

# An Integrated Monitoring Approach Using Multiple Reference Sites to Assess Sustainable Restoration in Coastal Louisiana

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**Abstract**—Achieving sustainable resource management in coastal Louisiana requires establishing reference conditions that incorporate the goals and objectives of restoration efforts. Since the reference condition is usually considered sustainable, it can be a gauge to assess the present condition of a (degraded) system or to evaluate progress of management actions toward some target system state (the reference or desired conditions).

In 2003, the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) Task Force and the Louisiana State Wetlands Authority adopted the “Coastwide Reference Monitoring System – Wetlands” (CRMS–Wetlands) for Louisiana. This system will provide data from multiple reference sites to explore the properties of a sustained reference condition. CRMS–Wetlands provides links between project-specific and system-wide objectives, criteria for selecting reference sites or conditions, a more robust statistical design, and critical monitoring variables. In addition, a system-wide assessment and monitoring plan (SWAMP) is being developed that incorporates and evaluates existing monitoring efforts (to the extent possible) within a system-wide experimental design. The SWAMP will integrate monitoring of biological, chemical, physical, and climatological variables in four modules: wetlands (CRMS–Wetlands), barrier islands, inshore waters and rivers, and nearshore coastal waters. Data and information collected under SWAMP will contribute to developing a systems-synthesis model for coastal Louisiana.

Regional restoration project leaders in coastal Louisiana acknowledge the mutual dependence of monitoring and modeling the coastal landscape. For example, experiments or measurements should not be conducted independently of modeling and vice versa. Assessment should be directed at reducing scientific uncertainty to improve confidence in modeling and monitoring tools and ultimately to assist management actions. An adaptive environmental assessment and management process prescribes modeling, monitoring, and research activities to be conducted from initial stages of restoration planning to optimize the ability to assess and achieve sustainable restoration.

## Introduction

The Mississippi River Deltaic and Chenier Plains of coastal Louisiana consist of diverse geomorphological basins with distinct vegetation zones and patterns of landscape development. Within each of these geomorphological basins are ecological habitats that can be distinguished by the adaptation of plants to soil fertility, relative water levels, and salinity (Buresh and others 1980, DeLaune and others 1989, Gosselink and others

1998). Marshes in coastal regions that differ in geomorphology and nutrient (fresh water and sediments) loading have evolved different plant strategies in response to resource availability and abiotic stressors (Hopkinson and Schubauer 1984, White and Howes 1994), resulting in different patterns of marsh stability. Although this coastal landscape is one of the most productive and biologically diverse in the contiguous United States, it is also suffering from one of the greatest environmental problems in North America—catastrophic wetland loss. Louisiana has the

highest rate of coastal wetland loss in the nation, reaching a peak of 108.4 km<sup>2</sup>/yr in the 1970s (Barras and others 2003, Gagliano and others 1981, Turner and Cahoon 1987). Although the rate has declined since the 1980s (Britsch and Dunbar 1993), nearly half of the wetlands present in the 1930s, an area equal to the size of Rhode Island (Boesch and others 1994), have been lost. This recent net loss of coastal landscape contrasts with the historical fluctuation of coastal area, which depended on a balance between the progradational processes of active delta formation and degradational processes during river abandonment, that lead to stable coastal landscapes.

There are several factors in the environmental setting of coastal Louisiana that contribute to the present inability of wetlands to maintain surface elevation causing an unstable landscape. These factors include: (1) high rate of regional subsidence (Penland and Ramsey 1990); (2) reduced sediment load in the Mississippi River (Kesel 1988); (3) elimination of spring overbank flooding of the Mississippi River and direct delivery of river sediment to floodplain marshes (Day and others 1997, Templet and Meyer-Arendt 1988); and (4) extensive landscape and hydrologic alterations from human activities, including energy related activities such as the construction of canals and navigation channels (Turner and Cahoon 1987). Determining the relative significance of these causal mechanisms to controlling surface elevation (such as mineral vs. organic matter accumulation; waterlogging vs. salinity stress) is important in developing the conceptual framework and hypotheses of a restoration or rehabilitation program.

