with each of the other structural components included in the Recommended Plan. It should be noted that revisions were made to the H&H data in April 2020, the results of this incremental analysis using the December 2019 H&H data are provided for informational purposes only. The results of this analysis are presented in Table 40 and the CSRM Economic analysis presented in Appendix E-1.

Later refinement of the Recommended Plan confirmed that the beach and dune measure along Bolivar Peninsula is a necessary component to support function of the storm surge gate over the period of analysis. Therefore, the incremental analysis presented below predates the engineering assessment of the beach and dune measure as an NED feature that supports the function of the storm surge gate. The combination of Galveston Ring Barrier and Storm Surge Gate is not a viable standalone alternative of the larger system.

The NFS has acknowledged the critical role of the beach and dune during the period of analysis and after. A bill is pending in the Texas State Legislature to create an entity with the authority and funding to commit to project maintenance at the end of the 50-

year period of analysis.

Table 40 demonstrates the Coastal Texas Protection and Restoration Study Integrated Feasibility Report Incremental Analysis of Components of Recommended Plan's Expected and Equivalent Annual Damages and Benefits Intermediate Sea Level Rise Scenario ($ Millions)

Table 40 -Recommended Plan Equivalent Annual Damages and Benefits Intermediate Sea Level Rise Scenario ($ Millions)

Incremental Features with Surge Gate	Equivalent Annual Benefits (FY20)	Annual Costs (FY21)	Annual Net Benefits	B/C Ratio
Recommended Plan-Structural	$2,004	$1,260	$744	1.59
Surge Gate Only	$1,049	$764	$284	1.37
Surge Gate with Galveston Ring	$1,767	$966	$801	1.83
Surge Gate with Bolivar and Galveston Dunes	$1,292	$1,059	$232	1.22
Surge Gate with Galveston Ring and Both Dunes	$2,009	$1,260	$749	1.59
Incremental Features without Surge Gate	**Equivalent Annual Benefits (FY20)**	**Annual Costs (FY21)**	**Annual Net Benefits**	**B/C Ratio**
Surge Gate	$1,049	$764	$284	1.37
Galveston Ring	$718	$201	$517	3.57
Bolivar and Galveston Dunes	$243	$295	($52)	0.82

This Appendix provides the detailed summary and output of the three iterations of planning. The Main Report presents the final, specific benefit and cost summaries of the Recommended Plan, and a summary of important considerations for its implementation and estimated impacts. A brief, feature summary is presented in Table 41. A

Table 41 – CSRM Recommended Plan Features and Function Summary

<table>
<tr><th>PLAN FEATURE</th><th>PERFORMANCE – RISK REDUCTION</th></tr>
<tr><td colspan="2">COASTAL STORM RISK FEATURES IN RECOMMENDED PLAN*</td></tr>
<tr><td colspan="2">Galveston Bay Storm Surge Barrier System</td></tr>
<tr><td>Bolivar Roads Gate System:
• Deep-draft-navigation 650’ sector gates
• Sector gates
• Vertical Lift Gates
• Shallow Water Environmental Gates (SWEG)
• Galveston Island Control/ Visitor
• Center
• Bolivar Auxiliary Control Center
• Bypass Channel
• Combi-wall and Levee Tie-In
• Anchorage areas</td><td>• Lowers Water Surface Elevations as a result of storm surge around bay
• Provides circulation points in gate system
• Accommodates navigation during and after construction.
• 21.5’ height balances performance and cost considerations since it is the least adaptable feature of the system.
• 21.5’ achieves the 1% target level design, and given the large buffer capacity of Galveston bay, any overtopping (leakage) should be absorbed without significant increase in stages to back bay development.
• The gate and supporting feature design are interdependent to function as a risk reduction system. A lower gate height would require the dependent system features, such as (GRBS) to be built higher to reduce storm surge and inundation.
• The higher storm surge gate allows the supporting features to be lower to maintain views and reduce impacts while achieving 1% design function</td></tr>
</table>

