APPENDIX I

ADAPTIVE MANAGEMENT / MONITORING PLAN

Louisiana Coastal Area (LCA) Program: Convey Atchafalaya River Water to Northern Terrebonne Marshes Project And Multipurpose Operation of Houma Navigation Lock Feasibility-Level Monitoring and Adaptive Management Plan

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DRAFT

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1.0 INTRODUCTION

This document outlines the feasibility-level monitoring and adaptive management plan for the Louisiana Coastal Area (LCA) Convey Atchafalaya River Water to Northern Terrebonne Marshes (ARTM) 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 Convey Atchafalaya River Water to Northern Terrebonne Marshes 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 Memorandum 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 Coastal Protection and Restoration Authority (CPRA), 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).

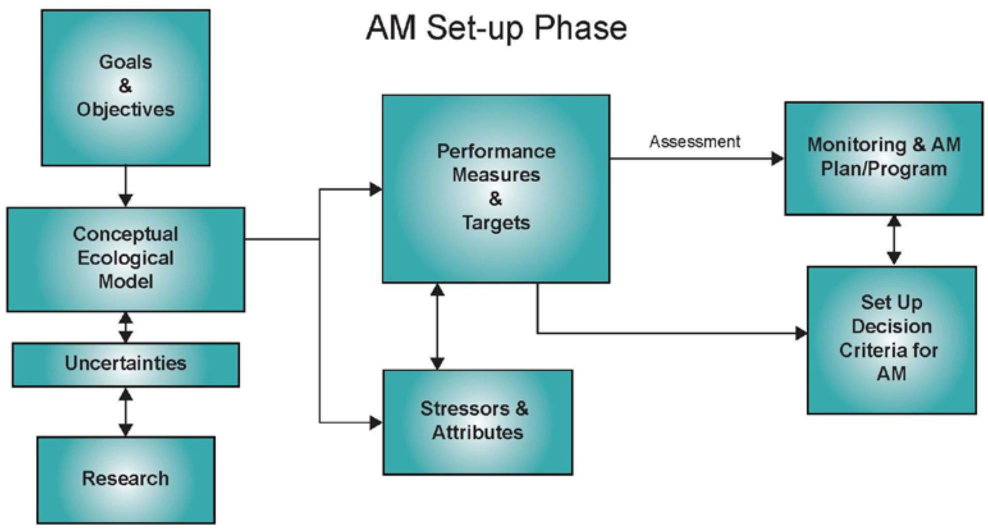

Figure 1. Set-up Phase of the LCA Adaptive Management Framework.

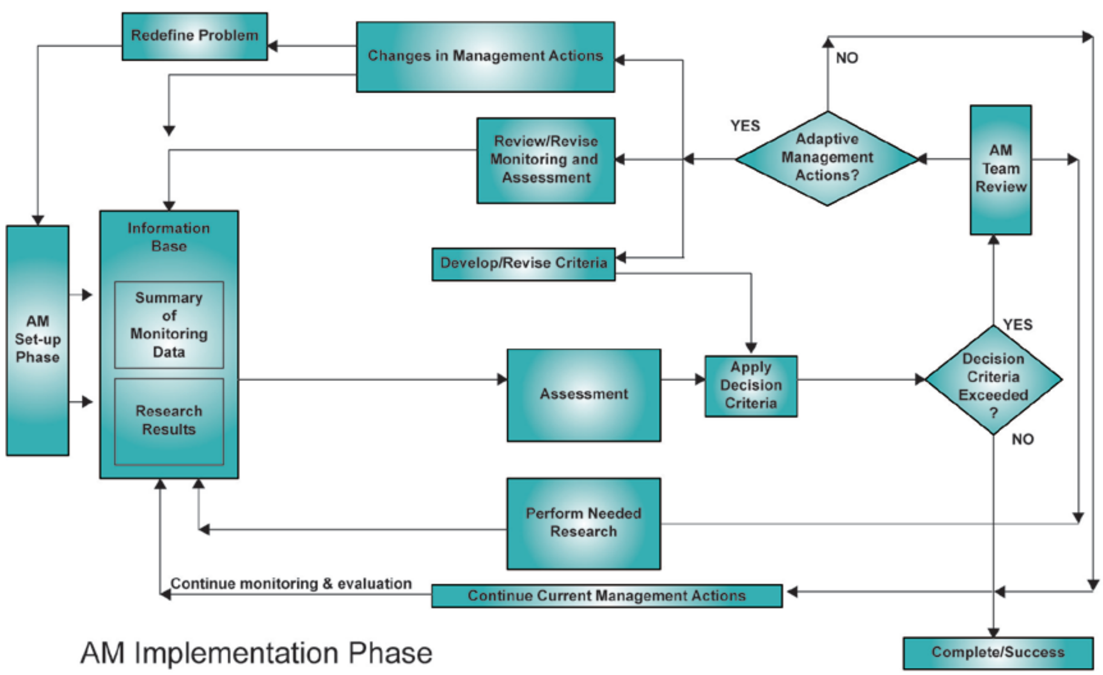

Figure 2. Implementation Phase of the LCA Adaptive Management Framework.

