APPENDIX I

ADAPTIVE MANAGEMENT / MONITORING PLAN

Louisiana Coastal Area (LCA) Program:

Terrebonne Basin Barrier Shoreline Restoration Project

Feasibility-Level Monitoring and Adaptive Management Plan

September 29, 2010

OFFICE OF
Coastal Protection
and Restoration

US Army Corps
of Engineers®
New Orleans District

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1.0 INTRODUCTION

This document outlines the feasibility level monitoring and adaptive management plan for the Louisiana Coastal Area (LCA) Terrebonne Basin Barrier Shoreline Restoration (TBBSR) Project. The LCA Adaptive Management Framework Team developed this monitoring and adaptive management plan with assistance from the Project Delivery Team (PDT). This plan identifies and describes the monitoring and adaptive management activities proposed for the TBBSR Project and estimates their cost and duration. This plan will be further developed in the preconstruction, engineering, and design (PED) phase as specific design details are made available.

1.1 Authorization for Adaptive Management in the LCA Program

The LCA Ecosystem Restoration Study Chief's Report (2005) states (for the 15 near-term features aimed at addressing the critical restoration needs)

> *"…the feasibility level of detail decision documents will identify specific sites, scales, and adaptive management measures, and will optimize features and outputs necessary to achieve the restoration objectives…to ensure that LCA ecosystem restoration objectives are realized, monitoring and adaptive management must be a critical element of LCA projects."*

Section 7003(a) of Water Resources Development Act of 2007 (WRDA 2007) stipulates:

> *"The Secretary may carry out a program for ecosystem restoration, Louisiana Coastal Area, Louisiana, substantially in accordance with the report of the Chief of Engineers, dated January 31, 2005."*

Additionally, Section 2039 of WRDA 2007 directs the Secretary of the Army to ensure that, when conducting a feasibility study for a project (or component of a project) for ecosystem restoration, the recommended project includes a plan for monitoring the success of the ecosystem restoration. The implementation guidance for Section 2039, in the form of a CECW-PB Memo dated 31 August 2009, also requires that an adaptive management plan be developed for all ecosystem restoration projects.

At the programmatic level, knowledge gained from monitoring one project can be applied to other projects. Opportunities for this type of adaptive management are common within the LCA Ecosystem Restoration Study (USACE 2004), which also builds upon lessons learned in other related efforts such as the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA). Oversight by the LCA Science and Technology (S&T) Program and the LCA Adaptive Management Planning Team provides the basic structure to ensure that knowledge gained is effectively shared across programs and projects.

1.2 Procedure for Drafting Adaptive Management Plans for LCA Projects

The U.S. Army Corps of Engineers, Mississippi Valley Division, New Orleans District (USACE MVN), Louisiana Office of Coastal Protection and Restoration (OCPR), and the LCA S&T Office collaborated to establish a general framework for adaptive management to be applied to all LCA projects. The framework for adaptive management is consistent with the previously mentioned implementation guidance, as well as with the guidance provided by the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration's (NOAA) "Availability of a Final Addendum to the Handbook for Habitat Conservation Planning and Incidental Take Permitting Process” in Federal Register vol. 65, No. 106 35242. The LCA adaptive management framework includes both a set-up phase (Figure 1) and an implementation phase (Figure 2).

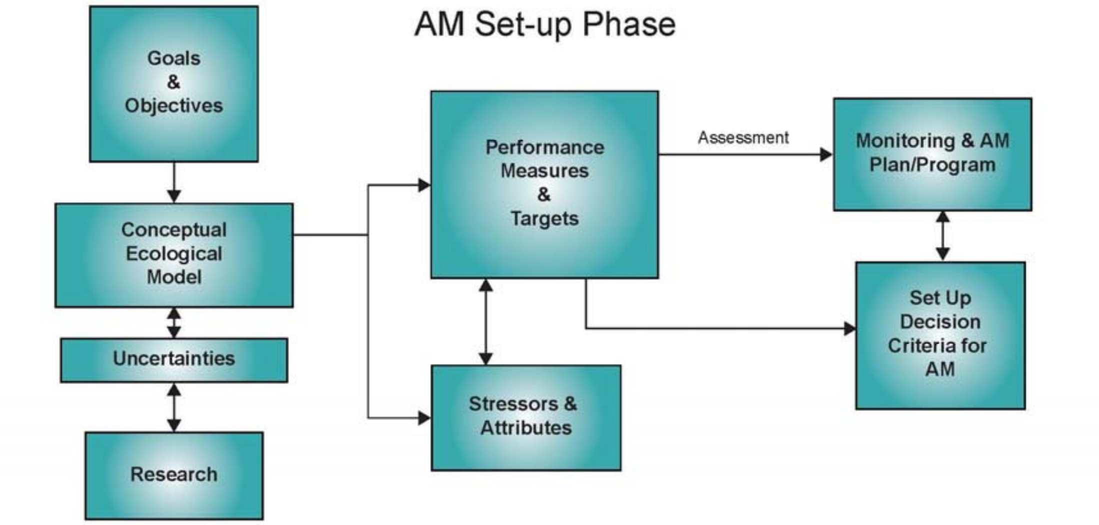

Figure 1. Set-up Phase of the LCA Adaptive Management Framework.

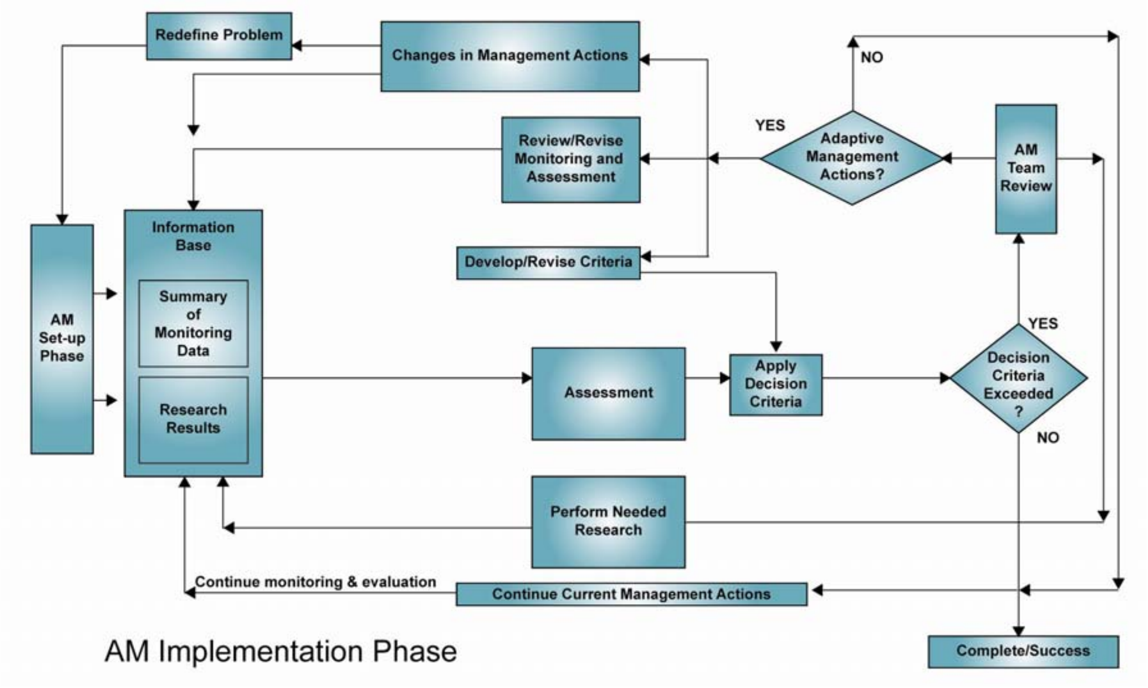

Figure 2. Implementation Phase of the LCA Adaptive Management Framework.

1.3 LCA Communication Structure for Implementation of Adaptive Management

To execute an adaptive management strategy for the LCA Ecosystem Restoration Study, a communication structure has been identified (Figure 3). The structure includes an establishment of clear lines of communication between LCA Program Management, an Adaptive Management Planning Team, the S&T Office, PDTs, and stakeholders. Successful implementation will require the right resources being coupled at the right time to support the framework components.

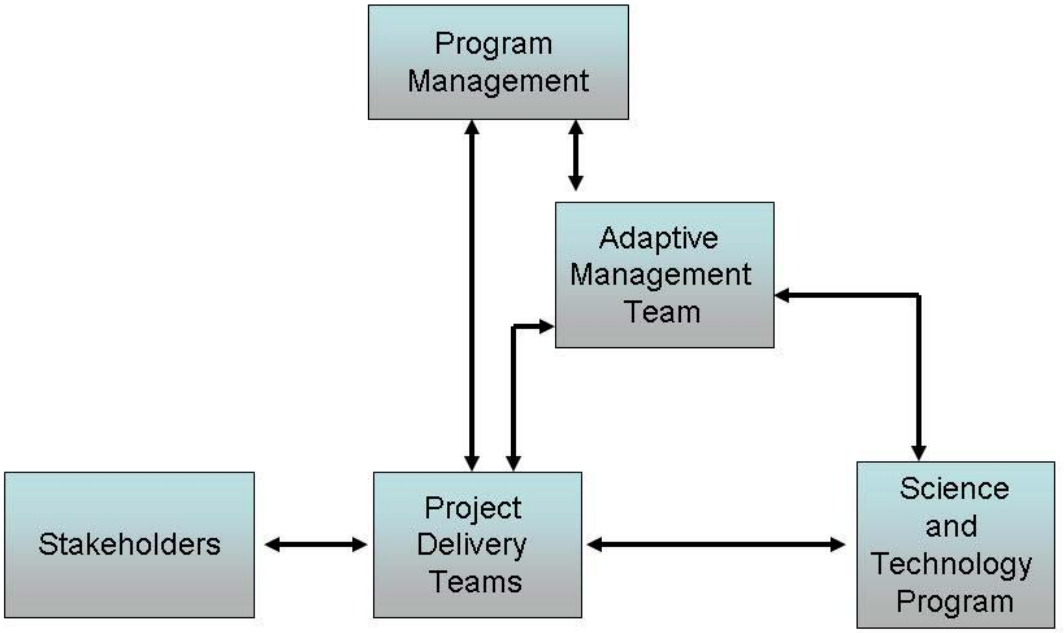

Figure 3. LCA Communication Structure for Implementation of Adaptive Management.

As part of the LCA Program communication structure for implementation of adaptive management (Figure 3), an LCA Adaptive Management Planning Team will be established. This team will be led jointly by a Senior Planner from the USACE and a counterpart from the OCPR. Other team members include USACE and State support staff and representatives from USFWS, NOAA, Natural Resources Conservation Service (NRCS), and Louisiana Department of Wildlife and Fisheries (LDWF). These members will be selected in part based on their knowledge of ecosystem restoration, coastal Louisiana ecosystems and adaptive management. Other resources and expertise will be brought in as needed. This team will be responsible for presenting project and program adaptive management action recommendations to the LCA Management Team.

