Appendix I

ADAPTIVE MANAGEMENT/ MONITORING PLAN

Louisiana Coastal Area (LCA) Program:

Amite River Diversion Canal Modification Project

Feasibility-Level Monitoring and Adaptive Management Plan

July 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) Program: Amite River Diversion Canal Modification 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 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:

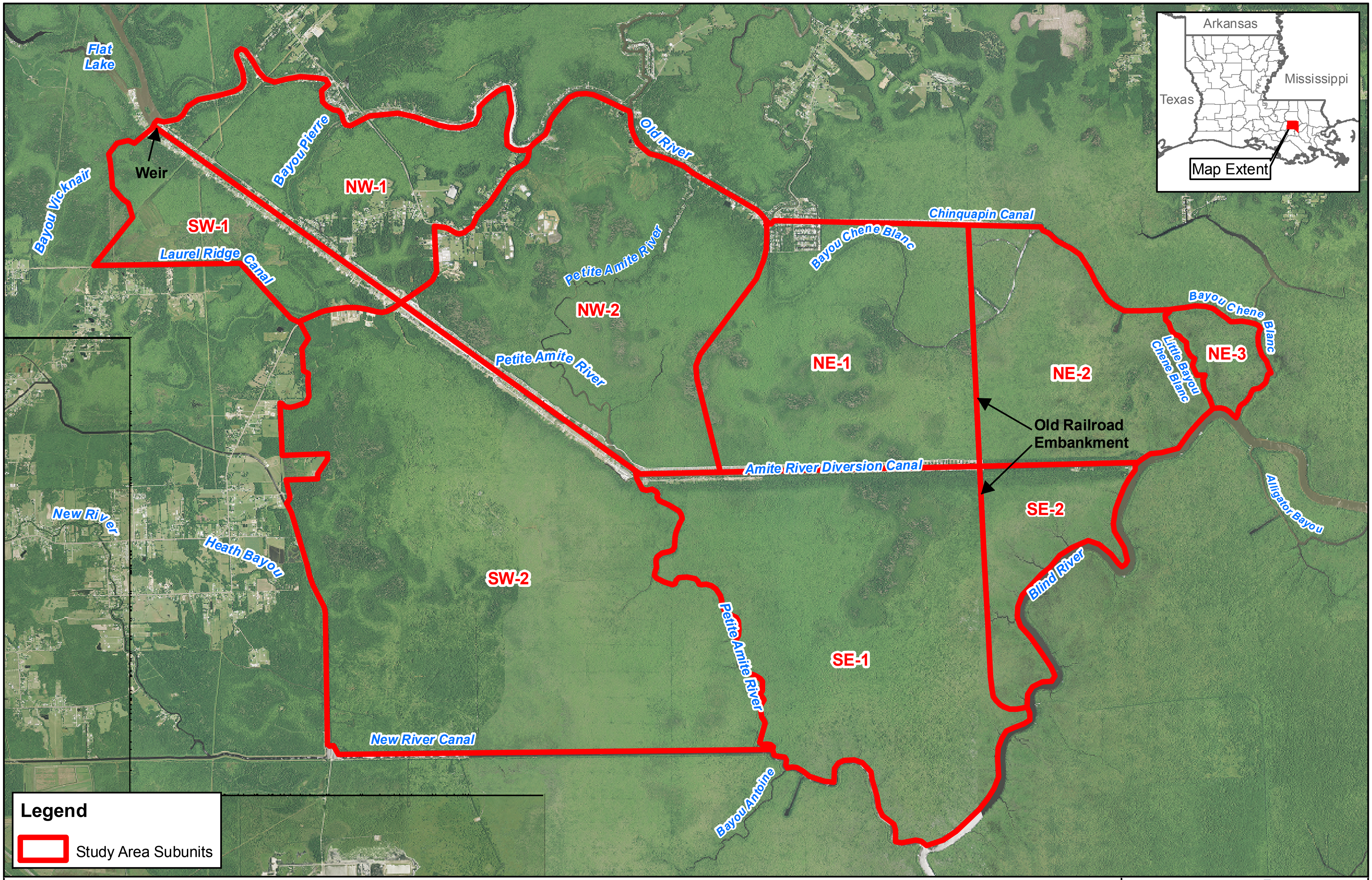
> *"The Secretary may carry out a program for ecosystem restoration, Louisiana Coastal Area, Louisiana, substantially in accordance with the report of the Chief of Engineers, dated January 31, 2005*."

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 for the projects 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



STUDY AREA AND SUBUNITS

Amite River Diversion Canal Modification
Ascension and Livingston Parishes, Louisiana

Image: 2009 Ascension and Livingston Parishes USDA-FSA-APFO NAIP MrSID Mosaic

Figure: 2	
Date: October 2009	
Scale: 1:80,000	
Source: USDA/GEC	
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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).

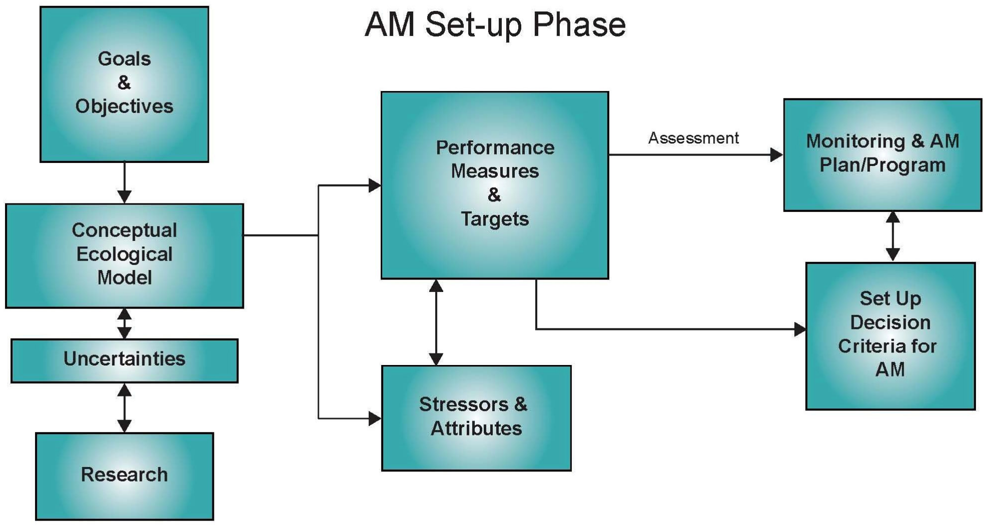

Figure 1. Set-up Phase of the LCA Adaptive Management Framework.