Restoring functionality to hasten ecosystem rehabilitation is simply the manipulation of ecological succession to obtain a specific goal or purpose. Knowledge of the ecological theory that pertains to ecosystem development fosters more effective restoration planning that is less expensive, can be effectively implemented, and gives a more desirable final result (Christensen and others 1996). Ecosystem restoration can demonstrate much about how ecosystems work, provided we compare the effectiveness of system response to original hypotheses of causal mechanisms (Ewel 1987). In order to increase our knowledge of ecosystem dynamics it requires diagnostic capabilities that are based on ecological theory of succession and ecosystem development. These diagnostic capabilities are presently limited by the ability of scientists to: (1) anticipate ecological responses of ecosystems to specific manipulations or site conditions; (2) monitor responses of ecosystems at sufficient space and time scales to validate the responses; and (3) modify or prescribe new operations of rehabilitation projects according to the response of the ecosystem to attain specific goals. One of the most difficult tasks in restoring ecological systems is the

selection of the proper set of criteria for site manipulations that will rehabilitate habitats and result in a specifically defined structure and function comparable to some reference condition. Thus, a fundamental need of restoration programs is to develop practical tools and approaches that can be used to predict, monitor, and validate the response of ecosystems to rehabilitation criteria.

Louisiana has been at the forefront of coastal wetland restoration and rehabilitation efforts for the past two decades. The passage of the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) in 1990 provided the necessary authorization and funding to accelerate construction of restoration projects throughout coastal Louisiana. From 1990 to 2003, the CWPPRA program has constructed 68 projects that are expected to create, restore, or protect 29,000 ha of wetlands. These projects address localized problems (for example, saltwater intrusion, flooding) and are primarily associated with hotspots of wetland loss within the coastal landscape.

The focus of CWPPRA is limited to project-specific approaches to restore coastal Louisiana and does not address evaluation of larger scale deltaic processes of ecosystem sustainability. In December 1998, the Coast 2050 Plan, the first ecosystem approach for restoring coastal Louisiana's wetlands and associated waters (LCWCRTF 1998), was completed. The strategic goals of the plan are to: (1) assure vertical accumulation to achieve sustainability; (2) maintain estuarine gradient to achieve diversity; and (3) maintain exchange and interface to achieve system linkages. To be sustainable, Louisiana's marshes require organic and inorganic soil accumulation sufficient to keep pace with sea level rise and subsidence, a dynamic salinity gradient, and effective coupling of subsystems in the estuarine landscape that exchange energy and materials. Theories of ecological succession and ecosystem development have provided the conceptual framework of how a delta works, but the challenge is to implement and evaluate these ecosystem concepts. Particular difficulty is in understanding the natural variability of functional processes within coastal wetland ecosystems in deltaic environments. A regional monitoring program was needed to provide comprehensive measurements of the major forcing functions at sufficient spatial and temporal scales to validate our conceptual framework of ecosystem dynamics in a deltaic setting. Additionally, tools were needed to predict trajectories in structural and functional ecosystem attributes in space and time to assess sustainability. In 2002, the Louisiana Coastal Area (LCA) Ecosystem Restoration Study (USACE 2004) developed conceptual and numerical models to integrate ecosystem attributes into measures that can be used to evaluate the effectiveness of restoration actions. Without both monitoring and

modeling capabilities, it would be difficult to design or evaluate restoration projects that are intended to achieve ecosystem-level goals of the Coast 2050 plan.

This paper describes the regional monitoring and modeling tools and technologies that have been developed under the CWPPRA and the LCA Plan. The proposed integration of ecosystem attributes that is critical to assess sustainable restoration at ecosystem scales has also been discussed.

