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2017 Coastal Master Plan

Appendix F: Adaptive Management

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Coastal Protection and Restoration Authority

This document was prepared in support of the 2017 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties, and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every five years) and annual plans. CPRA's mandate is to develop, implement, and enforce a comprehensive coastal protection and restoration master plan.

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Executive Summary

Adaptive management was first proposed nearly four decades ago as a way to develop more resilient policies for managing ecosystems using techniques that reduce uncertainty. The premise for adaptive management suggests using the best available knowledge to design and implement management plans, while establishing an institutional structure that enables learning from outcomes to adjust and improve decision making. Louisiana's dynamic coastal environment lends itself to adaptive management, given the shifting baselines associated with ongoing landscape change and, consequently, the difficulty in predicting the future effects of protection and restoration actions. The goal of this adaptive management plan is to maximize the success of the coastal protection and restoration program by iteratively incorporating new information into each step of the master plan decision making process. The adaptive management process aims to reduce scientific uncertainty in the development, evaluation, and formulation of the master plan in order to improve programmatic decisions. This plan describes how each of the existing master plan steps fit within the larger adaptive management process of defining the problem, developing system models, identifying uncertainties, formulating a plan, monitoring, and assessment. Through each of the adaptive management activities, stakeholders are engaged and information is exchanged to build a knowledge base that supports decision making. The development of the master plan has already successfully incorporated many aspects of adaptive management and this plan identifies opportunities for further application of the process and explicitly identifies actionable steps to successfully implement adaptive management.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ACS	American Community Survey
BICM	Barrier Island Comprehensive Monitoring
CERP	Comprehensive Everglades Restoration Plan
CLEAR	Coastal Louisiana Ecosystem Assessment and Restoration
CPRA	Coastal Protection and Restoration Authority
CRMS	Coastwide Reference Monitoring System
CSAP	Coastal Science Assistantship Program
CWPPRA	Coastal Wetlands Planning, Protection and Restoration Act
DOI	Louisiana Department of Insurance
DOTD	Louisiana Department of Transportation and Development
EAD	Expected Annual Damage
FDT	Framework Development Team
FWOA	Future Without Action
GOHSEP	Governor's Office of Homeland Security and Emergency Preparedness
ICM	Integrated Compartment Model
LCA	Louisiana Coastal Area
LDAF	Louisiana Department of Agriculture and Forestry
LDEQ	Louisiana Department of Environment Quality
LDNR	Louisiana Department of Natural Resources
LDWF	Louisiana Department of Wildlife and Fisheries
LED	Louisiana Economic Development
MAP	Monitoring and Assessment Plan
MDT	Modeling Decision Team
MPDT	Master Plan Delivery Team
O&E	Outreach and Engagement

PAT	Plan Assessment Team
RECOVER	Restoration Coordination and Verification
SEB	Science and Engineering Board
STL	Subtask Leader
SWAMP	System Wide Assessment and Monitoring Program
TACs	Technical Advisory Committees
WCRA	Wetlands Conservation and Restoration Authority

1.0 Introduction and Background

Due to the dynamics of riverine and marine processes, climate change, population growth, economic activity, and ongoing human reliance on the natural resources the coast provides future conditions of coastal Louisiana are highly uncertain. Managing such a complex system in which the natural and socio-economic systems are highly integrated is inherently difficult. Although there have been many large scale, comprehensive management plans and models developed over the last several decades (Gagliano et al., 1973; CWPPRA Task Force & WCRA, 1993; CWPPRA Task Force, 1998; Twilley, 2003), only recently has providing storm surge protection for communities and businesses been integrated with measures to sustain the natural landscape. With the passage of Act 8 of the First Extraordinary Session of 2005 (Act 8), the Louisiana Legislature mandated the integration of hurricane protection activities (e.g., levee construction) and coastal restoration activities (e.g., river diversions and marsh creation). The act created the Coastal Protection and Restoration Authority of Louisiana (CPRA) and charged it with coordinating the efforts of local, state, and federal agencies to achieve long-term and comprehensive coastal protection and restoration through the development of a coastal master plan. The master plan is legislatively mandated to be updated every five years, which inherently allows for an adaptive process enabling response to external change and the incorporation of new information. The routinely updated plan provides an opportunity to use new knowledge about system dynamics and project performance to reduce uncertainty and to incorporate new project ideas for restoration and risk reduction. This is a real application of the concept of adaptive management, a structured process for making decisions over time through active learning and making adjustments in program implementation as new information is gleaned. Adaptive management embraces a systematic approach that involves identifying explicit goals and objectives, developing and implementing management actions, assessing the system's response to the action(s), and then using that knowledge to make management decisions. It is designed to be iterative, allowing for the incorporation of new knowledge through every step of the process.

The first section of this adaptive management plan defines adaptive management and why its application is appropriate for Louisiana's coastal protection and restoration program. In the following sections, a series of activities are outlined to demonstrate that the implementation is feasible within the context of the existing coastal program. This plan draws upon peer-reviewed literature, government documents, conference proceedings, and independent reports to identify the key processes of adaptive management and provide guidance on the importance of information exchange to build a knowledge base that supports decision making. This plan is tailored to meet the specific needs of the coastal master plan and demonstrates how the approach is consistent with established theoretical aspects of adaptive management. The plan builds upon on Adaptive Management Framework (The Water Institute of the Gulf, 2013) developed with oversight from an advisory panel that consisted of individuals with national and international experience in developing and implementing adaptive management in systems with complex human and environmental interactions.

2.0 What is Adaptive Management?

Adaptive management was first proposed nearly four decades ago as a way to develop more resilient policies for managing ecosystems using techniques that reduce uncertainty (Holling, 1978). The premise for adaptive management suggests using the best available knowledge to design and implement management plans, while establishing an institutional structure that enables learning from outcomes to adjust and improve decision making (McLain & Lee, 1996).

The process involves a series of activities to define the problem and to identify current understanding in order to implement beneficial actions that improve the system, while allowing for continued learning through monitoring and assessment. Throughout all phases of adaptive management, effective stakeholder engagement is essential for achieving common understanding, reaching consensus, and reducing conflicts. Stakeholder engagement not only involves disseminating information to improve understanding among those impacted by management actions, but also provides an opportunity to receive new science and creative solutions for addressing the goals and objectives. A fundamental aspect of adaptive management is the progressive nature of the process in which assessment of outcomes leads to improved decision making and adjustment of management actions (Murray & Marmorek, 2003). "Closing the loop", in terms of assessing actions and revising actions or policies using what has been learned, is often thought to be most critical in the process although it has rarely been achieved in restoration (Westgate et al., 2013). The key to this process is understanding that not all outcomes may be anticipated, but opportunities exist for learning even from undesirable results.

The original concept of adaptive management summarized in Rist et al. (2013a) consists of seven activities:

1. Stakeholder engagement;
2. Defining and bounding of the management problem;
3. Representing existing understanding through system models;
4. Identifying uncertainty and alternate hypotheses based on experience;
5. Formulating a plan to allow continued resource management or production while learning;
6. Monitoring the effect of implementing new polices; and
7. Reflecting on, and learning from, monitoring results.

Through iterative repetition of this cycle, management actions will reduce uncertainty and lead to improvement in management outcomes over time. Since the inception of the original concept, however, there has been much study and review of the process, in particular to the identification of obstacles that have prevented successful implementation of adaptive management. For instance, several authors have pointed to inadequate planning and design, insufficient learning opportunities or feedback loops, an unclear approach or definition of adaptive management, among others, as key challenges in successful implementation (Allen et al., 2011; Schreiber et al., 2004 & references therein). However, Rist et al. (2013b) assert that many of these challenges stem from a broader management framework, including the complex policy, social, and institutional environment in which all management occurs (not just adaptive management). Thus, successful adaptive management can only be evaluated for instances in which its application is actually appropriate and feasible. Adaptive management is considered appropriate when uncertainty is a key obstacle for management decisions and when systems are dynamic and are changing through time in response to conditions or management actions that may also vary through time (Rist et al., 2013b; Williams, 2011). The feasibility in applying adaptive management is largely dictated by two key factors: resource availability (e.g., logistical support, expertise, and finances) for management and management flexibility with respect to problem conception (uncertainty construction; Rist et al., 2013b). Thus, the plan described herein articulates an approach for implementing adaptive management for coastal Louisiana that both acknowledges uncertainty and devises an approach to address uncertainty through activities such as modeling, monitoring, and assessment while describing the support and expertise needed to implement the activities of adaptive management. This plan describes existing mechanisms that could be leveraged in order to ensure feasibility in implementing the plan; however, additional resources may be needed to ensure all activities can be effectively accomplished within each master plan cycle.

3.0 Programmatic Adaptive Management for Coastal Louisiana

Louisiana's dynamic coastal environment lends itself to adaptive management, given the shifting baselines associated with ongoing landscape change and, consequently, the difficulty in predicting the future effects of protection and restoration actions. Continued land loss, sea level rise, and subsidence as well as the periodic impact of tropical storms and hurricanes mean there is rarely, if ever, a high degree of certainty about how the effects of a project or an entire program will unfold over time. Changes in coastal populations, economic growth, and human reliance on natural resources will also affect managers' ability to both protect communities and sustain ecosystems. Sustaining such a complex system in which the natural and socio-economic systems are highly integrated is inherently difficult. To meet this challenge, adaptive management within the context of the five year cycle for updating the master plan provides a structured process for making decisions over time through active learning and enables adjustments in program implementation as new information becomes available.