1.3 LCA Communication Structure for Implementation of Adaptive Management

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

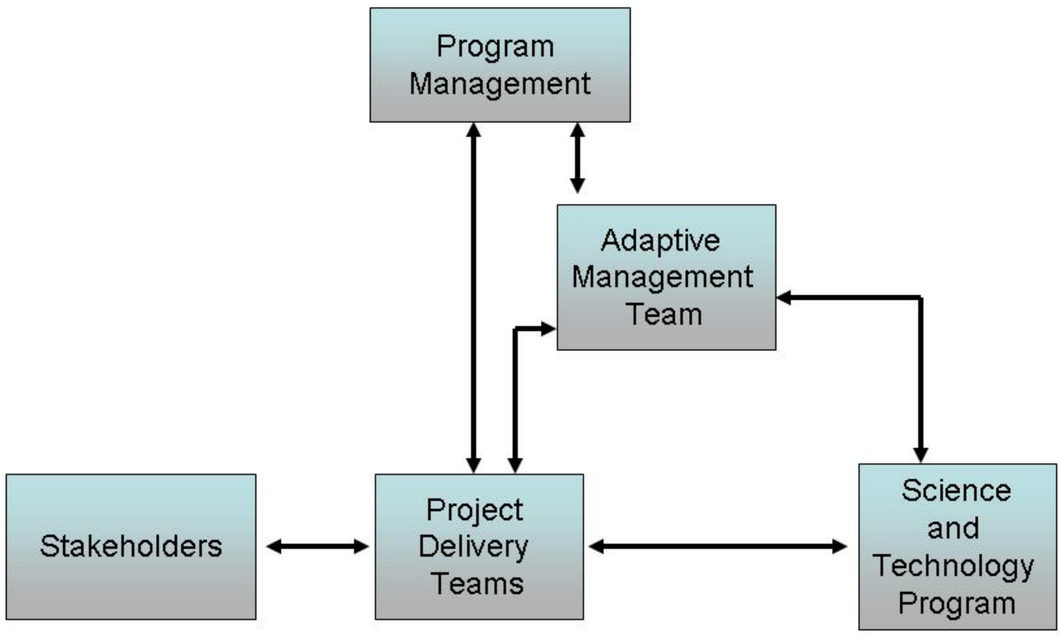

Figure 3. LCA Communication Structure for Implementation of Adaptive Management.

As part of the LCA Program communication structure for implementation of adaptive management structure (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 CPRA. 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 on the basis of 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 recommending project and program adaptive management actions 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 this 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, CPRA; Greg Steyer, USGS National Wetlands Research Center; and John Troutman, CPRA.

The resulting adaptive management plan for the Convey Atchafalaya River Water to Northern Terrebonne Marshes project describes and justifies whether adaptive management is needed in relation to the recommended plan (RP) 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 will define project success.

This 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 Convey Atchafalaya River Water to Northern Terrebonne Marshes 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, data management, assessment, decision-making, and implementation costs.

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, and 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 ARTM 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 the current trend of degradation of the Terrebonne marshes, so as to contribute towards achieving and sustaining a coastal ecosystem that can support and protect the environment, economy, and culture of southern Louisiana and thus the Nation. The specific restoration project objectives for the Convey Atchafalaya River Water to Northern Terrebonne Marshes project are to:

- Prevent, reduce, and/or reverse future wetland loss
- Achieve and maintain characteristics of sustainable marsh hydrology
- Reduce salinity levels in the project area
- Increase sediment and nutrient load to surrounding wetlands
- Increase residence time of fresh water
- Sustain productive fish and wildlife habitat

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 recommended plan (RP).

The RP is the NER Alternative, Alternative #2, which involves construction of 56 structures and other water management features in an effort to holistically address the declining health of the Terrebonne Marshes ecosystem. This alternative redistributes existing freshwater to benefit Terrebonne marshes using a variety of measures, including elimination of GIWW constrictions. Additionally, measures are proposed that restrict, increase, and control water in each of the three subunits. In the western portion of the study area (Bayou Penchant), dredging, a sediment plug, and a weir are proposed. In the central portion of the study area (Lake Boudreaux), culverts, levees, dredging, marsh terraces and berms, sediment plugs, modified operation of the future HNC (Houma Navigation Canal) lock complex, and a large sluice gated box culvert are proposed. In the eastern portion of the study area (Grand Bayou), culverts, dredging, gaps in canal spoil banks, marsh berms, sediment plugs, and removal of a weir and soil plug are proposed.

2.3 Conceptual Ecological Model for Monitoring and Adaptive Management

As part of the planning process, members of the ARTM 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 effects 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 coastal wetland systems included in the Convey Atchafalaya River Water to Northern Terrebonne Marshes project.

- Ability of the hydrologic model to predict project impacts/benefits
- Ability of Wetland Value Assessment (WVA) model to predict project impacts/benefits
- Ability of SAND2 (Boustany-ERDC model) to predict impacts/benefits of increases and decreases in freshwater inputs.
- Elevations/bathymetry throughout project area
- Correct engineering and design to address project objectives
- Correct operational regime to achieve project objectives

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 suggests management actions in relation to measured project performance compared to desired project outcomes. In the case of the Convey Atchafalaya River Water to Northern Terrebonne Marshes 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 among 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 Convey Atchafalaya River Water to Northern Terrebonne Marshes 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) Can project management actions be adjusted in relation to monitoring results?

A 'NO' answer to questions 1-3 and a "YES" answer to question 4 qualifies 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 and operating scenarios 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 Convey Atchafalaya River Water to Northern Terrebonne Marshes Project

An Adaptive Management Program for the Convey Atchafalaya River Water to Northern Terrebonne Marshes 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 of the ARTM 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 monitoring 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 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). CRMS-Wetlands provide system-wide performance measures that are evaluated to help determine the cumulative effects of restoration projects in coastal Louisiana. LCA monitoring plans will incorporate existing monitoring networks to the extent practicable and participate in the implementation of CRMS-Wetlands. Such participation can maintain the data consistencies necessary to conduct project and programmatic adaptive management.