The LCA Science and Technology (S&T) Office was established by the USACE and the State of Louisiana (the non-Federal sponsor) to effectively address coastal ecosystem restoration needs and to provide a strategy, organizational structure, and process to facilitate integration of science and technology into the adaptive management process. Under the Adaptive Management Framework, there are five primary elements in the LCA S&T Program, and each element differs in emphasis and requirements. These elements include: (1) science information Needs, (2) data acquisition and monitoring, (3) modeling, (4) research, and (5) data management and reporting (assessment).

Under the LCA S&T Office, an Assessment Team will be established. This team will be led by the S&T Director and a representative of the U.S. Geological Survey (USGS) who will also serve as direct liaisons between the S&T Assessment Team and the LCA Adaptive Management Planning Team. Other members will be identified from Federal and State agencies. Responsibilities of this team include analysis and reporting of data to the LCA Adaptive Management Planning Team and the LCA Program Management Team.

2.0 PROJECT ADAPTIVE MANAGEMENT PLANNING

Specific LCA PDTs assisted the LCA Adaptive Management Framework Team in developing the monitoring and adaptive management plan for each specific project. The members of the Adaptive Management Framework Team for this project were Tomma Barnes, USACE-MVN; Steve Bartell, E2 Consulting Engineers; Laura Brandt, U.S. Fish and Wildlife Service; Craig Fischenich, USACE/Engineer Research and Development Center; Barbara Kleiss, USACE Mississippi Valley Division; Carol Parsons Richards, OCPR; Greg Steyer, USGS National Wetlands Research Center; and Darin Lee, OCPR.

The resulting adaptive management plan for the TBBSR project describes and justifies whether adaptive management is needed in relation to the proposed project management alternatives identified in the Feasibility Study. The plan also identifies how adaptive management would be conducted for the project and who would be responsible for this project-specific adaptive management program. The developed plan outlines how the results of the project-specific monitoring program would be used to adaptively manage the project, including specification of conditions that would demonstrate project success.

The Adaptive Management Plan for this project reflects a level of detail consistent with the project Feasibility Study. The primary intent was to develop monitoring and adaptive management actions appropriate for the project’s restoration goals and objectives. The specified management actions permit estimation of the adaptive management program costs and duration for the project.

The following adaptive management plan section (1) identifies the restoration goals and objectives identified for the TBBSR project, (2) outlines management actions that can be undertaken to achieve the project goals and objectives, (3) presents a conceptual ecological model that relates management actions to desired project outcomes, and (4) lists sources of uncertainty that would recommend the use of adaptive management for this project. Subsequent sections describe monitoring, assessment, decision-making, and data management in support of adaptive management.

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. Components of the monitoring and adaptive management plan, including costs, were similarly estimated using currently available information. Uncertainties will be addressed in the preconstruction, engineering, and design (PED) phase a detailed monitoring and adaptive management plan, including a detailed cost breakdown, will be drafted as a component of the design document.

2.1 Project Goals and Objectives

During initial stages of project development, the project delivery team, with stakeholder input, developed restoration goals and objectives to be achieved by the TBBSR project. These goals and objectives were subsequently refined through interactions with the LCA Adaptive Management Framework Team. The overarching goal of this project is to reduce degradation and deterioration of the barrier island system in Terrebonne Basin. This project has been planned to help achieve and sustain a larger-scale coastal ecosystem that can support and protect the environment, economy, and culture of southern Louisiana and thereby contribute to the well-being of the Nation. The specific restoration objectives for the TBBSR project are to:

- Restore the barrier structures to ensure their ability to provide geomorphic and hydrologic form and function for the 50-year period of analysis.
- Restore and improve various barrier island habitats that provide essential habitats for fish, migratory birds, and other terrestrial and aquatic species, mimicking, as closely as possible, conditions which occur naturally in the area.
- Increase sediment input to supplement long-shore sediment transport processes along the gulf shoreline by mechanically introducing compatible sediment, and increasing the ability of the restored area to continue to function and provide habitat with minimum continuing intervention.

2.2 Management and Restoration Actions

The PDT performed a thorough plan formulation process to identify potential management measures and restoration actions that address the project objectives. Many alternatives were considered, evaluated, and screened in producing a final array of alternatives. The PDT subsequently identified a National Ecosystem Restoration (NER) Plan.

A four-island plan, which consists of Raccoon Plan E with Terminal Groin, Whiskey Plan C, Trinity Plan C, and Timbalier Plan E was selected as the NER Plan because it was a Best Buy that fulfills the planning objectives of the project. However, the NER Plan cannot be constructed under the current WRDA 2007 authorization. Therefore Whiskey Island Plan C, a subset of the NER Plan, has been proposed as the first component of construction. The plan restores the geomorphic form and ecological function of the island and provides an additional five years of protection from background erosion and subsidence. Immediately after construction (TY1), the first component of construction will add 469 acres of habitat (dune, intertidal, and supratidal) to the existing 803-acre island footprint, increasing the size of the island to 1,272 acres. This includes 65 acres of dune, 830 acres of supratidal, and 377 acres of intertidal habitat.

The island will require two renourishment intervals in order to maintain the geomorphologic form and ecologic function throughout the 50-year period of analysis. The first renourishment event will occur at TY20 and will include the addition of the same amount of dune and supratidal beach acres that was originally created in TY1 (i.e. add a Plan C to the remaining island structure at TY20). The second renourishment interval will occur at TY 40 and will include the addition of the same amount of dune and supratidal beach acres needed to construct a Plan B template. No additional marsh material will be added.

2.3 Conceptual Ecological Model for Monitoring and Adaptive Management

As part of the planning process, members of the TBBSR project PDT developed a conceptual ecological model to represent current understanding of ecosystem structure and function in the project area, identify performance measures, and help select parameters for monitoring (Annex 1). The model illustrates the affects of important natural and anthropogenic activities that result in different ecological stressors on the system. The effects of concern can be measured for selected performance measures defined as specific physical, chemical, and biological attributes of the system.

2.4 Sources of Uncertainty

Adaptive management provides a coherent process for making decisions in the face of uncertainty. Scientific uncertainties and technological challenges are inherent with any large-scale ecosystem restoration project. Below is a list of uncertainties associated with restoration of the barrier island ecosystems included in the TBBSR project.

- Rates of relative sea level rise;
- Detailed bathymetry data throughout the coast;
- Detailed topographic data throughout the coast;
- Sediment sources for reestablishment of barrier islands; and
- Physical processes that control the retreat of barrier islands in Louisiana.

In the future, a regional sediment budget should be developed to quantify the movements of sand and fine sediments in response to sea level rise, storm impacts, and longshore transport losses to inlets. The forcing functions within the sediment budget that would require quantitative data include profile response to sea level rise, gradients in longshore transport and sediment losses to ebb-tidal deltas. Monitoring of shoreline and volumetric losses above and below the water surface will be required to refine the sediment budget. The refined budget will be in turn used to refine the TBBSR design templates.

The 2004 LCA Plan includes best management practices specific to design and construction of barrier islands (USACE, 2004c). Elements of barrier island restoration that warrant further refinement and incorporation into future plans include:

- Depth of closure;
- Design template;
- Advanced fill;
- Monitoring and maintenance;
- Nourishment of both Gulf and Bay shorelines of barrier islands;
- Breach and inlet closures;
- Restoration priority; and
- Mainland and bay shorelines.

Potential climate change issues, such as sea level rise, in addition to regional subsidence rates are significant scientific uncertainties for all LCA projects. These issues were incorporated in the plan formulation process and will be monitored by gathering data on water levels, salinities, and land elevation. These data will inform adaptive management actions, but future climate change projections remain highly uncertain at this time.

3.0 RATIONALE FOR ADAPTIVE MANAGEMENT

The primary incentive for implementing an adaptive management program is to increase the likelihood of achieving desired project outcomes given the identified uncertainties. All projects face uncertainties with the principal sources of uncertainty 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.

Given these uncertainties, adaptive management provides an organized, coherent, and documented process that defines management actions in relation to measured project performance compared to desired project outcomes. In the case of the TBBSR project, the adaptive management program will use the results of continued project monitoring to manage the project in order to achieve the previously stated project goals and objectives. Adaptive management establishes the critical feedback of information from project monitoring to inform project management and promote learning through reduced uncertainty.

Several questions were considered to determine if adaptive management should be applied to the TBBSR project:

1) Are the ecosystems to be restored sufficiently understood in terms of hydrology and ecology, and can project outcomes be accurately predicted given recognized natural and anthropogenic stressors?

2) Can the most effective project design and operation to achieve project goals and objectives be readily identified?

3) Are the measures of this restoration project’s performance well understood and agreed upon by all parties?

4) Are project management actions sufficiently flexible to be adjusted in relation to monitoring results?

A ‘NO’ answer to questions 1-3 and a “YES” answer to question 4 identifies the project as a candidate that could benefit from adaptive management. The Framework Team and the PDT decided that the project meets these qualifications, and, therefore, is a candidate for adaptive management.

For this project, there are a number of uncertainties associated with ecosystem function and how the ecosystem components of interest will respond to the restoration project. In addition, there are associated uncertainties about the best design and operation for the project. Using an adaptive management approach during project planning provided a mechanism for building flexibility into project design and for providing new knowledge to better define anticipated ecological responses. This also enabled better selection of appropriate design to meet the project objectives.

Additionally, an adaptive management approach will help define project success and identify outcomes that should realistically be expected for the project.

3.1 Adaptive Management Program for the Terrebonne Basin Barrier Shoreline Restoration Project

An Adaptive Management Program for the TBBSR project is needed to ensure proper implementation of adaptive management. The Program will also facilitate coordination of projects within the LCA Program and coordination among PDTs, the LCA S&T, and LCA Program Management. The LCA Adaptive Management Planning Team will lead all LCA project and program adaptive management recommendations and actions. This team is responsible for ensuring that monitoring data and assessments are properly used in the adaptive management decision making process. If this team determines that adaptive management actions are needed, the team will coordinate a path forward with project planners and project managers. Other PDT members may be solicited as needed; for instance, if the adaptive management measure is operational, operations and hydraulics representatives might be asked to participate.

The LCA Adaptive Management Planning Team is also responsible for project documentation, reporting, and external communication. Tables 2 and 3 list the cost estimates for these adaptive management activities.

4.0 MONITORING

Independent of adaptive management, 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 a central component to the TBBSR adaptive management program.

4.1 Rationale for Monitoring

Monitoring must be closely integrated with all other LCA adaptive management components because it is the key to the evaluation and learning components of adaptive management. Project and system level objectives must be identified to determine appropriate indicators to monitor. In order to be effective, monitoring designs must be able to distinguish between ecosystem responses that result from project implementation (i.e., management actions) and natural ecosystem variability. In coastal Louisiana, there are many existing restoration and protection projects already constructed, and many more are being planned under different authorizations and programs. In combination, these projects will ultimately influence much of coastal Louisiana. Monitoring must therefore be conducted across a range of carefully selected scales to assess short-term project performance and to characterize longer-term, system-wide trends and conditions.