PLAN FEATURE	PERFORMANCE – RISK REDUCTION
Bolivar and West Galveston Beach and Dune System • Dune walkovers • Drive overs • Drainage Features • Landward dune: Finish el. 14’ • Gulfward dune: Finish el. 12’	• Supports regional resiliency, augments the performance of the NED feature, incrementally supported for reduction of water entering the bay and impacting communities around the bay • Establishes exterior line of protection from surge, extending in each direction from gate • Maintains bay and gulf system by anchoring the peninsula, maintains the landform as sea level changes • Provides ecological lift consistent with ER project purpose

Galveston Ring Barrier System Galveston Seawall Improvement West Harborside Breakwater
• Offatts Bayou Closure
    ○ Combiwall
    ○ Navigation gate
    ○ Env’l gates
    ○ Other gates
    ○ Tie In
    ○ Pump station
• ~17’ NAVD88 finish el. flood wall
• Seawall elevation on landward side of road
	• Supports regional resiliency, augments the performance of the NED feature
	• incrementally supported due to reduced exposure of portion of Galveston Island to wind driven surges in the bay that stack at closed gate and wind driven surges from certain storm directions
	• Supports exterior line of protection, flanking gate

Clear Lake Gate System Pump Station • Sector gates • 17’ finish elevation	• Address wind driven storm surge from water within the • bay • Pumping stations designed to address induced impacts from rainfall • Addresses residual risk, provides redundancy for larger gate to back bay communities

PLAN FEATURE	PERFORMANCE – RISK REDUCTION
Dickinson Bay Gate System Pump Station • Sector gates • 17’ finish elevation	• Address wind driven storm surge from water within the bay • Pumping stations designed to address induced impacts from rainfall • Addresses residual risk, provides redundancy for larger gate to back bay communities
Non-Structural Improvements • West Shore of Galveston Bay (Eagle’s Point to Morgan’s Point) • Channel View • Harborview Drive and Circle	• Addresses residual risks for those outside structural features

PLAN FEATURE	PERFORMANCE – RISK REDUCTION
COASTAL STORM RISK FEATURES IN RECOMMENDED PLAN*	
Lower Coast CSRM	
South Padre Island Beach Nourishment and Sediment Management • Dune and Berm • 10-year renourishment cycle	• Addresses erosion risk from coastal processes • Addresses inundation from coastal storms • Sustains habitat • Strengthens “first line of defense”

PLAN FEATURE	PERFORMANCE – ECOLOGICAL LIFT
ECOSYSTEM RESTORATION MEASURES IN RECOMMENDED PLAN	
G-28 Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection • Island restoration GIWW and West Bay shore) • Estuarine marsh restoration • Oyster reef creation on bayside of restored island • Breakwater	• Shoreline protection and restoration through the nourishment of marshes that are eroding and degrading and construction of breakwaters along unprotected segments of the GIWW on Bolivar Peninsula and along the north shore of West Bay • Restoration of a bird 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 • Strengthens first line of defense as buffer between coastal forces and developed areas • Net 1,295.4 AAHU; 1653 Acres
B2 Follets Island Gulf Beach and Dune Restoration	• Restoration of the barrier beach and dune complex on Gulf shorelines of Follets Island in Brazoria County • Restores sediment to the gulf side of the barrier islands that provide back bay communities with a natural buffer from coastal storm and inundation, and wind driven sediment from the features support the marsh environment on the bay side • Net 240.1AAHU691 Acres

<table>
<tr><th>PLAN FEATURE</th><th>PERFORMANCE – ECOLOGICAL LIFT</th></tr>
<tr><td>B12

West Bay and Brazoria GIWW Shoreline Protection

• Estuarine marsh restoration
• Breakwaters on the western side of West Bay, and Cowtrap Lakes, and along selected segments of
• the GIWW in Brazoria County
• Oyster reef creation</td><td>• 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 Net 1297.5 AAHU 1121 Acres</td></tr>
<tr><td>M8

East Matagorda Bay Shoreline Protection

• Breakwater constructed along
    ○ unprotected segments of the GIWW shoreline
    ○ associated marsh along the Big Boggy NWR shoreline
    ○ eastward to end of East Matagorda Bay
    ○ NOT where GIWW shoreline is stabilized by adjacent dredged material PAs
• Estuarine marsh restoration
• Island restoration in front of Big Boggy NWR
• Oyster reef creation on bayside of island</td><td>• 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 and eastward to the end of East Matagorda Bay,
• Restoration of an island that protected shorelines directly in front of Big Boggy National Wildlife Refuge
• Addition of oyster cultch to encourage creation of oyster reef along the bayside shorelines of the restored island
• Net 481.5 AAHU 766 Acres</td></tr>
</table>