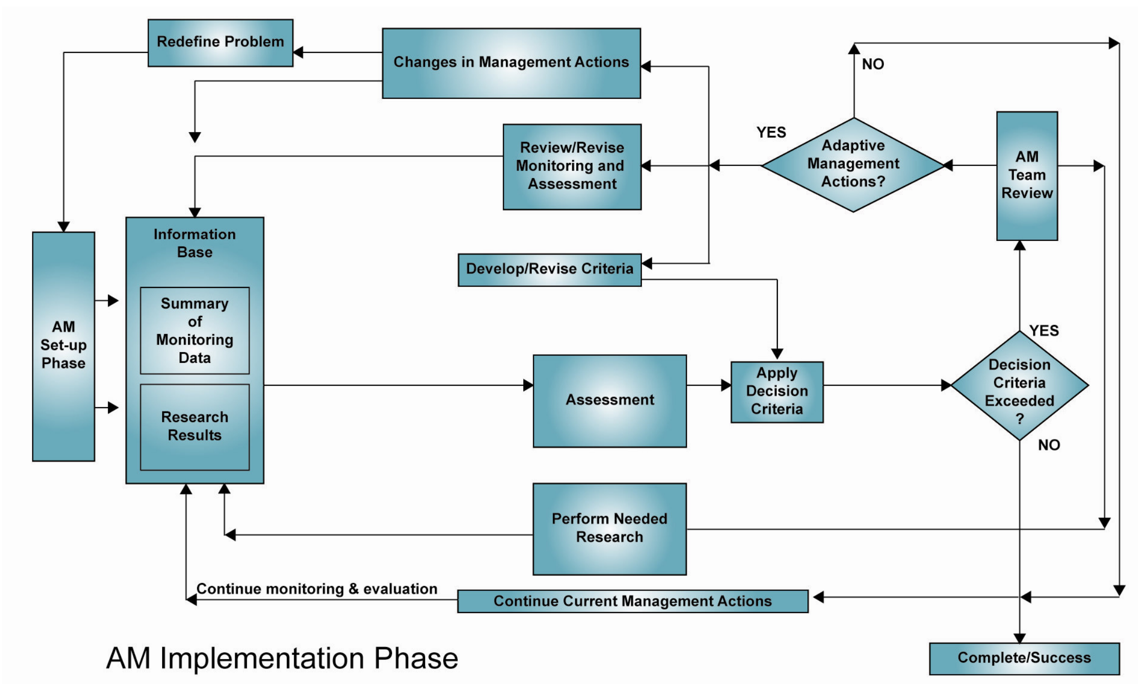

Figure 2. Implementation Phase of the LCA Adaptive Management Framework.

1.3 LCA Communication Structure for Implementation of Adaptive Management

To execute an adaptive management strategy for the LCA Ecosystem Restoration Plan, a communication structure has been identified (Figure 3). The structure establishes clear lines of communication between LCA Program Management, an 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.

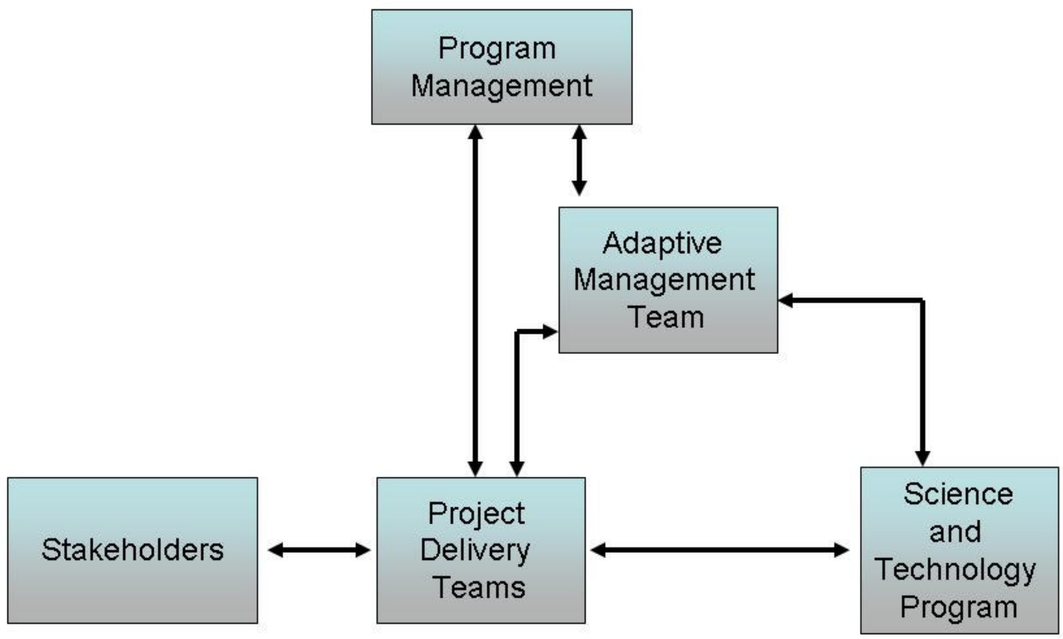

Figure 3. LCA Communication Structure for Implementation of Adaptive Management.

As part of the LCA Program communication structure for implementation of adaptive management (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 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 Adaptive Management Framework Team for this project were Tomma Barnes, USACE-MVN ; Steve Bartell, E2 Consulting Engineers; Laura Brandt, USFWS; 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 John Troutman, OCPR.

The resulting adaptive management plan for the Amite River Diversion Canal Modification project describes and justifies whether adaptive management is needed in relation to the tentatively selected plan (TSP) 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 Amite River Diversion Canal Modification 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. Subsequent sections describe monitoring, data management, and assessment in support of monitoring and 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, 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 Amite River Diversion Canal Modification project. These goals and objectives were subsequently refined through interactions with the LCA Adaptive Management Framework Team. The overarching goal of the LCA Program is to contribute toward achieving and sustaining a coastal ecosystem that can support and protect the environment, economy, and culture of southern Louisiana and thus the Nation. The goal of this project is to reverse the trend of degradation within the western Maurepas Swamp ecosystem. The swamp has been adversely affected by the construction of the Amite River Diversion Canal (ARDC) ....The specific restoration objectives of the project are to:

- Increase hydrologic connectivity between the degraded swamp and bottomland hardwood habitats within the study area and the ARDC by increasing the exchange of freshwater, sediments, and nutrients.
- Facilitate natural hydrologic cycles within the study area by reducing impoundment in degraded swamp and bottomland hardwood habitats adjacent to the ARDC which would improve tree productivity and seedling germination.
- Reduce habitat conversion of swamp to marsh and open water within the study area.
- Improve fish and wildlife habitat within the study area.

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 tentatively selected plan (TSP).

The project TSP is Alternative 33. This alternative has three openings on the north bank of the ARDC, with the westernmost cut also extending through the railroad grade; three bifurcated conveyance channels; side casting of dredged material; one cut in the railroad grade north of the ARDC; and dredged material berm (spoil bank) and swamp floor vegetative plantings.

2.3 Conceptual Ecological Model for Monitoring and Assessment

As part of the planning process, members of the Amite River Diversion Canal Modification project PDT developed a conceptual ecological model for the swamp ecosystem in the project area 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. There are many uncertainties associated with restoration of the coastal wetland systems included in the Amite River Diversion Canal Modification project. Some of the more significant uncertainties include the following:

- Effects of sea-level changes within the project area.
- Effect of subsidence within the project area.
- Effects of hurricanes over the next fifty years.

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 Amite River Diversion Canal Modification project, an adaptive management program would 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 Amite River Diversion Canal Modification 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 through 3 and a “YES” answer to question 4 identifies the project as a candidate that could benefit from adaptive management.

Answers to questions 1 through 3 were “NO.” However, the Adaptive Management Framework Team determined that the Amite River Diversion Canal Modification project was not a good candidate for adaptive management because there are no actions that could be taken in response to monitoring results that the USACE would define as adaptive management actions. That is, the answer to question 4 is “NO.” Although some activities could be conducted to adjust project performance, these actions would not be considered adaptive management activities. O&M for the selected plan include a yearly inspection of the bank opening locations and conveyance channels to ensure that there are no flow interruptions, such as from debris or fallen trees, which could improve project performance. However if monitoring data indicate that actions beyond yearly O&M (i.e changing the shape, size, branching, or number of conveyances channels or gaps) would be needed these would be considered structural changes and are beyond the adaptive management authority. The USACE and State of Louisiana can initiate the process for developing a new water resources project or pursue a design deficiency under the constructed project. The Framework Team also considered opportunities for active adaptive management by designing the project as a management experiment. The Team determined there were minimal active adaptive management opportunities for the project and that any lessons learned would be limited and would not likely apply to other coastal Louisiana restoration projects. While there are currently no apparent adaptive management opportunities, the Adaptive Management Planning Team can examine the performance of the project in the future. If it is determined during PED that adaptive management could help achieve any unfulfilled project objectives, the Team can recommend adaptive management for the project at that time.

