US Army Corps
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Galveston District

Appendix K

Monitoring and Adaptive Management Plan for Ecosystem Restoration Measures

for

Coastal Texas Protection and Restoration Feasibility Study

August 2021

Coastal Texas Protection and Restoration Feasibility Study

Final Feasibility Report

Monitoring and Adaptive Management Plan for Ecosystem Restoration Measures

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United States Army Corps of Engineers
Regional Planning and Environmental Center

Contents

1.0 INTRODUCTION

This document provides a feasibility-level monitoring and adaptive management plan for the Ecosystem Restoration (ER) features of the Coastal Texas Final Feasibility Report (FR) for the Coastal Texas Study, which proposes Coastal Storm Risk Management (CSRM) and Ecosystem Restoration (ER) opportunities within 18 coastal counties in Texas along the entire Texas Gulf coast. The FR presents the investigation of comprehensive water resources management for the Texas coast to ensure public safety and benefit to the Nation, while balancing the primary missions of navigation, flood and hurricane storm damage reduction, and environmental stewardship. This FR will be used to inform decision makers, stakeholders, and the public of the tradeoffs that should be considered in future decisions in order to maintain existing coastal storm risk levels and/or reduce coastal storm risk along the Texas coast.

This plan identifies potential and necessary monitoring activities for ER features, outlines how results from the monitoring would be used to assess ER success and, if needed, adaptively manage the project features to achieve the desired objectives. The plan specifies who would be responsible for monitoring and adaptive management activities, as well as provides estimated costs.

This Monitoring and Adaptive Management Plan (MAMP) was prepared by members of the Coastal Texas project delivery team (PDT) in consultation with resource agencies, which included Texas Parks and Wildlife Department, US Fish and Wildlife Service, Texas Commission on Environmental Quality, National Marine Fisheries Service, US Environmental Protection Agency, National Park Service, Bureau of Ocean Energy Management, and the Natural Resources Conservation Service. The level of detail in this plan is based on currently available data and information developed during plan formulation as part of the feasibility study. Uncertainties remain concerning the exact project features, monitoring elements, and adaptive management opportunities because of the variability of natural systems and the scale of the ER and CSRM features. Components of the MAMP, including costs, were similarly estimated using available information. Uncertainties will be addressed in the preconstruction, engineering and design (PED) phase; this plan will be revised during that phase to incorporate more detailed monitoring, adaptive management plans, and cost breakdowns.

1.1 Authorization for Monitoring and Adaptive Management

In accordance with the Water Resources Development Act of 2016, Section 1161 and subsequent implementation guidance (CECW-P Memorandum dated October 19, 2017), MAMP are required for both National Ecosystem Restoration (NER) project components and for any Mitigation Plan required for the National Economic Development (NED) component.

Section 1161 of WRDA 2016 amends Section 2039 of WRDA 2007, to specify information required to be included in monitoring plans for ER projects. Section 2039 of WRDA 2007, as amended, directs the Secretary of the Army to ensure that when conducting a feasibility study for a project (or component of a project), for ER, the recommended project must include a plan for monitoring the success of the ecosystem restoration. The implementation guidance for Section 2039 specifies that ER projects include plans to track and improve restoration success through monitoring and adaptive management. Guidance stipulates that the monitoring plan includes a description of the monitoring activities, the criteria for success, and the estimated cost and duration of the monitoring. It also specifies that monitoring will be performed until restoration success is achieved.

This MAMP includes all elements required by the WRDA 2016 implementation guidance for section 1161 for ER measures. The monitoring and adaptive management elements are also required for mitigation and are provided in the mitigation appendix (Appendix J of the FEIS).

1.2 Introduction to Monitoring and Adaptive Management

Monitoring and adaptive management provides a directed iterative approach to achieve restoration project goals and objectives by focusing on strategies promoting flexible decision making that can be adjusted as outcomes from restoration management actions and other events become better understood. Initiating a formal MAMP early in the study process enables the study team to identify and resolve key uncertainties and other potential issues that can positively or negatively influence project outcomes during every stage of the planning and project implementation process. Therefore, early implementation of monitoring and adaptive management will result in a project that can better succeed under a wide range of uncertain conditions and can be adjusted as necessary. Furthermore, careful monitoring of project outcomes both advances scientific understanding and helps adjust policies and/or operations as part of an iterative learning process.

Adaptive management acknowledges the uncertainty about how ecological systems function and how they may respond to management actions. Monitoring and assessment that analyzes responses is essential to implementation of the project as restoration progresses. The MAMP was developed in order to:

- Allow scientists and managers to collaboratively design plans for managing complex and incompletely understood ecological systems.
- Reduce uncertainty over time.
- Implement systematic monitoring of outcomes and impacts.
- Incorporate an iterative approach to decision-making.
- Provide a basis for identifying options for improvements in the design, construction and operation of restoration through adaptive management.
- Ensure interagency collaboration and productive stakeholder participation as they are key elements to success.

1.2.1 Monitoring and Adaptive Management Process

The monitoring and adaptive management program and process is complimentary to the USACE Project Life Cycle (planning, design, construction, and operation and maintenance). The process is not elaborate or duplicative and enhances activities already taking place. The basic process was adapted from a technical note published by the Engineering Research and Development Center (ERDC)[1].

Elements of the program include an iterative process that involve:

1. Planning a program or project;
2. Designing the project;
3. Building the project;
4. Operating and maintaining the project;
5. Monitoring and assessing project performance;
6. Continuing, adjusting, or terminating a project if the goals and objectives are not being achieved.

1.2.2 Adaptive Management Team

As part of the monitoring and adaptive management process, a team is set up to implement the process. The MAMP provides the framework and guidance for an Adaptive Management Team (AMT) to review and assess monitoring results. In addition, the AMT will recommend adaptive management actions when ecological success is not achieved and decision criteria are triggered. The AMT members shall work together to make recommendations relevant to implementing the MAMP. The AMT is composed of USACE staff, the non-Federal sponsor (NFS), interested resource agencies, and other stakeholders. Although the USACE has coordinated with the entities that will comprise the AMT in development of the Feasibility Report and Environmental Impact Statement (FR-EIS), the AMT will not be officially established until the PED phase of the project.

The AMT focuses on maintaining the ecological function of coastal habitats through management actions within the project area. The AMT shall review the monitoring results and advise on recommended actions that are consistent with the project goals. These goals should reflect the current and future needs of the habitat and the species they support within the project area. The NFS and USACE shall have final determination on all adaptive management actions recommended.

The NFS and USACE are responsible for ensuring that monitoring data and assessments are properly used in the adaptive management decision-making process. If the NFS and USACE determine that adaptive management actions are needed, they will coordinate with the AMT

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[1] Fischnecich, C., et al. 2012. The Application of Adaptive Management to Ecosystem Restoration Projects. EBA Technical Notes Collection. ERDC TN-EMRRP-EBA-10. Vicksburg, MS: US Army Engineering Research and Development Center. www.wes.army.mil/el/emrrp.

for implementation of those actions. The NFS and USACE are also responsible for project documentation, reporting, and external communication.

The AMT shall meet a minimum of once per year, as scheduled by the NFS and USACE during the monitoring period, to review the results of monitoring and assess whether project objectives are being met. If objectives are not being met, the AMT may recommend that adaptive management actions be taken in response to monitoring results and decision-making triggers.

The AMT may also consider other related projects in the hydrologic basin in determining the appropriate adaptive management actions and may consult with other recognized experts or stakeholders as appropriate, to achieve project goals.

Recommendations for adaptive management should be based on:

- Monitoring data from previous years,
- Consideration of current habitat conditions,
- Consideration of current and potential threats to habitat establishment success, and
- Past and predicted responses to threats by target species and habitats.

1.2.2.1 Team Structure

The AMT shall include representatives from USACE, Galveston District and the Regional Planning and Environmental Center (RPEC), and the NFS. The USACE may be represented by the Project Biologist(s), as well as the Project Hydrology and Hydraulics (H&H) representative and the Project Geotechnical representative as needed. Other USACE attendees may include the Project Manager, Project Real Estate Specialists, and/or Operations and Maintenance designees, as needed.

The Texas General Land Office (GLO) is the NFS for the Feasibility Study portion of this project. Following the execution of a feasibility cost share agreement in November 2015, the GLO actively participated in the scoping of the study and contributed a non-Federal cost share, which includes work-in-kind and contracting with GLO professional service providers. The GLO has worked alongside the USACE on the Feasibility Report (FR) in the formulation and screening process and will continue to provide assistance throughout the entire Coastal Texas Study process.

A NFS for the construction phase will be identified by the Texas Legislature. The GLO is also working to identify construction sponsors on the local level. Local construction sponsors could include local governments, such as counties, cities, levee improvement districts, drainage districts, municipal utility districts, or other special taxing entities that could be created for this project.

The AMT should also include representatives from resource agencies who would serve in an advisory capacity, to assist in evaluation of monitoring data and assessment of adaptive management needs. The agencies may include, but not limited to:

- U.S. Fish and Wildlife Service
- Texas Parks and Wildlife Department
- Texas General Land Office, Coastal Protection
- Texas Commission on Environmental Quality
- National Marine Fisheries Service
- U.S. Environmental Protection Agency
- National Park Service
- Natural Resources Conservation Service

1.3 Monitoring and Adaptive Management and OMRR&R Responsibilities

Monitoring and adaptive management are not to be used as a substitute for OMRR&R. Per WRDA 1986, as amended by Section 210 of WRDA 1996, the NFS would be responsible for all OMRR&R. This includes operations and maintenance (O&M) that provides day-to-day activities necessary to properly operate a component of a system and routine maintenance activities to keep the system operating as designed. This also include non-routine or beyond the scope of typical O&M activities of repair or fixing damage caused by an event; rehabilitation or fixing long-term wear and tear; and replacement of components when the useful life is exceeded.

Funding for OMRR&R actions is not included in the NER cost estimate. Specifically for the recommend plan, the hardened structure features (only breakwaters) are designed for a 50-year life span using intermediate sea level rise conditions. Unless there are needs for emergency repairs (e.g., collision with barge, scour hole), which would be the responsibility of the NFS, breakwaters are designed to last and perform for the intended 50-year project period without ongoing OMRR&R. For the other features which are all non-mechanical and non-structural (marsh, island, oyster, beach and dune restoration), renourishment actions would be needed after the NFS's O&M responsibilities cease for an ER project; therefore, no OMRR&R is required for these non-structural features.

Section 1161 of WRDA 2016 allows ecological success monitoring to be cost-shared for up to ten years post-construction. Once ecological success has been achieved, which may occur in less than ten years post-construction, no further monitoring would be performed. If ecological success cannot be determined within the ten-year post construction period of monitoring, any additional required monitoring would be the responsibility of the NFS.