## Regional Monitoring

Wetland restoration efforts under CWPPRA require an evaluation of the effectiveness of individual projects, as well as a measure of the cumulative effects of all projects in restoring, creating, enhancing, and protecting the coastal landscape. In 1994, a monitoring program was established to evaluate project-specific goals and objectives over each project's 20-year lifespan by using sound scientific procedures. This monitoring program relied heavily on the establishment of paired reference sites or areas. By 1998, the effectiveness of this approach was declining because of: (1) the inability to find comparable reference areas for the large number of restoration projects implemented, (2) the inability to discern the cumulative effects of all restoration projects conducted under multiple mandates, and (3) the inability to assess coastwide status and trends due to inconsistency of the variables measured across multiple projects. Recognizing the benefits of a comprehensive and flexible monitoring program and also realizing the increasing limitations of identifying paired reference sites, the CWPPRA Task Force and the Louisiana State Wetlands Authority adopted the Coast-wide Reference Monitoring System (CRMS-*Wetlands*) in 2003 as the future protocol for CWPPRA monitoring.

The CRMS-*Wetlands* will provide an avenue to evaluate the effectiveness of the Coast 2050 plan, and determine whether entire coastal ecosystems are being restored, rather than just the areas directly affected by individual projects. The focus of the CRMS-*Wetlands* program is to establish monitoring sites in both project and non-project (reference) areas, with reference sites spanning an entire range of structural and functional response characteristics. Reference sites will therefore have similarities as well as differences with project sites and through assessments over time will determine the degree of ecological variation that was restored. The distribution of these sites will also allow ecological comparisons within and between hydrologic basins to evaluate temporal changes at an array of spatial scales ranging from vegetation types to entire geomorphic regions.

CRMS-*Wetlands* was designed to maximize its analytical flexibility while providing information across a representative subsample of the major vegetation types in coastal Louisiana wetlands. A total of 700 stations were identified representing combinations of geomorphology, hydrologic basin, project/non-project areas, and vegetation type. The experimental design (with identifying stratification, sample size, and sample distribution) is described in Steyer and others (2003). Within each strata, locations were randomly selected and the sites were allocated to represent each marsh type to facilitate the evaluation of the stability of the entire ecosystem and the effectiveness of the restoration program on a large, ecosystem scale. The selection of monitoring variables was based on our conceptual understanding of the dominant stressors and the response variables that form our coastal landscape. Because of resource constraints, however, the selection of variables needed to be further narrowed. Following the recommendations by Rapport (1992) and Schindler (1995), only those variables that are thought to be most critical and are the targets of management actions (such as the objectives of the CWPPRA program and Coast 2050 plan) are selected. The selected variables are crucial in determining the effectiveness of the CWPPRA program and include water level, surface salinity, sediment elevation, soil organic matter and bulk density, vegetation cover and species composition, and pore water salinity. Aerial photography will also be collected and analyzed on a 1-km<sup>2</sup> area surrounding each site to document changes in land and water areas over time and calculate rates of land loss or land gain. Sampling methodologies for these variables are described in Steyer and others (1995).

The added values inherent in this design (Steyer and others 2003) are that many of the selected stations represent a 35-year history of vegetation change, and that the transects on which the design is based have been used by the Louisiana Department of Wildlife and Fisheries (LDWF) not only for vegetation surveys, but also for alligator, nutria, muskrat, and water bird surveys. These historical survey data from the reference sites provide valuable information on past conditions and degrees of variability. The monitoring variables that will be collected under CRMS-*Wetlands*, combined with LDWF coast-wide datasets, will provide information on the response of vegetated wetlands and the habitats they support. Using geographic information system's analytical applications, resource managers have the flexibility to characterize and compare ecological change, from the project scale to the entire coast. Resource managers will also be able to compare the effects of a specific type of restoration effort such as diverting freshwater or sediment in a certain basin, or across the coast.