4.2. Monitoring Plan for the Convey Atchafalaya River Water to Northern Terrebonne Marshes 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 LCA ARTM 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 ARTM project, monitoring for ecological success 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. 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.

Additional monitoring is identified as supporting information needs that will help to further understand and corroborate project effects.

Objective 1: Prevent habitat conversion and reduce and/or reverse future wetland loss

Performance Measure 1: habitat and land:water classification

Desired Outcome: Reduce the rate of land loss (10 year post-construction trend) compared to the pre-project condition excluding storm events (1985 – 2012)

Monitoring Design: Habitats will be classified using Landsat TM scenes collected in two pre-construction, 5 construction and 10 post-project construction years and Digital Orthophoto Quadrangles for three construction and two post-project construction years, as well as any available field data in the study area to assess land:water trends and habitat distribution.

Monitoring Design: For ground-truthing of Landsat imagery, permanent vegetation monitoring stations will be established at 24 locations for assessing project area vegetation communities, and sampled annually. These stations will be monitored 2 years during PED, 5 years during construction, and 10 years post-construction.

Objective 2: Achieve and maintain characteristics of sustainable marsh hydrology.

Performance Measure 2: Depth, duration and frequency of marsh flooding

Desired Outcome: Maintain marsh hydrology in range of conditions that support sustainable fresh, intermediate and brackish marsh

Monitoring Design: Marsh hydrology will be assessed at 24 stations within the project area and additional hydrologic stations located in marshes adjacent to Bayou Copasaw, Minors Canal, Houma Navigational Canal, and Grand Bayou. The need for additional stations will be determined during pre-construction engineering and design.

Desired Outcome: Maintain hydrology that matches the predicted salinity, temperature, discharge and flooding characteristics from modeling of selected plan at particular points in time

Supporting Information Need: Salinity, temperature, discharge (velocity and cross-channel profile), conductivity, turbidity, pH, and water surface elevation

Monitoring Design: The water gauging network (12 stations) that was established for model development will continue to be monitored during two years during pre-construction, 5 years during construction and 10 years post-project construction.

Objective 3: Reduce salinity levels in project area

Performance Measure 3: Pore water and surface salinity

Desired Outcome: Maintain range of variability in salinities at desired locations that will be identified from modeling output from recommended plan to maintain baseline vegetation community types.

Monitoring Design: Marsh salinity will be assessed at 24 stations within the project area and additional hydrologic stations located in marshes adjacent to Bayou Copasaw, Minors Canal, Houma Navigation Canal, and Grand Bayou, as needed. The need for additional stations will be determined during pre-construction engineering and design.

Objective 4: Increase sediment and nutrient load to surrounding wetlands

Performance Measure 4: Elevation and accretion

Desired Outcome: Maintain marsh elevation within tidal frame (relative sea level rise = 0 cm yr^{-1}).

Monitoring Design: Marsh elevation and accretion will be assessed at 24 stations within the project area and at additional hydrologic and salinity stations located in marshes adjacent to Bayou Copasaw, Minors Canal, Houma Navigation Canal, and Grand Bayou, as needed. The need for additional stations will be determined during pre-construction engineering and design.

Supporting Information Need: Total suspended sediment and macro nutrients

Desired Outcome: Increase sediment and nutrient load

Monitoring Design: Collection of total suspended sediment and nutrients (total nitrogen, nitrate + nitrite, total phosphorus) will be used to evaluate change compared to existing conditions using a subset of the water and salinity gauging network (12 stations) in proximity to Bayou Copasaw, Minors Canal, Houma Navigation Canal and Grand Bayou.

Objective 5: Sustain productive fish and wildlife habitat

Performance Measure: Fish population data

Desired Outcome: Sustain current levels of productive fish and wildlife habitat after project construction

Monitoring Design: Pre- and post-project data collected by LDWF will be utilized to determine status and trends of fishery populations in the project area. Assessments utilizing this data will be performed as long as data are made available. Expansion of the current LDWF sampling regime is not proposed at this time. If it is determined, in coordination with LDWF and other resource agencies, that additional sampling is needed, it will be considered during pre-construction engineering and design.

4.2.1 Monitoring Procedures

The following monitoring procedures will provide the information necessary to evaluate the previously identified project objectives for the Convey Atchafalaya River Water to Northern Terrebonne Marshes project. Unless otherwise stated, monitoring will begin during PED for two years, continue for 5 years during construction, and continue for another 10 years post-construction.

Land:Water and Habitat Classification: Land:water and habitat summaries will be performed on classified Landsat TM scenes for 1985, 1987, 1990, 1998, 1999, 2001, 2002, 2004, 2005, 2006, 2008, 2009, 2010, 2011, and 2012 in the project area. Linear regression will be used to calculate land change trends based on those years, excluding anomalous data. Post-project trends calculated from Landsat TM scenes classified annually will be compared to the pre-project trends to determine whether conversion of land to open water is being reduced in the project area. Digital Orthophoto Quarter Quadrangles (DOQQ) of the project area will need to be flown and habitat analysis completed to capture land cover for one pre-construction and two post-construction years.