PLAN FEATURE	PERFORMANCE – ECOLOGICAL LIFT
CA5 Keller Bay Restoration • Breakwaters • Oyster reef creation	• Construction of rock breakwaters along the shorelines of Keller Bay in order to protect submerged aquatic vegetation and marsh • Construction of oyster reef along the western shorelines of Sand Point in Lavaca Bay by installation of reef balls in nearshore waters • Net 240.1 AAHU 300 Acres
CA6 Powderhorn Shoreline Protection and Wetland Restoration • Breakwater for shoreline stabilization fronting portions of Indianola, the Powderhorn Lake estuary, and Texas Parks and Wildlife's Powderhorn Ranch • Estuarine marsh 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 Powderhorn Ranch State Park and Wildlife Management Area • Net 18.4 AAHU 2416 Acres
SP1 Redfish Bay Protection and Improvement • Breakwater along unprotected GIWW shorelines along the backside of Redfish Bay and on the bayside of the restored islands • Island restoration • Oyster reef creation between breakwater and island	• 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, for a total of six islands, • Construction of breakwaters on the bayside of the restored islands • 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 submerged aquatic vegetation • Net 3500.5 AAHUs 3453 Acres

PLAN FEATURE	PERFORMANCE – ECOLOGICAL LIFT
W3 Port Mansfield Channel, Island Rookery, and Hydrologic Restoration • Dredge 6.9 miles of Port Mansfield Ship Channel o Hydrologic restoration of Lower Laguna Madre o Beach nourishment along Gulf Shoreline • Bird Island Restoration: o Breakwater o Island restoration	• Restoration of the hydrologic connection between Brazos Santiago Pass and the Port Mansfield Channel via dedicated dredging of the Port Mansfield Channel, • Restoration of Mansfield Island (a bird rookery island) Construction of additional rock breakwaters around Mansfield Island • 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 • Net 13,936.6 AAHU 56,858 Acres

The EIS was prepared pursuant to the National Environmental Policy Act (NEPA), and in compliance with the NEPA regulations issued by the Council on Environmental Quality (CEQ) (40 CFR Part 1500-1508) and issued by the Corps (33 CFR Part 230).

These regulations allow NEPA studies for large and complex projects to be carried out in a two-stage or tiered process. This tiered approach involves the preparation of an initial NEPA document (in this instance an EIS) that makes broad level decisions, while considering the full range of potential effects to both the human and natural environments of the entire plan.

Due to the scale of the recommended plan and the complexity of the project features, design and operation of critical components will continue in the Pre-Construction, Engineering, and Design (PED) phase. Several features will be further refined in the PED phase since their design is dependent upon the ultimate design and operation of the storm surge gate or require additional agency coordination. These are considered “Tier One” features, which will require supplemental NEPA documents to fully evaluate impacts and document compliance with all environmental laws and regulations. Features that have full environmental compliance at the time of the signed Chief’s Report are considered “Actionable” features. Table 42 clarifies whether project features are Actionable or Tier One.

Table 42 - Actionable and Tier One Measures

Recommended Plan (RP) Component	Actionable	Tier One*
G-28 – Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection	✓	
B-2 – Follets Island Gulf Beach and Dune Restoration		✓
B-12 – West Bay and Brazoria GIWW Shoreline Protection	✓	
CA-5 – Keller Bay Restoration	✓	
CA-6 – Powderhorn Shoreline Protection and Wetland Restoration	✓	
M-8 – East Matagorda Bay Shoreline Protection	✓	
SP-1 – Redfish Bay Protection and Improvement	✓	
W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration		✓
South Padre Island Beach Nourishment		✓
Bolivar Roads Gate System		✓
Bolivar and West Galveston Beach and Dune System		✓
Galveston Seawall Improvements		✓
Galveston Ring Barrier System		✓
Clear Lake Surge Gate System		✓
Dickinson Surge Gate System		✓
Non-structural Measures		✓

* Requires additional NEPA analysis and environmental compliance consultation