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 central to properly assessing the effects of the Amite River Diversion Canal Modification project.

4.1 Rationale for Monitoring

Monitoring must be closely integrated with all other LCA program 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 discern ecosystem responses caused by project implementation (i.e., management actions) from natural variability. In coastal Louisiana, there are many existing restoration and protection projects already constructed, and many more are planned under different authorizations and programs. In combination, these projects will ultimately influence much of coastal Louisiana. Monitoring must therefore be conducted at project and system-wide scales to evaluate long-term, large-scale status and trends and short-term performance.

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 monitoring efforts that are underway in coastal Louisiana. For example, the CWPPRA produced a program that 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 Coast-wide 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 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. Such participation can maintain the data consistencies necessary to conduct project assessment and programmatic adaptive management.

4.2. Monitoring Plan for the Amite River Diversion Canal Modification 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 Amite River Diversion Canal Modification project Monitoring and Assessment 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 Amite River Diversion Canal Modification 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 necessary to evaluate success within the project area. Although the law allows for a ten-year cost-shared monitoring plan post construction, 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 post construction, 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 assessment of the project. 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 to help further understand and corroborate project effects. The monitoring plan focuses on sampling locations within the project area in order to make decisions regarding project success. Monitoring sites within the study area are also proposed for use as reference sites.

Objective 1: Increase hydrologic connectivity between the degraded swamp and bottomland hardwood habitats within the study area and the ARDC by increasing the exchange of freshwater, sediments, and nutrients.

Performance Measure 1: Freshwater distribution during operational events

Desired Outcome: Increase hydrologic connectivity and area of extent of freshwater movement into project area above pre-project conditions.

Monitoring Design: Synoptic hydrologic surveys, using salinity, temperature, dissolved oxygen, and velocity as tracers, will be conducted during selected low flow and high flow operational events to track distribution of freshwater. Sampling will be conducted twice annually in the first three years and as required thereafter.

Objective 2: Facilitate natural hydrologic cycles within the study area by reducing impoundment in degraded swamp and bottomland hardwood habitats adjacent to the ARDC which would improve tree productivity and seedling germination.

Performance Measure 2a: Swamp vegetation production and extent

Desired Outcome: Increase in basal area increment of baldcypress & tupelo in the swamp from existing conditions (existing conditions defined from pre-construction measurements from CRMS-Wetlands stations and Southeastern Louisiana University historical monitoring)

Monitoring Design: Diameter at breast height (dbh) and overstory tree cover will be measured in the fall in two pre-construction years and four post-construction years (within the first 10 years).

Performance Measure 2b: Number of baldcypress and tupelo saplings

Desired Outcome: A 25% increase in the number of naturally recruited baldcypress and tupelo saplings per acre from pre-project conditions ten years after project implementation. Performance of this measure is most dependent on achieving extended dry periods in the swamp.

Monitoring Design: Understory vegetation (herbaceous, seedling, and sapling) will be measured in the fall in two pre-construction and four post-construction years (within the first 10 years) to assess regeneration and changes in cover classes

Performance Measure 2c: Depth, duration and frequency of flooding in the swamp

Desired Outcome: Increase or decrease from pre-project conditions average flood durations (existing conditions defined from pre-construction measurements from CRMS-Wetlands stations)

Desired Outcome: Maintain dry periods (moist soils) in the swamp for a minimum 7-35 days during summer and early fall for seed germination and maintain water levels below seedling height to promote seedling survival.

Monitoring Design: Water-level recorders will be deployed in six key areas to measure water depths at the needed frequencies. Recorders will be established 3 years prior to construction to determine existing conditions and will be monitored for 10 years post-construction or until desired outcomes are achieved.

Supporting Information Need: A deep rod-surface elevation table (RSET) rod will be installed where hydrologic measurements are taken to establish an elevation benchmark.

Objective 3: Reduce habitat conversion from swamp to marsh and open water within the study area.

Performance Measure 3: Habitat and land:water classification

Desired Outcome: Maintaining immediate pre-construction acreage of baldcypress-tupelo swamp acreage after 10 years.

Monitoring Design: Habitats will be classified using Landsat Thematic Mapper (TM) scenes and Digital Orthophoto Quarter Quadrangles (DOQQs) for one pre- and four post-project years in the study area to assess trends in conversion between swamp, herbaceous marsh, and open water.

Supporting Information Need: Salinity data will be collected in order to characterize potential salinity stress associated with low water conditions in the fall, droughts, and intrusions associated with tropical cyclone events.

Objective 4: Improve fish and wildlife habitat within the study area.

Performance Measure 4: No applicable performance measure

Desired Outcome: Swamp production and hydroperiod measures will be used to assess this objective.

Monitoring Design: Fish and wildlife habitat is linked to the performance measures associated with objectives 1-3, focused on improving habitat. Therefore, no specific monitoring is proposed for this objective.

4.2.1 Monitoring Procedures

The following monitoring procedures will provide the information necessary to evaluate the objectives for the Amite River Diversion Canal Modification project:

Vegetation: Swamp production, regeneration, and mortality will be assessed at 3 locations within the project area and 3 reference locations, twice pre-construction and in four post-construction years. Retention and/or increase of overstory tree cover from pre-project levels will be determined using a spherical densiometer and hemispherical photography techniques as described in the CRMS-Wetlands standard operating procedures manual (Folse et al. 2008).

Densiometer readings and hemispherical photographs will be taken within sampling plots at fixed time intervals. In order to track the growth of trees within the project and reference areas, especially baldcypress and tupelo, all trees (i.e., ≥ 5 cm dbh) within each 20m x 20m sampling plot will be identified to species level, tagged with a numbered aluminum tree tag, and the diameter measured at 4.5 ft above the ground (Folse et al. 2008 and references therein). The dbh of all tagged trees will be measured at regular fixed intervals at which time both "new" trees (i.e., grew to ≥ 5 cm dbh from previous sampling time) and dead trees will also be identified. The dbh data will be used to calculate basal area increment (BAI) which will provide estimates of primary productivity (Megonigal et al. 1997). BAI is the difference in basal area (calculated from dbh) of individual trees between sampling times. The understory (i.e., < 5 cm dbh and 50 cm – 137 cm tall) and herbaceous (i.e., < 5 cm dbh and < 50 cm tall) will be sampled according to Folse et al. (2008) to determine if baldcypress and tupelo are regenerating.

Hydrology: To determine whether the hydrology in the project area is being restored and maintained to that of a natural swamp, water level, salinity, temperature, and dissolved oxygen within the swamp will be measured hourly with datasondes at 3 locations within the project area and at 3 reference locations for three pre-construction years and up to 10 years post-construction. The extent of post-construction hydrology measurements will be dependent upon whether extended dry periods are achieved within initial years following project completion. Each water level gauge will be surveyed relative to the top of the RSET (NAVD88) and will be serviced approximately 9 times per year. Duration and frequency of flooding will be calculated using water levels and the average elevation of the marsh surface. During selected operational events, synoptic hydrologic surveys will be conducted to track distribution of fresh water. Returning the hydroperiod of the project area to that of a typical swamp is essential to decreasing the mortality rate of baldcypress and tupelo trees and increasing biomass and regeneration of these species.