Channel Hydrology: Continuous salinity, temperature, velocity and water surface elevation measurements will be conducted at 12 locations along the GIWW, Bayou Copasaw, Minors Canal, Houma Navigation Canal, Bayou Grand Caillou, Cutoff Canal and Grand Bayou. Discharge will be measured at these stations using velocity and the channels cross-sectional area. Measurements will be taken at the mouth and downstream of the mouth of each bayou/canal. Stations will be serviced and data downloaded quarterly or on an as-needed basis.

Marsh Hydrology: To determine whether sustainable marsh hydrology is being maintained in the project area, water levels in marshes adjacent to flow pathways will be measured hourly with datasondes at 24 stations within the project area. Each water level gauge will be surveyed relative to the top of a rod-surface elevation table (RSET) to NAVD88 and will be serviced approximately 9 times per year. Duration and frequency of flooding will be calculated using water levels along with the average elevation of the marsh surface.

Water Quality: Measuring and monitoring various water quality parameters, including salinity, nutrients, conductivity, turbidity, pH, and total suspended solids (TSS) will indicate whether riverine inputs are impacting water quality in the project area. Monitoring these parameters will document the water quality of the diverted water. To determine if riverine inputs are flushing high salinity waters from the project area, the concentration of salt in surface water will be measured hourly at hydrology locations and discretely by using a porewater sipper device when sondes are serviced (Folse et al. 2008). Synoptic measurements of nutrients (total nitrogen, Nitrate+Nitrite, total phosphorus) and total suspended solids will be taken 6 to 9 times per year at a subset of the water and salinity gauging network in proximity to Bayou Copasaw, Minors Canal, Houma Navigation Canal and Grand Bayou according to methods described in Day et al. (2001) and Edwards (1999). Duration of this sampling schedule will be dependent upon final project design and operations. Water samples will be collected in 500-mL acid-washed polyethylene bottles, stored on ice and taken to a laboratory for processing. Within 24 hrs, 60 mL from each water sample will be filtered through pre-rinsed 25-mm 0.45-µm Millipore filters. Samples and filters will be frozen until analyzed within one month of collection. Nitrate and nitrite will be determined separately using automated cadmium reduction method, ammonium by automated phenate method and phosphate by automated ascorbic acid reduction method (Standard Methods 1992). Suspended solids will be sampled at points in the center, left and right of the channel cross-section with a depth-integrated sampler.

Vegetation: Vegetation sampling will occur at the 24 marsh hydrology stations and begin in PED for 2 years, continue for 5 years during construction, and for 10 years post-construction. Sampling will occur annually between August and October at each site, and will consist of sampling ten replicate 2-m x 2-m stations located along a transect within a 200-m x 200-m square.

Species composition and percent cover for each station will be determined using visual estimates of cover following the Braun-Blanquet cover scale (Mueller-Dombois and Ellenburg 1974). The species composition data obtained from vegetation sampling will be used as a means for ground-truthing the land:water and habitat classifications.

Sediment Accretion and Elevation: Sediment accretion and elevation will be assessed at the 24 marsh hydrology stations semi-annually, and begin in PED for 2 years, continue for 5 years during construction, and for 10 years post-construction. Sediment elevation within the project area will be measured over time by using the rod-surface elevation table (RSET) technique which is described in Folse et al. (2008) and references therein. The RSET allows for precise, repeated measurements of the soil elevation. Marker horizons consisting of feldspar clay will be used to determine vertical accretion/loss within the project area (Folse et al. 2008).

Fisheries: Monitoring procedures for fisheries status and trends monitoring will follow established LDWF protocols.

4.2.2 2 Use of Monitoring Results and Analyses

Project monitoring is the responsibility of the CPRA and the USACE. However, because of the need to integrate monitoring for programmatic adaptive management, extensive agency 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 (SWAMP).

The results of the monitoring program will be communicated to an Assessment Team (AT) that will use the information to assess system responses to management, evaluate overall project performance, construct project report cards, and recommend modifications (i.e., adaptation) of the Convey Atchafalaya River Water to Northern Terrebonne Marshes project 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 S&T Office, and further developed by the LCA S&T Data Management Working Group.

Data standards, quality assurance and quality control procedures and metadata standards will be prescribed 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 ARTM 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 ARTM Assessment Team, project managers, and decision-makers.

6.0 ASSESSMENT

The assessment phase of the framework describes the process by which the results of the monitoring efforts will be compared 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 ARTM 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 adaptive management program. The assessments will continue through the life of the project or until it is decided that the project has successfully achieved its goals and objectives.

6.1 Assessment Process

The Assessment Team assigned to the ARTM 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 evaluating project effectiveness.

Appropriate statistical comparisons (e.g., hypothesis testing, ANOVA, multivariate methods, etc.) will be used to summarize monitoring data as they are obtained and compare these data summaries with the 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) termination of operation of the ARTM 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 evaluating 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 project.

6.3 Frequency of Assessments

Ideally, the frequency of assessments for the ARTM 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 ARTM 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 Convey Atchafalaya River Water to Northern Terrebonne Marshes 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. Specific decision criteria will be developed during the pre-construction engineering and design phase of the project.

To meaningfully manage these parameters, hydraulic models may need to be revisited and recalibrated based on field data and observations prior to change in management of a project. Additional modeling or experimental efforts might be required to understand and manage observed biotic responses.

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 marsh creation, terracing, canal modification, gate aperture controls at water control structures, spoil bank gapping, or additional culverts, shoreline protection features, and modifications to the Houma Navigation Canal Lock Complex.