The goal of Louisiana's adaptive management plan is to maximize the success of the coastal protection and restoration program by iteratively incorporating new information into each step of the coastal master plan decision making process. The adaptive management process aims to reduce scientific uncertainty in the development, evaluation, and formulation of the master plan in order to improve programmatic decisions. The adaptive management approach balances the urgent need for action and the inherent uncertainty involved in large-scale coastal planning by ensuring new information is utilized in all aspects of the planning process. This adaptive management plan describes a formalized, structured approach that identifies the pathways and mechanisms by which information is integrated into the five year coastal master plan cycle. Rather than a comprehensive literature review, key lessons and points that support the development of a programmatic adaptive management plan for coastal Louisiana are drawn from a variety of sources. The approach builds on the adaptive management activities identified in the previous section and identifies an additional component, generate knowledge base, to represent avenues through which information is exchanged (Figure 1). For clarity, the exchange of information across activities and the information produced are described within the activity itself.

This plan does not describe project-level adaptive management and uncertainty associated with individual projects, although the overall approach could be adapted for the development of project-level adaptive management plans. Further, project-level templates can be developed to ensure consistency of the approach across master plan projects. Some of the key differences between programmatic and project-level adaptive management have been previously described (The Water Institute of the Gulf, 2013).

This adaptive management plan embraces the master plan technical process that has been followed for the development of the 2012 and 2017 plans (Figure 2). The plan describes how each of these existing steps fit within the larger adaptive management process. Any adjustments recommended to the master plan process shown in Figure 2 to more explicitly demonstrate adaptive management activities in Figure 1 will be incorporated in the 2022 master plan. How each activity in Figure 1 is applied in the master plan process is described, including entities that support the completion of the activity and how decisions are made to ensure it is completed.

Although the activities are presented in a linear fashion, in actuality many may overlap in time or occur at multiple times throughout the process. A summary of when the activities occur is also provided to illustrate how they are interrelated within the context of the five year master plan cycle (Figure 3).

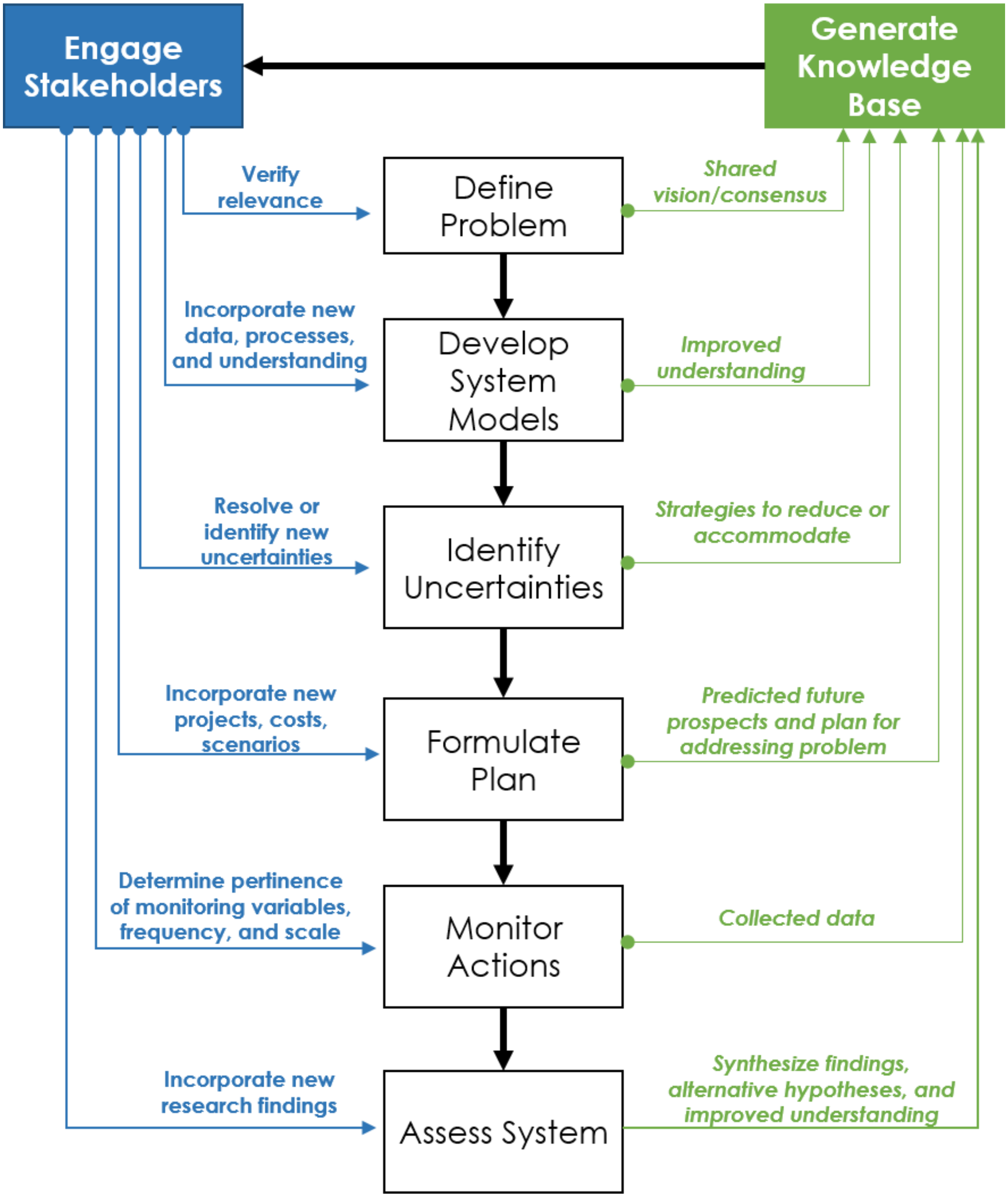

Figure 1: Adaptive Management Activities with a Focus on How Information from Stakeholders is Incorporated and What Information is Generated throughout the Process.

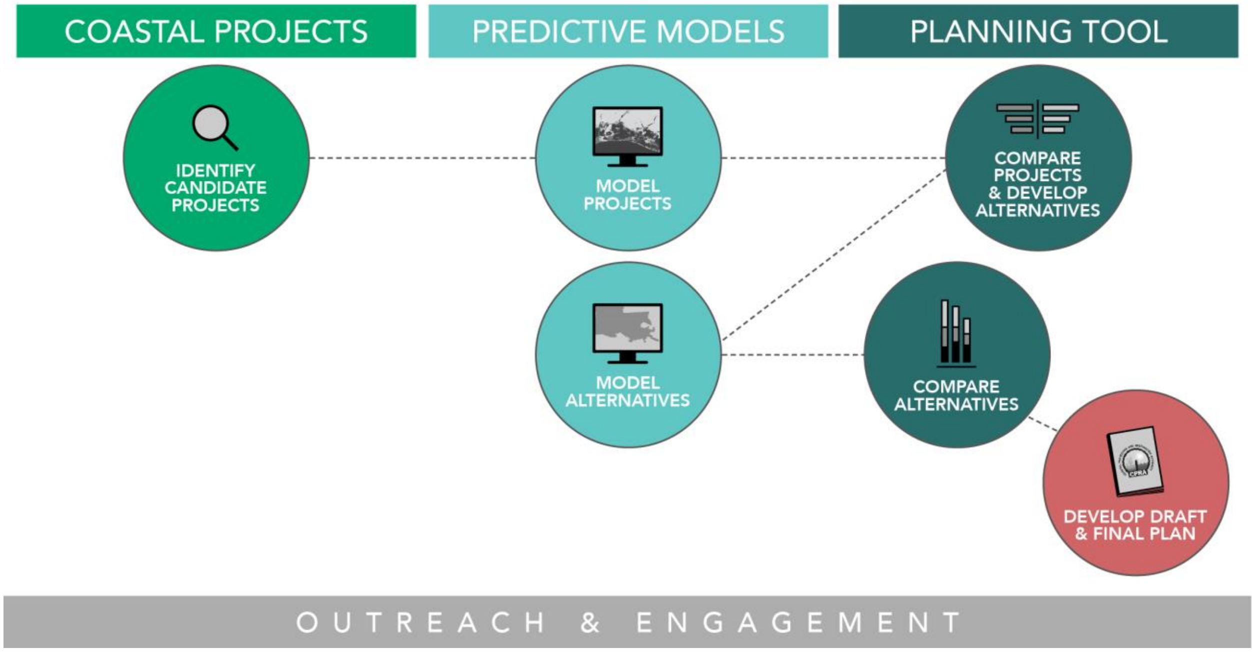

Figure 2: Technical Process for Developing the 2017 Coastal Master Plan.