Land:Water and Habitat Classification: Land:water and land cover 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 swamp to marsh and open water is being reduced in the project area. DOQQs of the project area will need to be flown and habitat analysis completed to capture land cover for one pre-construction and four post-construction years.

4.2.2 Use of Monitoring Results and Analyses

Project monitoring is the responsibility of the OCPR 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.

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 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 http://www.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 Amite River Diversion Channel Modification 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. The data managers, with input from the Adaptive Management Planning Team, 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 project assessment should be identified. The data managers should collaborate with the LCA Adaptive Management Planning Team in developing a data management plan to support project assessment.

5.2 Data Storage and Retrieval

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 Data Management Working Group.

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 assessment and programmatic adaptive management efforts in order to provide reports for the Amite River Diversion Canal Modification project 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 monitoring and assessment plan.

The results of the Amite River Diversion Canal Modification 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. 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 Amite River Diversion Canal Modification project will utilize 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.

The 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 utilized to evaluate trajectories of change within the project area.

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 of 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 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 execute any of the above stated recommendations.

6.3 Frequency of Assessments

Ideally, the frequency of assessments for the Amite River Diversion Canal Modification 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 Amite River Diversion Canal Modification project. The Assessment Team will work with the project monitoring team and monitoring workgroup to produce an annual Amite River Diversion Canal Modification project report card 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 PROJECT CLOSE-OUT

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

- Pre- and post-construction comparison of survival rates of regenerated species
- Hydrologic connectivity
- Swamp regeneration

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 ASSESSMENT PROGRAM

The costs associated with implementing the LCA 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 and monitoring and assessment elements, the costs estimated in Table 1 (below) will be refined in the PED phase during the development of the detailed monitoring and assessment plan.

8.1 Costs for Implementation of Monitoring Program

Costs to be incurred during the PED phase include monitoring site construction and establishment and two years of pre-construction and construction data acquisition that establish baseline conditions. Cost calculations for post-construction monitoring are displayed as annual costs and 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 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 and assessment program for this project is $2,971,200. Unless otherwise noted, costs will begin at the onset of the PED phaseand will be budgeted as construction costs.

Table 1. Preliminary Cost Estimates for Implementation of the Monitoring and Assessment Program for the LCA Amite River Diversion Canal Modification Project (Alt. 33).

Category	Activities	1 yr PED Set-up & Data Acquisition	1 yr Construction	10 yr Post-Construction	Total
Monitoring: planning and management	Monitoring workgroup, drafting detailed monitoring and assessment plan during PED, working with PDT on performance measures	$119,000	$16,800	$194,500	$330,300
Monitoring: data collection	Landrights, site construction, and surveying	$80,800			$80,800
	Vegetation	$20,000	$28,700	$94,900	$143,600
	Hydrology	$70,700	$72,500	$837,500	$980,700
	Land:Water	$6,700	$6,800	$79,000	$92,500
	Habitat classification	$16,400		$77,900	$94,300
	Water quality	$13,500	$13,900	$160,500	$187,900
Database Management	Database development, management, and maintenance; webpage development for communication of data to stakeholders	$20,500	$21,100	$243,100	$284,700
Assessment				$243,100	$243,100
TOTAL		**$420,800**	**$193,400**	**$2,357,000**	**$2,971,200**

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ANNEX 1. LCA Amite River Diversion Canal Modification 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, 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). 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 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).

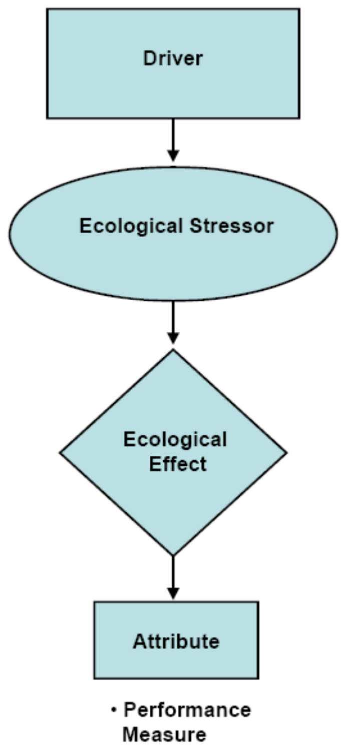

Figure 1. Conceptual Ecological Model Schematic Diagram.

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 Amite River Diversion Canal Modification 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 Amite River Diversion Canal Modification project was identified as a near-term critical feature in the *Louisiana Coastal Area (LCA),Louisiana - Ecosystem Restoration Study* (2004 LCA Plan) (USACE 2004a). 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 Amite River Diversion Canal Modification project was included in that plan along with near-term critical restoration features throughout coastal Louisiana. Including the Amite River Diversion Canal Modification 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 restoring baldcypress-tupelo swamp habitat near the Amite River Diversion Canal by constructing gaps in the dredged material berms that border the canal. 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 following project implementation 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 Amite River Diversion Canal Modification project is to reverse the trend of degradation in the western portion of the Maurepas Swamp, so as to contribute toward 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 habitat conversion and future land loss;
- Establish hydrologic connectivity to allow seasonal drying in which the swamps are drained to promote seedling germination, establishment, and survival;
- Introduce nutrients and sediment to swamps;
- Promote water circulation to improve water quality (including salinity reduction);
- Increase swamp vegetation productivity;
- Restore and preserve fish and wildlife habitat; and
- Protect vital socioeconomic resources including cultures, community, infrastructure, business and industry, and flood protection features.

2.2.2 Project Description

The study area is located in LCA Subprovince 1 in Livingston and Ascension parishes, in the vicinity of Head of Island, Louisiana, encompassing portions of Louisiana's Sixth and Third Congressional Districts (Figure 2). The study area contains approximately 19,000 acres of baldcypress-tupelo swamp habitat in the western Maurepas Swamp. The study area includes the Amite River Diversion Canal, a 10.6-mile-long flood control channel between the Amite and Blind rivers. Dredged material excavated during channel construction was deposited in dredged material berms on either side of the canal. These dredged material berms have disrupted the natural hydrologic regime in the study area. Prior studies have documented degradation in the baldcypress-tupelo swamp adjacent to the diversion canal and have demonstrated a need for ecosystem restoration of this swamp habitat through the reintroduction of a natural hydrologic regime. The proposed project involves restoration of impaired swamp habitat within the study area by gapping the dredged material berms along the diversion canal to promote hydrologic exchange between flows within the diversion canal and the adjacent swamp habitat. Gapping the banks of other waterbodies and a relict railroad grade that transects the study area were also evaluated as part of the proposed project.

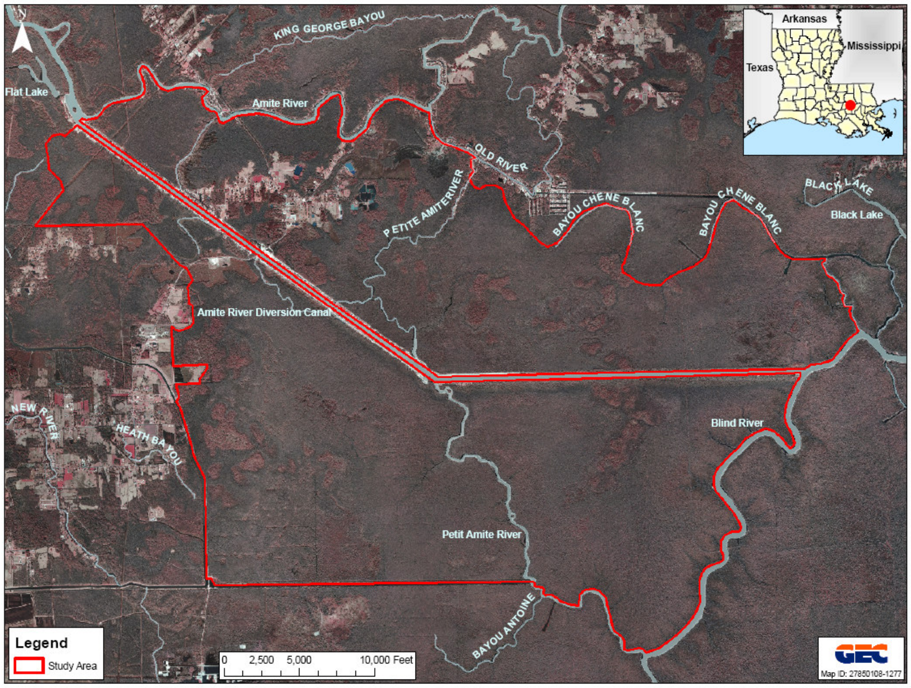

Figure 2. Amite River Diversion Canal Modification Project Study Area.