Achieving monitoring objectives will require monitoring that focuses on different spatial and temporal scales. Spatially, a project might achieve local objectives, but have little or no measurable effect at larger scales. Temporally, monitoring designs need to consider the amount of time it could take for slowly changing ecological variables to respond to management actions. Additionally, monitoring should be designed to measure the persistence of near-term effects. Larger-scale effects will generally take longer to develop and longer to detect than more localized effects.

Monitoring for large scale effects can be more difficult than for local effects because the ecological linkages become more complicated as factors outside project boundaries influence processes and biota that affect desired project outcomes. The benefits of improved habitat in one location may be counteracted by degradation at another location, thus showing no overall benefit at large scales. In addition, monitoring at large scales can involve changes in underlying conditions over time or space and be very labor intensive. When possible, specific monitoring and large scale information needs should be interrelated. In some cases, large scale monitoring may be just an extension of local monitoring in space and time, but it may also involve designs and procedures that are separate from site specific monitoring and extend beyond the purview of the project teams.

When possible, specific monitoring and large scale information needs should be integrated with existing monitoring efforts that are underway in coastal Louisiana. For example, the CWPPRA program has been monitoring restoration and protection projects in coastal Louisiana since 1990 (Steyer and Stewart 1992, Steyer et al. 1995). The monitoring program incorporates a system-level wetland assessment component called the Coastwide Reference Monitoring System (CRMS-Wetlands, Steyer et al. 2003). The Barrier Island Comprehensive Monitoring (BICM) Program (Troutman et al. 2003) was established under the LCA S&T Office in 2005 as called for in the LCA Plan to complement CRMS-Wetlands and integrate coastal shoreline monitoring for numerous restoration efforts. CRMS-Wetlands and BICM provide system-wide performance measures that are evaluated to help determine the cumulative effects of restoration and protection projects in coastal Louisiana. LCA monitoring plans should benefit from existing monitoring networks to the extent practicable and participate in the implementation of CRMS-Wetlands and BICM. Such participation can maintain the data consistencies necessary to conduct project and programmatic adaptive management.

4.2. Monitoring Plan for the Terrebonne Basin Barrier Shoreline Restoration Project

According to the CECW-PB Memo dated 31 August 2009, “Monitoring includes the systemic 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 key components of a monitoring plan that will support the project Adaptive Management Program.

The plan identifies performance measures along with desired outcomes (i.e. targets) in relation to specific project goals and objectives. A performance measure includes specific feature(s) to be monitored to determine project performance. In addition, if applicable, a risk endpoint was identified. Risk endpoints measure undesirable outcomes of a management or restoration action. A monitoring design was established to determine if the desired outcome or risk endpoint is met.

Upon completion of the TBBSR project, monitoring for ecological success and adaptive management will be initiated and will continue until ecological success is achieved, as defined by the project-specific objectives. This monitoring plan includes the minimum monitoring actions to evaluate success and to determine adaptive management needs. Although the law allows for a ten-year cost-shared monitoring plan, ten years of monitoring may not be required. Once ecological success has been achieved, which may occur in less than ten years post-construction, no further monitoring will be performed. If success cannot be determined within that ten-year period of monitoring, any additional monitoring will be a non-Federal responsibility. This plan estimated monitoring costs for a period of ten years because that is the maximum allowed federal contribution to monitoring As soon as ecological success is achieved, monitoring will cease.

The following discussion outlines key components of a monitoring plan that will support the LCA TBBSR project Adaptive Management Program. The plan identifies performance measures along with desired outcomes and monitoring designs in relation to specific project goals and objectives. Additional monitoring is identified as supporting information needs that will help further understand and corroborate project effects.

Objective 1: Restore the barrier structures to ensure their ability to provide geomorphic and hydrologic form and function.

Performance Measure 1a: Aerial extent

Desired Outcome: Reduce land loss within the TBBSR project area below the historic average (1880s – 2005)

Desired Outcome: Maintain an aerial extent that matches the predicted aerial extent of the associated design template at a particular point in time

Monitoring Design: Aerial photography and LiDAR surveys will be used to assess the island's dimensions over time. One pre-construction and four to five post-construction acquisitions will be obtained.

Performance Measure1b: Island volume

Desired Outcome: Maintain an island volume that matches the predicted island volume of the associated design template at a particular point in time

Desired Outcome: Reduce volume loss within the TBBSR project area below the historic average (1880s – 2005)

Monitoring Design: LiDAR and bathymetric surveys will be used to assess the island's volumes over time. One pre-construction and five post-construction acquisitions will be obtained.

Objective 2: Restore and improve various barrier island habitats that provide essential habitats for fish, migratory birds, and other terrestrial and aquatic species, mimicking, as closely as possible, conditions which occur naturally in the area.

Performance Measure 2: Habitat composition

Desired Outcome: Provide a distribution of acreage between habitat types that matches the predicted acreages of the associated design template at a particular point in time

Monitoring Design: Habitats will be classified using aerial photography to assess trends in conversion of beach and marsh to open water. One pre-construction and four post-construction acquisitions will be obtained.

Objective 3: Increase sediment input to supplement long-shore sediment transport processes along the gulf shoreline by mechanically introducing compatible sediment, and increasing the ability of the restored area to continue to function and provide habitat with minimum continuing intervention.

Performance Measure 3: Island elevation changes

Desired Outcome: Maintain elevation and bathymetric profiles that match the predicted profiles of the associated design template at a particular point in time

Monitoring Design: Bathymetric and topographic surveys will be used to determine the cross-shore profile and volumes of the barrier islands in order to characterize the changes that are occurring in the sediment budget, barrier platform stability, and inlet response over time. One pre-construction and five post-construction acquisitions will be obtained.

Supporting Information Need: Geotechnical and sediment properties will be identified using push cores and grab samples to better understand sediment transport processes

Risk Endpoint: Erosion rates

Desired Outcome: Avoid inducing or increasing down drift erosion through the use of hard structures. The benefits and/or impacts of hard structures on sediment transport can be assessed by comparing the actual longshore erosion rate measured along the beaches to the predicted erosion rates of the associated design template at a particular point in time. Because impacts can occur at a distance from the structure(s), monitoring should cover the entire reach.

Monitoring Design: LiDAR and bathymetric surveys will be used to determine downdrift erosion. One pre-construction and five post-construction acquisitions will be obtained.

Supporting Information Need: Potential scouring around hard structures will be assessed using field reconnaissance

Risk Endpoint: Sediment capture and hypoxia

Desired Outcome: Understand sediment pathways, evolution of the side slopes and environment (hypoxia) of borrow pits after dredging and over a period of time

Monitoring Design: A close-spaced grid-pattern bathymetric survey will be conducted followed by sampling of bottom sediments. The bathymetric survey will be appended to any such survey undertaken in the vicinity. One pre-construction and five post-construction acquisitions will be obtained.

4.2.1 Monitoring Procedures

The following monitoring procedures will provide the information necessary to evaluate the previously identified project objectives for the TBBSR project. This plan proposes one year of intensive monitoring concentrated on Raccoon Island during PED to establish a detailed baseline condition. This intensive monitoring will continue three years post-construction to evaluate immediate response to the proposed restoration of Raccoon Island. This intensive monitoring will followed by seven years of data collected through the Barrier Island Comprehensive Monitoring (BICM) Program to evaluate influences of the project on the Terrebonne Basin Barrier Shoreline system.

The BICM data collection program, a collaborative program between the State of Louisiana, the USACE, USGS, and the University of New Orleans, is designed to monitor the mainland shoreline of the south Louisiana coast, with special emphasis on the barrier shorelines and barrier islands. Variables monitored by BICM include bathymetry, topography, shoreline change, habitats, and storm assessment protocol. The BICM Program began in 2005.

The purpose of this project is to contribute to the overall structure and function of the Terrebonne Barrier Shoreline system by maintaining aerial extent and habitat distribution on Raccoon Island. This plan proposes monitoring accordingly, by focusing on the structure and function of Raccoon Island initially to be followed by monitoring of system-level structure and functionality. The PDT is assuming that by providing island and system structure and function, specific vegetation and wildlife will respond accordingly; therefore, these responses are not proposed for monitoring.

Bathymetric/Topographic Surveys: A combination of bathymetric and topographic surveys will be used to determine the cross-shore profile and volumes of the barrier islands. One pre-construction topographic and bathymetric survey will be conducted and used with existing LiDAR topographic surveys acquired in August 2001, October 2002 and 2006, and a bathymetric survey conducted in 2006 under the BICM program, as the standards for future changes in the island's dimensions. Five post-construction topographic and bathymetric surveys will be conducted within the first 10 years and data collected will be used to develop elevation models to compare elevation and volumetric changes within compatible survey areas. LiDAR surveys will be conducted as per methods detailed in Hansen and Howd (2008). LiDAR surveys will cover the complete island shoreline and extend inland approximately 1 km to cover the whole island including the marshes. The resulting data will provide a density of approximately 1 elevation point per square meter and are accurate to approximately 10 - 15 cm vertical elevation depending on LiDAR system used.

Bathymetry data will be collected as per Miner et al. (2009) along transects every 1500 ft (457.2 m) on both the gulf and bay sides of the island out to 2 km. Gulf transects extend to 4 km offshore. Data will be collected along transects 4500 ft (1371.6 m) apart from 2 km to 4 km offshore. . Project surveys conducted as part of the design and construction process will occupy pre-existing transects at a minimum, and data will be collected at a minimum of every 100 ft or at any major change in elevation. The borrow sites will also be surveyed as part of any survey effort. Also included with surveys will be tying in elevation of any settlement plates or structures installed on each island during construction.

Aerial Photography/Habitat Classification/Shoreline Position: To determine shoreline position changes and habitat types and changes of vegetated and non-vegetated areas within the project area, near-vertical, color-infrared photography will be acquired during pre-construction and used with existing habitat classifications conducted in 1996, 2002, 2004, and 2005 and shoreline position assessments from 1887, 1934, 1996, 2004, and 2005 as a pre-construction standard for future changes in the islands habitat classification and shoreline position (island dimensions and vegetation communities). Four post-construction near-vertical, color-infrared photographic acquisitions will be conducted within the first 10 years and data collected will be used to develop habitat and shoreline change models to compare with predicted habitat and island dimensions. The photography will be geo-rectified, mosaiced, and classified using standard operating procedures (Fernley et al. 2009, Martinez et al. 2009) developed under the BICM program. Analysis and mapping of habitat classes and shoreline positions will also follow BICM methodologies.

Geotechnical and Sediment Properties: Grab samples or push cores will be collected at 7 locations along 5 cross-shore transects; back-barrier marsh, dune, berm, mean low water, depth approximately one third of depth of closure, depth approximately two thirds of depth of closure and depth of closure. The long-shore spacing of sediment transects will be consistent with BICM sampling techniques. Additional grab samples will be collected within borrow pits to characterize sediment properties. The samples will be visually described and those with greater than or equal to 70% sand content will be analyzed to determine sediment characteristics. Sediment samples will be collected once in pre-construction and five times within the first 10 years post-construction. Data collected will be analyzed to investigate the change in sediment composition over time. It is expected that the grain size analyses will provide information on sediment texture for restoration monitoring and planning, coastal processes, and sediment dispersal patterns to evaluate fill performance as well as to determine the seaward boundary of the active profile.