7.3 Project Close-Out

Close-out of the project would occur when at 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 the project objectives have been met, or when it is clear that they will be met based upon the trends for the site conditions and processes. Project success would be based on the following:

- Stabilization in the total area of marsh habitat
- Stabilization of elevations
- Stabilization of plant relative abundance
- Improvement in water quality

There may be issues related to the sustainability of the project that would require some monitoring and management beyond achieving these objectives. Due to the 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 PED during the development of the detailed monitoring and adaptive management plans. The current total estimate for implementing the monitoring and adaptive management programs is approximately $21,189,500. Unless otherwise noted, costs should begin at the onset of construction and should be budgeted as construction costs.

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. It is proposed that all data collection activities follow consistent and standardized processes regardless of the organization responsible for monitoring. Costs were estimated for monitoring equipment, monitoring station establishment, data collection, quality assurance/quality control, data analysis, assessment, and reporting for the proposed monitoring elements and are summarized in Table 1 below. 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 approximately $19,209,500. 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 Convey Atchafalaya River Water to Northern Terrebonne Marshes Project.

Category	Activities	2 yr PED Set-up & Data Acquisition	5 yr Construction	10 yr Post Construction	Total
Monitoring: planning and management	Monitoring workgroup, Drafting detailed monitoring plan, Working with PDTs on performance measures	$135,900	$91,015	$221,127	$448,042
Monitoring: data collection	Landrights, site construction, and surveying	$387,900			$387,900
	Land:Water	$40,500	$110,925	$269,498	$420,957
	Habitat Classification		$203,049	$493,320	$696,369
	Channel Hydrology	$501,400	$1,372,051	$3,333,488	$5,206,916
	Marsh Hydrology	$687,500	$1,881,280	$4,570,693	$7,139,433
	Water Quality	$54,900	$150,175	$364,859	$569,911
	Vegetation	$194,600	$532,438	$1,293,592	$2,020,594
	Sediment accretion and elevation	$77,800	$212,975	$517,437	$808,238
	Fisheries	$0*	$0*	$0*	$0*
Database Management	Database development, management, and maintenance, Webpage development for communication of data to stakeholders	$145,500	$398,191	$967,430	$1,511,128
TOTAL		**$2,226,000**	**$4,952,099**	**$12,031,444**	**$19,209,488**

*Costs have not been included for fisheries monitoring because it is assumed to be provided by existing LDWF monitoring.

8.2 Costs for Implementation of Adaptive Management Program

Costs for the project adaptive management program were based on level of effort. The current total estimate for implementing the adaptive management program is $1,980,000. 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 Convey Atchafalaya River Water to Northern Terrebonne Marshes Project.

Category	Annual Cost	7 yr Total
Detailed AM Plan and Program Set-up (During PED and Construction)	$100,000	$700,000
TOTAL	**$100,000**	**$700,000**

Table 3. Preliminary Cost Estimates for Implementation of Adaptive Management Program for the LCA Convey Atchafalaya River Water to Northern Terrebonne Marshes 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 Convey Atchafalaya River Water to Northern Terrebonne Marshes 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 FUNCTION 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, knowns and unknowns about the 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 species 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 are 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 diverge from the desired effect;
- Outlining further restoration and/or research and 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 providing 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” (Fischenich 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 and Mazzotti 2005). The LCA team has decided to utilize the Ogden model (Ogden and Davis 1999). The LCA team recognizes that CEM development, like plan formulation, 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 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 the attribute is responding to projects designed to correct adverse effects of stressors (i.e., to determine success of the project).

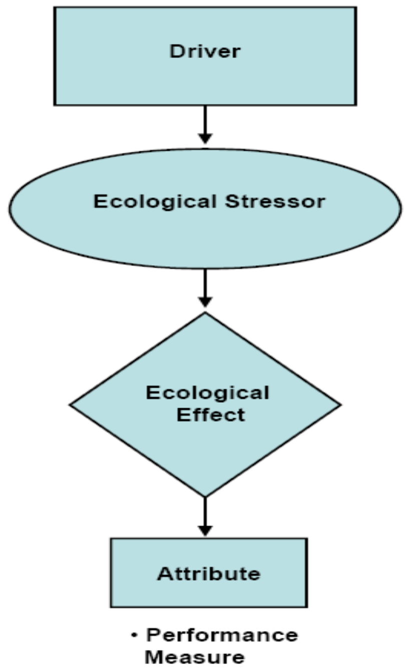

Figure 1. Conceptual Ecological Model Schematic Diagram.

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 Convey Atchafalaya River Water to Northern Terrebonne Marshes (ARTM) 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 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 ARTM 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 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. This 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 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 increasing Atchafalaya River influence to central and eastern Terrebonne marshes via the Gulf Intracoastal Waterway (GIWW) by enlarging channel constrictions and increasing Atchafalaya flows into the GIWW. This Feasibility Study is authorized by the 2004 LCA Plan and the 2007 Water Resources Development Act (WRDA 2007), which requires 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.

Pursuant to the completion of this Feasibility Study, a CEM was developed to establish causal hypotheses that best explain the major alterations in the natural systems within the study area, to identify attributes of the natural system that are likely to exhibit a response to project features, and to identify performance measures that can be monitored to determine the degree of project success with respect to countering or correcting the natural system alterations.