1.4 Recommended Plan

The Recommended Plan includes a combination of ER and CSRM features that function as a system to reduce the risk of coastal storm damages to natural and built infrastructure and to restore degraded coastal ecosystems through a comprehensive approach employing multiple lines of defense. Focused on redundancy and robustness, the proposed system provides increased resiliency along the Bay and is adaptable to future conditions, including relative sea level change. The Recommended Plan can be broken into three groupings: a Coastwide ER plan, a lower Texas coast CSRM plan, and an upper Texas coast CSRM plan.

Coastwide ER Plan: A Coastwide ER plan was formulated to restore degraded ecosystems that buffer communities and industry on the Texas coast from erosion, subsidence, and storm losses. A variety of measures have been developed for the study area, including construction of breakwaters, marsh restoration, island restoration, oyster reef restoration and creation, dune and beach restoration, and hydrologic reconnections. Figure 1 shows the location of the ER measures and the following describes what each measure includes:

- Bolivar Peninsula and West Bay Gulf Intracoastal Waterway (GIWW) Shoreline and Island Protection (G-28):
  - Shoreline protection and restoration through the nourishment of 664 acres of eroding and degrading marshes and construction of 40.4 miles of breakwaters along unprotected segments of the GIWW on Bolivar Peninsula and along the north shore of West Bay,
  - Restoration of 326 acres (approximately 5 miles) of an island that protected the GIWW and mainland in West Bay, and
  - Addition of oyster cultch to encourage creation of 18.0 acres (26,280 linear feet) oyster reef on the bayside of the restored island in West Bay.
- Follets Island Gulf Beach and Dune Restoration (B-2)
  - Restoration of 10.1 miles (1,113.8 acres) of beach and dune complex on Gulf shorelines of Follets Island in Brazoria County.

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

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

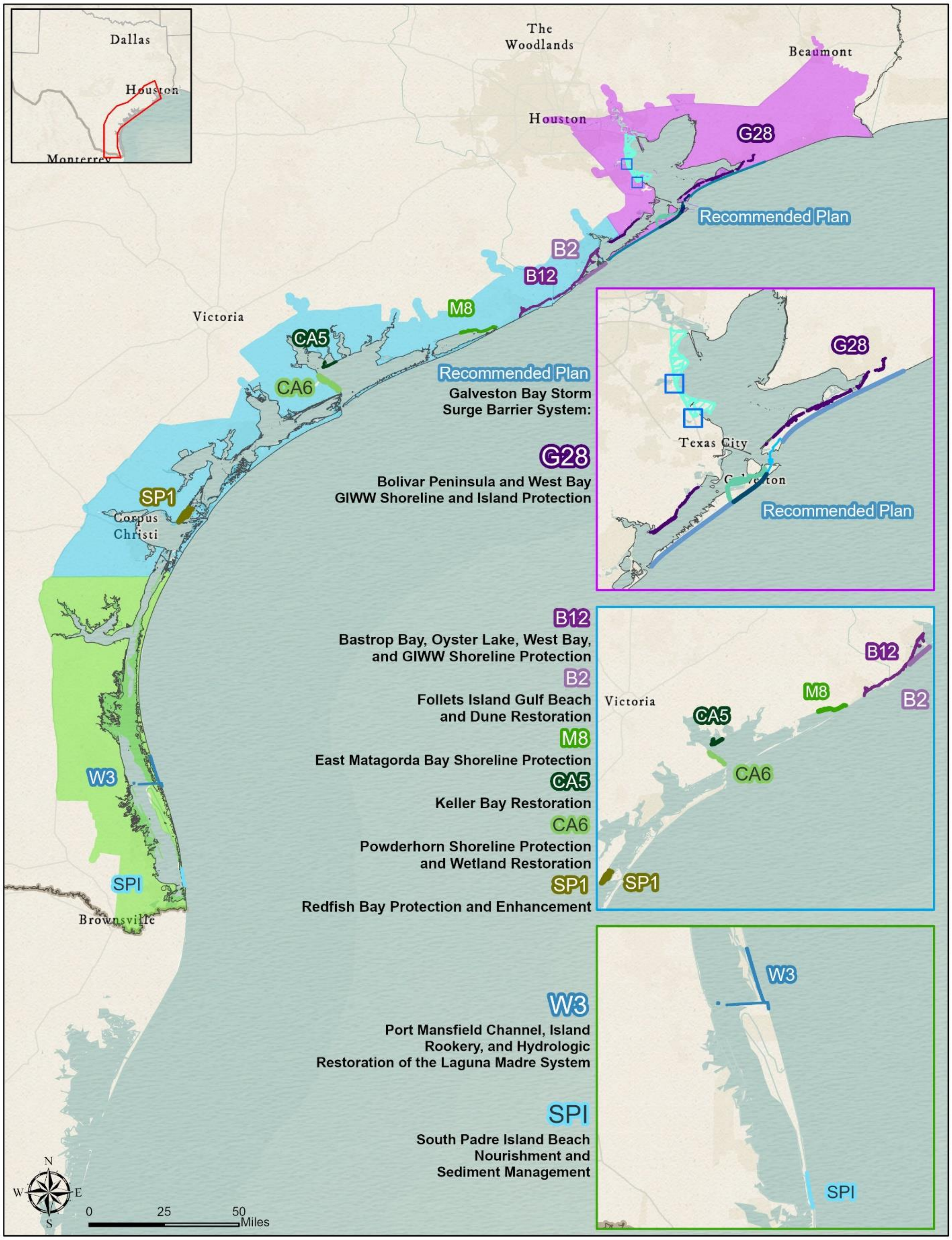

Figure 1. Recommended Plan

South Padre Island Sediment Management: The lower Texas coast component of the recommended plan includes 2.9 miles of beach nourishment at South Padre Island to be completed on a 10-year cycle for the authorized project life of 50 years (Figure 2).

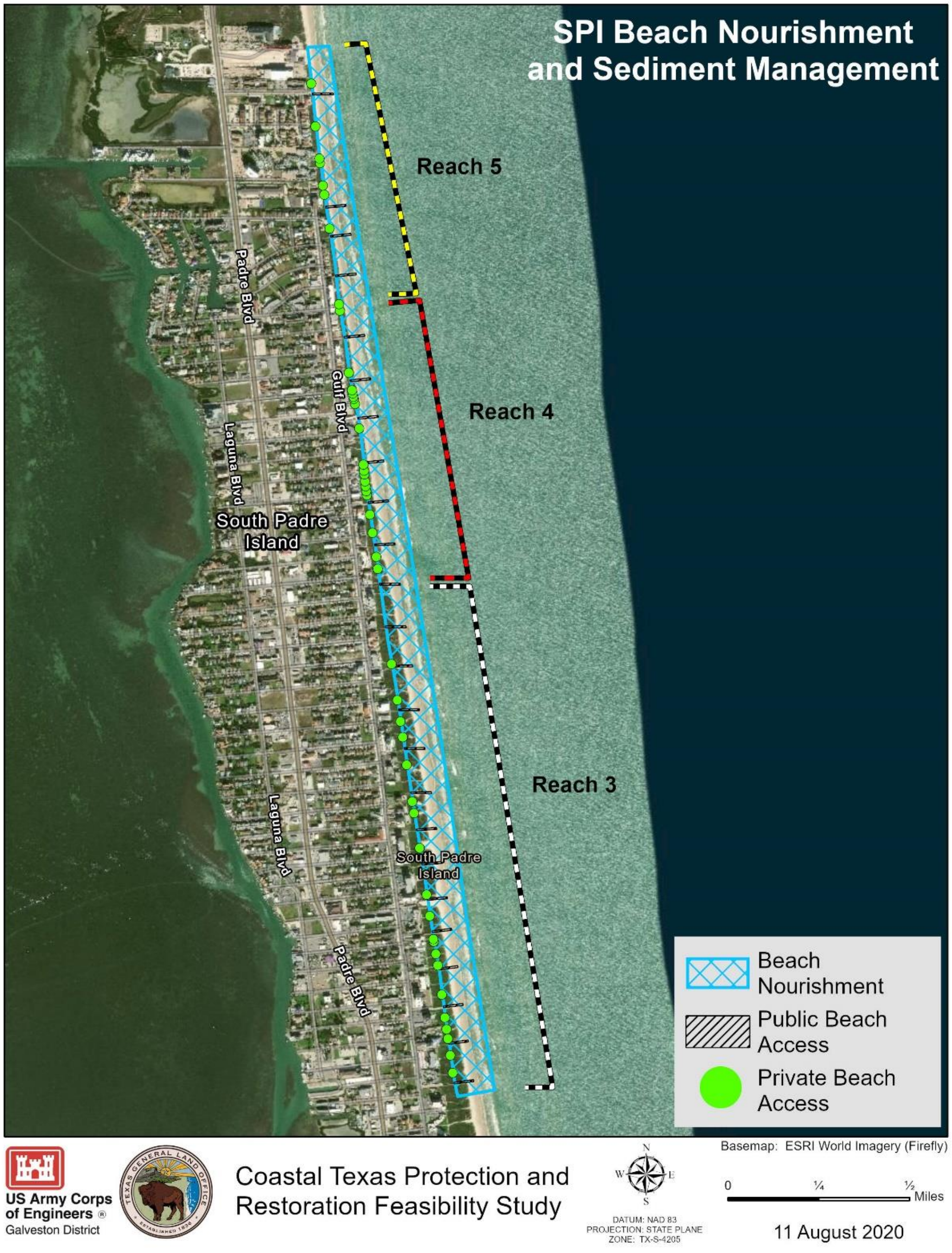

Figure 2.South Padre Island CSRM

Upper Texas Coast Plan: The upper Texas coast component of the recommended plan includes a multiple-lines-of-defense system known as the Galveston Bay Storm Surge Barrier System. The system is designed to provide a resilient, redundant, and robust solution to reduce risks to communities, industry, and natural ecosystems from coastal storm surge. The system includes a Gulf line of defense which separates the Galveston Bay system from the Gulf of Mexico to reduce storm surge volumes entering the Bay system. It also includes Bay defenses which enable the system to manage residual risk from waters already in Galveston Bay. Figure 3 shows the spatial relationship between the Gulf and Bay lines of defense. Measures which make up the system include:

- The Bolivar Roads Gate System, across the entrance to the Houston Ship Channel, between Bolivar Peninsula and Galveston Island (Figure 4);
- 43 miles of beach and dune improvements on Bolivar Peninsula and West Galveston Island that work with the Bolivar Roads Gate System to form a continuous line of defense against Gulf of Mexico surge, preventing or reducing storm surge volumes that would enter the Bay system (Figure 4);
- Improvements to the existing 10-mile Seawall on Galveston Island to complete the continuous line of defense against Gulf surge (Figure 4);
- An 15.8-mile Galveston Ring Barrier System (GRBS) that impedes Bay waters from flooding neighborhoods, businesses, and critical health facilities within the City of Galveston;
- 2 surge gates on the west perimeter of Galveston Bay (at Clear Lake and Dickinson Bay) that reduce surge volumes that push into neighborhoods around the critical industrial facilities that line Galveston Bay; and
- Complementary nonstructural measures, such as home elevations or floodproofing, to further reduce Bay-surge risks along the western perimeter of Galveston Bay.