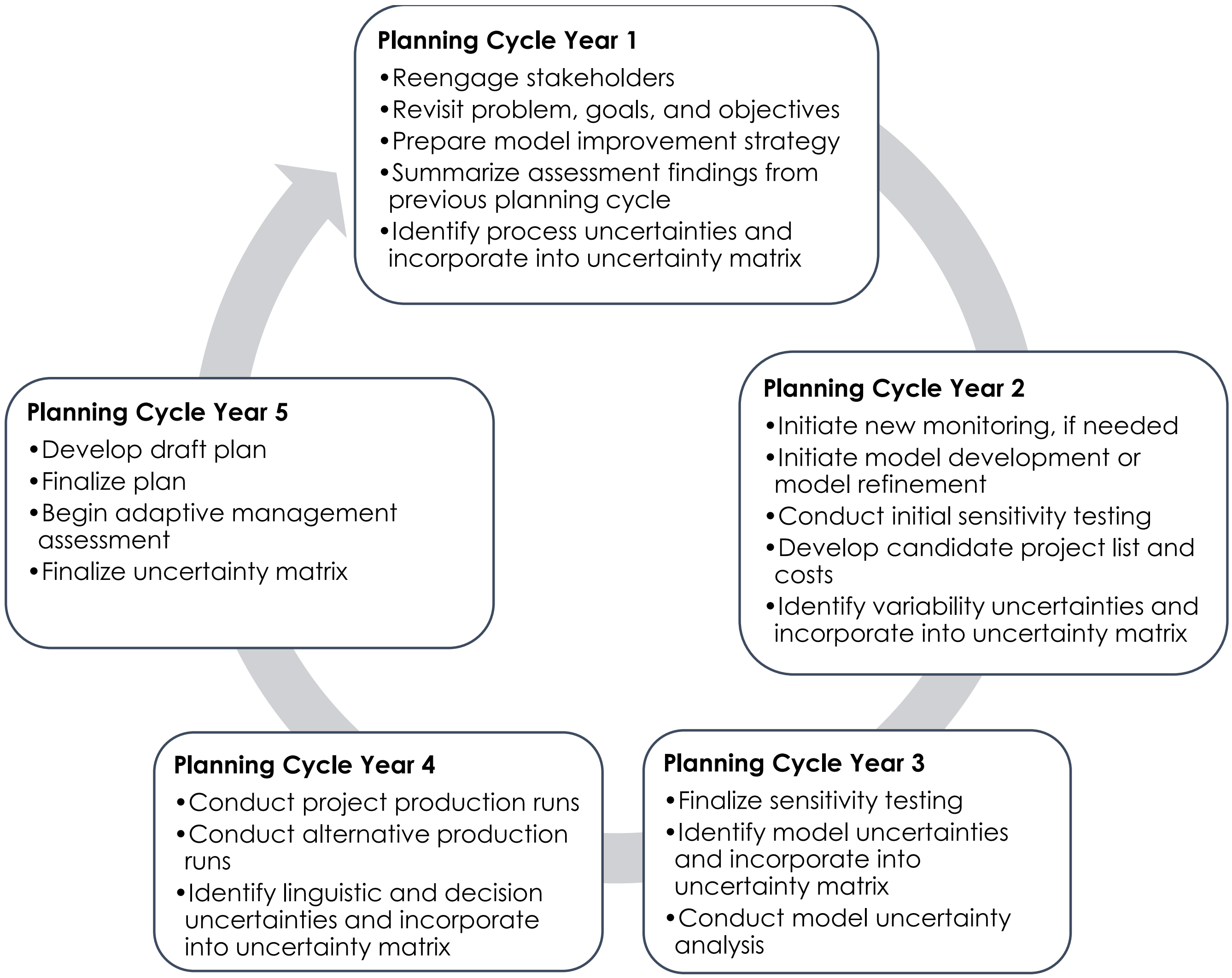

Figure 3: Timeline of Adaptive Management Activities Applied to the Master Plan.

3.1 Stakeholder Engagement

3.1.1 Rationale

Role of this Step
• Identify potential coastal projects • Avoid/manage conflict • Technical advice and feedback • Ensure process is technically sound and widely understood

Stakeholders are the individuals and groups that participate in the development of or are affected by the proposed actions in the master plan. The benefits of stakeholder engagement include (adapted from RECOVER, 2006):

- Building better collective understanding of the resource issues and the science used in the planning process;

- Promoting relationships and trust as well as establishing lines of communication, which often can take considerable time to build;
- Enabling cooperative learning, especially regarding issues that may be confusing, unclear, or unknown;
- Providing forums to promptly identify and address key issues and concerns related to potential master plan actions;
- Creating networks for disseminating new or updated information to improve understanding as master plan implementation unfolds;
- Developing creative solutions that address varying stakeholder interests while fulfilling master plan goals and objectives

3.1.2 Application to the Coastal Master Plan

Stakeholder engagement (Figure 1) is already integrally connected across the master plan process and begins at the onset of the master plan cycle (Figure 3). There are a number of avenues by which stakeholders are engaged from advisory boards and technical committees to citizen groups and meetings with elected officials (Table 1). This section briefly describes each of the existing groups and their purpose and summarizes how information obtained from these groups informs the decision making process. Stakeholder engagement is also revisited in subsequent activities to highlight their role during the adaptive management process and indicate when their engagement occurs during each of the remaining activities.

Within the current master plan framework, the CPRA Board, the Master Plan Delivery Team (MPDT), and the Outreach and Engagement (O&E) Team each have roles in facilitating and guiding stakeholder engagement. The CPRA Board is structured to ensure a number of government agencies and boards are engaged in the protection and restoration program (Box 1). The Board also includes representatives of other groups, such as the Governor's Advisory Commission, that have been formed to engage a broader array of stakeholders and interest groups as well as members appointed by the governor. The Board is responsible for seeing the coastal protection and restoration program in a larger context (Table 1) and keeping focus on the problem (Figure 1-Define Problem) while proactively seeking input from others. The Board is a venue for the inclusion of new projects and ideas, and the Board ultimately approves the coastal master plan updates prior to submission to the legislature (Figure 1-Formulate Plan).

The MPDT is responsible for developing the plan and coordinating review of the master plan process by national or international experts. Part of plan development includes the identification of new restoration and protection project concepts to evaluate through

Box 1: The CPRA Board

The CPRA Board comprises:

- The Executive Assistant to the Governor (Chair)
- The secretaries of the Louisiana Department of Natural Resources (LDNR); the Louisiana Department of Transportation and Development (DOTD); the Louisiana Department of Environmental Quality (LDEQ); the Louisiana Department of Wildlife and Fisheries (LDWF); the Louisiana Department of Economic Development (LED); the commissioners of the Louisiana Department of Agriculture and Forestry (LDAF); the Louisiana Department of Insurance (DOI); and the Louisiana Division of Administration (DOA); the Director of the Governor's Office of Homeland Security and Preparedness (GOHSEP); and the Chair of the Governor's Advisory Commission on Coastal Protection, Restoration, and Conservation
- Seven members appointed by the Governor to representing the police juries and levee boards of Louisiana

the master plan process, and stakeholders are encouraged to submit project proposals. The O&E Team focuses on engagement of the public and other Louisiana interests to ensure the plan is rooted in realities experienced by people who live and work on the coast every day. The MPDT and O&E Team collectively engage with a series of technical advisory committees, citizen groups, and elected officials (Table 1). Technical advisory boards and committees include the Science and Engineering Board (SEB; Appendix G) and Technical Advisory Committees (TACs; Appendix G). These groups consist of scientists, engineers, and practitioners with technical expertise that can offer working-level guidance and review of the plan's elements and can provide recommendations on ways to improve the scientific basis and credibility of the master plan. Several meetings are held with each of the groups during subsequent adaptive management activities, including the development of system models, identification of uncertainties, and development of the master plan (Figure 1). The groups provide timely feedback that may result in model improvements for inclusion in the current master plan cycle or for future refinements or guidance on synthesizing information and developing alternatives for future master plan cycles (Table 1).

The Framework Development Team (FDT) serves as the primary mechanism for engaging with local representatives. The team includes members from federal, state, and local governments, non-governmental organizations, business and industry, academia, and coastal communities. FDT members offer specific guidance on major elements of the master plan and, as key advisors and liaisons to the broader community, they work collaboratively to identify, discuss, and reach a common understanding about the tough choices that lie at the heart of protecting and restoring Louisiana's coast (Table 1). Similar to the FDT, focus groups are designed to integrate the perspectives of those in key sectors, representing each of the following areas: community, fisheries, landowners, energy and industry, and navigation. At least one member of the FDT supports each of the focus groups, and results from focus group discussions are reported at subsequent FDT meetings. The focus groups discuss topics centered on plan development and implementation options for projects in key areas and the potential affects to communities, businesses, and industries in south Louisiana (Table 1).

Table 1: Summary of Stakeholders Engaged in the Master Plan Process and the Exchange of Information that Occurs Across Adaptive Management Activities.

Stakeholder Group	Information Discussed	Relevance to Adaptive Management Activities
CPRA Board	Briefings and discussion at key benchmarks in the master plan process	Information is used to ensure all activities remain relevant to the coastal protection and restoration program in a larger context.
Predictive Models-TAC	Technical details on the modeling used to support the master plan	Information is used to refine and improve system models as well as identify knowledge uncertainties (as defined in Section 3.4).
Resiliency TAC	Technical details of the flood risk and resilience program and the underlying analysis	Information is used to refine and improve the flood risk and resilience program and communicate to those affected.
SEB	Technical overview of analytical tools and how they are used to produce the master plan	Information is used to refine and improve system models, formulate the plan, as well as identify linguistic and decision uncertainties (as defined in Section 3.4).
FDT	Regular summaries of	Information is used to ensure all activities remain

Stakeholder Group	Information Discussed	Relevance to Adaptive Management Activities
	progress including project information, scenario specification, model results, preliminary formulations, etc.	relevant to the realities experienced by people who live and work on the coast every day.
Focus Groups	Sector specific information on projects, metrics, and issues of concern	Information is used to ensure all activities remain relevant to coastal communities and can aid identifying linguistic and decision uncertainties (as defined in Section 3.4).
Flood Risk and Resilience Subcommittee	Specific insight into future nonstructural measures and activities	Information is used to enhance decision making, focus resources on critical areas of need, and provide recommendations on policies and procedures for nonstructural implementation.
Parish Floodplain Managers Group	Guidance into the implementation of nonstructural projects	Information is used to guide policies and procedures for nonstructural implementation.
State Steering Committee	Updates and discussion at key benchmarks in the master plan process	Information is used to ensure all activities receive input from the state departments and agencies to establish shared ownership.