3.0 CONCEPTUAL ECOLOGICAL MODEL DISCUSSION

The CEM developed for the Amite River Diversion Canal Modification project is presented in Figure 3. Model components are identified and discussed in the following subsections.

3.1 Drivers

3.1.1 Canal Construction

The Amite River Diversion Canal is a 10.6-mile-long channel that extends from the Amite River at Mile 25 to Mile 4.8 of the Blind River. Construction of the canal was authorized by Senate Report No. 1029 (89^{th} Congress, 1^{st} Session), which authorized construction of improvements on the Amite and Comite rivers and Bayou Manchac, Louisiana, in the interest of flood control and major drainage. The canal was constructed in accordance with provisions of the U.S. Army Corps of Engineers (USACE) New Orleans District publication *Survey of Amite River and Tributaries, Louisiana* (USACE 1955), which was conducted under the authority of the Flood Control Act of 1944. The survey report recommended the construction of a diversion channel for the Amite River with a length of 10 miles, extending from Mile 25 of the Amite River to Mile 5 of the Blind River. Construction of the Amite River Diversion Canal was completed in October 1963. Dredged spoil generated in the construction of the canal was placed in two dredged material berms on either side of the canal. These dredged material berms form topographic high points within the study area.

Because of an inadequate understanding of the natural systems operating within the study area, construction of the Amite River Diversion Canal has had unforeseen, adverse environmental effects. Canal construction has altered physical defining characteristics, including water storage, sheet flow, and nutrient and sediment input levels within the baldcypress-tupelo swamp habitat in the study area.

3.1.2 Hurricanes

Coastal storms, particularly tropical cyclone events, also 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 14 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 1851-2007, and at least 52 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.

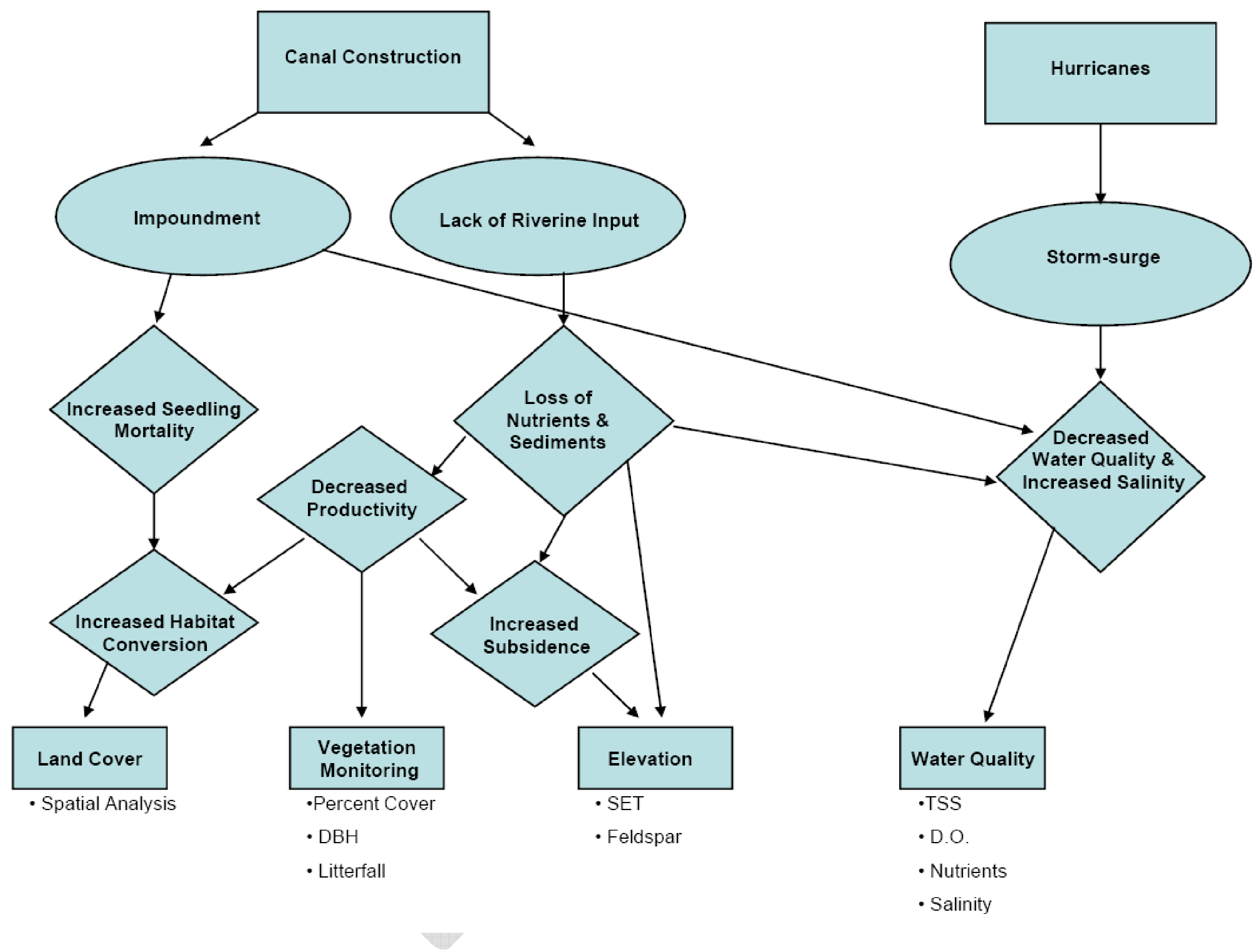

Figure 3. Conceptual Ecological Model, LCA Amite River Diversion Canal Modification Project.

Principal impacts to the study area as a result of tropical cyclone events are windfall mortality and storm surges originating from Lake Maurepas. Windfall mortality typically exerts the greatest impact upon mature or diseased trees, sparing younger, healthier specimens. Storm surges exert a considerably greater and more widespread stress upon vegetation through the introduction of storm surge waters that exhibit higher salinity concentrations than are present in surface waters within the study area. The four hurricanes identified above each resulted in measurable storm surges within the study area. Water gage data collected from a U.S. Geological Survey (USGS) monitoring station on the Amite River at Louisiana Highway (LA-) 22 and from Louisiana Department of Natural Resources (LDNR) gages established in the eastern study area in 2005 recorded storm surges from hurricanes Katrina and Rita that inundated the Amite River Diversion Canal within the study area at an average of 2.0 and 3.3 feet above mean annual water level, respectively. Water gage data collected from the USGS monitoring station on the Amite River at LA-22 recorded storm surges from hurricanes Gustav and Ike within the study area at an average of 3.2 and 4.4 feet above the 2007 mean annual water level, respectively.