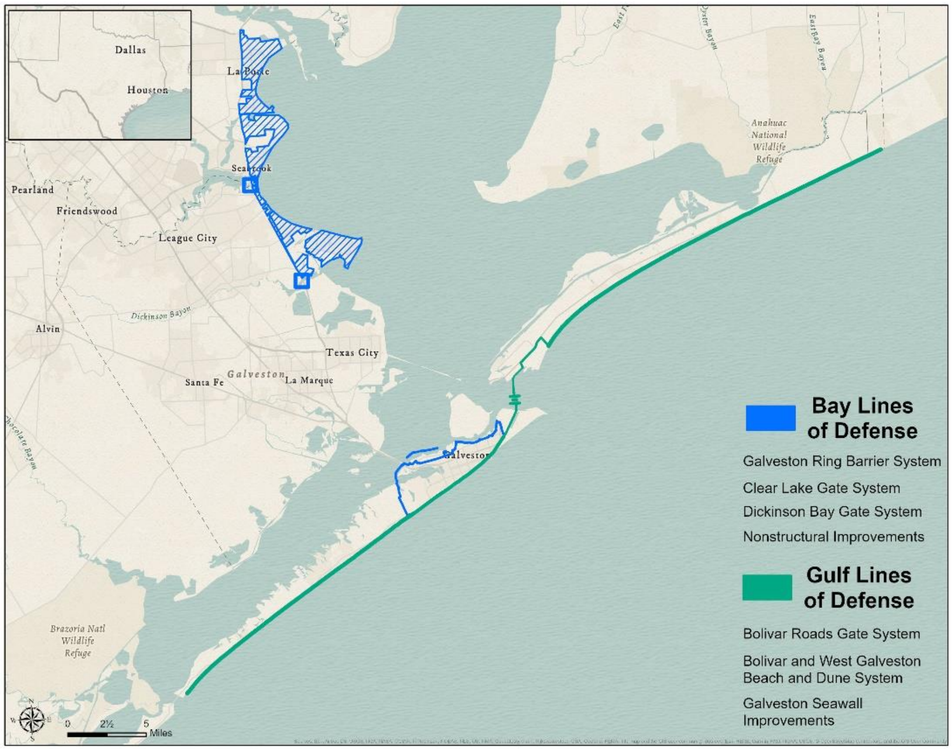

Figure 3. Galveston Bay Storm Surge Barrier System

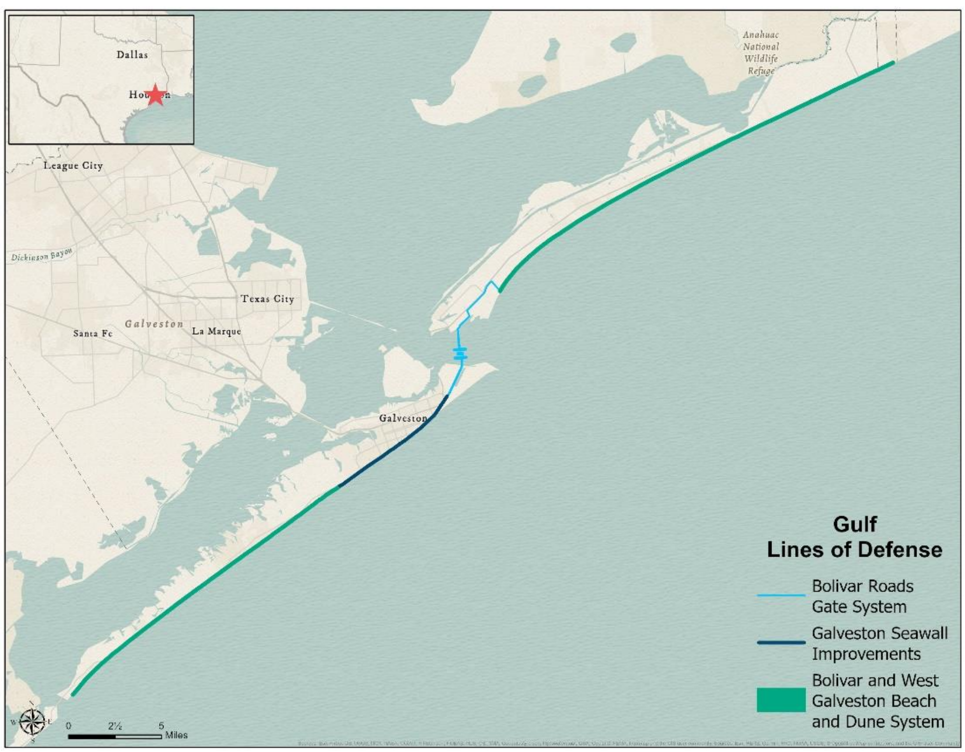

Figure 4. Gulf Lines of Defense of the Galveston Bay Storm Surge Barrier System

Monitoring and adaptive management are applicable to ER features because of the variability and uncertainty that are associated with these systems. For instance, coastal marshes are highly complex transition zones between terrestrial and aquatic ecosystems and restored marshes require time to develop the ecological functions and services of natural marshes. The sediments used to create the substrate in marsh restoration projects do not possess the biogeochemical properties and functions of natural wetland soils. These processes are not well understood and there is considerable variation in ecosystem trajectories and outcomes. Therefore, monitoring these sites is essential to identifying the sources of uncertainty in order to provide the data that are necessary to guide decision making and adaptive management. Similarly, monitoring is crucial for other types of projects such as beach and dune restoration and island creation. Dune and beach restoration projects can increase the amount of habitat for threatened and endangered species. Effective monitoring is a risk reduction strategy that can mitigate adverse impacts to these listed species.

2.0 MONITORING

An effective monitoring program will be required to determine if the project outcomes are consistent with original project goals and objectives. The power of a monitoring program developed to support adaptive management lies in the establishment of feedback between continued project monitoring and corresponding project management. A carefully designed monitoring program is the central component of the adaptive management plan as it supplies the information to assess whether the project is functioning as planned.

Monitoring must be closely integrated with the adaptive management components because it is the key to the evaluation of adaptive management needs. Objectives must be considered to determine appropriate indicators to monitor. In order to be effective, monitoring must be able to distinguish between ecosystem responses that result from project implementation (i.e. management actions) and natural ecosystem variability.

2.1 Monitoring Plan

According to the USACE implementation guidance memo for WRDA 2016, Section 1161, "Monitoring includes the systematic collection and analysis of data that provides information useful for assessing project performance, determining whether ecological success has been achieved, or whether adaptive management may be needed to attain project benefits."

The following discussion outlines a monitoring plan that will support the Coastal Texas Study Adaptive Management Plan. The plan identifies performance measures along with desired outcomes and monitoring design in relation to specific objectives. A performance measure includes specific feature(s) to be monitored to determine project performance. Additional monitoring may be identified to help further understand interrelationships of restoration features, external environmental variability, and to corroborate project effects.

Ecological success criteria, or decision-making triggers, are related to each performance measure and desired outcome in order to identify the need for potential implementation of adaptive management actions with the AMT. These criteria/triggers are identified in Section 3.2.1.

Overall, monitoring results will be used to evaluate habitat restoration project objectives and to inform the need for adaptive management actions to ensure successful restoration is achieved.

2.1.1 Monitoring Period

Pre-construction/baseline data, during construction, and post-construction monitoring will be utilized to determine restoration success. Baseline monitoring will begin during PED prior to project construction and continue during construction when possible. Monitoring will continue until the trajectory of ecological change and/or other measures of project success are determined as defined by project- specific objectives.

There may be issues related to sustainability of the project that would require some monitoring and adaptive management beyond achieving the project objectives. For example, bird islands may be susceptible to colonization by invasive species. Invasive plants such as salt cedar (*Tamarix ramosissima*) and Chinese tallow (*Triadica sebifera*) can become established on higher elevation areas with lower salinity, which would degrade the nesting habitat of some avian guilds. Invasive animals, such as coyotes and fire ants can have negative impacts on nesting colonial waterbirds. Due to the variable nature of the coastal environment, the monitoring baseline may change during the period of analysis. Consequently, it may be appropriate to consider extending project-specific monitoring and adaptive management beyond 10 years; however, this additional monitoring would be the responsibility of the NFS.

Per USACE policy, cost-shared monitoring would cease if additional monitoring beyond what is described in this plan (e.g. need for more frequent monitoring, change in monitoring protocols, etc.) would result in monitoring costs exceeding 1 percent of the total project cost minus the costs of adaptive monitoring and adaptive management of the restoration features.

2.1.2 Monitoring Elements

Defining and assessing progress towards project objectives are crucial components of the MAMP. The following section outlines the proposed performance measure criteria, desired outcomes and monitoring design needed to measure restoration progress, determine ecological success and support the adaptive management program should changes need to be made to improve project performance.

The elements described in this section are based on the available project information from the monitoring and adaptive management plans for the Jefferson County Ecosystem Restoration (JCER) study, the Sabine-Neches Waterway Channel Improvement project, and the Sabine Pass to Galveston Bay CSRM / ER study. The project objectives, performance measures, ecological success criteria, and timetables for the Coastal Texas study are consistent with these previous projects. In addition, the majority of the monitoring techniques in this study will utilize remote sensing and GIS in manner that is similar to the methods of the aforementioned projects. However, the monitoring and adaptive management plan for this study will be updated and refined during PED.

Note: For the following monitoring descriptions, the term “ER Measure” refers to the overall ER measure (e.g. marsh in G-28, breakwaters in G-28, beach nourishment in W-3, oysters in CA-5, etc.). A number of restoration units make up the ER measure. A “restoration unit/area/site” refers to the individual restoration areas that occur without any breaks.

1. Marsh Restoration

Objective 1: Reduce shoreline erosion and stabilize GIWW shorelines to protect adjacent marshes.

Performance Measure: Shoreline Change. The extent of marsh along the GIWW is eroding at a rate of about 4 feet per year. In addition to physical loss of marsh lands, shoreline erosion promotes saltwater intrusion into more interior marshes and changes in hydrologic regimes which then result in further conversion or loss of interior marshes.

Monitoring Purpose: By assessing the shoreline position pre- and post-construction the rate of shoreline change can be monitored to determine whether the breakwaters are successful in reducing erosion and land loss.

Monitoring Design: Aerial or satellite imagery will be obtained and analyzed to identify and compare historic shoreline positions to post-construction protected shoreline positions. Historic imagery will serve as a pre-construction condition to determine the rate of change observed in the past and serve as a pre-construction standard for future changes in shoreline position. Additional aerial or satellite imagery acquisitions post-construction should be used to supplement shoreline surveys to determine the overall rate of erosion. Opportunities should be sought to utilize existing aerial imagery (e.g. Google Earth, county/state contracted flights, etc.) if the data are comparable to previous surveys (i.e. timing is similar). The extent of historic imagery that should be assessed to determine the historic rate of change will need to be determined during PED, but at a minimum, at least 3 historic years should be assessed, including one survey completed prior to construction beginning, and span at least 30 years. If imagery or other data is unavailable for sufficient historical context, the average rate of 4 feet per year should be the pre-construction condition rate of change. Post-construction imagery should be obtained for Years 1, 3, and 6.