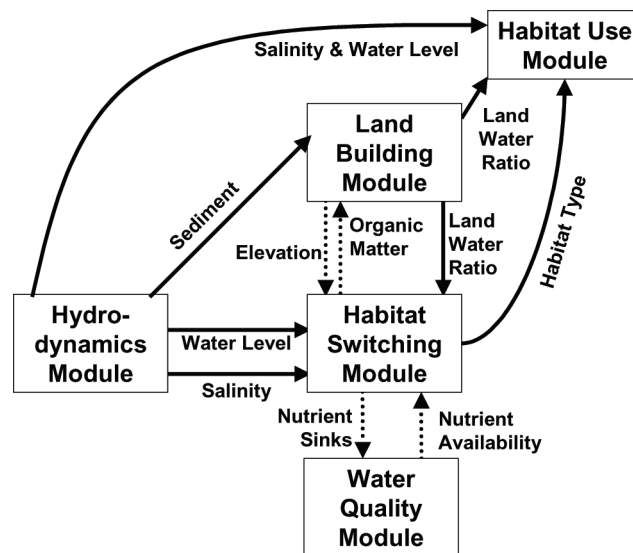
The multiple reference design will provide an understanding of natural variability of the functional processes within coastal wetland ecosystems. Achieving sustainable restoration requires reference conditions that embody the goals and objectives of restoration efforts. Reference conditions can be considered a gauge to assess the present condition of a system or to evaluate progress of management actions toward some target system state (the reference or desired condition). Establishing reference conditions for restoration is a critical component of managing for sustainability, since the reference condition is usually considered to be sustainable. Unfortunately, limitations arise, in many large-scale ecosystem restoration projects or programs, due to insufficient data and information on the temporal and spatial variability of ecosystems.

In addition to the direct benefits of the CRMS-*Wetlands* design to the CWPPRA monitoring program, this integrated approach will also provide information on areas that are currently outside of CWPPRA restoration projects which may one day be included within project boundaries. By establishing a history of data collection at these sites, background data will readily be available to speed up the process and provide information which could improve the design and effectiveness of future projects.

Although project evaluation was a significant impetus for the development of CRMS-*Wetlands*, an equally important benefit is the interdependence of CRMS-*Wetlands* data with the development of ecosystem and hydrodynamic models. CRMS-*Wetlands* will provide the necessary data to select and scale variables to be used in developing, validating and refining functional models of response to project-influenced environmental changes. In this manner, CRMS-*Wetlands* will provide a database that will aid in understanding the way the coastal system operates and how it will change in the future.

## LCA Conceptual and Numerical Models

Models are conceptual or numerical approximations of systems depicting key structural components and system drivers that assist us when considering the context and scope of the processes that effect ecological integrity (Karr 1991). They also provide a heuristic device to expand our consideration across traditional discipline boundaries (Allen and Hoekstra 1992). Conceptual models thereby provide a framework for understanding the relationships between physical form and ecological function. In the case of restoring deltaic processes, conceptual models provide a framework to integrate



**Figure 1.** The current ecosystem model for coastal Louisiana developed under LCA. Solid arrows reflect current linkages among the different modules. Stippled arrows reflect known linkages that are currently not incorporated in the model.

physical processes, geomorphic features, and ecological succession (Twilley 2004).

During the planning phase of the LCA, conceptual and numeric models (fig. 1) were developed under the Coastal Louisiana Ecosystem Assessment and Restoration (CLEAR) program (Twilley 2004). CLEAR developed tools to evaluate the degree to which different restoration alternatives, that utilize strategies of reintroducing historical flows of fresh water, nutrients and sediments to coastal wetlands, will achieve the Coast 2050 goals. Developing and evaluating restoration alternatives of the LCA to achieve these goals required linking the changes in environmental drivers (processes such as riverine input) to specific restoration endpoints (hydrodynamic, ecological and water quality) using a variety of modeling approaches. These modeling efforts were designed to evaluate how various combinations of conceptual restoration features would reduce ecosystem stress, and identify ecological benefits spatially across the deltaic and chenier plains. This was accomplished by combining existing conceptual models of delta evolution and ecological succession. Assumptions of causal mechanisms and expected responses were used to forecast site conditions necessary to render ecosystem state change.