3.2 Ecological Stressors

3.2.1 Impoundment

The placement of dredged material in dredged material berms along either side of the Amite River Diversion Canal disrupted sheet flow within the study area and formed topographic high points that prevented the drainage of baldcypress-tupelo swamps into waterbodies within the study area during intervals of low surface flow. This activity, in conjunction with the construction of other features, such as the relict logging railroad grade that traverses the eastern study area from north to south, resulted in the permanent impoundment of baldcypress-tupelo swamp habitat within the study area.

Swamp impoundment is particularly pronounced in the eastern portion of the study area (i.e., east of the Petite Amite River), as demonstrated by hydrograph data collected in 2005 in this area for a Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) project nominee for the Priority Project List (PPL) 16, *Hydrologic Restoration in the Swamps West of Lake Maurepas*. Approximately 11 months of water gage data were collected in the eastern study area from three water gages that were set within the Amite River Diversion Canal and inundated swamp habitat on the left descending bank. The results of this data collection analysis, as presented in Shaffer et al. (2006), indicate that the swamp habitat along the left descending bank of the diversion canal in the eastern study area is impounded; water levels within this area never receded below 2.2 feet above mean sea level (msl), including periods in which water levels within the canal receded below that level.

Impoundment within the study area has resulted in decreased water quality and increased seedling mortality, which in turn has resulted in increased habitat conversion to marsh and open water (see Section 3.3 for additional discussion).

3.2.2 Lack of Riverine Input

Historically, hydrologic conditions within the study area were dominated in the north and west by the Amite River, in the south by overbank flow from the Mississippi River, and in the east by tidal influence from Lake Maurepas. Periodic flooding of the Amite and/or Mississippi rivers resulted in the inundation of baldcypress-tupelo habitat within the study area. Flooding occurred within the study area and vicinity on a cyclical basis, with peak water elevations in the late spring or early summer. As floodwaters receded, surface waters in the study area were conveyed eastward via sheet flow until they were received by Bayou Chene Blanc or the Blind River, by which they were conveyed to Lake Maurepas.

The implementation of flood control projects from the early to mid-20th century, including the channelization of the Amite River, construction of flood protection levees on the Mississippi River, and especially the construction of the Amite River Diversion Canal, disrupted the natural hydrologic regime within the study area. River channelization and levee construction greatly reduced overbank flooding in the study area, causing a loss of nutrients and sediments in the ecosystem, decreased water quality, and increased subsidence (see Section 4.3 for additional discussion).

3.2.3 Storm Surge

Tropical cyclone events exert a stochastic but severe stress upon the swamp habitat through salinity spikes associated with saline storm surge events (see Section 3.3 for additional discussion). The introduction of saline storm surge water into the impounded swamps results in reduced biomass production and impaired health, which in turn causes increased tree mortality, decreased soil production and integrity, and a consequent increase in relative subsidence (see Section 3.3 for additional discussion). Periodic influxes of saline storm surge waters remain trapped in the impounded swamps, resulting in stochastic but periodic cumulative increases in salinity in impounded waters and soils in the study area. Saline storm surge waters become impounded in the swamp by the dredged material berms that border the Amite River Diversion Canal and is not allowed to drain out the swamps during seasonal low flow events or to be flushed out by seasonal river bank overflow events. Saltwater introduction into formerly freshwater wetlands has been demonstrated to reduce photosynthetic rates of baldcypress and water tupelo and reduce productivity of swamp forest tree species and other freshwater vegetation.

3.3 Ecological Effects

3.3.1 Increased Seedling Mortality

Increased seedling mortality is a biological response to the impoundment produced in the study area by the dredged material berms that border the Amite River Diversion Canal (see Section 4.2.1). Seedling germination and establishment is an essential component for ensuring the sustainability of baldcypress-tupelo swamp habit through the replacement of trees lost to windfall mortality or disease. However, baldcypress and tupelo seedling establishment is currently impaired within the study area as a result of the persistent flooding conditions that result from impoundment (CWPPRA Task Force 2002).

Souther and Shaffer (2000) reported that in the early 20th century, baldcypress swamps were harvested *en masse* in coastal Louisiana, and that in many harvested areas, natural regeneration did not occur; instead, these areas converted to marsh or open water. The study concluded that prolonged flooding or complete submergence within the swamps may have suppressed germination or growth rates of young seedlings and even caused mortality (see Section 3.3.1). Neither baldcypress nor tupelo seeds can germinate when flooded (Hamilton and Shaffer 2001). Seeds of both species remain viable when submerged in water and can germinate readily when floodwaters recede (Kozlowski 1984). However, the seedlings require seasonal drying periods, and the substrate compaction associated with these drying periods, for their root systems to become properly established in the swamp substrate. With minimal ability to drain and persistent flooding, the typical seasonal drying of the swamp does not usually occur, leading to failure of seedlings to establish themselves and replace older trees that have been lost to other natural processes (CWPPRA Task Force 2002).

3.3.2 Loss of Nutrients and Sediments

Loss of nutrients and sediments is a physical response to the lack of riverine input caused by the construction of the Amite River Diversion Canal (see Section 3.2.2). Effler et al. (2006) examined the importance of nutrient influxes that accompany freshwater diversions or other hydrologic connectivity projects to swamp productivity. Nutrient augmentation of baldcypress and tupelo trees in the Maurepas Swamp (similar to nitrate loading rates expected from a small freshwater diversion) increased radial growth of both species (especially baldcypress) in degraded forest stands. Nutrient augmentation also increased nitrogen in foliage for both tree species. These findings support hypotheses that swamps in southeastern Louisiana are nutrient-limited, and existing trees can utilize, benefit, and act as nutrient sinks for nutrient-laden river water accompanying diversions.

Further evidence of nutrient starvation within the study area was identified in Shaffer et al. (2001). This study determined the nutrient augmentation significantly enhanced (by about 33 percent) biomass production of herbaceous vegetation at monitoring stations within the western Maurepas Swamp during 2000. Furthermore, several studies conducted over the last decade have demonstrated that nutrient augmentation to baldcypress seedlings doubles growth rates in the western Maurepas Swamp (Boshart 1997, Forder 1995, Greene 1994, Myers et al. 1995), further indicating that the baldcypress-tupelo swamp in the study area and vicinity is nutrient-limited.

Shaffer et al. (2008) presented data at the Society of Wetland Scientists meeting on tree growth in the Maurepas Swamp. For the period 2000-2007, diameter growth was measured for over 1,800 trees. Diameter growth in the measured trees was significantly less than established growth levels for trees in healthy freshwater swamp systems. The study determined that in interior swamp locations such as the study area, the primary factor inhibiting diameter growth was nutrient-poor stagnant standing water and the lack of nutrient-rich freshwater throughput caused by the loss of hydrologic connectivity with riverine systems.

3.3.3 Decreased Water Quality and Increased Salinity

Decreased water quality and increased salinity is a chemical response to both the impoundment produced in the study area by the dredged material berms that border the Amite River Diversion Canal (see Section 3.2.1) and the introduction of saline storm surge waters associated with tropical cyclone events (see Section 3.2.3). The Maurepas Swamp is characterized by nutrient-poor surface waters. Day et al. (2001) conducted a water quality analysis in support of CWPPRA Project PO-29 *Mississippi River Reintroduction into Maurepas Swamp*. The observed concentrations of nitrate, ammonium, and nitrogen at surface water sampling stations within the western Maurepas Swamp were all reduced with respect to observed concentrations in the Mississippi River. The results of sampling of water quality parameters shows that for some nutrient forms, the Maurepas basin has relatively low nutrient concentrations compared to the

Mississippi River and other systems studied. The results of this study indicate that the baldcypress-tupelo swamp within the study area and vicinity is severely nutrient-limited.