Desired Outcome: Land loss and erosion along the protected shorelines would be reduced by at least 50%, which is consistent with observations in other locations where a similar breakwater structures have been implemented.

Ecological Success Criteria: Post-construction shoreline erosion rates are reduced by 50% when compared to pre-construction and historic rates of shoreline change for the same area.

Objective 2: 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.

Performance Measure 1: Marsh Elevation. The elevation of the marsh platform is critical to the long-term success of the target marsh type and affects the establishment of desired vegetation species and the hydrologic regime of the marsh. If marshes are not within the optimal range, non-target marsh or upland habitat types could establish if the elevation is too high, while if the elevation is too low, the area could convert to open water.

Monitoring Purpose: Marsh elevation monitoring can be used to confirm the target elevation (ecological success) has been achieved and identify areas of concern such as where erosion, subsidence or accretion rates are not conducive to maintaining the target marsh type.

Monitoring Design Summary: One LiDAR topographic survey covering all restoration units will be collected prior to construction (completed as a PED task for engineering and not included as part of the monitoring costs here) and recollected three times post-construction in Year 1, 3, and 6. LiDAR data will be used to assess overall marsh elevation throughout the restoration unit. The resulting data will provide a density of approximately 1 elevation point per square meter accurate to approximately +/-15 cm (root-mean square-error [RMSE]) vertical elevation and +/-1.5 m (RMSE) horizontal position. The data would be used to identify low lying areas by surface elevation. LiDAR surveys will be collected one time before construction begins and three times after construction is completed in Year 1, 3, and 6 to determine overall elevation throughout the entire restoration unit. If success has not been achieved by Year 6 additional LiDAR collection will be necessary and will need to be determined by the AMT when the next collections should occur.

Surface elevation will be measured from a rod-surface elevation table (RSET) benchmark established within or adjacent to the vegetation survey plots using the RSET technique developed by Cahoon et al[2]. This technique provides a non-destructive process that precisely measures the sediment elevation of wetlands over long periods of time relative to a fixed subsurface datum. Marker horizons, indicated with white feldspar clay, would be used in conjunction with the RSET to measure vertical accretion. When used simultaneously, the RSET and marker horizon techniques can provide information on above and below ground processes that influence elevation change. The data will also be used to determine rates of elevation change, particularly relative to sea level change, to ground-truth LiDAR data and assess significant changes in advance of the more intensive LiDAR surveys. This methodology is a relatively inexpensive way to annually measure elevation changes in a subset of the restoration units and indicate whether areas need additional monitoring or adaptive management actions. Surface elevation will be sampled one-time preceding construction, then annually for a period of 10 years post-construction, or until ecological success is achieved, whichever comes first.

Desired Outcome: Establish marsh elevation post-construction sufficient for healthy marsh.

Ecological Success Criteria: Marsh elevation in restored marsh restoration units (following de-watering and settlement) is sustained between +1.2 MSL and +2.2 MSL (local datum) for at least 5 years. Local conditions and future rates of projected RSLR will dictate the exact target elevation of each restoration unit to achieve ecological success and will be determined during PED.

Interim Target: Marsh elevation in restored marsh restoration areas (following de-watering and settlement) is at the target elevation identified for each specific restoration area.

Performance Measure 2: Vegetation Composition. The vegetation composition of a marsh is telling of the health and success of the habitat type. If vegetation or desired species fail to establish or undesirable species establish, the valuable ecological process and functions that vegetation provides, such as food, cover and shelter for wildlife or water quality filtering capabilities, would be diminished or unavailable.

Monitoring Purpose: Identify the vegetation composition and percent cover of desirable species to confirm the target marsh habitat type is being established and maintained.

Monitoring Design Summary: Vegetation will be sampled annually, at each restoration site. Permanent 100 m vegetation monitoring stations and/or transects will be established for assessing the vegetation community at each site. For purposes of this plan, it is assumed that one vegetation transect per 25 acres should be established for and 2 references sites for each ER measure location (i.e. two reference sites established for G-28) would be established. The distance between transects will be dependent on the project site area and variability. Monitoring will measure percent cover of native and non-native plant species and structural diversity. Photographs stations will also be established along the transect to document vegetation conditions. All transects and photograph stations will be documented via Global Positioning System (GPS) coordinates in order to reacquire their positions in each year of sampling.

In addition to community composition, each station will be sampled for water level, above- and below-ground biomass, and soil parameters such as pH, temperature, salinity, and redox potential. General observations, such as fitness and health of plantings, native plant species recruitment, and signs of drought stress should be noted during the surveys. Additionally, potential soil erosion, flood damage, vandalism and intrusion, trampling, and pest problems would be qualitatively identified.

Sites will be sampled in the spring one time prior to construction and then annually in the spring beginning one year after construction is complete until success is determined.

Ecological Success Criteria: Average cover of 80% desirable vegetation of which less than 5% of the cover is composed of invasive, noxious, and/or exotic plant species on marsh restoration sites at Year 6 when compared to pre-construction conditions.

Interim Target: One year following completion of final construction activities achieve a minimum average cover of 25%, comprised of native herbaceous species. Three years following construction, achieve a minimum average cover of 75% native species with less than 5% invasive, noxious, and/or exotic plant species. For the period beginning 5 years post-construction and continuing through project success, maintain a minimum average cover of 80%, comprised of native herbaceous species and less than 5% of invasive, noxious, and/or exotic plant species.

2. Island Restoration/Creation

Objective 1: Restore and/or create islands to reduce shoreline erosion and storm damage impacts to mainland coasts.

Performance Measure 1: Island Morphology The ability of the islands to limit erosion and storm impacts to mainland coasts depends upon the islands' ability to maintain sufficient width and elevation. Under the current conditions, islands erode at an average of 2.7 feet per year.

Monitoring Purpose: Confirm island elevations and aerial island extents are being maintained over a period of time. Monitoring will be used to measure project performance against success criteria and to identify breaches that would trigger adaptive management actions.

Monitoring Design Summary: To capture changes to elevation and surface area, a combination of aerial imagery, remote sensing, and/or LiDAR surveys would be acquired at least four times after construction during the 10-year period (at a minimum in years 1, 3, 6, and 10). Each dataset would be analyzed to determine the perimeter measurements and surface area of the island, as well as to generate a cross-section profile from elevation data. To evaluate the effectiveness of the restoration design, design template measurements would be compared with post-construction measurements.

Desired Outcome: Maintain the predicted profiles of the associated design template for elevation and surface area at Year 10.

Success Criteria: Net loss of original island restoration surface area is not greater than an average of 3 percent per year over the 10-year monitoring period. Net loss of original elevation (following de-watering and settlement) is less than 1 percent per year over the 10-year monitoring period.

Objective 2: Restore and diversify the habitat types present on the islands to promote quality foraging, roosting, nesting, and rearing habitat for a wide array of migratory birds, colonial waterbirds, and coastal shorebirds.

Performance Measure: Habitat Composition. The habitat composition of the island will dictate what species of birds, flora and fauna will establish. Maintaining a mix of upland habitats, such as scrub-shrub, thornscrub brush, and grasslands, along with marsh, mud flats, and beach habitats will promote use by desired species while limiting the potential for predator populations to establish.

Monitoring Purpose: Document changes in habitat diversity and the acreage of each habitat type over time. This monitoring will be used to measure project performance as a success criterion.

Monitoring Design Summary: High resolution aerial imagery will be used to map island habitat types. Aerial imagery will be collected at least 4 times after construction is complete. If LiDAR data is acquired for the monitoring area during any period of time for other monitoring purposes, the data can be analyzed and mapped as part of this monitoring effort. Field investigations using photopoint surveys will be conducted to ground-truth various geomorphic and vegetation habitats in the field with corresponding signatures on aerial photography. As an estimate for this plan, assume 1 point for every 10 acres will be necessary to complete ground truthing efforts, although this number is likely to be refined during PED. All mapping efforts would result in a quantification of acreage of island habitat types, which can then be compared to the design template and each post-construction monitoring period in order to assess trends in conversion of habitats. At least four post-construction surveys will be acquired.

Desired Outcome: Provide a distribution of acreage between habitat types that matches the predicted acreages of the associated design template at year 10.

Success Criteria: Less than 15% of any habitat type is lost within 10 years post-construction relative to the design template.

3. Oyster Restoration

Objective: Restore oyster populations to self-sustaining levels that mimic historic oyster populations in the same habitats so that established reefs can directly or indirectly provide valuable ecosystem services such as providing physical habitat for feeding, breeding, and nursery grounds; shoreline protection; and improving water quality.

Performance Measure 1: Reef Structure. The structural characteristics of a reef (e.g. reef area, relative height (relief) and density) can influence oyster attachment, establishment, and growth. Measurements of reef structure are critical to assessing reef persistence through time, oyster population abundance, and ultimately the quantity of the ecosystem services proved by the restored oyster reef. Site selection for settlement from the plankton to the benthos by the oyster larva is influenced by a suite of environmental factors including substrate type and location. Once a larva permanently cements itself to hard substrate, it remains fixed in that location for life. When adequate substrate is limited, oyster recruitment and survival rates are reduced.

<u>Monitoring Purpose:</u> Assess the availability of adequate substrate and reef height pre- and post-construction to provide a basis for determining success and making adaptive management decisions.

<u>Monitoring Design Summary:</u> A sidescan sonar survey with bathymetry will be performed at each restoration unit and reference site. Data would be geo-referenced, imported into ArcGIS and converted into layers or shapefiles, which will determine the area of hard substrate available for oyster recruitment and colonization. Surveys would cover all areas of the restoration unit and the reference sites (established under performance measure 2). Surveys of each location would be completed prior to construction, approximately 60 days after construction is complete, and annually thereafter until ecological success is achieved.

<u>Desired Outcome:</u> The area of hard substrate is equal to or greater than the design template profile in each restoration unit and reef height is increasing over the design template profile.

<u>Success Criteria:</u> The net loss of hard substrate in each restoration unit is less than 5% of the design template profile and the reef height is maintained consistent with the design template profile for that unit for at least three consecutive surveys.

<u>Interim Target:</u> The area of hard substrate is equal to or greater than the design template profile for each restoration unit 60 days after construction is complete.

Performance Measure 2: Abundance and Distribution. The size and number of oysters on a reef provide information on population age structure and can indicate success in establishment and subsequent recruitment. The balance between degradation and accretion from recruitment and growth of oysters (shell budgets) is critical to developing carbonate-dominated habitats and determines the long-term stability of the reef (Powell and Klinck, 2007; Powell et al., 2006; Waldbusser et al., 2013). Without new recruits, the restoration effort is ineffective.

<u>Monitoring Purpose:</u> Standard stock assessment of oysters provide information on the health, condition, and trajectory of the reef and thus the success of the reef substratum. Monitoring will be used to measure project performance against success criteria and to identify any need for adaptive management.