4.2.2 Use of Monitoring Results and Analyses

Project monitoring is the responsibility of the Louisiana OCPR and the USACE. However, because of the need to integrate monitoring for programmatic adaptive management, extensive interagency coordination is required. A monitoring workgroup, led by the LCA S&T Program and the USGS, will be responsible for ensuring that project-specific monitoring plans are technically competent and appropriately integrated within a system-wide assessment and monitoring plan.

The results of the monitoring program will be communicated to an Assessment Team that will use the information to assess system responses to management, evaluate overall project performance, and construct project report cards. Recommended modifications (i.e., adaptation) of the TBBSR project will be provided as appropriate.

5.0 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 for the LCA projects will be archived as prescribed in the “LCA Data Management Strategic Plan” developed for the LCA Science and Technology Office, and further developed by the LCA S&T Data Management Working Group.

Data collected for LCA with similar data types and collection frequencies as those data collected under the CRMS program will be managed by the Louisiana Strategic Online Natural Resources Information System (SONRIS). Pre-existing standard operating procedures built for SONRIS cover issues such as data upload process and format, quality assurance/quality control, and public data release. Storage of all other LCA collected data (spatial or non-spatial) will be handled by the LCA project specific data libraries on LCA.GOV.

Where applicable, Open Geospatial Consortium standards will be used to facilitate data sharing among interested parties. Data analysis and reporting responsibilities will be shared between project assessment and adaptive management efforts in order to provide TBBSR project reports for the LCA Program Management Team.

5.1 Description and Location

The data management plan should identify the computing hardware and any specialized or custom software used in data management for an adaptive management program. Opportunities exist to develop either a centralized or distributed data management system. With input from the LCA Adaptive Management Planning Team, the data managers should determine which approach best suits the needs of the overall adaptive management program.

Individuals with responsibility for data management activities (data managers) in support of an adaptive management program should be identified. The data managers should collaborate with the Adaptive Management Planning Team in developing a data management plan to support the adaptive management program. The data management plan should be incorporated into the overall program adaptive management plan, either in the main body of the adaptive management plan or as an appendix.

5.2 Data Storage and Retrieval

Data standards, quality assurance and quality control procedures and metadata standards will be prescribed by the Data Management Working Group, and will be complementary with the CRMS-Wetlands program and SONRIS database. Data will be served using a map services tool, similar to that currently employed by the CRMS-Wetlands project.

5.3 Analysis, Summarizing, and Reporting

Data analysis and reporting responsibilities will be shared between project and programmatic adaptive management efforts in order to provide reports for the TBBSR project Assessment Team, project managers, and decision-makers.

6.0 ASSESSMENT

The assessment phase of the framework compares the results of the monitoring efforts to the desired project performance measures and/or acceptable risk endpoints (i.e., decision criteria) that reflect the goals and objectives of the management or restoration action. The assessment process addresses the frequency and timing for comparison of monitoring results to the selected measures and endpoints. The nature and format (e.g., qualitative, quantitative) of these comparisons are defined as part of this phase. The resulting methods for assessment should be documented as part of the overall adaptive management plan.

The results of the TBBSR project monitoring program will be regularly assessed in relation to the desired project outcomes as described by the previously specified project performance measures. This assessment process continually measures the progress of the project in relation to the stated project goals and objectives and is critical to the project's adaptive management program. The assessments will continue through the life of the project or until it is decided that the project has successfully achieved (or cannot achieve) its goals and objectives.

6.1 Assessment Process

The Assessment Team assigned to the TBBSR project will identify a combination of qualitative (i.e., professional judgment) and quantitative methods for comparing the values of the performance measures produced by monitoring with the selected values of these measures that define criteria for decision-making.

Appropriate statistical comparisons (e.g., hypothesis testing, ANOVA, multivariate methods, etc.) will be used to summarize monitoring data and compare these data with the TBBSR project decision criteria. These continued assessments will be documented as part of the project reporting and data management system.

6.2 Variances and Success

The project Assessment Team will collaborate with project managers and decision-makers to define magnitudes of difference (e.g., statistical differences, significance levels) between the values of monitored performance measures and the desired values (i.e., decision criteria) that will constitute variances. Meaningful comparisons between monitoring results and desired performance will require characterization of historical and current spatial-temporal variability that define baseline conditions. Variances (or their absence) will be used to recommend adaptive management actions, including (1) continuation of the project without modification, (2) modification of the project within original design specifications, (3) development of new alternatives, or (4) successful close-out of the TBBSR project.

Conceptual models have been developed for each project describing the linkages between stressors and performance measures. The assessments will help determine if the observed responses are linked to the project. Each project has been formulated to address as many system stressors as feasible. If the stressors targeted by the project have changed and the performance measure has not, the linkages in the conceptual model should be examined to determine what other factors may be influencing the performance measure response.

The assessments will also determine if the responses are undesirable (e.g., are moving away from restoration goals) and if the responses have met the success criteria for the project. If performance measures are not responding as desired because the stressor has not changed enough in the desired direction, then recommendations should be made concerning modifications to the project. If the stressor has changed as expected/desired and the performance measure has not, additional research may be necessary to understand why.

From a system-wide perspective, scientific and technical information would be generated from the implementation of a system–wide monitoring effort. Information generated from this effort should be linked to evaluation LCA performance and system response. From a project-level perspective, monitoring plans should be designed to inform adaptive management decision making by providing monitoring data that are relevant to addressing uncertainty.

Similarly, for given multiple performance measures and corresponding monitoring results, the Assessment Team will determine the number and magnitude of variances within a single assessment that will be required to recommend modifications to the TBBSR project.

6.3 Frequency of Assessments

Ideally, the frequency of assessments for the TBBSR project would be determined by the relevant ecological scales of each performance measure. The project’s technical support staff will identify for each performance measure the appropriate timescale for assessment. The project should have a combination of short-, medium-, and long-term performance measures. Assessments should be performed at a five year interval at a minimum; however, depending on the timescale of expected responses of the specific measure and frequency of data collection, it may be determined during PED that more frequent reporting may be necessary.

6.4 Documentation and Reporting

The Assessment Team will document each of the performed assessments and communicate the results of its deliberations to the managers and decision-makers designated for the TBBSR project. The Assessment Team will work with the project monitoring team and monitoring workgroup to produce periodic reports that will measure progress towards project goals and objectives as characterized by the selected performance measures. The results of the assessments will be communicated regularly to the project managers and decision-makers.

7.0 DECISION-MAKING

Adaptive management is distinguished from more traditional monitoring in part through implementation of an organized, coherent, and documented decision process. For the TBBSR Adaptive Management program, the decision process includes (1) anticipation of the kinds of management decisions that are possible within the original project design, (2) specification of values of performance measures that will be used as decision-criteria, (3) establishment of a consensus approach to decision making, and (4) a mechanism to document, report, and archive decisions made during the timeframe of the Adaptive Management Program.

7.1 Decision Criteria

Decision criteria, also referred to as adaptive management triggers, are used to determine if and when adaptive management opportunities should be implemented. These criteria are usually ranges of expected and/or desirable outcomes. 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. A potential decision criterion is identified below, based on the project objectives and performance measures. More specific decision criteria will be developed during the pre-construction engineering and design phase of the project.

<u>Aerial photography for habitat classification and shoreline position</u>. This indicator can detect increased shoreline erosion on adjacent islands due to implementation of hardened structures, and the effect from a higher frequency and intensity of storm events than predicted.

- Compare pre-project vegetation coverage (in acres) with vegetation coverage five years after construction to determine if vegetation is propagating as predicted;
- Compare vegetation coverage at year five (as a percentage of the total island acreage) with vegetation coverage (as a percentage of the total island acreage) after year five to determine if the proper habitat conditions are being maintained;
- Compare pre-construction land loss rates to post-construction land loss rates.

To effectively implement adaptive management, predicted outcomes from modeling may need to be revisited and recalibrated in the light of field observations and field data, so that the Adaptive Management Planning Team can develop appropriate recommendations for changes. Additional modeling might be required to understand and manage observed island responses. An adaptive management action should include incorporation of findings into future island design templates.

7.2 Potential Adaptive Management Measures

The project report card, drafted by the Assessment Team, will be used to evaluate project status and adaptive management needs. The Assessment Team may submit recommendations for adaptive management actions to the Adaptive Management Planning Team. The Adaptive Management Planning Team will investigate and further refine adaptive management recommendations and present them to the Program Management Team. Some potential adaptive management actions for this project may include additional vegetative plantings and/or sand fencing, supplementing original project features with additional sediments to create more beach, dune and marsh, and the addition and/or removal of structural restoration measures such as breakwaters or terminal groins.

7.3 Project Close-Out

Close-out of the project would occur when it is determined that the project has been successful or when the maximum ten year monitoring period has been reached. Success would be considered to have been achieved when project objectives have been met or when it is clear that they will be met based upon the trend for the site conditions and processes. Project success would be based on the following:

- Decline in current trend in conversion of beach and marsh to open water
- Increase in elevation
- Reduction in duration of flooding and tidal prism

There may be issues related to the sustainability of the project that would require some monitoring and management beyond achieving the project objectives. Due to variable nature of the Louisiana coastal zone, 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 ten years.

8.0 COSTS FOR IMPLEMENTATION OF MONITORING AND ADAPTIVE MANAGEMENT PROGRAMS

The costs associated with implementing these monitoring and adaptive management plans were estimated based on currently available data and information developed during plan formulation as part of the feasibility study. Because uncertainties remain as to the exact project features, monitoring elements, and adaptive management opportunities, the costs estimated in Tables 1, 2, and 3 (below) will be need to be refined in the PED phase during the development of the detailed monitoring and adaptive management plans.

Costs were estimated based on monitoring concentrated on each of the four islands for one year during PED and three years post-construction, and seven years of system -level monitoring through the Barrier Island Comprehensive Monitoring (BICM) Program for determining impacts on the entire Terrebonne Basin Barrier Shoreline system. The total cost for implementing the monitoring and adaptive management programs is $10,995,000.*

* This total cost represents a correction from the previously provided cost of $10,595,000.

8.1 Costs for Implementation of Monitoring Program

Costs to be incurred during the PED and construction phases include drafting of the detailed monitoring plan, monitoring site establishment and pre-construction and construction data acquisition to establish baseline conditions. Cost calculations for post-construction monitoring are displayed as a ten-year (maximum) total. If ecological success is determined earlier (prior to ten years post-construction), the monitoring program will cease and costs will decrease accordingly.

It is intended that monitoring conducted under the LCA program will utilize centralized data management, data analysis, and reporting functions. All data collection activities follow consistent and standardized processes regardless of the organization responsible for monitoring. Cost estimates include monitoring equipment, monitoring station establishment, data collection, quality assurance/quality control, data analysis, assessment, and reporting for the proposed monitoring elements (Table 1). These estimates account for a 2.6% annual inflation rate, adopted from the CWPPRA Program. The current total estimate for implementing the monitoring program is $9,315,000. Unless otherwise noted, costs will begin at the onset of the PED phase and will be budgeted as construction costs.