The conceptual models (developed for hydrodynamics, land building, habitat switching, habitat use and water quality) identified the key ecosystem properties (drivers, stressors and response variables) that control ecosystem development (table 1). These conceptual models represented the inputs and outputs to various numeric models used to estimate benefits of several restoration alternatives at a regional scale.

**Table 1.** Variables included in the LCA ecosystem model.

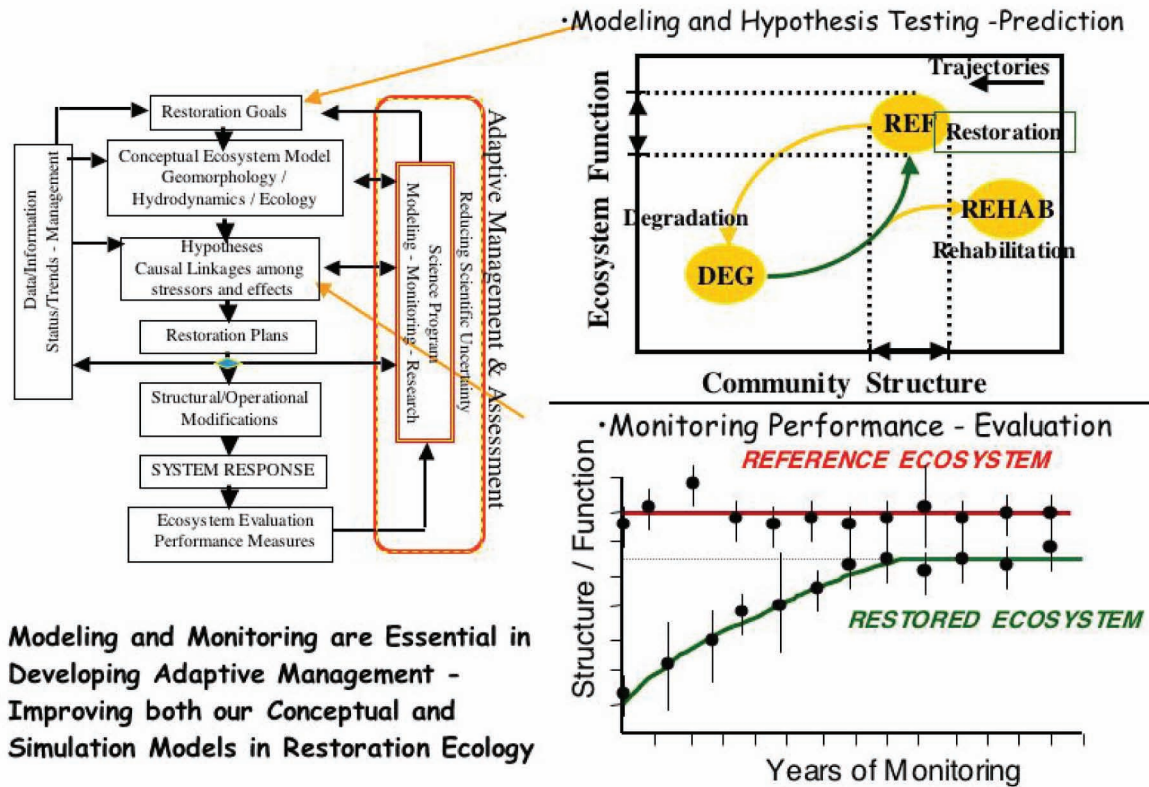
Variable	Module				
	Hydro-dynamics	Land Change	Water Quality	Habitat Switching	Habitat Use
Wind speed and direction	Input				
Initial water level	Input				
Initial salinity	Input	Input			
Initial temperature	Input				
River temperature	Input				
Historic land change rates		Input			
River sediment load		Input			
Sediment retention factor		Input			
Bulk density of deltaic soils		Input			
Initial land area	Input	Input			
Bathymetry	Input	Input	Input		
Land elevation	Input	Input	Input	Input	Input
Diversion flows	Input	Input	Input		
River nitrogen			Input		
Nourishment factor	Output	Input			
Salinity	Output		Input	Input	Input
Water level	Output		Input	Input	Input
Water residence time	Output		Input		
Water temperature	Output		Input		Input
Wetland area		Output	Input	Input	Input
Habitat type				Output	Input
Nitrogen removal			Output		
Water primary production			Output		
Wetland primary production				Output	
Habitat quality alligator,					Output
Habitat quality dabbling duck					Output
Habitat quality mink					Output
Habitat quality muskrat					Output
Habitat quality otter					Output
Habitat quality Atlantic croaker					Output
Habitat quality brown shrimp					Output
Habitat quality gulf menhaden					Output
Habitat quality largemouth bass					Output
Habitat quality oyster					Output
Habitat quality spotted sea-trout					Output
Habitat quality white shrimp					Output