3.2 Defining the Problem

3.2.1 Rationale

Role of this Step

- Serves as the foundation of master plan planning and implementations
- Sets focus and expectations

A clearly defined problem statement articulates the underlying reason for why action is needed on the coast and thus establishes a foundation for the development and implementation of the program. The problem statement is supported by clearly defined goals and objectives, which set the stage for all subsequent activities of the adaptive management process. Defining the problem ensures common expectations among stakeholders of what the plan will address and what is beyond its scope.

3.2.2 Application to the Coastal Master Plan

The CPRA Board has overall responsibility for defining the problem that the master plan addresses. While the problem statement has remained essentially the same since the first master plan in 2007, any revision by the Board would consider stakeholder input to ensure the problem statement remains relevant in the larger context of the coast. Goals and objectives have been developed to address the problem and serve as the foundation for the master plan to ensure a common vision for program success. The goals and objectives of the master plan were defined during the 2007 planning cycle and revisited in 2012 to include the fifth objective (Box 2). In 2017, the objectives were revisited by the FDT at the beginning of the master plan cycle (Figure 3), and it was determined that no additional changes were needed. To adhere to the adaptive management approach, it is important that the problem, goals, and objectives are revisited at the beginning of each planning cycle (Figure 3). The current goals and objectives of the master plan are sufficiently broad to provide suitable guidance to planning and appropriate expectations of the public in terms of what the program is trying to achieve. Modifications to the goals and objectives, or their approval without modification, is the responsibility of the CPRA Board, as informed by their staff and advised by other groups. As part of the master plan cycle, revisiting the goals and objectives needs to occur once the findings of the assessment (Figure 1) from the previous cycle are available.

If the goals or objectives are revised, the types of projects that are evaluated using the models and the plan formulation procedure would be revised to reflect the revisions. Adjustments to goals and objectives may be merited under any of the following circumstances:

- When projects originally considered to contribute to achieving the objective are not producing meaningful change, and no viable alternative projects can be identified. Given the general nature of the program objectives, this is unlikely to lead to an elimination of objectives, but it may lead to some reframing in order that public expectations of the program are clear;
- When an unanticipated change occurs due to an external factor(s) results in a new need. For example, if extensive sea level rise leads to periodic flooding of agricultural land, reinterpretation of infrastructure being protected could be required; and

Box 2: 2017 Coastal Master Plan Goals and Objectives

Goals:

1. Protection – Use a combination of restoration, nonstructural, and targeted structural measures to provide increased flood protection for communities.
2. Restoration – Use an integrated and synergistic approach to ensure a sustainable and resilient coastal landscape.

Objectives:

1. Flood Protection – Reduce economic losses from storm surge based flooding to residential, public, industrial, and commercial infrastructure.
2. Natural Processes – Promote a sustainable coastal ecosystem by harnessing the natural processes of the system.
3. Coastal Habitats – Provide habitats suitable to support an array of commercial and recreational activities coast wide.
4. Cultural Heritage – Sustain the unique cultural heritage of coastal Louisiana by protecting historic properties and traditional living cultures and their ties and relationships to the natural environment.
5. Working Coast – Promote a viable working coast to support regionally and nationally important businesses and industries.

- When a change in program scope is introduced by statute.

These circumstances illustrate that modification of goals and objectives should only be undertaken due to major shifts in policy or coastal circumstances, and that those modifications are determined by information from the knowledge base (Figure 1) or by higher-level decision making. For example, these circumstances may originate if the combination of coastal change and rising seas result in conditions that make it clear that emphasis is needed on transitions and adaptation rather than providing flood protection for all communities.

3.3 Developing System Models to Make Predictions

3.3.1 Rationale

Role of this Step

- Predictions of future change with and without projects over plausible future environmental conditions
- Assessment of uncertainties
- Evaluation of projects and project groups in terms of the master plan objectives

Conceptual and numerical models are used to explicitly describe the relationship between actions and the system response, including articulation of key assumptions, and to assist in identifying uncertainties (Schreiber et al., 2004). Numerical models also provide an opportunity to test and evaluate the sensitivity of the system to uncertainty. Using simulation models to predict how projects and project groups (i.e., alternatives), including no action, may impact a system serves three functions: 1) it allows for identification and communication of the overall situation (i.e., potential system response to change) among scientists, engineers, managers, and stakeholders; 2) it makes it possible to screen solutions to eliminate those that are not suitable or effective; and 3) it helps to identify how knowledge gaps and uncertainty influence model results (Walters, 1997).

3.3.2 Application to the Coastal Master Plan

The master plan modeling effort is used to evaluate restoration and protection projects that build and sustain the landscape and reduce the risk to communities from storm surge based flooding (Appendix C). The information needed to run the model simulations is dependent on the underlying processes the models are designed to represent (Table 2). The linkages among subroutines that represent landscape and ecosystem processes is described and depicted in Appendix C, Chapter 3. Models are used to evaluate individual restoration and protection project effects, compared to a future without action (FWOA), to assess the interactive effects of multiple projects, and to quantify outcomes of master plan implementation. Project effects results are provided to the Planning Tool for each scenario, and the Planning Tool applies constraints such as available funding, the amount of sediment in borrow areas, etc., to identify high performing sets of projects (Appendix D). Model outputs are also combined in different ways to generate metrics (Attachment C4-11) that can also be used to assess performance against the master plan objectives. Sets of projects, or alternatives, are then modeled to identify potential synergistic or conflicting effects among projects and to determine the net effects of implementation over time. Additional details on how model output leads to the development of the master plan are briefly described in the plan formulation activity and in more detail in Appendices C and D.

The Modeling Decision Team (MDT) is responsible for the implementation and quality of the modeling effort. The team includes a technical lead, technical advisor, support staff, and technical staff from CPRA. The technical lead is responsible for directing the overall modeling effort and has broad expertise in modeling. The advisor provides insight based on previous and ongoing modeling efforts, reviews work products, and leads external reviews. These two individuals are typically senior-level experts with understanding of modeling capabilities and the underlying scientific assumptions and processes that are modeled. CPRA staff provide technical knowledge, oversight, act as liaisons to other MPDT members, and review work products. The MDT also coordinates regularly with a larger team of subtask leaders involved in developing and executing the modeling. The MDT and subtask leaders regularly engage with outside groups such as the SEB and TACs to review model work products and gain more information on potential model improvements.

To adhere to the adaptive management approach, a modeling improvement strategy needs to be developed by the MDT at the beginning of each master plan cycle (Figure 3). This lays out the improvements needed for modeling system dynamics, including the addition, refinement or removal of any modeling components. The strategy may be guided by peer-review of the models used in the previous cycle, comments from the modelers, the stakeholder engagement process (e.g., comments from TACs and SEB), and the adaptive management assessment (Figure 1). Prioritization of model improvements should be guided in part by sensitivity testing and uncertainty analyses conducted during the previous planning cycle in order to determine which processes/variables are most critical to the plan formulation. A model improvement strategy was developed for the 2017 Coastal Master Plan and an overview of improvements made to the modeling tools since 2012, including descriptions of entirely new subroutines and/or processes is provided in Appendix C, Chapter 3. One of the most substantial improvements made for the 2017 Coastal Master Plan is the integration of previously disparate landscape and ecosystem models (eco-hydrology, vegetation, wetland morphology, and barrier islands) into an Integrated Compartment Model (ICM). Model improvement may also occur during the planning cycle during stakeholder engagement with the TACs and SEB (Table 1), although CPRA ultimately determines the feasibility in making the changes within the timeline of an individual planning cycle.

Table 2: Summary of Modeling Components to the 2017 Coastal Master Plan.
The model is designed to represent 'real-world' processes using a variety of model subroutines and statistical tools. These tools require data that function as forcings, drivers, or inputs and are used to generate output that may feed to other models or be used in the Planning Tool to evaluate projects and alternatives.

Model	Subroutine	Real-World Processes and Dynamics	How Subroutines Represent the Real World	Forcings, Drivers, or Inputs	Subroutine Output
ICM	Hydrology	Hydrodynamics and water quality dynamics in the coastal estuary	Simplified physics mass-balance compartment models that includes bed resuspension and sedimentation processes	Precipitation, evapotranspiration, river input, air temperature, wind speed/direction, sea level rise, Gulf of Mexico water levels and salinity	Water temperature, estuary salinity, estuary water level, suspended sediment concentration, waves, sediment deposition (open water, marsh surface)
	Morphology	Elevation change and marsh collapse	Relative elevation change model based on accretion (inorganic and organic) and relative sea level rise rates; pre-set threshold for wetland-water conversion	Topography/bathymetry, soil bulk density/organic matter, sediment accumulation, subsidence, marsh edge erosion	Land and water area, elevation
	Vegetation	Distribution of emergent vegetation and submerged aquatic vegetation	Probability-based model to predict establishment and mortality of vegetation species based on environmental conditions	Salinity, water level variability, initial vegetation cover	Percent cover of selected vegetation species
	Habitat Suitability Index	Distribution of wildlife, fish and shellfish	Relative suitability or capacity of an area to support a species based on statistical or literature-derived relationships to environmental conditions	Salinity, temperature, water level, and wetland type	Habitat suitability for selected wildlife, fish, and shellfish species
	Barrier Island	Barrier island dynamics	Long-shore sediment transport model that includes cross-shore components, island breaching and relative sea level rise rates	Gulf water level, waves (storm and non-storm), overwash, sediment properties (e.g., grain sized distribution)	Barrier island topography and bathymetry