Table 1. Preliminary Cost Estimates for Implementation of the Monitoring Program for the LCA Terrebonne Basin Barrier Shoreline Restoration Project.

Category	Activities	PED Data Acquisition	10 yr Total
Monitoring: planning and management	Monitoring workgroup, drafting detailed monitoring plan, working with PDTs on performance measures		$195,000
Monitoring: data collection	Landrights, site construction, and surveying	$83,600	$83,600
	Bathymetry/ Topography	$1,845,000	$5,636,400
	Habitat Mapping	$446,700	$1,500,000
	Sediment Sampling	$446,000	$1,500,000
Database Management	Database development, management, and maintenance, Webpage development for communication of data to stakeholders	$167,500	$400,000
TOTAL		**$2,988,800**	**$9,315,000**

8.2 Costs for Implementation of Adaptive Management Program

Costs for the project adaptive management program were based on estimated level of effort. The current total estimate for implementing the adaptive management program is $1,680,000. Unless otherwise noted, costs will begin at the onset of the PED phase and will be budgeted as construction costs.

Table 2. Preliminary Cost Estimates for Set-up of Adaptive Management Program for the LCA Terrebonne Basin Barrier Shoreline Restoration Project.

Category	Annual Cost	4 yr Total
Detailed Adaptive Management Plan and Program Set-up (During PED and construction)	$100,000	$400,000
TOTAL	**$100,000**	**$400,000**

Table 3. Preliminary Cost Estimates for Implementation of Adaptive Management Program for the LCA Terrebonne Basin Barrier Shoreline Restoration Project.

Category	Annual Cost	10 yr Total
Management of AM Program (Post Construction)	$50,000	$500,000
Assessment	$47,000	$470,000
Decision Making	$31,000	$310,000
TOTAL	**$128,000**	**$1,280,000**

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ANNEX 1. LCA Terrebonne Basin Barrier Shoreline Restoration Project Conceptual Ecological Model

1.0 INTRODUCTION

1.1 Conceptual Ecological Model Definition

Although the term “conceptual ecological model” (CEM) may be applied to numerous disciplines, CEMs are generally simple, qualitative models, represented by a diagram, that describe general functional relationships among the essential components of an ecosystem. CEMs typically document and summarize current understanding of, and assumptions about, ecosystem function. When applied specifically to ecosystem restoration projects, CEMs also describe how restoration actions propose to alter ecosystem processes or components to improve system health (Fischenich 2008). To describe ecosystem function, a CEM usually diagrams relationships between major anthropogenic and natural stressors, biological indicators, and target ecosystem conditions.

1.2 Purpose and Functions of Conceptual Ecological Models

CEMs can be particularly helpful with the Louisiana Coastal Area (LCA) Program and its projects by providing assistance with four important tasks: ecosystem simplification, communication, plan formulation, and science, monitoring and adaptive management.

1.2.1 Ecosystem Simplification

Because natural systems are inherently complex, resource managers must utilize tools that simplify ecosystem relationships and functions within the target ecosystem. An understanding of the target ecosystem is paramount to planning and constructing effective ecosystem restoration projects. During CEM development, known and unknown connections and causalities in the systems are identified and delineated (Fischenich 2008).

CEMs can promote ecosystem simplification through the following processes:

- Organization of existing scientific information;
- Clear depiction of system components and interactions;
- Promotion of understanding of the ecosystem;
- Diagnosis of underlying ecosystem problems;
- Isolation of cause and effect relationships; and
- Identification of elements most likely to demonstrate an ecosystem response.

1.2.2 Communication

CEMs are an effective tool for the communication of complex ecosystem processes to a large diverse audience (Fischenich 2008). It is vitally important that project teams understand ecosystem function in order to realistically predict accomplishments to be achieved by restoration projects. CEMs can facilitate effective communication between project team members about ecosystem function, processes, and problems, and can assist in reaching consensus within the project team on project goals and objectives.

Because CEMs summarize relationships among the important attributes of complex ecosystems, they can serve as the basis for sound scientific debate. Stakeholder groups, agency functions (e.g., planning and operations), and technical disciplines typically relate to systems resource use and management independently, but CEMs can be used to link these perspectives.

The process of model development is at least as valuable as the model itself and affords an opportunity to draw fresh insight as well as address unique concerns or characteristics for a given project. Workshops to construct CEMs facilitate brainstorming sessions that explore alternative ways to compress a complex system into a small set of variables and functions. This interactive process of system model construction facilitates communication between project team members and almost always identifies inadequately understood or controversial model components.

CEMs can promote communication by facilitating the following:

- Integrating input from multiple sources and informing groups of the ideas, interactions, and involvement of other groups. (Fischenich 2008);
- Assembling project/study managers with the project team and stakeholders to discuss ecosystem condition, problems, and potential solutions;
- Synthesizing current understanding of ecosystem function;
- Developing consensus on a working set of hypotheses that explain habitat changes;
- Developing consensus on indicators that can reflect project specific ecological conditions; and
- Establishing a shared vocabulary among project participants.

1.2.3 Plan Formulation

Formulating a plan for an effective ecosystem restoration project requires an understanding of the following elements:

1. The underlying cause(s) of habitat degradation;
2. The manner in which causal mechanisms influence ecosystem components and dynamics; and
3. The manner in which intervening with a restoration project may reduce the effects of degradation.

These three elements should form the basis of any CEM applied to project formulation (Fischenich, 2008).

CEMs can provide valuable assistance to the plan formulation process through the following:

- Supporting decision-making by assembling existing applicable science;
- Assisting with formulation of project goals and objectives, indicators, management strategies, and results;
- Providing a common framework among team members from which to develop alternatives;
- Supplementing numerical models to assess project benefits and impacts; and
- Identifying biological attributes or indicators that should be monitored to best interpret ecosystem conditions, changes, and trends.

1.2.4 Science, Monitoring and Adaptive Management

Through the recognition of important physical, chemical, or biological processes in an ecosystem, CEMs identify aspects of the ecosystem that should be measured. Hypotheses about uncertain relationships or interactions between components may be tested and the model may be revised through research and/or an adaptive management process. Indicators for this process may occur at any level of organization, including the landscape, community, population, or genetic levels; and may be compositional (i.e., referring to the variety of elements in a system), structural (i.e., referring to the organization or pattern of the system), or functional (i.e., referring to ecological processes) in nature.

CEMs can be helpful in restoration science, monitoring, and adaptive management through the following:

- Making qualitative predictions of ecosystem response;
- Identifying possible system thresholds that can warn when ecological responses may divergent from the desired effect;
- Outlining further restoration and research and/or development needs;
- Identifying appropriate monitoring indicators and metrics;
- Providing a basis for implementing adaptive management strategies;
- Interpreting and tracking changes in project targets;
- Summarizing the most important ecosystem descriptors, spatial and temporal scales, and current and potential threats to the system;
- Facilitating open discussion and debate about the nature of the system and important management issues;
- Determining indicators for monitoring;
- Helping interpret monitoring results and explore alternative courses of management;
- Establishing institutional memory of the ideas that inspired the management and monitoring plan;
- Forecasting and evaluating effects on system integrity, stress, risks, and other changes;
- Identifying knowledge gaps and the prioritization of research;
- Interpreting and monitoring changes in target indicators; and
- Assisting in qualitative predictions and provide a key foundation for the development of benefits metrics, monitoring plans, and performance measures.

1.2.5 Limitations of Conceptual Ecological Models

CEMs cannot identify the most significant natural resources within the target ecosystem or prioritize project objectives. They do not directly contribute to the negotiations and trade-offs common to ecosystem restoration projects. CEMs are not *The truth*, but are simplified depictions of reality. They are not *Final*, but rather provide a flexible framework that evolves as understanding of the ecosystem increases. CEMs are not *Comprehensive* because they focus only upon those components of an ecosystem deemed relevant while ignoring other important (but not immediately germane) elements. CEMs do not, in and of themselves, quantify restoration outcomes, but identify indicators that can be monitored to determine responses within the target ecosystem to restoration outputs.

Good conceptual models effectively communicate which aspects of the ecosystem are essential to the problem, and distinguish those outside the control of the implementing agency. The best conceptual models focus on key ecosystem attributes, are relevant, reliable, and practical for the problem considered, and communicate the message to a wide audience.

1.3 Types of Conceptual Ecological Models

CEMs can be classified according to both their composition and their presentation format. They can take the form of any combination of narratives, tables, matrices of factors, or box-and-arrow diagrams. The most common types of CEMs are narrative, tabular, matrix, and various forms of schematic representations. A comprehensive discussion of these types of CEMs is provided in Fischenich (2008). Despite the variety in types of CEMs, “no single form will be useful in all circumstances” (Fischenich 2008). Therefore, it is of vital importance to establish the specific plan formulation needs to be addressed by the CEM, and develop the CEM accordingly because “[c]onceptual models . . . are most useful when they are adapted to solve specific problems” (Frischenich 2008).

1.3.1 Application of Conceptual Ecological Models to LCA Projects

CEMs have been widely used in other regions of North America when planning large-scale restoration projects (Barnes et al., 2005). The LCA team has decided to utilize the Ogden model (Ogden and Davis, 1999). Like the plan formulation process, the LCA team recognizes that CEM development is likely to be an iterative process, and that CEMs developed for LCA projects during early plan formulation may be dramatically changed before project construction.

1.3.2 Model Components

The CEM structure utilized for LCA projects follows the top-down hierarchy of information using the components established by Ogden and Davis (1999). The schematic organization of the CEM is depicted in Figure 1 and includes the following components:

> *Drivers*- This component includes major external driving forces that have large-scale influences on natural systems. Drivers may be natural (e.g., eustatic sea level rise) or anthropogenic (e.g., hydrologic alteration) in nature.
>
> *Ecological Stressors*- This component includes physical or chemical changes that occur within natural systems, which are produced or affected by drivers and are directly responsible for significant changes in biological components, patterns, and relationships in natural systems.
>
> *Ecological Effects*- This component includes biological, physical, or chemical responses within the natural system that are produced or affected by stressors. CEMs propose linkages between one or more ecological stressors and ecological effects and attributes to explain changes that have occurred in ecosystems.
>
> *Attributes*- This component (also known as indicators or end points) is a frugal subset of all potential elements or components of natural systems representative of overall ecological conditions. Attributes may include populations, species, communities, or chemical processes. Performance measures and restoration objectives are established for each attribute. Post-project status and trends among attributes are measured by a system-

wide monitoring and assessment program as a means of determining success of a program in reducing or eliminating adverse effects of stressors.

Performance measures- This component includes specific features of each attribute to be monitored to determine the degree to which attribute is responding to projects designed to correct adverse effects of stressors (i.e., to determine success of the project).