2.2.1 Project Goals and Objectives

The goal of the ARTM project is to reduce the current trend of degradation of the Terrebonne marshes, so as to contribute towards achieving and sustaining a 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:

- Prevent, reduce, and/or reverse future wetland loss;
- Protect vital socioeconomic resources including cultures, community, infrastructure, business and industry, and flood protection;
- Achieve and maintain characteristics of sustainable marsh hydrology;

- Reduce salinity levels in the project area;
- Increase sediment and nutrient load to surrounding wetlands;
- Increase residence time of fresh water; and
- Sustain productive fish and wildlife habitat.

2.2.2 Project Description

The ARTM study area comprises approximately 1,100 square miles (~700,000 acres) in southern Louisiana in the vicinity of the City of Houma and Terrebonne Parish. The study area is contained within the larger LCA Ecosystem Restoration Study Area, which has been identified as the Louisiana coastal area from Mississippi to Texas. The proposed project is located in the Deltaic Plain within Subprovince 3, one of the four Subprovinces identified in the LCA Study Area.

The study area is bound to the west by the Lower Atchafalaya River, to the east by the Bayou Lafourche ridge, and to the north by the Bayou Black ridge from the Lower Atchafalaya River to the City of Houma and by the GIWW from the City of Houma to the Bayou Lafourche ridge. The southern boundary of the project was roughly based on the 2007 delineation between brackish and saline marsh habitat as identified by Sasser et al. (2008).

3.0 CONCEPTUAL ECOLOGICAL MODEL DISCUSSION

The CEM developed for the ARTM project is presented in Figure 2. Model components are identified and discussed in the following subsections.

3.1 DRIVERS

3.1.1 Anthropogenic Alterations – Altered Hydrology

The central and eastern marshes of the project area do not receive adequate amounts of fresh water or sediments from the Atchafalaya River (via the GIWW) or from the Mississippi River (via Bayou Lafourche). Anthropogenic controls regulating the volume of water entering the Atchafalaya River and Bayou Lafourche from the Mississippi River, in addition to the distance of the marshes from these potential sources of fresh water and sediments, limit the benefits to the central and eastern marshes. Consequently, subsidence and sea level rise are outpacing accretion in most central and eastern marshes, resulting in increased submergence of marsh vegetation and eventual marsh loss. In addition, canals and associated spoil banks, constructed for navigation and/or oil and gas development, can be found throughout the project area. The canals serve as easy routes for fresh and saltwater movement, serving as conduits for beneficial freshwater to escape the system and for harmful saltwater to enter the system. In addition, spoil banks compartmentalize wetlands, restricting water and animal movement between areas.

3.1.2 Storms and Hurricanes

Coastal storms, particularly tropical cyclone events, exert a stochastic but severe influence on the study area. Data obtained from the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center indicate that the storm centers of at least 19 tropical cyclones with a Saffir-Simpson Hurricane Scale of Category 2 or higher have passed within 50 miles of the study area during the interval 1851-2008, and at least 31 such tropical cyclones have passed within 100 miles of the study area during the same interval. The most recent tropical cyclones to affect the study area were Hurricanes Katrina and Rita, which occurred in August 2005 and September 2005, respectively, and Hurricanes Gustav and Ike, which occurred in September 2008.

Principal impacts to the marshes in the study area as a result of tropical cyclone events are due to storm surge and associated erosion and saltwater intrusion. Storm surge exerts widespread stress upon vegetation through the introduction of storm surge waters that exhibit higher salinity concentrations than are normally present in surface waters within the study area and by direct erosion of marsh plants and soils. Hurricanes Rita and Ike resulted in measurable storm surges within the study area. Water gage data from the Houma Navigation Canal indicate storm surges from Hurricanes Rita and Ike of approximately 5.0 feet and 6.3 feet above average water levels, respectively.