Model	Subroutine	Real-World Processes and Dynamics	How Subroutines Represent the Real World	Forcings, Drivers, or Inputs	Subroutine Output
Ecopath with Ecosim (EwE)		Distribution and abundance of fish and shellfish	Trophic food web model	Salinity, water temperature, total Kjeldahl nitrogen, total suspended solids, bathymetry, land-water distribution	Biomass for each fish and shellfish species
ADCIRC/UnSWAN		Storm surge and wave generation and transformation across coastal landscape	Physics-based modeling approach for synthetic storm surge and wave climate with an unstructured mesh	Elevation data at each model node, surface roughness characteristics, river flow, synthetic hurricane wind fields, synthetic hurricane pressure fields, and tides at open ocean boundary	Flood stage time series, maximum wave height, and peak wave period data
CLARA		Economic risk resulting from storm surge based flooding	Probability of storm surge based flooding (overtopping, system fragility and interior drainage) at different depths and the economic damages resulting from flooding using asset inventory, asset valuation	Peak storm surge, wave heights, presences of barriers (e.g., levees), landscape characteristics (e.g., topography), assets and asset value, depth-damage curves	Flood depth and damage exceedance values, at a selected set of annual exceedance probabilities; expected annual damage (EAD) from storm surge based flood events)

3.4 Identifying Uncertainties

3.4.1 Rationale

Role of this Step
• Uncertainty matrix created • Confidence bounds established • Approaches for reducing uncertainties over time

Adaptive management is employed when uncertainty precludes effective management decisions. Thus, quantifying this uncertainty serves a critical role in the adaptive management process and is used to understand modeling limitations, identify confidence in planning processes, and target future research. Several different uncertainty typologies have been defined in the decision-support literature to classify uncertainties and identify their sources, although many terms overlap and there is no commonly shared terminology. Here the terminology from Ascough et al. (2008) is adapted as the authors synthesize and identify overlaps and differences in the currently used terminology to develop a scheme that can broadly be applied to both the biophysical and human system analyses that are undertaken to support the master plan. The four uncertainty typologies are knowledge, variability, linguistic, and decision uncertainties (Table 3). Given the significant role of uncertainties, their connections to model development, plan formulation, assessment, and the different methods used to address them in the adaptive management process, this section is organized according to the different typologies identified in Table 3 and their application to the master plan is described.[1]

3.4.2 Application to the Coastal Master Plan

3.4.2.1 Knowledge Uncertainty

Knowledge uncertainty encompasses both process understanding and model uncertainty (defined in Table 3). Model uncertainty is currently handled more explicitly than process understanding in the master plan. However, increasing process understanding in the adaptive management procedure can be achieved via feedbacks from the knowledge base (Figure 1), including peer-reviewed literature and targeted research. The 2017 Coastal Master Plan included peer-review of several new components of the ICM, such as the new approach for sediment distribution onto the marsh surface (Appendix C, Attachment C3-1) and the revisions to the CLARA model (Appendix C, Attachment C3-25) in part to ensure models appropriately represent real-world conditions (Table 2). As part of the adaptive management process, a strategy for identifying and addressing process understanding is needed. Process uncertainties should be identified by the MDT and subtask leader (STL) during model development (Figure 3) and this information can be used to guide the model improvement strategy for the subsequent planning cycle. Uncertainty analysis can be used to evaluate the confidence level in the models' predicting ability (Meselhe & Rodrigue, 2013), while sensitivity analysis can then be used to rank the relative importance of the uncertainties in terms of predicting future outcomes. In order to address process uncertainties, several avenues for targeted research exist and are further explored in the assessment activity later in this report (Section 3.7).

[1] Given that this typology has not been previously applied in Louisiana, additional detail is provided above and beyond previous sections in which terminologies and procedures for addressing are largely in place and described in reports.

Table 3: Uncertainty Typologies, Types, Definitions (Ascough et al., 2008) and Examples from the Master Plan.

Typology	Type		Definition/Source	Master Plan Example
Knowledge Uncertainty	Process Understanding		The limits of scientific understanding including spatial and temporal scales at which knowledge applies	The processes controlling marsh edge erosion and marsh collapse
	Model Uncertainty	Parametric Data	Model parameters which may arise from measurement error, type of data, or length of data record	Errors in LIDAR data; dated bathymetric surveys
		Structure	Use of surrogate variables, exclusion of variables, relationships among variables, and approximations from functional forms, equations, and mathematical expressions used to represent the system	Vegetation response as dictated by salinity and water depth look-up tables
		Technical	Software or hardware; coding; algorithms	Sensitivity to floating point calculation that lead to changes in model outcomes
		Output	Accumulated uncertainty propagated through model; discrepancy between true value of an outcome and model predicted value	Joint probability model used to estimate flood depths in the CLARA model
Variability Uncertainty	Natural		Inherent randomness of nature, i.e., the chaotic and unpredictable quality of natural processes	Frequency and location of storms
	Human		Values and attitudes of the environmental manager/decision maker, current political climate	Elevation standards for nonstructural flood protection
	Institutional		Social, economic, and cultural dynamics (societal variability)	Response of populations to coastal change and flooding
	Technological		New developments or breakthroughs in technology or unexpected consequences (‘side-effects’) of technologies	Project costs associated with dredge/placement of material

Typology	Type	Definition/Source	Master Plan Example
Linguistic Uncertainty	Vagueness	When a precise description of a quantity or entity is not available	Habitat suitability as a way to describe relative importance of an area to an organism, such as blue crabs
	Ambiguity	Words have more than one meaning	Land loss as a term to describe coastal change when many do not consider wetlands as land
	Under specificity	Unwanted generality in the data	Exact sampling location for a data point is not recorded (e.g., Lake Lery as opposed to the exact GPS coordinates)
Decision Uncertainty	Goals/Objectives	Ambiguity in how to quantify or compare objectives	Whether metrics based on model results can meaningfully represent the outcomes anticipated by the master plan objectives
	Assessment Criteria	Quantitative policy analysis after the estimation of risk has been generated	Planning Tool algorithms used to rank based on metrics and model outputs
	Future Courses of Actions	The way model predictions are interpreted and communicated, especially with regard to future courses of action	Whether project design and implementation timelines have been estimated accurately and whether other factors will influence actual time to project execution; availability of funding streams over time

Model uncertainty analysis was conducted for the 2012 Coastal Master Plan landscape and ecosystem models (Habib & Reed, 2013). The results revealed that although the accumulated model output uncertainties did grow over the 50-year prediction period, uncertainty did not confound the prediction of land change with the master plan relative to FWOA. For the 2017 update, an approach for evaluating ICM uncertainty was developed by the modelers with input from the MDT and the PM-TAC (part of stakeholder engagement; Figure 1; Table 1). The goals of the ICM uncertainty analysis were to:

- Establish the confidence bounds in the numerical models' predictions of land area and assess their ability to discern the impacts of restoration projects;
- Identify areas or elements of weakness and high uncertainties in the models to the extent that these uncertainties mask the model predictions and limit their use; and
- Provide insights and recommendations to reduce such uncertainties. These recommendations can be incorporated in the design of future data collection programs.

For the CLARA model, the need for an expanded model uncertainty approach for the 2017 Coastal Master Plan was identified through stakeholder engagement with the SEB, to include how model uncertainty propagates throughout the modeling steps. This was especially significant for the flood risk assessment, as the CLARA model uses many assumptions about the frequency and spatial distribution of storms in determining flood depths. A parametric uncertainty analysis was conducted (Appendix C, Attachment C3-25) enabling the CLARA model to report results with their associated levels of confidence.

3.4.2.2 Variability Uncertainty

The inherent variability in natural and human systems has the potential for significant impacts on the decision making process as these are uncertainties driven by random or stochastic processes that are poorly understood (Ascough et al., 2008). For example, the location and force of storms, floods, and droughts is inherently unpredictable. These types of natural uncertainties are the basis for the scenario approach used in the master plan. Environmental scenarios account for unpredictable variations in subsidence (which could also be considered a knowledge uncertainty), eustatic sea level rise, precipitation, evapotranspiration, and storm frequency and intensity (Appendix C, Chapter 2). The CLARA model also uses a scenario approach related to structure fragility and levee failure, which could be considered technological uncertainties. Future flood depths, land loss, and assumptions about how population growth/decline responds to these factors (i.e., institutional uncertainty) are used to develop scenarios of asset distributions across the coast that are used in the CLARA model damage calculations.

In addition, policy changes made by others (e.g., U.S. Army Corps of Engineers' approach to Mississippi River management) can be considered a human uncertainty and can influence the effectiveness or rate of plan implementation. Technological changes and variations in the price of fuel and labor clearly influence costs and cannot be known with certainty in advance. It is important to recognize that these sources of uncertainty differ from knowledge uncertainty described above in that their magnitudes may be difficult to quantify or, in some cases, they may be irreducible altogether. Nevertheless, an assessment of these uncertainties by the MPDT is useful in the plan formulation process when considering future actions and their outcomes. As part of the adaptive management process, stakeholder engagement with the TACs (Table 1) can aid in addressing these variability uncertainties during planning cycle year 2 (Figure 3). This already occurs with the setting of scenarios used by the models, but can be expanded as these types of uncertainties are more explicitly identified.