Restoration planning also requires a monitoring program that measures actual system responses to evaluate the assumptions of model development and to assure the basic elements of adaptive environmental assessment and management (AEAM). Therefore, the monitoring of system responses should be based on indicators that reflect the key ecosystem properties (drivers, stressors and response variables) highlighted in the ecosystem model. The outputs of the LCA ecosystem model can serve as some of the performance measures that must be identified in AEAM protocol.

## Future Directions

Effective monitoring programs can benefit the process of numerical modeling by providing descriptions of system response (fig. 2). This process is required to

adequately test causal hypotheses of system degradation upon which restoration measures are designed. This feedback provides a strategic process in performing adaptive environmental assessment and management. Sensitivity analyses during model development provide science programs insights as to what parameters may be the most significant ones to system behavior. These exercises can also provide insights as to the most cost-effective monitoring variables to include in evaluating ecosystem response. Uncertainties in model simulations not only depend on the natural variability of the ecosystem, but also on the lack of knowledge in selecting parameters and model development. Monitoring programs can help reduce the knowledge-based uncertainty by providing data on those parameters that can improve simulation capabilities. This feedback improves numerical models and reduces scientific uncertainty in understanding causal mechanisms associated with system degradation (fig. 2).



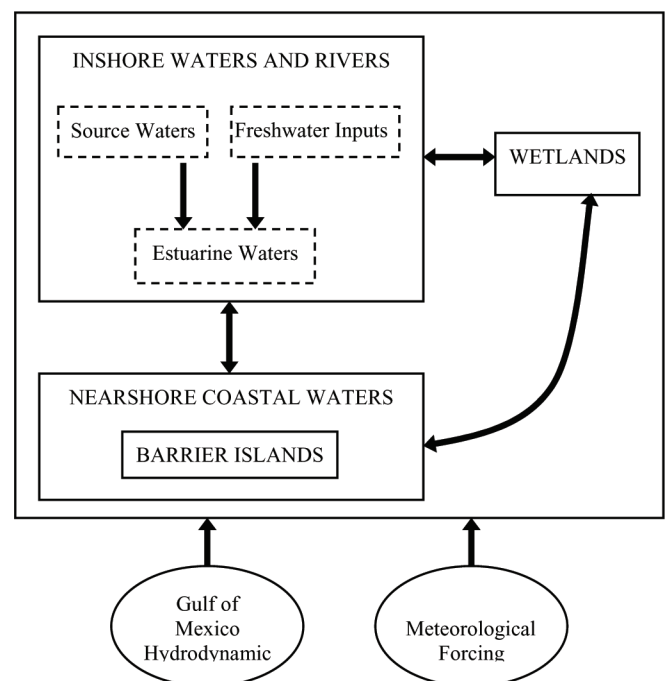
**Figure 2.** The linkage of modeling, monitoring and research programs in an integrated adaptive environmental assessment and management structure.

