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2017 Coastal Master Plan

Appendix C: Modeling

Chapter 5 - Modeling Conclusions and Looking Forward

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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

The modeling conducted to support the 2017 Coastal Master Plan included many new developments and improvements compared to the work done for the previous master plan. This chapter reflects on the extensive modeling effort conducted to support the 2017 Coastal Master Plan and highlights both major accomplishments and potential future improvements. The chapter is based on comments provided by external subject matter experts (Predictive Models Technical Advisory Committee (PM-TAC), "lessons learned" developed in fall 2016 by the modeling team, and additional input received from the Science and Engineering Board and independent external reviewers. The possible improvements herein are not intended to represent action items for 2022 Coastal Master Plan. Rather, the team documents these reflections while the work is still fresh in their minds as a resource both for future modelers seeking to capture the complex dynamics of coastal systems to support protection and restoration planning.

The PM-TAC noted that the modeling effort for the 2017 Coastal Master Plan substantially improved the 2012 approach and that the modeling team made good progress in integrating model components, addressing uncertainty, incorporating scenarios, and more. The modeling identified accomplishments in several areas which are described here including: landscape modeling, fish and shellfish modeling, storm surge and risk modeling, the overall modeling process, and team coordination and engagement.

A number of opportunities for improvement have been identified. Aspects of the landscape modeling that could be revisited and potentially enhanced in the future include: marsh collapse thresholds, nutrients and vegetation biomass, soil organic accretion, mapping of storm sediment deposition, sensitivity of landscape change to storm tracks, sediment grain size considerations, improvements in channel hydraulics, marsh links, refinement of hydrologic compartments, marsh edge erosion and fetch, and barrier island modeling. Many of these are interrelated and changes and improvements would influence ecological outcomes as well as hydro-geomorphic aspects of the landscape. Some of the tools used are already mature for storm surge and risk modeling. However, additional types of risk metrics might be considered for future model applications as well as different types of risk reduction projects. Continued future attention to detail on topographic changes, especially related to structures and levees, is needed. Additional ideas are presented on how to revisit the water quality subroutine and improve fish and shellfish modeling, including potential interface between habitat suitability and Ecopath with Ecosim (EwE) approaches.

Continued improvement in available data could support a number of future model improvements. In addition, the chapter highlights how automation in addition to expert review can improve quality review of project outputs in a timely manner. Using the current modeling approach to evaluate small scale projects remains a challenge that should be considered as future improvements to the modeling framework are made.

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List of Abbreviations

1D	One-dimensional
ADCIRC	Advanced Circulation (model)
BIMODE	Barrier Island Model
BICM	Barrier Island Comprehensive Monitoring
Chl a	Chlorophyll a
CLARA	Coastal Louisiana Risk Assessment (model)
CPRA	Coastal Protection and Restoration Authority
CRMS	Coastwide Reference Monitoring System
DEM	Digital Elevation Model
DIN	Dissolved Inorganic Nitrogen
EAD	Expected Annual Damage
EwE	Ecopath with Ecosim (model)
HSI	Habitat Suitability Index
ICM	Integrated Compartment Model
LiDAR	Light Detection and Ranging
MDT	Modeling Decision Team
PM-TAC	Predictive Models Technical Advisory Committee
SEB	Science and Engineering Board
SWAMP	System-wide Assessment and Monitoring Program
SWAN	Simulating WAves Nearshore
TKN	Total Kjeldahl Nitrogen
QA/QC	Quality Assurance and Quality Control
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

1.0 Overview

As described in previous chapters, the modeling conducted to support the 2017 Coastal Master Plan included many new developments and improvements compared to the work which was conducted for the previous master plan. The legislative timeline set for each update of the master plan also sets a timeline for the modeling and analysis. While the modeling work is undertaken, ideas emerge on how aspects of the analysis could be further improved, and new approaches and technologies also become available which the team does not have time to take advantage of. This chapter reflects on the extensive modeling effort conducted to support the 2017 Coastal Master Plan and highlights both major accomplishments and potential future improvements. The chapter is based on comments provided by the PM-TAC and "lessons learned" developed in fall 2016 by the modeling team. Additional comments were received from the Science and Engineering Board (SEB), and external reviewers that can also be considered in the future. These are described in general terms here and detailed in Attachment C5-2. The possible improvements outlined here are not intended to represent action items for the 2022 Coastal Master Plan. Rather, the team documents these reflections while the work is still fresh in their minds as a resource for future modelers seeking to capture the complex dynamics of coastal systems and to support protection and restoration planning.

This chapter begins with the modeling team's review of key accomplishments, a brief description of the higher level PM-TAC recommendations. This is followed by lessons learned from the modeling conducted to support the 2017 Coastal Master Plan and additional input received from external sources.

2.0 Modeling Accomplishments and Highlights

Accomplishments and highlights of the 2017 Coastal Master Plan modeling effort are many. Here, they are separated into five categories: landscape modeling, fish and shellfish modeling, storm surge and risk modeling, modeling processes, and team coordination and engagement. This section is intended to serve as a high-level overview with references to specific technical appendices where applicable.