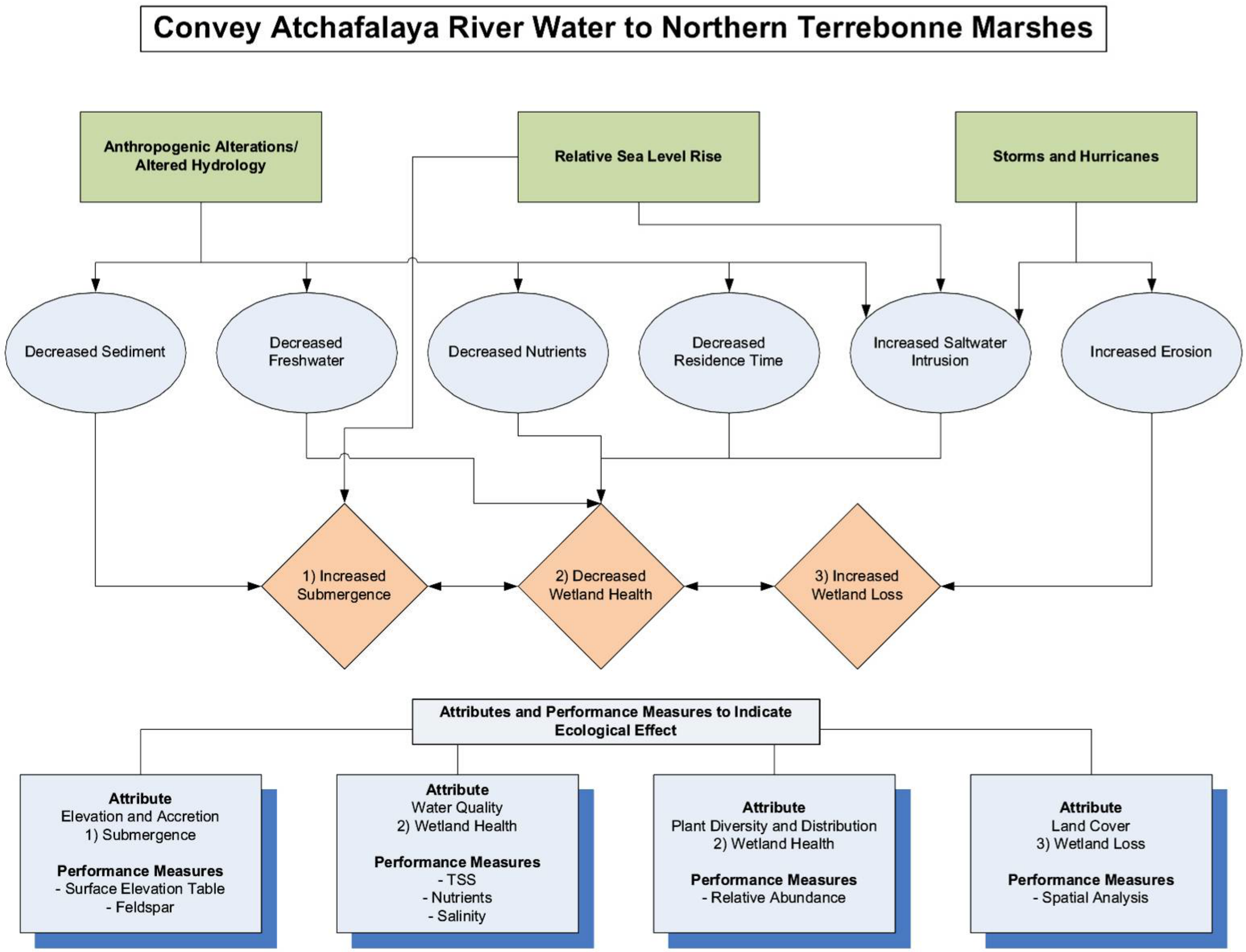

Figure 2. Conceptual Ecological Model, LCA Convey Atchafalaya River Water to Northern Terrebonne Marshes Project.

3.1.3 Relative Sea Level Rise

Relative sea level rise consists of eustatic sea level rise combined with subsidence. Eustatic sea level rise is defined as the global increase in oceanic water levels primarily due to changes in the volume of major ice caps and glaciers, and expansion or contraction of seawater in response to temperature changes. Baseline (i.e. recent) eustatic sea level rise in the project area is approximately 0.75 feet/century. Subsidence is the decrease in land elevations, primarily due to consolidation of sediments, faulting, groundwater depletion, and possibly oil and gas withdrawal. Subsidence in the project area is approximately 2.35 feet/century. Relative sea level rise affects project area marshes by gradually inundating marsh plants. Marsh soil surfaces must vertically accrete to keep pace with the rate of relative sea level rise or marshes eventually convert to open water due to the depth of submergence.

3.2 ECOLOGICAL STRESSORS

3.2.1 Decreased Freshwater, Sediment, Nutrients, and Residence Time

The altered hydrology of the project area results in less freshwater and associated sediment and nutrients being delivered to marsh vegetation. Lack of freshwater facilitates increased saltwater intrusion and its associated effects on marsh vegetation. Vertical accumulation of wetland soils is achieved by accretion of mineral sediment inputs and/or organic accumulation resulting from above and below-ground plant productivity (DeLaune et al. 1983; DeLaune et al. 1990a). The survival and productivity of marshes is reliant on these soil-building processes to offset submergence and sea level rise (DeLaune et al. 1978; DeLaune et al. 1979; DeLaune et al. 1990b). As the natural hydrology of the project area marshes has become short-circuited by canals, the residence time of the limited freshwater inputs has also decreased. Shorter residence times result in less settling of suspended sediments and less uptake of nutrients.

3.2.2 Increased Saltwater Intrusion

The altered hydrology of the project area facilitates increased saltwater intrusion and increased tidal exchange by providing efficient conduits for loss of freshwater and intrusion of saltwater. Wetland plant species have evolved different levels of tolerance to salinity and respond to salinity with different mechanisms. Numerous studies have demonstrated that elevated salinity can negatively affect all wetland species and can contribute to large-scale vegetation dieback (Chabreck and Linscombe 1982; McKee and Mendelssohn 1989). Storm surge can also be a mechanism for saltwater intrusion. This form of saltwater intrusion can be particularly detrimental to areas that have been hydraulically isolated, leading to extended durations of saltwater inundation.

3.2.3 Increased Erosion

Significant and immediate erosion of marsh vegetation and associated soils can occur as a result of storm surge events. Losses may be more significant in areas that are already under stress from other ecological stressors, but healthy marsh systems can be significantly impacted as well.

3.3 ECOLOGICAL EFFECTS

3.3.1 Increased Submergence

Wetland plants employ different physical and/or metabolic mechanisms that enable them to tolerate and grow in flooded soils. However, in almost all cases plants are dependent on the maintenance of soil surface elevations to sustain the flooding regime to which they are adapted. Increases in flooding depth and duration stress plants by altering metabolic function and negatively impacting productivity, survival, and regeneration. Relative sea level rise in the project area combined with insufficient accretion results in marsh systems with reduced productivity, survival, and regeneration due to submergence. Organic matter accumulation is also reduced, further exacerbating the impacts of submergence.