3.4.2.3 Linguistic Uncertainty

Linguistic uncertainty arises as meanings of words change over time and language is often context dependent (Asough et al., 2008). Expert knowledge, qualitative data, or other instances in which information does not fit precisely into a quantity or entity can also lead to linguistic uncertainty. In the master plan, 'habitat suitability' for a species has been defined using simplified relationships, but the term itself is vague and may be interpreted differently among groups of stakeholders. In addition, some terms are used commonly by those working on coastal Louisiana that may not be understood in the same way by others. For example, land loss is a phrase frequently used to describe the changes seen in the coastal system, but some may not realize that the 'land' lost is mostly wetland. Expected annual damages and cost-effectiveness are also vague terms that contribute to linguistic uncertainty. This type of uncertainty can be reduced through effective stakeholder engagement with focus groups and the FDT (Table 1) and thoughtful communication to those less familiar with the issues. The O&E Team is responsible for awareness of this uncertainty and reducing it where possible.

3.4.2.4 Decision Uncertainty

Decision uncertainty stems from the uncertainty associated with valuing the master plan goals and objectives and interpreting and communicating model predictions. For such a complex, multi-faceted problem as the restoration and protection of coastal Louisiana, decisions will always be made on the basis of assumptions, and while it is helpful to quantify the plan's effectiveness relative to the specific objectives, this introduces yet another level of uncertainty. In the master plan for 2012 and for the 2017 update, various decision drivers and metrics are used by the Planning Tool to summarize model outputs, rank projects relative to one another, and to identify cost-constrained groups of high performing projects. The way in which these input data for the Planning Tool are generated may inherently contain bias, above and beyond the model outputs themselves, e.g., not all aspects of the working coast are explicitly considered. Knowledge, variability, and linguistic uncertainties can propagate through to decision uncertainty, much like parametric uncertainties propagate through models. Decision uncertainty is currently not explicitly quantified; however, the Planning Tool can evaluate and rank projects using different types of metrics. Sensitivity testing could be conducted to determine whether any project types, geographic areas, or vulnerable communities would be predisposed to low (or high) ranking under any of the metrics used. This could lead to improvement of the metrics or inclusion of new ones in future planning cycles. Identifying this type of uncertainty and understanding the assumptions that have been made both in the lead up to the decision and in the decision itself is important in the adaptive management process. Decision uncertainty can be determined by the MPDT with input from the SEB during plan formulation (Figure 3).

3.4.2.5 Developing an Uncertainty Matrix

While uncertainty is considered at many stages of the master plan analysis, tracking it over master plan cycles so the information can actively be considered by decision makers and understood by stakeholders requires a structured approach. Therefore, an uncertainty matrix needs to be developed during this adaptive management activity to organize the identified uncertainties, quantify (quantitatively or qualitatively) their relative magnitudes, determine whether they can be resolved and an approach to resolve them, and determine their relative significance in the ability to develop and implement the master plan (Table 4). Examples of such tables can be found in the Comprehensive Everglades Restoration Plan adaptive management plan (RECOVER, 2015).

Table 4: Example of an Uncertainty Matrix Approach for Summarizing Uncertainties and the Potential Strategies for Reducing Uncertainties Over Time. This is presented for illustrative purposes only.

Uncertainty	Typology	Type	Details	Degree of Uncertainty	Relevance to Decision Making	Potential Strategies for Reducing
Stage	Knowledge Uncertainty	Parametric Data	Stage is tracked in all ICM compartments and one value is determined for each compartment on each time step. Exchanges among compartments are calibrated using past conditions but as future conditions change, the nature of the compartments and exchanges can be very different from the calibration period.	Medium	Medium	Reduction in compartment size
Marsh Edge Erosion	Knowledge Uncertainty	Process and Structure	Erosion of marsh edges generated by wave action is a significant known mechanism for wetland loss in Louisiana (Day et al., 2000). However, existing wave power regression equations are not adequate for coast wide predictions possibly due to the heterogeneity of the marsh system and the simplicity of the wave interaction model (2017 Coastal Master Plan).	Low	Low	Targeted research to improve equations or develop other approaches
Response of populations to coastal change and flooding	Variability Uncertainty	Institutional	The distribution of populations and assets 50 years into the future may change substantially. While there are demographic data that can be used to quantify the social vulnerability of various populations and model disaster response, existing models have not yet matured sufficiently to incorporate into definitions of scenarios of future population and asset growth (2017 Coastal Master Plan).	High	Medium	Literature review of studies/ targeted research examining linkages between population vulnerability, coastal disasters, and migration

Uncertainty	Typology	Type	Details	Degree of Uncertainty	Relevance to Decision Making	Potential Strategies for Reducing
Planning Tool Metrics	Decision Uncertainty	Assessment Criteria	Metrics are used in addition to the main decision drivers, land area and EAD, to rank projects, formulate alternatives, compare alternatives or improve understanding of the effects of the plan and its included projects on the coast. The metrics are derived by combing model outputs as a way to represent qualitative objectives.	High	Medium	Planning Tool sensitivity testing to evaluate whether certain project types are predisposed to rank lower than others as a result of metrics used

3.5 Plan Formulation

3.5.1 Rationale

Role of this Step

- Strategy for meeting goals and objectives
- Development of flexible and robust project list

Comprehensive plans are developed to solve defined (yet complex) problems and achieve specific goals and objectives. Plans should be designed in a manner that is robust and flexible to the underlying uncertainties previously identified. This includes creating a base plan for implementing actions over a set time frame and include options in the event the plan is not performing as anticipated. Existing approaches, such as adaptive pathways (e.g., Haasnoot et al., 2012), can be used to outline a path forward and create "road maps" for plan implementation in the face of multiple uncertainties. Road maps allow the plan to make adjustments as the system changes unexpectedly or when tipping points are reached. Tipping points are reached when it is clear that action(s) have not met or are no longer meeting the intended goals and objectives. Several statistical- and model-based methods have recently been developed to assist with anticipating tipping points in the natural or human system (e.g., Carpenter & Brock, 2006; Dakos et al., 2012; Drake & Griffen, 2010).

3.5.2 Application to the Coastal Master Plan

Plan formulation, i.e., identification of the projects to be included in the master plan, is supported by a computer-based, decision-support tool, called the Planning Tool, and by stakeholder input. The Planning Tool was developed as part of the 2012 Coastal Master Plan and was used to 1) make analytical and objective comparisons over a 50-year period of hundreds of different risk reduction (including nonstructural protection measures) and restoration projects, 2) identify and assess alternatives that could make up comprehensive solutions, and 3) display the hard decisions (i.e., tradeoffs) interactively to support iterative deliberation over alternatives (Groves & Sharon, 2013). The use of the Planning Tool was considered a significant improvement relative to the 2007 Coastal Master Plan, which was more conceptual in nature, and it allowed the MPDT to evaluate many different combinations of solutions to address land loss and reduce flooding risk for coastal communities. The Planning Tool continues to be refined (e.g., improved visualization of outputs, ability to compare 2012 versus 2017 information, and adjustments to project selection procedures) and can be adjusted during each planning cycle as needs change.

The two fundamental model outputs used by the Planning Tool to inform plan formulation are the extent of land (output from the ICM) and reduction in expected annual damages, which is output from the risk model, CLARA. These are termed 'decision drivers' and were selected to meet the overarching goal of the master plan: to reduce risk and build land. Costs for each project are also developed based on assumptions about design and conditions at the time of construction. For each restoration and structural protection project, the cost-effectiveness of the project in terms of each of the decision drivers is used to select the optimal group of projects for a given stream of funding and future scenario (environmental, fragility, and population growth), subject to other constraints such as sediment availability. For nonstructural protection projects, other criteria such as future flood depths are considered in addition to cost-effectiveness. In addition to the decision drivers, a number of additional metrics are derived from the model outputs and used by the Planning Tool to explore the effects of individual projects and alternatives on other aspects of the coastal system. These metrics are used to evaluate the plan relative to the five master plan objectives (Box 2). The Planning Tool is ultimately used to guide development of the draft master plan that is then shared with stakeholders. The O&E Team assists in stakeholder engagement throughout the planning process and ensures the draft plan is communicated to all those potentially impacted by the plan. The goal of the outreach is to:

- Bring a variety of citizens to the planning table and engage them in the hard choices confronting the State;
- Learn from stakeholders more about the issues that should be incorporated into the planning cycle;
- Gain ideas from a range of people about areas of possible agreement or disagreement related to some of the decisions; and
- Discuss the constraints (funding and availability of sediment) that must be factored in as planning proceeds, so that these constraints become a standard point of reference in dialogue about the coast's future.

Public acceptance plays a critical role in the success of the plan, and thus the outcomes of the stakeholder engagement may result in project modifications and additional testing using the Planning Tool. As a result, the final master plan is based on both scientific and technical analysis, as well as expert-adjusted modifications and public input. The plan currently consists of one potential "road map" of projects, but a potential future adaptation that could be considered by the MPDT as part of the adaptive management process is developing different "road maps" or adaptive pathways to meet different master plan objectives or different road maps based on future scenarios. Such approaches have recently been tested for the Rhine Delta of the Netherlands (Haasnoot, 2013; Haasnoot et al., 2014; Kwakkel et al., 2015).

In each planning cycle, the projects identified during the previous master plan that have not yet been built are modeled again along with newly proposed projects as part of the adaptive management process (Figure 1). As a result, it is possible that a project recommended in one planning cycle may not be selected in subsequent planning cycles. However, projects on the ground or those undergoing implementation are not ranked relative to newly proposed projects by the Planning Tool, although they are modeled in the landscape, and their effects are included in future predictions. Further, the master plan process is not designed to assess the performance of existing projects, but instead used to select projects that should be considered for implementation. Once a project is selected for inclusion in the master plan, it then undergoes a series of additional steps prior to implementation, which may include additional modeling using more advanced tools that incorporate additional processes and scales not included in the master plan planning-level models. Although beyond the scope of this programmatic adaptive management plan, project-level implementation, including engineering and design, monitoring, and assessment should also follow an adaptive management process consistent with the approach described in this report, and provide information back to the master plan process.