<u>Monitoring Design Summary:</u> A reference reef should be identified within 1 mile of the restoration unit and within the same bay. Restoration units and reference sites should be divided into 1,000-linear foot monitoring segments. Within each segment, four random 0.25-m^2 quadrat sampling stations will be established for each monitoring

period (i.e. sampling locations will vary for each monitoring effort) to prevent damage to the reef.

Divers will place the quadrat on the reef, measure and record sediment depth in the four corners of the quadrat and in the approximate center. Divers will collect all surface oyster and shell material from the top shell layer within the quadrat using grab sample tongs or other similar recommended methodology by TPWD. All live and dead oyster material will be counted and measured for length (market size ≥3 inches and sub-market size <3 inches). Dead shell will be examined for spat set. Spat will be identified (0.3mm to 26 mm), counted and recorded. *Crepidula* or barnacles should be noted, but not counted as oyster spat set. In addition, general observations of the quality and condition of the oysters will be recorded and a count of mud crabs, oyster drills, sponges, other mollusks, tunicates, and boring clams collected in the sample should be kept in order evaluate the level of predation and competition on the reef. All shell material, live and dead shells, will be returned to the reef after examination.

Monitoring efforts for each restoration unit and the reference site would occur 60 days after shell placement and semi-annually until ecological success is achieved. The semi-annual monitoring would occur once in late spring (June/July) and each winter (November/December).

Desired outcome: Establish self-sustaining native oyster populations consisting of a diversity of size classes and observe spat set within each restoration unit.

Success Criteria: Each restoration unit achieves 80% of the market oyster density of the reference site and spat set is observed TY5.

Interim Target: Oyster density, including recruitment, is ≥ $25/m^{-2}$ and/or 50% of the mean density of the reference site by TY 3.

4. Dune and Beach Restoration

Objective: Restore and/or enhance beaches and dunes along the Gulf of Mexico to promote conditions which more closely mimic natural conditions.

Performance Measure 1: Shoreline Profile Change. The shoreline profile determines its vulnerability to erosion and submergence.

Monitoring Purpose: Beach and dune profile surveys describe the morphology and key beach features. Monitoring will be used to measure project performance against success criteria and to identify significant profile changes that would trigger adaptive management actions.

Monitoring Design Summary: Topographic and bathymetric surveys (beach profile surveys) would be completed annually until ecological success is achieved. Beach profile surveys would be conducted along multiple shore perpendicular transects spaced approximately 1,000 feet apart that would initiate on the toe of the leeside of the dune and extend over the dune, across the beach and offshore to the depth of closure. Pre-construction and any historic beach profile data available for the site would be compared to the post-construction beach profile data to compare volumetric and position change.

<u>Desired Outcome:</u> Maintain the shoreline profiles of the associated design template at Year 10.

<u>Success Criteria:</u> Net loss of the dune profile is less than 5% of the template profile over the 10-year monitoring period. Net loss of the beach and nearshore is equivalent to or less than the historic rate of loss for 5 consecutive years.

Performance Measure 2: Dune Vegetation. The density of plants, species composition, and root penetration of individual stems influences land loss by dissipating wave energy reaching sheltered shores, encouraging accumulation of organic and inorganic sediment, and acting as a sediment binder that resists erosion.

<u>Monitoring Purpose:</u> Document the establishment and sustainability of appropriate dune vegetation which will encourage sediment accumulation and reduce the movement of the dune. Monitoring will be used to measure project performance against success criteria and to identify poor vegetation vigor and/or recruitment that would trigger adaptive management actions.

<u>Monitoring Design Summary:</u> Point-intercept transects should be established every 1,500 feet along the planted dune and at a reference site. Transects will be laid perpendicular to the shore. The transitions between the foredune, mid-dune, upperdune, and back dune should be recorded for each transect so that vegetative composition, density, etc. is appropriate for the dune location. At every meter along the transects, record all plant species intercepting the transect and measure the root depth (from the top of the root ball down) of at least 25% of all plants found along the transect. Quadrats along each transect should be placed within each vegetation zone of the dune to take measurements of density and survival pattern. To measure the density, a count of all stems by species in the plot will be recorded. The survival pattern will be assessed by visually observing and recording the health/vigor and above-ground growth of each stem in the plot.

The length/size of each transect and quadrat, as well as how many are needed, will be dependent on-site specific conditions and will be determined during PED. One pre-construction survey should be completed no less than one year before construction begins. Approximately 180 days following completion of construction in the planting unit, a post-construction survey should be completed and followed with annual surveys until ecological success is achieved.

Desired Outcome: Restore dune vegetative communities comparable to the reference site that is sustained through TY10.

Success Criteria:

Composition: Average cover of 80% desirable vegetation of which less than 5% of the cover is composed of invasive, noxious, and/or exotic plant species on marsh restoration sites at year 3 when compared to pre-construction conditions.

Density: At least as many stems per square foot as the reference site.

Survival Pattern: A minimum of 80% of all quadrats within each planting zone width is occupied by surviving plants by year 3. An exception may be made in cases where it can be documented that plant survival has been adversely impacted by unexpected pedestrian traffic.

Root Penetration: A minimum of 80% of randomly selected dune plants in each quadrat have achieved a root penetration of at least 9" for all units, as measured from the top of the root ball down.

Interim Target: 80% of plants survive 180 days after planting

Performance Measure 3: Benthic and Infaunal Species. The sediment and sand bottom present in the beaches and shallow waters adjacent to the beach provides habitat for multiple species of benthic and infaunal species that are important food sources for shorebirds. Previous benthic macroinfauna community studies found that taxa richness and densities varied significantly by location due to the dynamic nature of these systems and exposure to frequent disturbances (e.g., sediment disposal, storm action, and maritime activity), and species tended to be either tolerant of disruption or capable of rapidly recolonizing disturbed areas (USACE 2009; Rakocinski et al., 1990, 1993, 1998, Wilber et al 2007). It is anticipated that benthic and infaunal communities will be displaced in the short-term due to dredging and placement of dredged material.

Monitoring Purpose: Document benthic and infaunal communities (density and diversity) on and around the beach nourishment restoration action units prior to and after construction to evaluate reestablishment of benthic populations post construction at placement sites. The monitoring will provide supplementary information needed for shorebird compliance monitoring that is anticipated to be required in future BO(s) issued for the beach nourishment actions.

Monitoring Design Summary: The protocol is to determine the characterization of benthic communities at beach nourishment placement areas, and appropriate references areas, and includes the sorting, identification, and enumeration of benthic macroinvertebrate organisms collected in each area. Sediment texture and organic content would be determined at each location where benthic macroinfaunal samples are collected. Hydrographic measures will also be taken at each sampling locations. Surveys would be conducted during the November/December timeframe prior to construction activities and post-construction. The winter survey is for determination of pre-construction and post-construction habitat characteristics and macroinfaunal assemblages on beaches used by piping plover and red knot. At least four post-construction surveys should be completed with the first occurring approximately 6 months after construction is complete and continuing annually until ecological success is achieved.

Samples would be collected along beach transects associated with beach nourishment actions. Sample locations should include sites in which piping plover and/or red knots are actively foraging on and pre-sand placement and reference sites. Two sampling stations will be arrayed along each transect at mean the lower low water and mean high tide lines. To capture tidally exposed flats and wet sand samples. Both wet sand and high tide line intertidal samples would be collected within a 1-meter^2 sampling zone in homogenous beach or flat environment. Beach/subtidal samples would be collected with a 3 inch hand core (to a depth of 6”) which samples an area approximately 0.0044 m^2.

At each station, standard hydrographic measurements, including temperature, conductivity, salinity, pH and dissolved oxygen concentration, would be taken at mean lower low water surface, depths prior to benthic sampling.

In the laboratory, benthic samples would be properly inventoried, rinsed, and preserved for processing. Macroinvertebrates would be sorted representing a major taxonomic group. All sorted macroinvertebrates would be identified to the lowest practical identification level. The number of individuals of each taxon, would be recorded. Additionally, each sample would be analyzed for wet-weight biomass (g/m2) of the major taxonomic groups identified to facilitate evaluation of piping plover and red knot feeding habitat.

For data analysis, the macroinfaunal data would be analyzed using univariate and multivariate approaches to identify any differences in community structure between project and reference station groups. The numerical indices to be calculated for each sample should include abundance, density, species richness, taxa diversity, and evenness. Data interpretation would consist of habitat characterization (water depth, salinity, sediment texture) and benthic community characterization including faunal composition, abundance, and community structure, numerical classification analysis and taxa assemblages. The data can then be used to evaluate the suitability of the sediment for feeding habitat.

<u>Desired outcome:</u> Re-establish benthic and infaunal species population densities and diversity in placement areas to pre-construction baseline levels post-construction.

Success Criteria : The post-construction average biomass level within the project area is at least 70% of the pre-project average biomass level for at least two consecutive years.

Interim Target: The post-construction average biomass level within project area is at least 50% of the pre-project average biomass level in year 1.

5. Hydrologic Restoration

Objective: Restore 112,864.1 acres of the Lower Laguna Madre by restoring the hydrologic connection between the Lower Laguna Madre and the Gulf of Mexico.

Performance Measure 1: Salinity. Salinity is a significant factor affecting the type and extent of aquatic habitats in the Lower Laguna Madre. As the salinity changes, the aquatic habitats also respond through degradation or conversion to different habitats, which then also affects species diversity and abundance.

Monitoring Purpose: Document and assess the changes in salinity within the Lower Laguna Madre to measure success in restoring conditions more conducive to supporting historic habitats and species assemblages.

Monitoring Summary: Time-series salinity data would be collected from automated data loggers from at least 5 locations, to be determined during PED, spread throughout the Lower Laguna Madre. Sites would be sampled every 6 to 8 weeks, for a total of 8 samples per year pre-construction and for at least 3 years post construction. Collected data would be compared to pre-construction values and collected historic values.

As part of the monitoring effort, historical monitoring reports/results performed within the Laguna Madre should be obtained for purposes of comparing water quality during periods when Mansfield Channel was open and biotic communities were at optimal conditions.

Desired Outcome: Post-construction lagoon salinity conditions are similar to values measured prior to 2011 when Mansfield Channel began closing.

Success Criteria: The mean salinity within the Lower Laguna Madre is within 10% of the target historic salinity conditions.

Performance Measure 2: Submerged Aquatic Vegetation (Seagrasses). Seagrass meadows are dynamic and can respond to natural or anthropogenic disturbances rapidly, sometimes on the scale of a few weeks or months. Because of the relatively rapid response to deteriorating ecosystem condition, seagrass monitoring is a reliable indicator of changing estuarine condition.

Monitoring Purpose: Document and assess changes in seagrass extent and community composition/structure conditions.