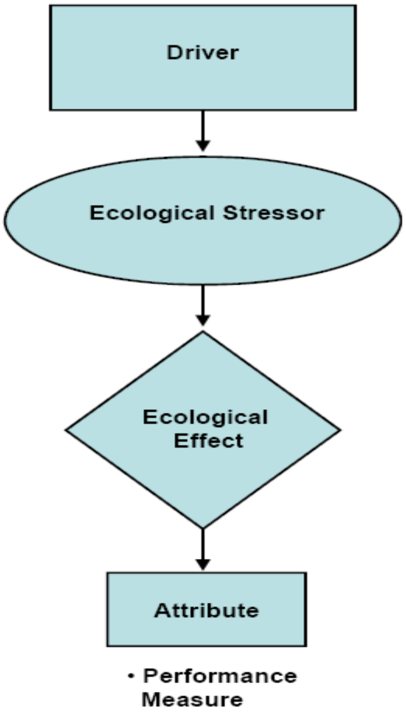

Figure 1. Conceptual Ecological Model Schematic Diagram.

This CEM does not attempt to explain all possible relationships or include all possible factors influencing the performance measure targets within natural systems in the study area. Rather, the model attempts to simplify ecosystem function by containing only information deemed most relevant to ecosystem monitoring goals.

2.0 CONCEPTUAL ECOLOGICAL MODEL DEVELOPMENT

2.1 Methodology

A CEM was developed for the Terrebonne Basin Barrier Shoreline Restoration (TBBSR) Project by members of the interagency Project Delivery Team. The creation of this CEM was an interactive and iterative process. Prior to model development, the project team reviewed existing information on the ecosystem within the study area. A small team meeting was then convened to identify and discuss causal hypotheses that best explain both natural and key anthropogenically-driven alterations in the study area. A list of appropriate stressors and consequent ecological effects in the study area ecosystem was developed from these discussions. Additionally, a series of attributes was identified that exhibited characteristics that ideally suited them to serve as key indicators of project success through the measurement and analysis of assessment performance measures associated with these attributes. The project team used these hypotheses and lists of components to develop an initial draft of the model and to prepare a supporting narrative document to explain the organization of the model and science supporting the hypotheses. Additional information about the components of this CEM is presented below.

2.2 Project Background

The TBBSR project was identified as a near-term critical feature in the *Louisiana Coastal Area (LCA) Louisiana - Ecosystem Restoration Study* (2004 LCA Plan)(USACE, 2004). The 2004 LCA Plan was recommended to the Congress by a Chief of Engineers report dated January 31, 2005, which recommended a coordinated, feasible solution to the identified critical water resource problems and opportunities in coastal Louisiana. The TBBSR project was included in that plan along with other near-term critical restoration features throughout coastal Louisiana. Including this project, 10 additional projects were recommended for further studies, in anticipation that such features would be subsequently recommended for future Congressional authorization. The 2004 LCA Plan was developed by the State of Louisiana and the United States Army Corps of Engineers (USACE) in order to implement some of the restoration strategies outlined in the 1998 report *Coast 2050: Toward a Sustainable Coastal Louisiana*.

The purpose of this study is to investigate the feasibility of simulating historical conditions by enlarging the barrier islands (width and dune crest) and reducing the current number of breaches. This Feasibility Study was authorized by the 2004 LCA Plan and the 2007 Water Resources Development Act (WRDA 2007), which required the completion of a Feasibility Study and the incorporation of the study findings into a signed Chief of Engineers Report, which must be submitted to Congress by the Secretary of the Army by December 31, 2010.

This plan incorporated the elements of the previous efforts as well as input from private citizens, local governments, state and federal agencies, and the scientific community. Unlike the previous plans, the Coast 2050 Plan took an ecosystem-level approach to coastal restoration. It provided an overall template for the selection, development and construction of restoration projects and outlined a set of restoration strategies for restoring south Louisiana's wetlands to a sustainable level. The Coast 2050 Plan evolved into the Louisiana Coastal Area Comprehensive Coastwide Ecosystem Restoration Study (2004 LCA Plan).

The 2004 LCA Plan began in 2000, building upon the restoration strategies presented in the Coast 2050 Pplan, and outlined a series of projects that were thought to be necessary to achieve a sustainable coast. The 2004 LCA Plan serves as the implementation phase for the large-scale strategies outlined in the Coast 2050 Plan and focuses on large-scale civil works projects that are beyond the scope and funding level of CWPPRA.

Understanding the critical nature of the land loss situation, a near-term LCA Plan was derived from the large coastwide study. The Near-Term LCA Plan included a prioritized list of projects that could be implemented within the next 10 years. The LCA Plan was completed in 2004 and submitted to Congress. In the Water Resources Development Act of 2007, Congress contingently authorized six projects, subject to feasibility reports due no later than December 31, 2008. Included in these projects was the Terrebonne Basin Barrier Shoreline Restoration (TBBSR).

The TBBSR project includes the Isles Dernieres (Raccoon Island, Whiskey Island, Trinity Island, and East Island) and Timbalier Island (East Timbalier and West Timbalier) Reaches, which are located in Terrebonne and Lafourche Parishes.

2.2.1 Project Goals and Objectives

The goal of the TBBSR project is to reverse the continuing degradation and deterioration of the Isles Dernieres (Raccoon Island, Whiskey Island, Trinity Island, East Island, and Wine Island) and Timbalier Islands (Timbalier Island and East Timbalier Island) in order to achieve a sustainable coastal ecosystem that can support and protect the environment, economy, and culture of southern Louisiana and thus the Nation.

The objectives of the project include the following:

- Minimize future land loss;
- Restore the geomorphic setting of the Isles Dernieres and Timbalier Islands, which are essential to providing a boundary between the Gulf of Mexico and the Terrebonne estuary;
- Restore and improve various barrier island habitats that provide essential habitat for fish, migratory birds, other terrestrial and aquatic species;
- Protect vital socioeconomic resources including cultures, community, infrastructure, business and industry, and flood protection features;
- Reduce damage from wave energy on interior bays and marshes; and
- Maintain and enhance long-shore sediment transport processes.

2.2.2 Project Description

The Project, located in LCA Subprovince 3, provides for the restoration of the Timbalier and Isles Dernieres barrier island chains located in Terrebonne Parish and Lafourche Parish, Louisiana. The Project area (Figure 2) is located in the 3rd Congressional District. The barrier islands projected for restoration are depicted in Figure 2.

The Isles Dernieres Reach represents a barrier island arc approximately 22 miles long in Terrebonne Parish and extends from Caillou Bay east to Wine Island Pass. Raccoon Island, Whiskey Island, Trinity Island, and East Island, the primary islands that comprise the Isles Dernieres barrier island chain (Figure 2), are backed by Bay Blanc, Bay Round, Caillou Bay, and Terrebonne Bay, and bordered by the Gulf of Mexico (GOM) on the seaward side.

The Timbalier Reach is comprised of Timbalier Island and East Timbalier Island. Timbalier and East Timbalier islands are on the western edge of the Lafourche barrier shoreline and are located about 60 miles southwest of New Orleans, Louisiana. This barrier island shoreline is approximately 20 miles long and backed by Terrebonne and Timbalier Bay to the north and delimited by Raccoon Pass to the east and Cat Island Pass to the west (Figure 2).

Prior studies have documented degradation of the Terrebonne Basin Barrier Islands and have demonstrated a need for island restoration. The proposed project involves restoring the islands in an effort to prevent future land loss where it is predicted to occur, preserving the endangered and critical geomorphic structure of the islands, and protecting vital local, regional and national infrastructure.

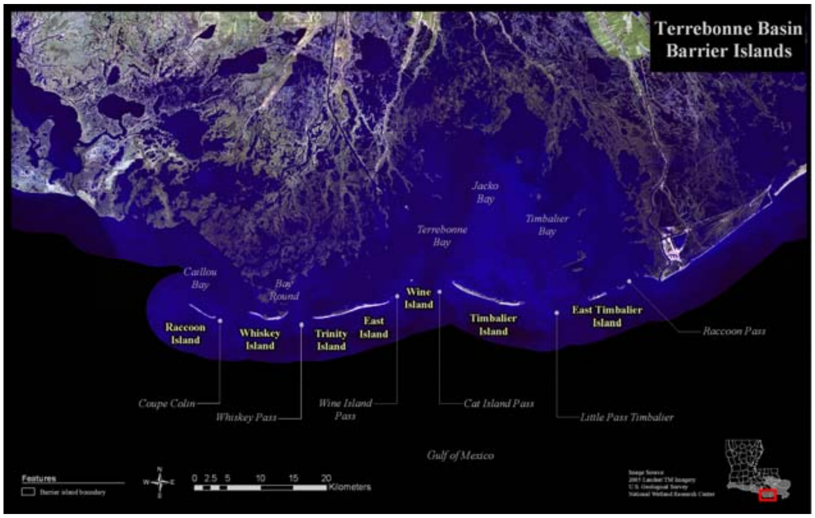

Figure 2. Terrebonne Basin Barrier Shoreline Restoration Project Study Area

3.0 CONCEPTUAL ECOLOGICAL MODEL DISCUSSION

The CEM developed for the TBBSR Project is presented in Figure 3. Model components are identified and discussed in the following subsections.

3.1 Drivers

3.1.1 Coastal Processes

The Louisiana coastal zone is one of the most dynamic environments that exist in nature. The morphology and integrity of that zone, and specifically the Terrebonne Basin barrier island chain, is directly related to the supply of sediment contributed and the physical processes operating on the coast of Louisiana. The same processes that built the barrier islands are also partly responsible for their erosion and fragmentation. The major coastal processes operating to shape the Terrebonne Basin barrier islands include tides, relative sea-level rise, and long-shore sediment transport (USACE 2004).

Geologic faulting, compaction of muddy and organic sediment, and sea level change have shaped the coastal Louisiana landscape for thousands of years (Kulp 2000; Reed 1995). Over millennia, sea level change and subsidence were offset by delta building in the Deltaic Plain. Erosion of barrier shorelines and disruption of fragile organic marshes has resulted in land loss, but also contributed to habitat and wildlife diversity. There is little direct evidence that any of these natural processes have changed in the mid to late 20th century, therefore it is assumed that these coastal processes will continue to act as major forcings on Louisiana's barrier islands (USACE 2004).

3.1.2 Atmospheric Processes

Barrier islands form the first line of defense for protecting coastal Louisiana from the direct effects of wind, waves, and storms. The barrier systems serve multiple purposes to: 1) reduce coastal flooding during periods of storm surge; 2) prevent direct ocean wave attack, which would accelerate rates of erosion and degradation of marshes and other wetlands; and 3) help maintain gradients between saline and freshwater, thereby preserving estuarine systems (USACE 2004).

The Louisiana inner shelf is an example of a low-energy environment where significant hydrodynamic activity is generated almost exclusively by local storms, including both tropical (summer) and extratropical (winter) storms. In an average year, 20 to 30 cold fronts will pass through coastal Louisiana. The resulting response of the coastal waters is the initial increase in tidal amplitudes, which causes waves to break higher on the beach, overwashing low barrier islands. Elevated tides increase the flow of ocean water into the bays and marsh systems behind the barrier islands. As floodwaters reside and exit the inlets with passage of the front, abrupt changes in wind direction from southerly to northerly cause increased wave heights in the bays. This continuous process is believed to be responsible for the chronic shoreline erosion behind the barrier islands.