The importance of quantifying uncertainties is made evident during plan formulation, as ranking of projects should be done so with the underlying uncertainties in mind. This is especially important for projects that are moving towards implementation, but are not yet implemented by the next planning cycle and thus are evaluated again against newly proposed projects. Unnecessary halting or delays of project implementation should only occur if the models show strong evidence of poor project performance over time. This will prevent a master plan stalemate of constantly revising project lists without ever moving forward to implementation because of unfounded project rankings.

3.6 Monitoring

3.6.1 Rationale

Role of this Step

- Establish a design that allows for the assessment of status and trends in management-relevant variables
- Provide data necessary for model setup, calibration, and validation

Monitoring is advocated in adaptive management as a means to track performance against expectations and advance scientific understanding in order to adjust policies as part of the learning process (National Research Council, 2004). A long-term monitoring program can support adaptive management by: 1) producing information on the status of critically important natural and socio-economic resources, 2) enabling assessments of how systems are changing, and 3) allowing determination of whether goals or targets are being achieved for both sustainable landscapes and resilient communities. In order to be successful, the quality, scale, and resolution of the data must be appropriate to meet the monitoring program's specific objectives. As a result, thorough planning of the objectives, analysis, design, and measurement choices must be conducted prior to the actual data collection.

3.6.2 Application to the Coastal Master Plan

Box 3: SWAMP Goals

- Document the drivers (natural and anthropogenic) and their effects on the system
- Provide early warning indications of changes in the system state
- Monitor the effects of natural or anthropogenic disturbances;
- Reduce uncertainties regarding changing conditions or system state;
- Evaluate the performance of coastal protection and restoration programs and support decision making;
- Improve, validate, and calibrate numerical models
- Support planning, engineering, and designing activities

Programmatic monitoring is conducted under the System Wide Assessment and Monitoring Program (SWAMP). The purpose of the monitoring program is to ensure a comprehensive network of coastal data collection activities is in place to support the development, implementation, and adaptive management of the coastal protection and restoration program within coastal Louisiana (Hijuelos & Hemmerling, 2016). Monitoring plans have been developed for both the natural and human systems using an iterative process to identify the overarching goal of the program (Box 3), and monitoring variables, objectives, and sampling designs. The monitoring variables and objectives identified by SWAMP fall under the general categories of weather and climate, biotic integrity, water quality, hydrology, physical terrain, population and demographics, housing and community characteristics, economy and employment, ecosystem dependency, residential properties protection, and critical infrastructure and essential services protection. A rigorous statistical analysis, examination of modeling needs, and thorough reviews of previous planning and monitoring efforts were conducted to develop the sampling designs for the natural and human system monitoring plans. The program builds upon several existing data collection networks, such as the Coastwide Reference Monitoring System (CRMS) and the Barrier Island Comprehensive Monitoring (BICM) programs, along with agency-specific monitoring efforts such as the fisheries independent monitoring through the Louisiana Department of Wildlife and Fisheries (LDWF) and the American Community Survey (ACS) conducted by the U.S. Census Bureau. Ongoing data collection can provide direct insight on the effects of extreme events, such as hurricanes and droughts, on system dynamics and ultimately master plan effectiveness. Building on these programs, therefore, provides an important long-term context for the evaluation of individual events that may occur during a five year master plan cycle.

The data produced in SWAMP directly supports both the modeling and assessment activities of the adaptive management process (Figure 1). Data such as topography and bathymetry serve as important model inputs (Table 2), while assessing changes in wetland biomass, nekton community, human population changes, or reliance on natural resources, may indicate a change in system state and a call for action. Monitoring occurs throughout the planning cycle although the temporal frequency of individual variables is subject to the type of data being collected and its utility (for more information, see Hijuelos & Hemmerling, 2016).

Given that monitoring is conducted by several different agencies, a monitoring inventory database should be developed by the SWAMP team and updated during each five year planning cycle in order for the most relevant and recent datasets to be incorporated into the development of system models, as well as for use in the assessment activity (described below). A monitoring inventory database was developed in 2013 by The Water Institute and was used during the model refinement stage to identify the most recent datasets available for model setup, calibration, and validation. As part of the adaptive management process, the inventory database should be updated to incorporate any changes to the existing monitoring programs. The SWAMP team could be established to be responsible for the updated monitoring database, as well as the development of monitoring QA/QC processes and ensuring variables remain relevant and are collected at appropriate spatial and temporal scales. Representatives from the SWAMP team will also participate in the plan assessment team (PAT), as described in the assessment activity below.

3.7 Assessment

3.7.1 Rationale

The assessment activity in adaptive management is designed to assess programmatic performance, resolve uncertainties to increase understanding and predictive capability, and can also be used to identify the need to change course. The activity can lead to adjustments to many of the key components described previously by providing a deliberate check on progress and learning and feeding that information back into the planning process. It is often identified as a necessary but difficult activity in the adaptive management process (Gosselin, 2009).

Role of this Step

- Determine model sensitivities to uncertainties and constraints
- Assess system performance

3.7.2 Application to the Coastal Master Plan

The assessment activity of the adaptive management plan must include a systematic process of evaluating data and new research findings, and assimilating them into the master plan process. The assessment is a combination of data analyses and interpretation to ‘create the story’ about how the system is changing and whether it differs from what was expected or hypothesized at the start of the planning cycle. The assessment activity includes steps for evaluating different types of uncertainties through modeling and data analysis and developing evidence based storylines to describe how and why the system is changing. The activity is carried out by the PAT, a multi-faceted team that consists of individuals with different skillsets including:

- Experts knowledgeable in data analysis for their area of expertise (e.g., vegetation change, population change). These experts will select and analyze data available from SWAMP or other sources in accordance with protocols identified by the PAT as a whole;
- Technical experts involved in master plan development (e.g., member(s) from the MPDT or MDT) to provide continuity with the master plan process and examine analytical results relative to master plan model predictions; and
- Technical stakeholders, such as representatives from the FDT, broadly knowledgeable in coastal change to provide insight on the storylines from a broader coastal context.

The PAT will be established by CPRA and membership will be revisited during each planning cycle. The PAT will be co-led by a CPRA staff member and an external knowledgeable expert. PAT members will include experts from different background with appropriate skills sets. The participation of experts not directly involved with the development of the master plan will be essential to ensure objective evaluation of monitoring data and research findings. The PAT will be charged with identifying whether master plan implementation is reaching its desired goals and objectives, if alternate actions are needed, and/or how new ideas and concepts can be incorporated into future planning cycles. As the adaptive management planning cycle timeline is established, the work of the PAT can be planned to ensure it is responsive to the most up to date information while providing input at the appropriate stage of the master plan cycle (Figure 3). Key uses of the assessment in the adaptive management are consideration of:

- Whether the master plan goals or objectives need to be revised;
- Which projects types are included in future iterations of the master plan;
- Which processes are modeled.

3.7.2.1 Evaluating Model Sensitivity to Uncertainties during Planning

As previously described, there are several types of uncertainties that can affect the development of system models and subsequently the formulation of the master plan. Variability uncertainties such as system drivers (e.g., storm impacts) and boundary conditions (e.g., river discharge regime) are uncertain at the beginning of an adaptive management cycle and are thus assumed during the model development and plan formulation activities. Further, important constraints such as availability of funds, permitting timelines, and construction timelines, are also uncertain at the start of any adaptive management cycle. Lastly, the ways in which existing projects, such as river diversions or flood control structures are operated has to be assumed during modeling, thus how project effects are represented on the landscape will be based on these assumptions. For those variability uncertainties that have been resolved by the end of the cycle (e.g., Mississippi River flow, storm impacts), the PAT should coordinate an evaluation to determine the sensitivity of model predictions to these uncertainties. This sensitivity testing will help evaluate the role of specific system drivers (e.g., Mississippi River flow) or constraints on the future outcomes used in plan formulation. Documenting the effects of extreme events such as hurricanes or droughts on the natural and human systems, and how the models can and cannot reflect these influences, will be an important outcome of these analyses. This information will also help inform the data analysis and interpretation, described below, as the drivers and constraints can affect the system's response and change over time.

3.7.2.2 Data Analysis and Interpretation

The PAT will evaluate how the system has changed over the planning cycle period. The scale of the analysis should be informed by the design of SWAMP (i.e., basin wide or coast wide; see Hijuelos & Hemmerling, 2016), although incorporating other research studies and data collection efforts (including project-level data) may serve as an opportunity to drill down to finer scales and understand how projects are impacting the landscape. The analysis should be organized around the processes the master plan models and subroutines are designed to represent (Table 2). The assessment should first address the variability uncertainties and the model sensitivities to those, as described in Section 3.7.2.1. This involves the development of an 'evidence-based' story line describing how the system changed relative to conditions anticipated by the models. However, it is important to recognize the models are not forecasting models and do not necessarily represent exact time points into the future. Instead, they should provide, in a general sense, the direction and magnitude of change and the potential variability that may be experienced in the system over time. In other words, each modeled year should not be compared to actual years. A summary illustrating which data from SWAMP should be analyzed to evaluate changes in real world conditions relative to those predicted by the master plan analysis is provided in Table 5. The assessment may also inform the knowledge uncertainties in the master plan to evaluate whether the data supports the current understanding or whether alternate hypotheses may be used to explain patterns and processes.