Monitoring Summary: The protocol is based on implementing methods used in the Texas statewide seagrass monitoring program (Dunton et al. 2011 or the accepted protocol at the time of implementation), which is implemented by a variety of Texas partners and for which data will be directly comparable to estuary-wide or coast-wide sampling. The Texas program uses a three-tiered monitoring program: Tier 1 is remotely sensed mapping of seagrass extent, Tier 2 is broad scale rapid assessment using repeated visits at fixed stations to collect field indicators of seagrass condition and water quality, and Tier 3 entails detailed subsampling of transects to determine cause of changes to seagrass condition. Specifically for this monitoring plan, Tier 3 monitoring would be necessary only if Tier 1 and Tier 2 monitoring indicates a decline in extent or condition.

Tier 1 Protocol: Acquisition of remotely sensed images at 1:24,000 scale (digital true color), georectification of imagery, collection of ground truth data, interpretation of the images and delineation of vegetative areas, and importing the data into a GIS format for accuracy assessment, change detection, and reporting. The 1:24,000 scale photography acquisition should occur one-time pre-construction, 180 days post-construction, and biennially thereafter until ecological success is achieved.

Tier 2 Protocol: This approach uses a selection of permanent monitoring stations that are sampled annually during or shortly following peak seagrass standing crop (mid to late summer). The sites are randomly chosen within individual hexagons from a tessellated grid that overlays seagrass habitat. Field data collected under this protocol includes seagrass species composition, percent cover, and canopy height (measured as leaf length), as well as a series of abiotic measurements of water quality and light attenuation.

Hydrographic measurements are collected with a data sonde prior to deployment of any benthic sampling equipment. Water quality is determined from replicate water samples collected at each station in each of the cardinal directions from the vessel. Water transparency is calculated from simultaneous measurements of photosynthetically active radiation (PAR) at the surface and at a measured depth using spherical quantum sensors and the Beer Lambert equation for calculation of the diffuse attenuation coefficient (k_d). Estimate percent cover within 0.25 m^2 quadrats using an underwater digital camera mounted to a quadrat frame, or in shallow water, through direct observation through the water, or in extremely poor transparency conditions (Secchi <1m), make direct in situ measurements of the bottom with a mask and snorkel. Obtain morphometric data, biomass, shoot density, sediment characteristics, etc. using a ca. 9cm coring devise (or larger for *Thalassia*) deployed from the vessel. For each core sample, the maximum leaf length of each shoot and the overall canopy height would be recorded.

In addition to ground-based measurements, 1:9,600 scale, or larger, higher resolution true color aerial photography should be acquired to assess spatial landscape indicator patterns and produce metrics for patchiness, macroalgae accumulations, and deepwater edges of existing seagrass meadows in fringing habitats.

Tier 3 Protocol: Tier 3 studies are conducted at a relatively small number of stations and consist of experimental studies and intensive monitoring for assessment of baseline conditions. The specific protocols are designed to address specific hypotheses in response to measured environmental change and provide an opportunity to link the presumptive factors responsible for changes in seagrass landscape indicators as detected by high resolution 1:9,600 imagery to change in water quality and/or seagrass condition indices that are measured either continuously or frequently at permanent stations. Sampling methods could follow SeagrassNet, a global monitoring program, or National Estuarine Research Reserve (NERR) protocols.

Desired Outcome: Increase seagrass coverage by 5% and restore species diversity as compared to pre-Mansfield Pass closure extents by TY5.

Success Criteria: Restore the seagrass coverage to pre-Mansfield Pass closure extents by TY5. Increase seagrass shoot density by 5% by TY5.

2.1.3 Cost of Monitoring

Based on a high-level cost estimate, it is anticipated monitoring will cost $16,514,650 to complete all monitoring tasks as described in the previous section (Table 1). The estimated costs are further broken down for each monitoring effort in Table 2. This monitoring plan is approximately 1 percent of the estimated construction costs of the ER measures.

Table 1. Summary of Monitoring Costs

	Cost/year	**Total Cost over 10 years**
Planning and Management	$150,000	$1,500,000
Monitoring	Varies	$7,887,350
Data Management	$50,000	$500,000
Assessment and Reporting	$75,000	$750,000
Contingency	--	$5,877,300
	Total	**$16,514,650.00**

Table 2. Summary of Monitoring Actions and Cost

ER	Obj	Parameter	Methodology	# Transects/ Sampling Points	Monitoring Frequency	Estimated Cost/Survey	Estimated Total Cost
Marsh	1	Shoreline Change	Imagery	105 mi = 3,215 ac	Pre-construction, Yr 1, 3, 6 (4 flights)	$50,000	$200,000
	2	Elevation	LiDAR	1,985 ac	Pre-construction, Yr 1, 3, 6 (4 flights)	$111,250	$450,000
	2	Elevation	RSET	55 stations	Pre-construction, annually for 10 years (11 surveys)	$35,200* + $82,500 one-time set costs equipment	$469,700
	2	Vegetation	Transects	55 transects	Pre-construction then annually (11 surveys)		
Island	1	Island Morphology	Imagery	1,000 ac	Pre-construction, Yr 1, 3, 6 (4 flights)	$39,500*	$158,000
	2	Habitat Composition	Imagery	1,000 ac	Pre-construction, Yr 1, 3, 6 (4 flights)		
	2	Habitat Composition	Photopoint	87 points	Yr 1, 3, 6, 10 (4 surveys)	$36,000	$144,000
Oyster	1	Reef Structure	Sidescan Sonar	75 acres	Pre-construction, 60-days, annually (anticipate 3 years) (5 surveys)	$50,000	$250,000
	1	Abundance & Distribution	Quadrats/Grab Sampling	368	60-days, semi-annually (anticipate 5 years) (11 surveys)	$192,000	$2,112,000
Beach and Dunes	1	Shoreline Profile Change	Topographic Survey	70 transects	Pre-construction, annually (anticipate 10 years) (11 surveys)	$150,000*	$1,650,000
	1	Dune Vegetation	Transects/ Quadrats	70 transects/280 quadrats	Pre-construction, 180-days, annually (anticipate 3 years) (5 surveys)		
	1	Benthic & Infaunal Species	Transects/ sampling stations	70 transects/140 stations	Pre-construction, 180-days, annually (anticipate 3 years) (5 surveys)	$100,000	$500,000
Hydrologic Connection	1	Salinity	Sampling Stations	5	Pre-construction, every 6-8 weeks for 3 years (25 surveys)	$15,000*	$375,000
	2	Seagrass	Remote Sensing (Tier 1)	112,865 ac	Pre-construction, 180-days, biennially (anticipate 3 years) (5 surveys)	$225,730	$1,128,650
	2	Seagrass	Sampling Stations (Tier 2)	285 stations	Pre-construction, annually (anticipate 5 years) (6 surveys)	$75,000	$450,000
						Total	**$7,887,350.00**

* Data collection can be completed concurrent to another data collection effort resulting in minimal additional costs that have been factored into the overall cost of the survey.

2.1.4 Use of Monitoring Results and Analysis

Results of monitoring will be assessed in comparison to project objectives and decision-making triggers to evaluate whether the project is functioning as planned and whether adaptive management actions are needed to achieve project objectives. The results of the monitoring will be provided to the AMT who will evaluate and compare data to project objectives and decision-making triggers. The AMT will use the monitoring results to assess habitat responses to management, evaluate overall project performance, and make recommendations for adaptive management actions as appropriate. If monitoring results, as compared to desired outcomes and decision-making triggers show that project objectives are not being met, the AMT will evaluate causes of failure and recommend adaptive management actions to remedy the underlying problems.

As data is gathered through monitoring, more information will also be available to address uncertainties and fill information gaps. Uncertainties such as effective operational regimes, restoration design needs, benefits generated by restored features, and accuracy of models can be evaluated to inform adaptive management actions and future restoration needs.

3.0 ADAPTIVE MANAGEMENT

A fundamental tenet underlying the adaptive management process is achieving desired project outcomes in the face of uncertainties. Scientific uncertainties and technological challenges are inherent with any large-scale restoration project with the principal source of uncertainty typically including:

1. Incomplete description and understanding of relevant ecosystem structure and function,
2. Imprecise relationships between project management actions and corresponding outcomes,
3. Engineering challenges in implementing project alternatives, and
4. Ambiguous management and decision-making processes.

It is important to determine the type of risk each uncertainty comprises and to discern what constitutes sufficient knowledge to proceed considering those risks. There is significant institutional knowledge regarding the construction of the restoration measures; therefore, there is minimal uncertainty from a construction standpoint. Uncertainties relating to measure design and performance are mainly centered on site specific, design-level details (e.g. exact sediment quantities, invasive species removal needs, extent of erosion control needs, construction staging area locations, pipeline pathways, timing and duration of construction, engineering challenges, etc.), which would be addressed during the pre-engineering and design (PED) phase. Identified uncertainties with the Coastal Texas Recommended Plan include:

Uncertainties Common to All Restoration Measures

- **Relative Sea Level Change (RSLC)** including whether sea level rise will be greater than assumed in the design;
- **Climate Change**, such as drought or flood conditions, variability of significant storm frequency, intensity, and timing, warming waters, and ocean acidification;
- **Natural Variability** in ecological and physical processes; and
- **Project Feature Implementation Timing**, including schedule and timeline, availability of construction funds.

Uncertainties Specific to Marsh, Island, and Beach Restoration

- **Sediment Dynamics**, including subsidence and accretion rates;
- **Habitat Requirements** such as water, sediment, and nutrient requirements including magnitude and duration of inundation, annual sediment needs, and type and quantity of nutrients to achieve desired productivity; and

- **Invasive and Nuisance Species**, including invasive *Spartina* hybrids.

Uncertainties Specific to Oyster Restoration

- **Recruitment Rates**, including sufficient quantities of oyster larvae; and
- **Mortality Rates** influenced by dead zone encroachment, changes in weather patterns, predation, poaching, disease and parasitism.

Issues such as climate change, relative sea level rise, and regional subsidence are significant scientific uncertainties for most Gulf Coast restoration projects. These uncertainties were incorporated in the plan formulation process and will be monitored by gathering data on water levels, salinities, and land elevation. Specifically, for RSLC, USACE EC-11165-2-21 provides an 18-step process for developing a "low", "intermediate" and "high" future RSLR scenario and provides guidance to incorporate these potential effects into project management, planning, engineering, design, construction, operation and maintenance. The study team evaluated and designed the TSP and ultimately the Recommended Plan under the "intermediate" scenario in accordance with the EC-1165 (See Engineering Appendix). This information will be assessed and will inform adaptive management actions. In addition, procedures to evaluate sea level change impacts, response and adaptation will continue to be examined under USACE ETL 1100-2-1 which provides guidance for understanding the direct and indirect physical and ecological effects of projected future RSLR on USACE projects and systems of projects and considerations for adapting to those effects.

Many factors such as ecosystem dynamics, engineering applications, institutional requirements, and many other key uncertainties can change or evolve over a project's life. The MAMP will be regularly updated to reflect: data acquired during monitoring; new/revised protocols, metrics, and success criteria; resolution and progress on key uncertainties; and any new uncertainties tht may emerge. Specifically, the MAMP will be revised in the PED phase as more detailed project designs are developed and uncertainties are better understood. The MAMP would then be used during and after project construction to adjust the project as necessary to better achieve goals, objectives, and restoration results.