In addition, the trees are highly stressed, which appears to decrease productivity, increase mortality, and increase susceptibility to herbivory and parasites. Saltwater intrusion has increased in this general area, at least in part due to a combination of net subsidence and the lack of riverine freshwater inputs. Saltwater intrusion events observed in the western Maurepas Swamp in 1999 and 2000 caused greater than 97 percent mortality in planted baldcypress seedlings in the northwestern portion of the swamp (USACE 2004a). Salinity of three parts per thousand (ppt) can reduce growth of both baldcypress and tupelo saplings (Pezeshki 1990); and when combined with flooding stress, growth reduction in baldcypress was substantial. Clearly salinity can be a significant factor contributing to swamp deterioration, especially combined with other stressors (e.g., flooding, herbivory). Low-salinity water has been noted in the swamps north and south of the Amite River Diversion Canal (CWPPRA Task Force 2002).

The western Maurepas Swamp is characterized by saltwater intrusions that occur mostly during low-water periods in the fall (Shaffer et al. 2001). The mean salinity of the lake water measured at the Manchac Bridge also has increased gradually since 1951 (Thomson 2000), indicating that salinity levels appear to be increasing in the region. Additionally, storm surges originating from Lake Maurepas associated with tropical cyclone events exert a stochastic but severe stress upon the swamp habitat through salinity spikes in surface waters within the swamp. Recent tropical cyclone events, occurring at a rate of one to two per year, have produced measurable spikes in salinity within the western Maurepas Swamp (USACE 2004a). These salinity spikes are in turn exacerbated by the impoundment produced within the study area by the dredged material berms that border the Amite River Diversion Canal. The CWPPRA PPL 12 Environmental Work Group concluded that the dredged material berms appeared to restrict the ability of higher salinity water to be flushed from the system once it finds its way in (CWPPRA Task Force 2002). Storm surge waters currently remain trapped in the impounded swamps, resulting in stochastic but periodic cumulative increases in salinity in impounded waters and soils in the study area.

3.3.4 Decreased Productivity

Decreased productivity in vegetative communities in the study area is a biological response to the lack of riverine input caused by the construction of the Amite River Diversion Canal and the consequent loss of nutrients and sediments (see Sections 3.2.2 and 3.3.2). Comparison of productivity in swamps that are either managed, have more favorable hydrology, and/or are receiving nutrient enrichment suggest that the existing levels of productivity in the Maurepas Swamp are as low as 50 percent or even 25 percent of average values.

As part of the CWPPRA PPL 11 effort to launch a project diverting Mississippi River water into the Maurepas Swamp, Shaffer et al. (2001) examined woody and herbaceous vegetation at 20 study sites, each with two 625-square-meter (m^2) permanent stations, in the southern Maurepas Swamp, including several along the Amite River Diversion Canal near its eastern terminus. Within each of the forty 25-meter by 25-meter (625 m^2) permanent stations, four 4-meter by 4-meter (16 m^2) permanent herbaceous plots were established. Cover values were obtained by two independent estimates for all 160 plots from mid-June to early July and again in early September of 2000. To measure annual production, herbaceous (understory) primary productivity was estimated within one fertilized and one unfertilized herbaceous (4-meter by 4-meter) plot by clipping two randomly chosen (non-repeating) replicate subplots (of 0.25 m^2 area) twice during the growing season. Tree health and primary productivity were determined through the collection of annual litter. Annual tree diameter growth was measured to estimate wood production and calculate basal wood area per hectare of swamp. The measured tree diameters in each plot were then converted into basal wood area, summed and multiplied by 16 (as there are sixteen 625-m^2 plots to a hectare) to estimate the total area of basal wood per hectare for each plot for each of the 40 stations. Five litter traps were randomly installed at each of two 625-m^2 plots at 40 stations throughout the Maurepas Swamp, yielding a total of 200 litter traps deployed. The study concluded that salinity is an important stressor in the Maurepas Swamp, but that degradation of tupelo trees within the swamp has been occurring for decades and is almost certainly primarily due to altered hydrology and lack of throughput. The study determined that the low soil bulk densities and high soil organic matter content throughout much of this swamp are indicative of a lack of riverine influence. The results of the study indicated that all measures of ecosystem health collected in the southern Lake Maurepas region indicate that these swamps are highly degraded and would benefit from a substantial infusion of nutrients and freshwater from a river diversion. One drawback of this study, however, is that data were collected during the drought years of the late 20th and early 21st centuries, and may therefore be atypical of normal baseline conditions and responses to flooding of the swamp.

Results of studies in wetlands receiving secondary treated sewage suggest that introduction of nutrients as well as sediments from river water could stimulate production by 300 to 500 percent (Rybczyk et al. 2002, Hamilton and Shaffer 2001).

3.3.5 Increased Habitat Conversion

Increased habitat conversion to marsh and open water is a physical and biological response to both impoundment and the resulting increased seedling mortality (see Sections 3.2.1 and 3.3.1) and lack of riverine input and the resulting loss of nutrients and sediments and decreased productivity in vegetation communities (see Sections 3.2.2, 3.3.2, and 3.3.4). Hoeppner et al. (2007) concluded that the majority of the Maurepas Swamp is stressed and seems to be on a trajectory of slow degradation leading to a gradual conversion to marsh and open water. Stagnant flooding and nutrient deprivation appear to be the largest stressors in the swamp interior, while a combination of increased salinity, flooding stress, and nutrient deprivation is killing large proportions of the trees located along the lakeshore, particularly along the eastern margin of Lake Maurepas.

Natural regeneration throughout the Maurepas Swamp is very low and even absent at most sites. Land conversion observations on the Manchac land-bridge and Jones Island demonstrate what is expected in the Maurepas Swamp in the coming decades, if no restoration action is taken. In 1956, most of the area of the Manchac land-bridge was dominated by second-growth swamp. By 1978, much of this swamp had converted to marsh and shrub-scrub, and by 1990 the marsh had begun to break up and to convert to open water (Barras et al. 1994).

Consequently, it is expected that without restoration, the factors and processes that are contributing to stress and deterioration of the swamps in the vicinity of the Amite River Diversion Canal will continue and will result in loss of the swamp, with succession to open water. The remaining portion of the western Maurepas Swamp is composed of approximately 65 percent tupelo trees and 35 percent baldcypress trees, and as of 1990, covered an area within the Amite/Blind Rivers mapping unit of about 138,900 acres of swamp and 3,440 acres of fresh marsh (CWPPRA Task Force, 2002). The wetland loss rates for the Amite/Blind Rivers mapping unit for 1974-90 were estimated by USACE to be 0.83 percent per year for the swamps, and 0.02 percent per year for fresh marsh. Based on these rates, approximately 50 percent (or 69,450 acres) of swamp and 1.2 percent (or about 40 acres) of fresh marsh will be lost within 60 years (CWPPRA Task Force 2002). The USACE determined that, based on the low tree density, degraded condition, and expectation for mortality, the majority of swamp habitat within the study area will degrade to less than 33 percent canopy cover within 20 years (USACE 2004b).