3.1.3 Anthropogenic Activities

Primary anthropogenic activities that are affecting the project area are oil and gas canals, extraction of hydrocarbons, navigation canals, and coastal structures. Substantial oil and gas activity and infrastructure exists on and near the Terrebonne Basin barrier islands, primarily behind the islands in the Terrebonne and Timbalier bays. Approximately 2,000 Coastal Use Permits (LDNR 2008a) pertaining to the more than 20 oil and gas fields (LOSCO 2007c), 4,000 injection wells (LOSCO 2007b), 1,100 oil and gas pits (LOSCO 2007d), 110 platform structures (LOSCO 2007e), and a complex system of pipelines, (LOSCO 2007a) have been issued for these activities within a 6 mile buffer of the islands.

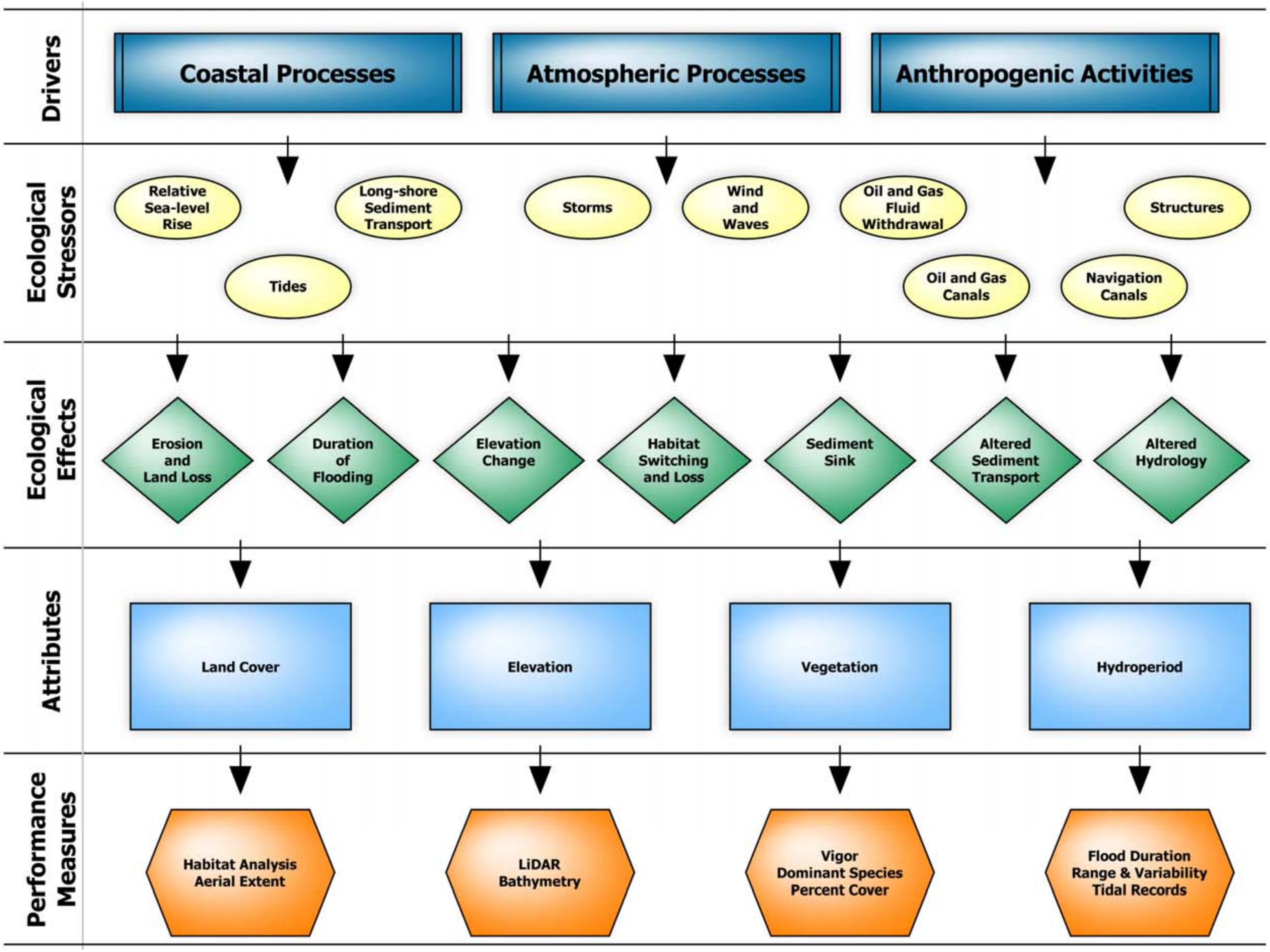

Figure 3. Conceptual Ecological Model, LCA Terrebonne Basin Barrier Shoreline Restoration Project

3.2 Ecological Stressors

3.2.1 Relative Sea-level Rise

The entire Louisiana coastal zone is experiencing relative sea level rise (RSLR). RSLR is defined here as the net effect of numerous processes that result in the downward displacement of the land surface relative to sea level. RSLR is controlled by several major factors that include eustatic sea level, geosynclinal downwarping, compaction of Holocene deposits, and faulting. Recent studies have shown that anthropogenic activities (subsurface fluid withdrawal) may be a contributor to RSLR (Morton et al. 2002), however the relative role of the natural and anthropogenic factors on net regional subsidence has not been well established, despite their potentially significant influence on coastal erosion patterns and sedimentation processes. Each process produces a range of subsidence rates dependent on local environmental factors and each process occurs across a unique set of scale (Reed and Yuill 2009). Changes in land elevation vary spatially along coastal Louisiana, however in areas where subsidence is high and riverine influence is minor or virtually nonexistent, such as in areas of western Barataria Basin and eastern Terrebonne Basin, wetland habitats sink and convert to open water.

Within the TBBSR project area, increased subsidence is a physical response to the lack of riverine input and the resulting loss of sediments and decreased productivity in vegetation communities. Subsidence, along with rising sea level, is also largely responsible for shoreline erosion and the transgressive nature of most of the barrier islands. Estimated subsidence rates for the Deltaic Plain are between 0.5 to 4.3 ft/century. Factoring in changes in land elevation and water levels, the average rate of relative sea level change along coastal Louisiana is currently estimated to be between 3.4 to 3.9 ft/century, and a rate of 0.4 inches per year for the Grand Isle area (USACE 2004). These are the highest rates of RSLR along the contiguous United States and help to explain coastal evolution in Louisiana.

3.2.2 Tides

Tidal currents in Louisiana are relatively small, due to the small tidal amplitude. In the absence of wind, density effects and barometric pressure gradients, these currents reach magnitudes of approximately 0.3 to 0.5 ft/s. Estimates and observations suggest that tidal currents are stronger at the surface of the water column and decrease with increasing depth. This occurrence is primarily due to the encounter of denser and heavier salty gulf waters in deeper regions, which are less likely to respond to small tide variations. Although small in magnitude in open coastal waters, tidal currents can reach velocities of approximately 1.7 ft/s at estuary and barrier island inlets, depending on the inlet dimensions. The amount of circulation attributed to rising and falling tides or tidal induced circulation is measured as a function of the spatial and temporal variability of tides along the Louisiana coast. There is a seven-hour lag before high water from the east coastal zone reaches the west coastal zone, with typical tidal ranges between 1 to 2 feet depending on the time of month and year.

Normal tides are affected by seasonal weather patterns. In an average year, 20 to 30 cold fronts will pass through coastal Louisiana. The resulting response of the coastal waters is the initial increase in tidal amplitudes, which causes waves to break higher on the beach, overwashing low barrier islands. Elevated tides increase the flow of ocean water into the bays and marsh systems behind the barrier islands. As floodwaters reside and exit the inlets with passage of the front, abrupt changes in wind direction from southerly to northerly cause increased wave heights in the bays. This continuous process is believed to be responsible for the chronic shoreline erosion behind the barrier islands (USACE, 2004c). High tides combined with anthropogenic features such as canals and spoil banks, can also result in increased flooding durations, which can lead to soil waterlogging and vegetation stress.

3.2.3 Altered Sediment Transport and Input

Longshore sediment transport is the movement of sediment parallel to the shore. This process is a result of breaking and shoaling waves suspending sand from the bottom and the displacement of the sediment down-drift by the longshore current. The magnitude of the longshore current intensifies with increasing wave height and breaker angle. In addition to these wave parameters, the rate of transport is a function of beach or barrier orientation, offshore shelf slope, local depth, shoreline erosion, and sediment deposition and patterns.

Alterations to the natural sediment transport and input systems are largely due to the addition of manmade structures along the coast. The sand transport system along the Timbalier Basin barrier islands has been greatly diminished due to the extent of coastal structures in the area. Such as the jetties at Belle Pass on the western end of the Caminada Headland, which interrupt the natural flow of sediment, thus reducing the volume transported drown drift. Additionally, the potential for transferring sand from the Caminada Moreau headland to the Timbalier islands is minimal, given the large width of Raccoon Pass and the net landward transport of sand to its flood tidal delta. (CEC and SJB, 2008).

3.2.4 Storms

The Gulf Coast region is affected by tropical and extra-tropical storms. These atmospherically driven storm events can directly and indirectly contribute to coastal land loss through a variety of ways: 1) erosion and breaches from increased wave energies; 2) removal and/or scouring of vegetation from storm surges; and 3) storm induced saltwater intrusion into interior wetlands. These destructive processes can result in the loss and degradation of large areas of coastal habitats in relatively short periods of time (days and weeks versus years). Since 1893, over 130 tropical storms and hurricanes have struck or indirectly impacted Louisiana’s coastline. On average, a tropical storm or hurricane affects Louisiana every 1.2 years. During the past 100 years, over 50 hurricanes and tropical storms have made landfall along the Louisiana coast with the highest incidence occurring in September (USACE, 2004a).

In 2005 and 2008 four hurricanes of unprecedented nature, Katrina, Rita, Gustav, and Ike devastated coastal Louisiana and impacted the entire nation. Specific to the Terrebonne Basin, the four hurricanes impacted the barrier islands, resulting in gulf shoreline erosion, overwash from beach/dune habitats to back-barrier habitats, land loss, and damage to oil and gas infrastructure.

3.2.5 Wind and Wave Activity

Wind can induce circulation in the form of set-up and set-down, seiche, and wind-waves. Similarly, the presence of front-like weather during the winter and storms during hurricane season enhances these processes by producing dynamic wind conditions. The speed and direction of these winds shift abruptly, creating strong gusts. Changing wind speed and direction cause the generation and transformation of waves along the Louisiana coast. Wind and barometric pressure induced circulation is critical and dominant in back bays, enclosed bays, and lakes, marshes, and sub-tidal areas. These processes are characterized by extreme water level fluctuations, and are responsible for a significant amount of the erosion taking place along the Louisiana coast.