3.1 Assessment

Assessment of the adaptive management framework describes the process by which the results of the monitoring efforts will be compared to the project performance measures, which reflect the objectives of the restoration actions.

The results of the monitoring program will be assessed annually through the AMT. Monitoring results will be compared to the desired project outcomes and decision-making triggers as set forth by the project performance measures.

This assessment process will measure the progress of the project in relation to the stated project objectives, evaluate project effectiveness and consider if adaptive management actions are needed. Assessments will also inform the AMT if other factors are influencing the response that may warrant further research.

USACE will document and report the monitoring results, assessments, and the results of the AMT deliberations to the managers and decision-makers designated for the Coastal Texas project. USACE, with assistance from the monitoring team, will also produce annual reports that show progress towards meeting project objectives as characterized by the performance measures. Results of the assessments will be used to evaluate adaptive management needs and inform decision-making.

3.1.1 Database Management

Database management is an important component of the monitoring plan and the overall adaptive management program. Data collected as part of the monitoring and adaptive management plans will be archived as prescribed in the refined monitoring and adaptive management plan developed during PED. The database manager will be responsible for storing final monitoring reports and other study documentation (decisions, agendas, reports) and making them available when requested. Monitoring reports and associated data will be searchable by a variety of fields determined by the project sponsors and AMT.

Data standards, quality assurance and quality control procedures and metadata standards will also be prescribed in the refined monitoring and adaptive management plan. The database will be designed to store and archive the monitoring and adaptive management data. The format of each data set will vary as appropriate to the type of monitoring. Therefore, data are expected to be archived separately, rather than collated in one master database. Each dataset will include: data and metadata transfer and input policies and standards; data validation procedures, and mechanisms to ensure data security and integrity.

3.2 Decision-Making

Decisions on the implementation of adaptive management actions are informed by the assessment of monitoring results. The information generated by the monitoring plan will be used by USACE and the NFS in consultation with other AMT members to guide decisions on adaptive management that may be needed to ensure that the ecosystem restoration projects achieve success. Final decisions on implementation of adaptive management actions are made by USACE.

If monitoring determines that a management threshold has been crossed (i.e., a ‘trigger’ has been “activated”) then there are three possible response pathways:

1. Determine that more data is required and continue (or modify) monitoring;
2. Select and implement a remedial action;

3. Revisit project goals and objectives if the data indicates they were inadequate and/or inaccurate (this option would only be considered as a last resort and upon careful consideration by and consensus of the PDT and AMT).

3.2.1 Decision Criteria

Decision criteria, also referred to as adaptive management thresholds or 'triggers', are used to determine if and when adaptive management opportunities should be implemented. They can be qualitative or quantitative based on the nature of the performance measure and the level of information necessary to make a decision. Desired outcomes can be based on reference sites, predicted values, or comparison to historic conditions. Several potential decision criteria are identified below, based on the project objectives and performance measures.

More specific decision criteria, possibly based on other parameters such as hydrology, geomorphology, and vegetation dynamics, may be developed during PED. If assessments show that any of these triggers are met, USACE would consult with the AMT to discuss whether an adaptive management action is warranted, and if so, what that action should be. Investigations may be required to determine the cause of failure in order to inform the type of adaptive management actions that should be implemented, if needed. Additionally, prior to enacting any adaptive management measures, USACE would assess whether supplemental environmental analyses are required.

Table 3 summarizes the triggers to initiate adaptive management actions, potential causes of not achieving the success criteria, and the most likely response option to put the restoration site on a trajectory toward success.

Table 3. Adaptive Management Response

ER	Obj	Parameter	Trigger	Potential Causes	Potential Response Options
Marsh	1	Shoreline Change	The erosion rate has not been reduced by at least 50% when compared to historic rates of shoreline change for the same area.	Deficiency in the breakwater structures, such as the height or width is insufficient to attenuate wave energies, higher rate of subsidence or RSLR than anticipated; loss of or insufficient size of rock; need for smaller/larger openings within and between structures misalignment of the structure. Complete redesign of the structure (e.g. new alignment, change in openings, insufficient rock size) is highly unlikely due to success and lessons learned from other projects.	Repairing and minor modification (e.g. change in height/width)
	2	Elevation	Target elevation is not sustained.	Loss of sediment through erosion or scour, minimal to no sediment input, or higher than expected subsidence or RSLR rate	A hydrologist will investigate the cause of failure and recommend minor topographic modifications including but not limited to: addition of dredged material, runnels to increase water conveyance, small berms to hold back drainage, drainage swales, straw wattles, erosion mats, or vegetative planting.
	2	Vegetation	<80% of the average cover is made up of desirable species and/or	Improper geomorphic, hydrologic, or biogeochemical conditions (e.g. erosion/scour, sedimentation, high redox potential, poor water quality including salinity, tidal influences), or natural events (e.g. loss during storm events or drought, herbivory or trampling).	Replant desired species. If issues of vegetation establishment persist beyond two years post-construction, an ecologist will investigate the cause of failure and recommend modifications to maintain the distribution of habitat types.
			Invasive, noxious, and/or exotic plant species make up >5% of the average cover.	Introduction of seed source by construction activities, other activities on adjacent lands, or natural sources (e.g. wildlife, wind, water); slow establishment of native species allowed undesired species to outcompete desired species.	Removal of invasive species by pulling or controlled herbicide use.
Island	1	Island Morphology	Net loss of island surface area and/or elevation is >3% and >1%, respectively.	Breakwater design inefficiencies (see Marsh, Obj 1, Shoreline Change) or sediment loss from excessive overwash or erosion/scour.	• Repairing and minor modification (e.g. change in height/width) • Placement of additional sediment
	2	Habitat Composition	The distribution of habitat types (acreage) deviates >15% from the design template.	Lack of seed bank or natural events (e.g. herbivory, trampling, storm events or drought) are the most likely causes. Other possible causes include improper geomorphic, hydrologic, or biogeochemical conditions (e.g. tidal influence, sedimentation, available nutrients, or sediment composition)	Plant/re-plant desired species in target locations. If issues of vegetation establishment persist beyond two years post-construction, an ecologist will investigate the cause of failure and recommend modifications to maintain the distribution of habitat types.
Oyster	1	Reef Structure	>5% loss of hard substrate and/or decrease in reef height is consistently recorded	Sedimentation is the most likely cause for loss of hard substrate. Other possible causes include improper salinities, water velocities/currents, or low nutrient levels.	• Add suitable substrate such as cultch or other manmade substrates • Assess sedimentation rates at site and recommend minor adjustments to location or design of structure/hard substrates if necessary.
	1	Abundance & Distribution	A restoration unit achieves <80% of the market oyster density of the reference site and/or no spat set is observed.	No natural recruitment	Placement of spat on shell
				Not enough substrate to support desired community	Add suitable substrate such as cultch or other manmade substrates
				Outbreak of disease	Work with TPWD and other resource agencies to determine possible remediation actions.
				Over- harvesting or loss from boating activities	

ER	Obj	Parameter	Trigger	Potential Causes	Potential Response Options
Beach and Dunes	1	Shoreline Profile Change	The dune profile changes is >5% from the template profile	Sand losses due to entrainment, aeolian transport or excessive erosion due to storm surge or wave action.	• Placement of additional sediment • Increase vegetation density • Install sand fencing
			The rate of beach and nearshore change is greater than the historic rate of loss.		Placement of additional sediment.
	1	Dune Vegetation	Average cover is <80% desirable vegetation	Improper geomorphic, hydrologic, or biogeochemical conditions (e.g. erosion/scour, sedimentation, overwash), or natural events (e.g. loss during storm events or drought, herbivory or trampling).	Replanting desired species. If issues of vegetation establishment persist beyond two years post-construction, an ecologist will investigate the cause of failure.
			The density (stems/ft^2) is less than the reference site.		
			Less than 80% of all quadrats in each zone has surviving plants.		
			Less than 80% of randomly selected dune plants has achieved a root penetration ≥9".		
			>5% of the cover is composed of invasive, noxious, and/or exotic plant species	Introduction of seed source by construction activities, other activities on adjacent lands, or natural sources (e.g. wildlife, wind, water); slow establishment of native species allowed undesired species to outcompete desired species.	Removal of invasive species by pulling or controlled herbicide use.
	1	Benthic & Infaunal Species	<70% of the pre-project average biomass is consistently documented.	Sediment deposited during beach nourishment may be too deep and prone to compaction. The overlying substratum may prevent invertebrates from migrating into the deposited sediments.	Tilling and/or grading the sediments to reduce compaction and bulk density.
Hydrologic Connection	1	Salinity	The mean salinity within the Lower Laguna Madre is >10% of the target water quality parameters.	Mansfield Channel is closing at a rate higher than expected and flows from the Gulf of Mexico have been reduced. As well, freshwater inflows into the lagoon have been reduced.	Pursue mechanisms to authorize and fund dredging Mansfield Pass regularly in the future or consider mechanisms to introduce more freshwater inflows into the lagoon.
	2	Seagrasses	Continued reduction in the percent coverage or density of seagrasses is consistently documented	A number of reasons could be causing continued reduction including: increasing or sustained salinity; reduction in water clarity, both from increased nutrient loading and increased turbidity; warmer water temperatures; damage by propellers, anchors, or marine species foraging for food; or disease.	

3.3 Costs of Adaptive Management

The MAMP establishes a feedback mechanism whereby monitored conditions will be used to adjust or refine construction or maintenance actions to better achieve project goals and objectives. Periodic monitoring of performance indicators which contain trigger values informs the iterative process of implementing specified adaptive management measures to help achieve ecological success. Gulf Coast marsh restoration and shoreline protection throughout Texas and Louisiana has proven to reach ecological success within 3 to 5 years post-construction. However, the project area is susceptible to several uncertainties that could significantly impact the ecological success of constructed restoration features as described in Section 3.0.

Costs for the adaptive management program were based on estimated level of effort and potential frequency of need, and include participation in the AMT and reporting. Only those actions which are most likely to be needed have associated costs. Measures included in the recommended plan have been successfully implemented with very similar designs throughout the coastal zone of Texas; therefore, the desired outcomes are expected and reasonable based on experience. The likelihood that extreme measures, such as relocation of the breakwater structures, is very low. Other adaptive management measures that could help achieve ecological success may require significantly more modeling, design, and feasibility analysis than permits with adaptive management. These include construction or modification of tidal exchange barriers (e.g. levees, dunes, or breakwaters) and introduction of freshwater flows.

The total estimate for implementing the adaptive management program is $41,745,180 (Table 4), or approximately 2.7 percent of the total estimated construction costs.

Table 5 shows the estimated costs for each adaptive management measure.