The ability to predict how ecosystems will respond to prescribed changes in environmental settings will be much improved with rigorous numerical modeling exercises as the initial stages of restoration planning. This modeling process is critical since it contributes to the development of ecological theory that can be immediately used in developing restoration strategies and provides a direct link between science and management.

### System-wide Assessment and Monitoring Plan

A System-wide Assessment and Monitoring Plan (SWAMP) is proposed that will evaluate the key processes and system linkages assumed to be causal mechanisms of system degradation in the LCA conceptual models. SWAMP will expand upon existing monitoring and modeling efforts within a system-wide experimental design by monitoring biological, chemical, physical, and climatological variables in four modules: wetlands (CRMS-Wetlands), barrier islands (Barrier Island Comprehensive Monitoring [BICM]), inshore waters and rivers, and nearshore coastal waters (fig. 3). The variables monitored will include those necessary to assess restoration project performance measures, as well as those variables identified through modeling efforts to be most critical to document the long-term restoration

of Louisiana's coastal ecosystems. The first of these modules, CRMS-Wetlands, as discussed earlier, was designed under the CWPPRA monitoring program and is



**Figure 3.** A proposed conceptual model for system-wide integration of monitoring in coastal Louisiana.

compatible with the conceptual framework utilized in the LCA modeling effort (fig. 1). The BICM Plan is currently in development and incorporates variables that are important to monitor and model barrier island changes. This plan was developed to incorporate variables necessary for barrier island project design, monitoring, evaluation, and predictive model development, and includes such variables as topography (LiDAR surveys), bathymetry, habitat classification, sediment properties, geophysical data (wave, current, water level, meteorological data) and vegetation composition.

The LCA Study and SWAMP have integrated the monitoring and modeling needs for coastal Louisiana to support refinement of ecological, hydrodynamic, and water quality models as well as restoration assessment (fig. 2). In addition to the integration of monitoring and modeling, however, a successful program needs an ongoing AEAM program to facilitate the continued feedback and institutional learning necessary to advance restoration science and improve the efficiency of wetland restoration and rehabilitation. In 2002, CWPPRA initiated an AEAM review on constructed restoration projects that incorporated input from multiple disciplines from state and federal agencies and academia. This review resulted in 51 project-specific recommendations, 94 lessons learned, 25 recommendations for improvement by project-type, and several recommendations to improve the overall program, illustrating the need for this approach to continue program advancement (Raynie and Visser 2002). The AEAM approach has also been embedded into the LCA Plan to ensure that the advancement of science continues and the implementation and management of restoration and rehabilitation projects improves with time.

The data gathered under CRMS-*Wetlands* and the other SWAMP modules will provide the robust datasets needed to improve the parameter quality and reduce the uncertainty associated with model development. Perhaps a major challenge facing the LCA Plan lies in the inherent uncertainty of how well a proposed restoration effort will work. This is particularly relevant for the LCA Plan since it depends on the results of a complex suite of hydrodynamic and ecological simulation models. Given the physical complexity of the Louisiana coastal ecosystems, the predictive abilities of such models are far from perfect. Climatic, hydrologic, and ecological data used as model inputs and boundary conditions are usually available at limited spatial and temporal sampling resolutions. Thus, the LCA recognized the critical need for integrated monitoring and modeling capabilities at a regional scale, and the need for an AEAM framework to support decision-making. The challenges for restoration monitoring

in Louisiana are in deciding which attributes of ecosystems to monitor, in determining which of the changes in attributes observed represent significant departures from expected natural variability, and in using that information to make the best informed management decisions.

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