3.3.2 Decreased Wetland Health

Decreased freshwater, decreased nutrients, decreased residence time, increased saltwater intrusion, and increased submergence all act to decrease the overall health of the project area marshes. As marsh plants become stressed by inundation and saltwater intrusion, their productivity, survival, and regeneration are all negatively impacted. Over time, healthy marshes gradually decline to more interspersed marshes and eventually convert to open water.

3.3.3 Increased Wetland Loss

Wetland loss in the project area can be the result of gradual decline of marsh vegetation due to inundation and saltwater intrusion eventually leading to complete loss of marsh vegetation or the result of storm surge events. As marsh vegetation is lost, underlying soils are more susceptible to erosion and are typically lost as well, leading to deeper water and precluding marsh regeneration. Significant accretion of sediments is then required in order for marsh habitat to reestablish.

3.4 ATTRIBUTESAND PERFORMANCE MEASURES

3.4.1 Elevation and Accretion

Ground surface elevation has been identified as a key indicator of project success with respect to increasing sediment and nutrient load within the study area. Comparison of pre-project elevations with post-project elevations would serve to determine if sediment input and soil accretion is occurring within the study area in response to project features. A post-project decrease in the rate of elevation decline would implicitly indicate the introduction of nutrients and sediment into the marshes as a result of the project. Two performance measures have been identified for this attribute, including surface elevation table (SET) measurements and feldspar marker horizon measurements.

- *Surface Elevation Table (SET) measurements* provide a constant reference plane in space from which the distance to the sediment surface can be measured by means of pins lowered to the sediment surface. Repeated measurements of elevation can be made with high precision because the orientation of the table in space remains fixed for each sampling. Elevation change measured by the SET is influenced by both surface and subsurface processes occurring within the soil profile.

- *Feldspar marker horizon measurements* involve the placement of a cohesive layer of feldspar clay on the ground surface. Soil borings are extracted at the marker horizon location periodically to measure the amount of soil deposition and/or accretion that has occurred above the horizon since placement. Significant quantities of soil atop marker horizons are indicative of soil building within the area, which in turn indicates an increase in relative elevation.

A post-project stabilization of elevation as evidenced by SET measurements or documented soil accretion atop a marker horizon within the study area would be an indication of significant project success, while a post-project decrease in the rate of decline in elevation would be an indication of moderate project success. Conversely, no change in the rate of elevation decline post-project within the study area would indicate that the project did not succeed in offsetting subsidence and, by extension, habitat conversion and future land loss.

3.4.2 Land Cover

Land cover has been identified as a key indicator of project success with respect to preventing, reducing, or reversing wetland loss in the study area. Comparison of pre-project land cover characteristics with post-project land cover characteristics would serve to determine if the rate of conversion of marsh habitat to open water within the study area declines post-project.

- *Spatial analysis* has been identified as a performance measure for the determination of the response of land cover 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 composition within the study area.

A post-project stabilization in the total area of marsh habitat would be an indication of significant project success, while a post-project reduction in the rate of marsh loss within the study area would be an indication of moderate project success. Conversely, no change in the rate of marsh loss within the study area would indicate that the project did not succeed in preventing habitat conversion and, by extension, future habitat loss.

3.4.3 Plant Diversity and Distribution

Plant diversity and distribution has been identified as a key indicator of project success with respect to preventing, reducing, or reversing wetland loss in the study area. Comparison of pre-project vegetation monitoring data with post-project vegetation monitoring data would serve to determine if plant communities within the study area change in response to project features. Relative abundance has been identified as the performance measure for this attribute.

- *Relative abundance* is a measure of the abundance or dominance of each species present in a sample. Relative abundance can be used to document the degree of impact in an area by measuring both species dominance and evenness. Relative abundance can be used to assess marsh health by comparing plant density before and after project implementation. The Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974) as described in Steyer et al. (1995) will be utilized to measure relative abundance.

A post-project stabilization of relative abundance within the study area would be an indication of significant project success, while a post-project reduction in the rate of decline of relative abundance would be an indication of moderate project success. Conversely, no change in the rate of decline of relative abundance post-project would indicate that the project did not succeed in increasing vegetation productivity.

3.4.4 Water Quality

Water quality has been identified as a key indicator of project success with respect to reducing salinity levels and increasing sediment and nutrient loads within the study area. Comparison of pre-project water quality with post-project water quality would serve to determine if freshwater throughput is introducing sediments and nutrients and flushing out saline waters within the study area in response to project features. Three performance measures have been identified for this attribute, including total suspended solids (TSS), nutrients, and salinity.

- *Total suspended solids* (TSS) is a measurement of the total volume of sediment suspended in a given volume of water. Project features are designed to increase the amount of freshwater, and consequently suspended sediments, delivered to marshes in the study area.
- *Nutrients* are chemical compounds or minerals contained in surface waters that are extracted by organisms for nourishment. Common nutrients in surface waters include nitrates, phosphates, and ammonia. Project features are designed to increase the amount of freshwater, and consequently nutrients, delivered to marshes in the study area.
- *Salinity* is a measure of the concentration of dissolved salt in a given volume of water. Surface waters within the study area often exhibit elevated salinity levels with respect to their historic levels due to the altered hydrology of the area and periodically due to storm surge. Project features are designed to increase the amount of freshwater in the project area and consequently reduce salinity levels.

Post-project improvements in water quality within the study area, as evidenced by analysis of these measures, would be an indication of significant project success, while a post-project stabilization or decline in water quality within the study area would indicate that the project did not succeed in increasing riverine influence on the study area.

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