Table 4. Total Adaptive Management Cost

	Cost
Adaptive Management Measures	$29,062,480
Management and Reporting	$750,000
Contingency	$11,932,700
Total	**$41,745,180.00**

Table 5. Estimated Adaptive Management Costs for the Recommended Plan.

Adaptive Measure	Assumptions	Cost
Marsh		
Breakwater deficiency	• Assume minor modifications would be required on 5% of breakwaters protecting marsh (approximately 5 miles) • $500,000/mile	$2,500,000
Renourishment of Marsh	• Assume 10% of each restoration unit would need thin-layer placement (assume 6" depth) of dredged material once in 6 years. (approximately 206 acres or 166,174 yd^3 of material) • Average incremental cost of placement for study is $20/$yard^3$ (assumes mob/demob and small quantity of yards per site) with the assumption that the adaptive management would be completed on the O&M cycle using the same dredge sites as initial placement.	$3,323,480
Minor topographic modifications (Re-grading/Runnels/ Small Berms)	• Assume one modification in a 6-year period would be needed for every 100 acres of restored marsh (21 sites). • $100,000 for small fixes/site (assume mob/demob, minimal work at each site = higher cost per site, difficulty in accessing the sites)	$2,100,000
Erosion Control	• Assume installation of erosion control (e.g. straw waddles, erosion mats) in one location for every 50 acres of restored marsh (41 sites) at least once in 6 years • $50,000/site (assumes mob/demob, minimal work at each site = higher cost per site, minimal heavy equipment need, difficulty in accessing the sites)	$2,050,000
Re-planting	• Assume that 10% of vegetation may require replanting in the 10 years. (approximately 206 acres) • $5,000/acre (most likely seed, few plugs/acre)	$1,030,000
Invasive and Nuisance Plant Control	• Assume that up to 5% of acreage may require treatment. (approximately 103 acres) • $5,000/acre	$515,000
Island Restoration		
Breakwater deficiency	• Assume minor modifications would be required on 5% of breakwaters protecting the island (approximately 1 mile) • $500,000/mile	$500,000
Addition of sediment to island	• Assume 10% of each island would need addition of dredged material (assume 12" depth) once in 10 years. (approximately 88 acres or 140,550 yd^3 of material) • Average incremental cost of placement for study is $30/$yard^3$ (assumes mob/demob, double handling, specialized equipment, long distance hauls, and small quantity yd^3 per site) with the assumption that the adaptive management would be completed on the O&M cycle using the same dredge sites as initial placement.	$4,216,500
Re-planting	• Assume that 10% of vegetation may require replanting in the 10 years. (approximately 88 acres)	$1,320,000

Adaptive Measure	Assumptions	Cost
	• $15,000/acre (assume plugs or root balls)	
Oyster Restoration		
Add Substrate	• Assume that 10% of the oyster reefs would need to have cultch or other substrate added once in 3 year (approximately 6 acres). • $100,000/acre	$600,000
Minor modifications	• Assume one minor modification (approximately 0.5 ac of placement of additional substrate) would be required at least once in 3 years for every 10 acres of oyster reef (5 sites). • $100,0000/acre	$250,000
Placement of spat	• Assume that 10% of the oyster reefs (6 acres) would need to have hatchery spat on shell placed on the reef once in 5 years. • $125,000/acre	$750,000
Dune and Beach Restoration		
Renourish beach	• Assume that 10% of the beach or dune would require addition of sediment in 10 years (approximately 1 mile or 180,100 yd^3) • Assume $50 yd^3 (assumes mob/demob, small quantity yd^3 handling and reworking on the beach)	$9,005,000
Sand fencing	• Assume 5% of the length of the dune/beach would require addition of sand fencing or modification to sand fencing placed during construction. (approximately 5,280 LF) • $50/LF	$262,500
Replanting	• Assume that 10% of vegetation may require replanting in the 10 years. (approximately 32 acres) • $15,000/acre (assume plugs)	$480,000
Invasive and Nuisance Plant Control	• Assume that up to 5% of acreage may require treatment. (approximately 16 acres) • $10,000/acre	$160,000
Hydrologic Connections		
Pursue other restoration actions	Assume any pursued actions would be funded through other mechanisms.	$0
Total		**$29,062,480**
Adaptive Management Team and Reporting		
Team Meetings	Assume 5, 1-day meeting per year over 10 years @ $5,000/meeting	$250,000
Annual Report	Assume 10 reports @ $50,000	$500,000
Total		**$750,000.00**

3.4 Project Close-Out

Once ecological success has been documented by the District Engineer in consultation with the Federal and State resource agencies, and a determination has been made by the Division Commander that ecological success has been achieved, no further monitoring or adaptive management will be required and the project can be closed-out. Ecological success will be documented through an evaluation of the predicted outcomes as measured against the actual results. Success would be considered to have been achieved when project objectives have been met or when it is clear they will be met based upon the trend of site conditions and processes.

The project could also be closed out when the maximum 10-year monitoring period has been reached. If that should occur prior to ecological success being achieved, the NFS would be responsible for monitoring and adaptive management beyond the 10 years.

4.0 REFERENCES

Adam, P. 2009. Salt marsh restoration. *In*: Perillo, G.M.E., Wolanski, E., Cahoon, D.R., and M.M. Brinson (Eds), *Coastal Wetlands: An Integrated Ecosystem Approach*. Elsevier, Amsterdam, The Netherlands. pp. 737-761.

Armstrong, N.E. 1987. The Ecology of Open Bay Bottoms of Texas: A Community Profile. U.S. Fish and Wildlife Service, Biological Report 85(7.12) 104 pp.

Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA. 96 pp.

Bahr, L.M. and W.P. Lanier. 1981. The Ecology of Intertidal Oyster Reefs of the South Atlantic Coast: A Community Profile. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. FWS/OBS-81/15 105 pp.

Bianchi, T.S. 2007. *Biogeochemistry of Estuaries*. Oxford University Press, New York N.Y. 689 pp.

Britton, J.C. and B. Morton. 1989. *Shore Ecology of the Gulf of Mexico*. University of Texas Press, Austin, TX. 387 pp.

Broome, S.W. and C.B. Craft. 2009. Tidal marsh creation. *In*: Perillo, G.M.E., Wolanski, E., Cahoon, D.R., and M.M. Brinson (Eds), *Coastal Wetlands: An Integrated Ecosystem Approach*. Elsevier, Amsterdam, The Netherlands. pp. 737-761.

Cahoon, D.R., J.C. Lynch, and R.M. Knaus. 2002. High-precision measurements of wetland sediment elevation; II, the rod surface elevation table. *Journal of Sedimentary Research* 72:734—739.

Collins, G.B., Russo Jr., E.J., and T.S. Bridges. 2015. Lessons Learned from Coastal Use Beneficial Features in Galveston Bay and Application with Engineering with Nature. Proceedings of the Western Dredging Association and Texas A&M University Center for Dredging Studies' Dredging Summit and Expo 2015. 13 pp.

Crain, D.A., Bolten, A.B., and K.A. Bjorndal. 1995. Effects of beach nourishment on sea turtles: Review and research initiatives. *Restoration Ecology* 3(2):94-105.

Culver, M.F. 2018. Beach Geomorphology and Kemp's Ridley (*Lepidochelys kempii*) Nest Site

Selection along Padre Island, TX, USA. Master's thesis, Texas A&M University-Corpus Christi. 121 pp.

Delaune, R.D. and K.R. Reddy. 2008. *Biogeochemistry of Wetlands: Science and Applications*. CRC Press, Boca Raton, FL. 816 pp.

Dunton, K.H., W. Pulich, Jr., and T. Mutchler. 2011. A seagrass monitoring program for Texas coastal waters: multiscale integration of landscape features with plant and water quality indicators. Final report delivered under contract #0627 to the Coastal Bend Bays and Estuaries Program, Corpus Christi, Texas.

Fischenich, J.C., Sarah J. Miller, S.J., and A. J. LoSchiavo. 2019. A Systems Approach to Ecosystem Adaptive Management: A USACE Technical Guide. Environmental Laboratory, U.S. Army Engineer Research and Development Center. 178 pp.

Leewis, L., van Bodegom, P.M., Rozema, J., and G.M. Janssen. 2012. Does beach nourishment have long-term effects on intertidal macroinvertebrate species abundance? *Estuarine, Coastal, and Shelf Science* 113:172-181.

Livingston, K. 2018. Rapid Assessment Method (RAM) for Evaluating Mitigation Projects on Texas Coastal Dunes. Master's thesis, Texas A&M University-Corpus Christi. 104 pp.

Mitsch, W.J. and J.G. Gosselink. 2015. *Wetlands, Fifth Edition*. John Wiley & Sons, Inc. Hoboken, N.J. 721 pp.

Patterson, J. 2005. Dune Protection and Improvement Manual for the Texas Gulf Coast, 5th Edition, Texas General Land Office. 32 pp.

Schoenbaechler, C., Guthrie, C.G., Q. Lu. 2011. Coastal Hydrology for the Laguna Madre Estuary, with Emphasis on the Lower Laguna Madre. Bays & Estuaries Program, Surface Water Resources Division, Texas Water Development Board. 29 pp.

Sears, N.E. and A. J. Mueller. 1989. A survey of the polychaetes of Bolivar Flats and Big Reef, Galveston, Texas. *The Southwestern Naturalist* 34(1):150-154

Smith, E.H. 2002. Colonial waterbirds and rookery islands. *In*: Tunnell Jr., J.W. and F.W. Judd (Eds.) *The Laguna Madre of Texas and Tamaulipas.* Texas A&M University Press, College Station, TX. pp. 182-197.

Texas General Land Office. 2019. Texas Coastal Resiliency Master Plan, March 2019. Texas General Land Office. 234 pp.

U.S. Fish and Wildlife Service. 2009. Revised designation of critical habitat for the wintering population of the piping plover (*Charadrius melodus*) in Texas. Federal Register 74:23476-23524.

U.S. Army Corps of Engineers (Corps). 1978. Handbook for Terrestrial Wildlife Development on Dredged Material Islands, Technical Report D-78-37. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

U.S. Army Corps of Engineers (Corps). 1986. Beneficial Uses of Dredged Material. Engineering Manual EM-1110-2-5026. U.S. Army Corps of Engineers, Washington, D.C.

U.S. Army Corps of Engineers (Corps). 2014. Coastal Use Permit/Consistency Determination, Caminada Headland Beach and Dune Restoration Project, Lafourche and Jefferson Parishes, Louisiana. U.S. Army Corps of Engineers, New Orleans District. 102 pp.

U.S. Army Corps of Engineers (Corps). 2017. Sabine Pass to Galveston Bay, Texas Coastal Storm Risk Management and Ecosystem Restoration Final Integrated Feasibility Report – Environmental Impact Statement. U.S. Army Corps of Engineers, Galveston District. 278 pp.

U.S. Army Corps of Engineers (Corps). 2019. Jefferson County Ecosystem Restoration Feasibility Study Integrated Feasibility Report and Environmental Assessment. U.S. Army Corps of Engineers, Galveston District. 260 pp.