In the event that change detected in the coastal system differs from the change predicted by the master plan modeling and cannot be explained by any ancillary data, project-level assessment, or peer-reviewed research, the assessment activity should describe the uncertainty using the typology defined in Table 3, update the uncertainty matrix, and generate alternate hypotheses that can then be tested during the subsequent planning cycle. This ensures the uncertainties are actively being addressed as part of the adaptive management process. The end results of the assessment activity are a series of summary reports highlighting the main storylines and any uncertainties that have (or have not) been resolved discussed. The storylines can be created for each of the processes represented in the master plan with supporting information on boundary conditions, events, or new targeted research findings, that may help explain the patterns and process observed. A synthesis report that ties each of the storylines together should be developed by the PAT to complete the assessment report. The Restoration Coordination and Verification (RECOVER) Monitoring and Assessment Plan (MAP) program for the Everglades produces System Status Reports and Scientific Knowledge Gained documents in addition to Peer Review Reports. The System Status Report evaluates current monitoring data to determine if the goals and objectives of the Comprehensive Everglades Restoration Plan (CERP) are being met. These reports could serve as useful templates to the development of a comprehensive analysis report for coastal Louisiana.

One of the areas the assessment activity seeks to identify is circumstances where plan implementation is not resulting in the expected changes in system state. The assessment should also identify why such deviations have occurred. While some of these deviations may be due to individual project performance, some may be programmatic in nature, for example, project interactions do not occur as anticipated. The programmatic planning process needs to incorporate this information in one of the following ways:

- Using updated conceptual or predictive models within the knowledge base that incorporate learning from the adaptive management assessment;

- Modifying the list of candidate projects based on prior performance of projects of a similar type; and
- Adjusting the sequencing of projects to improved expected plan performance.

Actions to reduce uncertainties emerging from the assessment can include expanded monitoring, but also targeted research. CPRA has previously funded research programs to reduce uncertainties such as the CPRA Applied Research Program and the Coastal Science Assistantship Program. The CPRA Applied Research Program sought out research projects that directly addressed the needs of master plan implementation, and it serves as an example as to how research can be incorporated into the adaptive management process. The Louisiana RESTORE Center of Excellence will oversee a competitive grants program to fund research that supports the implementation of the coastal master plan. Coastal Science Assistantship Program (CSAP) is another avenue that allows CPRA to direct scientific research to answer questions about planning, designing, constructing and evaluating coastal protection and restoration projects, which will ultimately contribute to program success.

Table 5: Example of an Assessment Strategy for the Adaptive Management Process.
This is presented for illustrative purposes only.

Model/ Subroutine	Data Used in Assessment	Approaches to Analysis	Questions the Analysis Should Inform
ICM/Hydrology	Continuous (i.e., sub-hourly or hourly) water temperature, salinity, water level, suspended sediment concentration; and ancillary information such as weather and climate	Evaluation of frequency distributions of variables, spatial analysis of variables	Did the model accurately capture the range of conditions, including variability, experienced on a basin or coast wide scale? Were there any conditions not captured by the model and if so, can they be explained by other events or variables? For example, changes in river discharge may result in unanticipated changes in water level and salinity at some locations.
ICM/Morphology	five year time step land and water distribution; ancillary information such as occurrence of tropical storms and cold fronts	Spatial and temporal analyses of land and water area	Did the model accurately capture land loss or gain over time? Did these changes occur where they were predicted to occur? If not, can the differences be explained by other events or changes that occurred in the system? For example, storms may result in the deposition of sediment on the marsh surface that would not have been anticipated in the model.
ICM/Vegetation Type	five year time step of wetland vegetation distribution and biomass; ancillary information such as water quality, weather and climate	Spatial and temporal analyses of wetland distribution by species and type; analysis of wetland above- and below-ground biomass change as supporting information	Did the model accurately capture change in wetland species or types over time? Did the changes occur where they were predicted to occur? If not, can the differences be explained by other changes that occurred to the system? For example, allocation of biomass (above-/below-ground) can indicate how plants are responding to the environmental conditions, and thus may serve as a precursor to future vegetation changes or explain vegetation changes that occurred during the planning cycle.
ICM/Habitat Suitability Index and Ecopath with Ecosim	Monthly fisheries-independent data; water quality, and ancillary information such as water quality and hydrology	Spatial and temporal analysis of relative abundance of key fish and shellfish species in relation to water quality and hydrology conditions (e.g., salinity, chlorophyll *a*, and water levels)	Did the model accurately capture relative abundances of each of the species of interest? Did these changes occur where they were predicted to occur? If not, can the differences be explained by other events or changes that occurred in the system? For example, increased chlorophyll *a* may indicate an abundance of phytoplankton, an important component of the trophic food web, which could result in increased abundances of select species.

Model/ Subroutine	Data Used in Assessment	Approaches to Analysis	Questions the Analysis Should Inform
ICM/Barrier Island	five year time step of barrier island topography and bathymetry	Spatial and temporal analyses of morphological changes in barrier islands	Did the model accurately capture barrier island change over time? Did changes occur where they were predicted to occur? If not, can the differences be explained by other events or changes that occurred in the system? For example, storms may result in the removal or movement of sand to other areas of the island that would not have been anticipated in the model.
ADCIRC/ UnSWAN/ CLARA	Waves and wind information during specific storm events; economic damage information, and asset inventory and valuation	Evaluation of storm surge and flooding in coastal communities	If a 1/100 storm event occurred during the planning cycle, did the model accurately capture flooding depth and duration during storm conditions and EAD? Did the flooding occur where it was predicted to occur? If not, can the differences be explained by other events or changes in the system?

4.0 Path Forward for Implementing Adaptive Management

Although some management contexts are judged to be predisposed to the unsuccessful application of adaptive management (e.g., if risks are high, problems extend over large areas, or uncertainties are unresolvable (Rist et al., 2013b)), the development of the master plan has already successfully incorporated many aspects of adaptive management, despite the complexity of the problem at hand:

- Stakeholders are engaged throughout all aspects of plan development;
- Clear goals and objectives have been identified to address the problem;
- System models have been developed and continue to be improved from one planning cycle to the next;
- Model uncertainties are identified during model development;
- The formulation of the plan continues to evolve as new ways to synthesize information are developed in order to evaluate projects and alternatives; and
- In addition, the implementation of SWAMP will support the development and refinement of master plan models and future assessment activities.

This plan also identifies opportunities for further application of the adaptive management process including:

- Formally establishing an adaptive management planning cycle timeline to indicate when major actions should occur (Figure 3);
- Revisiting the goals and objectives once the findings of the assessment Figure 1 from the previous cycle are available;
- Developing a model improvement strategy at the beginning of each planning cycle;

- Developing an uncertainty matrix for identifying uncertainties (beyond model uncertainties) in order to track them through the planning cycles;
- Sensitivity testing of the Planning Tool to determine whether effects of all project types are included;
- Updating monitoring database, develop monitoring QA/QC processes, and ensuring the variables remain relevant; and
- Establishing the PAT to conduct an explicit assessment activity.

Governance is key (The Water Institute of the Gulf, 2013) and an adaptive management coordinator within CPRA needs to be assigned responsibility for ensuring the adaptive management process is clear and followed. In order for the adaptive management plan to function well, a transparent tracking process should be made part of routine operations. This will require specific information regarding which groups or individuals are responsible for different parts of the process, how they interact, how their work is overseen, how they report, and how they are accountable for various parts of the process. The adaptive management coordinator should coordinate actions among groups and ensure activities remain relevant and consistent with the adaptive management process. The coordinator should work closely with each of the adaptive management teams and serve as a liaison to the CPRA Board to communicate the adaptive management activities and their status. A summary of the adaptive management teams, their roles, and what they ultimately produce in each adaptive management step is provided in Table 6.

It will also be necessary to identify resources to support key elements; for example, the establishment of the assessment activity and the mechanisms which ensure transparency (a key concern of the adaptive management guidance panel established in 2013; The Water Institute of the Gulf, 2013). While this report assumes a five year cycle for program level adaptive management, within each five year cycle there may be intermediate points at which decision makers need assurance of progress or require updated information. A detailed timeline needs to be established at the start of each cycle. Timelines will need to incorporate feedback through the project-level adaptive management process, but unforeseen issues such as project delays, hurricane impacts, new funding sources, etc. may impact the program as a whole and require interim assessment to be conducted.

Table 6: Roles and Responsibilities for Each of the Entities in the Adaptive Management Process.

Entities		Define Problem	Develop System Models	Identify Uncertainties	Formulate Plan	Monitor Actions	Assess System
Adaptive Management Coordinator	CPRA Board	Approves problem statement	Provides oversight	Provides oversight	Approves plan	Provides oversight	Receives assessment report
	MPDT / O&E Team	Leads activity; engages local stakeholders	Reviews products	Reviews products	Leads development; engages stakeholders		Representative(s) participate in PAT
	MDT / STL		Leads activity	Leads activity	Assists in development		Representative(s) participate in PAT
	Stakeholders	Provides local input	Provides technical input	Provides technical input	Provides local and technical input;		Select technical stakeholders participate in PAT
	Plan Assessment Team	Recommends refinements		Provides technical input		Recommends refinements	Leads activity
Key Adaptive Management Products/Outcomes		Problem statement, goals, and objectives	Model Improvement Plan; calibrated and validated models	Uncertainty matrix	Predicted future prospects and plan for addressing problem	Monitoring inventory and database	Synthesized findings and recommendations for plan refinements

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