3.2.6 Oil and Gas Canals

It is estimated that the direct effects (footprint) of canals has resulted in the loss of nearly 29,000 acres of marsh in Louisiana between 1955 and 1978 (Boesch et al. 1994 from Turner and Cahoon 1988). Besides the direct wetland loss, canals have dramatically altered the natural hydrology of coastal Louisiana and have been linked to significant indirect wetland loss in some areas. On barrier islands, canals can form sediment sinks and alter the natural barrier island rollover process by capturing overwashed sands during storm events.

The spoil banks, or piles of dredged material placed adjacent to canals during canal construction, can alter the natural hydrology of the backbarrier marsh by obstructing the sheet flow of water across the marsh and subsurface flow of water through the marsh. These barriers can result in prolonged flooding events, especially following storms. Impoundments or semi-impoundments created by the configuration of several spoil banks have been shown to reduce the frequency and increase the duration of flooding during tidal events. Prolonged flooding of a marsh can lead to waterlogged soils, stressed vegetation, and eventual marsh loss. The magnitude of these indirect effects continues to be a source of great controversy and is likely to vary by location, marsh and soil types, and level of pre-existing disturbance, among other variables.

3.2.7 Oil and Gas Fluid Withdrawal

The production, refinement, and transport of oil and gas have resulted in both short- and long-term negative environmental impacts to coastal Louisiana. Recent findings have indicated that oil and gas fluid withdrawal has resulted in regional subsidence and fault reactivation causing historical wetland losses in south-central Louisiana (Morton et al. 2005). As stressors, induced subsidence coupled with sea level rise can lead to elevation changes, increased flooding, and eventual habitat switching and loss.

3.2.8 Navigation Channels

The Terrebonne Basin drainage area encompasses approximately 1,455 square miles. Major navigation channels within the basin are the Atchafalaya River, Wax Lake Outlet, Houma Navigation Canal, Gulf Intracoastal Waterway (GIWW), and Lower Atchafalaya River (LOSCO, 1999). These navigation channels introduce and/or compound marine influences in many of the interior coastal wetlands and water bodies within the Terrebonne Basin (USACE, 2004a).

The HNC has direct influence on the Terrebonne Basin barrier shoreline as its mouth is situated in Cat Island Pass at the western end of Timbalier Island. Because of the close proximity of the canal to the western end of Timbalier Island, consideration must be given to ensure that the canal dredging does not adversely impact the westerly longshore transport of sand and remove sand from the barrier island system by serving as an artificial sediment sink. Periodic maintenance dredging of the HNC also provides an opportunity for the beneficial use of dredged material on Timbalier Island and Isles Dernieres.

3.2.9 Structures

Many human activities at the coast have interrupted or altered the coastal ecological processes. Some of these activities are widespread across the coast and can affect large areas. Within the coastal zone, manmade structures are often constructed to facilitate navigation or provide support for infrastructure, but can inevitably have long-term negative impacts on coastal ecosystems. Specific to the barrier islands is the construction of revetments, groins, and jetties, which can all alter long-shore transfer and sediment supply to barrier islands and wetlands, and limit island migration and the land building process.

3.3 Ecological Effects

3.3.1 Erosion and Land Loss

For barrier shorelines, complex interactions between storm events, longshore sediment supply, coastal structures, and inlet dynamics contribute to the erosion and migration of beaches, islands, and cheniers. Barrier islands are important elements of the geomorphic framework of the estuary. Barrier islands separate the gulf from the back-barrier estuarine environment helping to maintain the salinity gradients important to estuarine species. As islands erode and are breached, marine forces are allowed to affect the interior boundaries of the estuaries, thereby accelerating land loss. Barrier islands also serve as valuable storm buffers protecting communities, industry, and associated infrastructure from storm surges. Barrier island degradation is a natural process and represents the latter phase of the deltaic process, as described in section 1 INTRODUCTION. Marine influences, particularly those associated with tropical storm events, gradually erode and rework the structure of the islands until they eventually disappear. While the acreage amounts associated with the loss of barrier islands may not contribute appreciably to the total acreage of land loss in the study area, their disappearance can result in significant and profound impacts on coastal land loss and ecosystem sustainability. Barrier islands serve as natural storm protective buffers and provide protection and limit erosion of Louisiana's coastal wetlands, bays, and estuaries, by reducing wave energies at the margins of coastal wetlands. In addition, barrier islands limit storm surge heights and retard saltwater intrusion. The historic rates of land loss for Louisiana's barrier islands are varied, and can average as high as 50 acres per year (20.3 ha per year), over several decades. Hurricane events can push the rate of land loss to surpass 300 acres per year (122 ha per year). For example, the Isles Dernieres have decreased in acreage from approximately 9,000acres (3,645 ha) in the late 1880s to approximately 1,000 acres (405 ha) by 2000 (see Appendix D LOUISIANA GULF SHORELINE RESTORATION REPORT).

It is likely that within the next several years, erosion will accelerate due to the significant number of breaches, subjecting critical habitats to degradation by wave action and saltwater intrusion.

3.3.2 Duration of Flooding

Oil and gas canals, which were primarily dredged between 1950 and 1980, directly changed land to open water, and indirectly changed the natural hydrologic processes that are essential to a healthy coastal ecosystem through increased hydrologic connectivity. Additionally, the resulting spoil banks create impoundment areas within the marsh, reducing water exchange and increasing periods of inundation. These increased periods of submersion have detrimental effects on plant life and productivity. An important element of sustaining land elevations is the ability of the marsh to receive a fresh supply of sediments through re-suspension during storm passages. Much like the levee system of the Mississippi River, the spoil banks along oil and gas canals have limited nature's ability to renourish the marsh.

3.3.3 Elevation Change

Scouring caused by storms, coupled with relative sea level rise negatively affect the elevation of the barrier islands. Factoring in changes in land elevation and water levels, the average rate of relative sea level change along coastal Louisiana is currently estimated to be between 3.4 to 3.9 ft/century (USACE, 2004a).

3.3.4 Habitat Switching and Loss

Salinity, elevation, and inundation are the major driving forces in the distribution of coastal wetland habitats (Mitsch and Gosselink 2000), although these are modified by other factors including fertility, herbivory, disturbance and burial (Keddy 2001). Salinity predominantly drives the change among fresh, intermediate, brackish and saline habitats. Extreme salinities may lead to conversion of fresh and intermediate marshes to open water (Flynn et al. 1995). The salinity stress on a habitat may be worsened with inundation stress. At higher inundation levels, the salinity tolerance of the vegetation is lower, subjecting critical habitat to increased the likelihood of switching or loss, (LDNR, 2003)

Specific to the barrier island system, the aforementioned destructive processes and stressors can result in the loss and degradation of large areas of coastal habitats in a relatively short period of time (days and weeks versus years). As the number of breaches increases, erosion will accelerate, further subjecting critical habitats to degradation by wave action and saltwater intrusion.

3.3.5 Direct Land Loss

Large-scale conversion of barrier island habitat to open water occurs during hurricane events when breaches are formed and the island is overwashed exposing the underlying soft muddy substrates. Direct conversion has also occurred when canals were dredged. In addition to the direct loss of habitat, canals also leave the island more susceptible to breaching during storm events.

3.3.6 Sediment Sink

Navigation channels and oil and gas canals can disrupt the natural longshore sediment transport and barrier island rollover processes. The HNC which is located at the western end of Timbalier Island was constructed in 1962 and has a maintained depth of 18.8 feet NGVD. Between 1976 and 1990, all of the dredged material removed during routine maintenance of Cat Island Pass was placed in an Ocean Dredged Material Disposal Site (ODMS) (USACE undated).

Oil and gas location canals, pipeline canals, and canals maintained for recreational access purposes can also form sediment sinks by trapping sand during overwash events and disrupting the natural barrier island rollover process.

3.3.7 Altered Hydrology

Levees placed along the Mississippi River have altered the natural hydrology of the deltaic plain and have cut off the source of sediments that formed the barrier islands. Furthermore, thousands of miles of navigation channels and oil and gas canals in coastal Louisiana have played a major role in the loss of wetlands and barrier islands. These losses can be attributed to the direct conversion of barrier island habitats to open water, as well as by the indirect impacts associated with altered hydrology and saltwater intrusion. The existing and newly constructed oil and gas canals and the maintenance of navigation channels will continue to facilitate saltwater intrusion into interior coastal wetlands.

3.3.8 Altered Sediment Transport

The longshore movement of sediment and absence of sand-sized sediment is the principal cause of the barrier island’s instability (USGS 1995). Additionally, longshore currents redistribute the available sand from eroding headlands to the bays north of the barrier islands where they are no longer accessible to the sediment-starved islands (USGS 1995).

3.4 Attributes and Performance Measures

3.4.1 Habitat Analysis

Habitat has been identified as a key indicator of project success with respect to preventing habitat conversion and future land loss. Comparison of pre-project habitat characteristics with post-project habitat characteristics would serve to determine if the current trend in conversion of beach and marsh to open water within the study area has declined.

- Spatial analyses of habitat and extent have been identified as assessment performance measures for the determination of the response of habitat to the proposed project. Spatial analysis may involve comparative analysis of pre-project and post-project aerial or satellite imagery and may utilize thematic mapper analysis to determine relative changes in habitat within the study area.

3.4.2 Aerial Extent

Aerial extent has been identified as a key indicator of project success with respect to preventing future land loss. Comparison of pre- and post-project aerial extent would serve to determine if the current trend in conversion of land to open water within the study area has declined.

- The collapsing of previously described habitat inventory would act as a surrogate, and suffice for determining the sub-aerial extent of the Terrebonne Basin Barrier Islands. These datasets would be used to determine relative changes in aerial extent of the barrier islands within the study area.

3.4.3 Tidal Records

Hydroperiod in the study area has been identified as a key indicator of project success with respect to reducing hydrologic connectivity between the Gulf of Mexico and the back barrier bays and interior marsh. Comparison of pre-project and post-project hydrography would serve to determine if closure of breaches and restoration of the islands have reduced the duration of flooding and the tidal prism. Two assessment performance measures have been identified for this attribute, flood duration, and tidal range and variability.

- Flood duration has been identified as an assessment performance measure for the determination of the response of hydrology to the proposed project. This measure may be obtained from existing water level gauges.
- Tidal range and variability have been identified as an assessment performance measure for the determination of the hydrologic response to the proposed project. These measures may be obtained by using existing and future tidal records.

3.4.4 Elevation

Topographic surveys will be conducted along pre-determined transects by a professional survey crew prior to and immediately following construction. Post-construction topographic surveys will be conducted to document the horizontal and vertical change at the project area.

Elevation has been identified as a key indicator of project success with respect to reducing or reversing subsidence within the study area. Comparison of pre-project elevation levels with post-project elevation levels would serve to determine if sediment input and soil accretion is occurring within the study area in response to project features. A post-project increase in elevation would indicate the introduction and stabilization of sediment onto the islands as a result of the project. The assessment performance measure that has been identified for this attribute is the BICM topography.

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