Under the continued influence of these conditions, tree mortality will continue to increase and tree density will continue to decline, until most swamp habitat in the vicinity of the Amite River Diversion Canal converts to fresh marsh. Monitoring studies conducted for the CWPPRA PPL 12 proposal indicated that conversion of baldcypress-tupelo swamp to fresh marsh is already occurring in the study area, particularly north of the diversion canal in the eastern study area (CWPPRA Task Force 2002). The results of these monitoring studies indicate that many areas of interior swamp in the study area and vicinity that exhibit significantly stressed or dying overstory vegetation also contain bulltongue or arrow arum as understory vegetation. Additionally, the monitoring results indicate that many areas of bulltongue marsh in the greater southern Maurepas Swamp have converted to fragile spikerush flotant. Factors contributing to this conversion include the much greater tolerance of baldcypress and water tupelo with respect to herbaceous understory vegetation for long-term deep inundation, and the increasingly unconsolidated nature of swamp substrate caused by the reduction of below-ground productivity. Consequently, it is expected that the vast majority of swamp habitat adjacent to the Amite River Diversion Canal would convert to open water rather than stable marsh habitat without implementation of the proposed project.

3.3.6 Increased Subsidence

Increased subsidence is a physical response to lack of riverine input and the resulting loss of nutrients and sediments and decreased productivity in vegetation communities (see Sections 3.2.2, 3.3.2, and 3.3.4). The soil characteristics within the western Maurepas Swamp are indicative of a lack of riverine influence as evidenced by high soil organic matter content and low bulk density values (DeLaune et al. 1979, Hatton 1981, Messina and Conner 1998). Soil building within the Maurepas Swamp occurs almost exclusively as a result of organic productivity; in the swamps adjacent to the diversion canal, this productivity is substantially depressed compared to normal conditions (CWPPRA Task Force 2002). Subsidence in this area is classified as intermediate, at about 1.1 to 2 feet per century (USACE 2004a). With minimal soil building and moderately high subsidence, there has been a net lowering of ground surface elevation, leading to a doubling in flood frequency over the last four decades (Thomson 2000), so that the swamps are now persistently flooded.

Shaffer et al. (2003) conducted a subsidence investigation in the Maurepas Swamp immediately southeast of this project's study area in support of CWPPRA project PO-29 *Mississippi River Reintroduction into Maurepas Swamp*. Subsidence rates for the PO-29 project area were measured by the installation of two surface elevation tables at 13 representative study sites. The tables could be set in four compass directions and utilized the mean value of nine pin readings of soil elevation. Readings were collected during the interval October-November 2001 and compared against readings collected in October-November 2002 to provide an accurate estimate of the net subsidence rates within the Maurepas Swamp. The results of this subsidence investigation indicate an average net elevation decrease of slightly less than one centimeter for the study area during the interval between sampling, although actual rates varied considerably by habitat type.

3.4 Attributes and Performance Measures

3.4.1 Land Cover

Land cover has been identified as a key indicator of project success with respect to preventing habitat conversion and future land loss. Comparison of pre-project land cover characteristics with post-project land cover characteristics would serve to determine if conversion of baldcypress-tupelo swamp to freshwater marsh or open water within the study area experiences a post-project decline or ceases altogether. Additionally, post-project land cover analysis would determine if areas within the study area that had previously converted to freshwater marsh or open water experience undergo a post-project reversion to baldcypress-tupelo swamp as a result of improved seedling survival.

- *Spatial analysis* has been identified as an assessment 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 baldcypress-tupelo swamp coverage within the study area.

A post-project relative increase in the total area of baldcypress-tupelo swamp would be an indication of significant project success, while a post-project stabilization of baldcypress-tupelo swamp coverage within the study area would be an indication of moderate project success. Conversely, a post-project decline in baldcypress-tupelo swamp coverage within the study area would indicate that the project did not succeed in preventing habitat conversion and, by extension, future habitat loss.

3.4.2 Vegetation Productivity

Swamp vegetation productivity has been identified as a key indicator of project success. Comparison of pre-project vegetation monitoring data with post-project vegetation monitoring data would serve to determine if biomass production in plant communities within the study area increases in response to project features. A post-project increase in biomass production would also indicate the introduction of nutrients and sediment into the swamps as a result of the project. Three assessment performance measures have been identified for this attribute, including percent cover, diameter at breast height (dbh) and litterfall.

- *Percent cover* is the estimated percentage of the ground surface covered by vegetation. Canopy percent cover is the estimated percentage of the ground surface covered by tree canopies when the crowns are projected vertically. A high percent cover is indicative of significant productivity within the respective vegetation communities, and a higher canopy percent cover is indicative of significant productivity within woody species.

- *Diameter at breast height (dbh)* is the measurement of tree diameter at a height of 4.5 feet above the forest floor on the uphill side of the tree. A large annual increase in dbh is indicative of significant productivity with respect to the measured tree and adjacent forest community. Ongoing monitoring studies of baldcypress and tupelo trees within the western Maurepas Swamp by Dr. Gary Shaffer indicate that average annual dbh increase for trees within the eastern study area is approximately one millimeter per year, a growth level that is significantly lower than expected levels of 1-2 centimeters per year for healthy baldcypress or tupelo trees (Shaffer, personal communication 2009).

- *Litterfall* is the measurement of the movement of leaves, twigs, and other forms of organic matter from the biosphere to the litter layer found in soil via interception in collection traps. Large volumes of litterfall are indicative of significant biomass production within the constituent forest community.

A post-project relative increase in productivity within the study area as evidenced by these three measures would be an indication of significant project success, while a post-project stabilization of these measures would be an indication of moderate project success. Conversely, a post-project decline in these measures within the study area would indicate that the project did not succeed in increasing swamp vegetation productivity.

3.4.3 Elevation

Ground surface 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 implicitly indicate the introduction of nutrients and sediment into the swamps as a result of the project, and would also indicate an increase in vegetation productivity and the resulting litterfall that is a principal factor in soil accretion within the Maurepas Swamp. Two assessment 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.

Post-project increases in 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 stabilization of elevation as evidenced by these measures would be an indication of moderate project success. Conversely, a post-project decline in elevation within the study area would indicate that the project did not succeed in offsetting subsidence and, by extension, habitat conversion and future land loss.

3.4.4 Water Quality

Surface water quality in interior locations in the study area has been identified as a key indicator of project success with respect to establishing hydrologic connectivity between the Amite River Diversion Canal and the adjacent swamp habitat. Comparison of pre-project water quality with post-project quality would serve to determine if freshwater throughput is introducing nutrients and flushing out saline waters within the study area in response to project features. A post-project improvement in water quality would implicitly indicate the introduction of freshwater and the associated nutrients and sediment into the swamps as a result of the project. Four assessment performance measures have been identified for this attribute, including total suspended solids (TSS), dissolved oxygen (DO), nutrients, and salinity.

- *Total suspended solids* (TSS) is a measurement of the total volume of sediment and other solids suspended in a given volume of water. Because surface waters within the swamps adjacent to the Amite River Diversion Canal are hydrologically isolated from other waterbodies in the study area, TSS concentrations within swamp surface waters are expected to be lower than those of nearby waterbodies.
- *Dissolved oxygen* (DO) is a relative measure of the amount of oxygen that is dissolved in a given volume of water. Surface waters within the swamps in the study area are expected to exhibit lower DO concentrations than those of nearby waterbodies, because water movement (which exposes surface water to a greater volume of air through lateral movement and results in greater dissolution of oxygen) is virtually nonexistent in the swamps.
- *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. Surface waters within the swamps adjacent to the Amite River Diversion Canal have been demonstrated to be nutrient-poor with respect to other waterbodies in the area because the hydrology prevents the accumulation of nutrients from surface runoff.
- *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 other area waterbodies because saline storm surges introduced into the swamps during tropical cyclone events become trapped in the impounded swamps and are not allowed to drain out of the study area.

Post-project improvements in water quality within the study area as evidenced by analyses 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 reestablishing riverine input to the study area and the resulting reintroduction of nutrients and sediments associated with freshwater throughput.

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