2.1 Landscape Modeling

Of foremost achievement, as noted by the modeling team, is the successful integration of the individual model codes used in the 2012 Coastal Master Plan modeling effort and several new modeling components into what is referred to as the Integrated Compartment Model (ICM; Attachment C3-22). As was expected, a number of challenges presented themselves during the integration phase including the need to standardize coding language and parameters as well as spatial and temporal scales. Creating a unified code allowed for version control and the ability for various team members to do concurrent ICM simulations. Coding the ICM with modularity allows the user to turn off certain subroutines when they are not needed. For example, if the user is only interested in land/water output, the water quality subroutine can be turned off to expedite simulation time. Modularity is something the PM-TAC suggests for future use and development.

The development of the ICM allows for an "entire coast" modeling approach, which eliminates the artificial hydrologic boundaries between the western and central coast and the central and eastern coast that were unavoidable with three regional hydrology models used in the 2012

Coastal Master Plan modeling effort. Another general improvement is the annual updating of the landscape and feedback between hydrology, morphology, and vegetation. In the 2012 effort, the landscape was only updated once, at year 25, during the 50-year simulations.

More specific successes and improvements include the addition of new processes. These include marsh edge erosion (Attachment C3-2), impacts of storm events on the landscape (Attachment C3-3), and the addition of "marsh links" to aid in sediment distribution across the marsh surface during high water events (Attachment C3-1). The vegetation subroutine moved to species-level simulations, improved the way floating marsh is modeled, and improved the vegetation establishment and mortality matrices (Attachment C3-5). The barrier island model added several new processes, including onshore waves, cross-shore transport, and event-driven island breaches (Attachment C3-4).

In general, the ICM was driven by better hydrology data, which removed the need to "stitch" datasets together for a 50-year simulation, and more realistic precipitation and wind representations (Attachment C3-26). The 2017 modeling effort also used updated bathymetry, topography, and land use/land cover data (Attachment C3-27).

Calibration and validation of the landscape modeling components were more rigorous and included more parameters (e.g., vegetation) compared to the 2012 effort (Attachment C3-23). Lastly, an improved uncertainty analysis was performed (Attachment C3-24).

2.2 Fish and Shellfish Modeling

Existing HSIs for fish and shellfish were revamped with a statistical approach making them more robust and data-driven, and several new HSIs were included for this modeling effort (Attachments C3-6 – C3-19). Another highlight is the incorporation of EwE, a community fish and shellfish biomass model (Attachment C3-20). Both the HSIs and EwE were directly linked to the ICM, allowing for automated model runs. One highlight that is not necessarily technical in nature is the direct collaboration with the Louisiana Department of Wildlife and Fisheries, who not only provided data for this effort and participated in regular coordination calls during HSI development, but also reviewed and commented on HSI and EwE performance.

2.3 Storm Surge and Risk Modeling

Because the Advanced Circulation (ADCIRC) + Simulating Waves Nearshore (SWAN) models are well established, there are fewer new developments and highlights to report for these models. To accurately predict the movement of surge, propagation of waves, and overtopping volumes into enclosed areas, accurate definitions of topography are required. New sources of data were used to improve the definition of levees, roadways, and ridges throughout the model. These data include those provided by Louisiana Sea Grant in the form of local levee surveys, the United State Geological Survey (USGS) in the form of updated high resolution Light Detection and Ranging (LiDAR) survey, and the United States Army Corps of Engineers (USACE) current and future design elevations for federally maintained levees. New efficiencies in data formatting and transfer also allowed for more storms to be simulated.

Several improvements were made for the Coastal Louisiana Risk Assessment (CLARA) model when compared to previous modeling efforts. The spatial resolution was improved providing a more realistic representation of coastal Louisiana communities and assets. The CLARA parametric uncertainty framework was improved as were the fragility scenarios. Additional information on both the storm surge and risk models can be found in Attachment C3-25.

2.4 Modeling Processes

One key aspect of the 2017 Coastal Master Plan modeling effort is the ability to complete integrated assessments of both restoration and structural protection projects which was conducted during the project interactions/alternatives phase of the modeling work (Chapter 4). Real-time output visualization and the ability to share intermediate outputs with team members was found to be highly useful for timely troubleshooting and review.

A number of improved efficiencies in data sharing were made. Standardization of land use/land cover data (i.e., representing vegetation as absolute value instead of as percent vegetation type per 500 m cell) helped the storm surge team integrate the vegetation outputs from the ICM without labored pre-processing. Another improvement was sharing only a single output dataset (with standardized spatial resolution) from the ICM to the ADCIRC model, streamlining data resampling by the storm surge team. The 2012 modeling effort entailed multiple output files of varying spatial resolution being transferred for use by the storm surge team.

Upfront planning to secure adequate central processing unit capabilities for the storm surge modeling team saved time during the production run phase and allowed for additional simulations to be conducted.

Lastly, the entire 2017 modeling effort underwent a thorough and formal Quality Assurance and Quality Control (QA/QC) process as described in Attachment C4-1. This resulted not only in increased confidence in model outputs, but helped identify potential errors early in the modeling process, which provided the opportunity for improvements to be made as needed.

2.5 Team Coordination and Engagement

Strong communication both across modeling teams and with CPRA aided in a smoother effort. The number of regularly-scheduled in-person meetings, sub-team and full team webinars and calls, and frequent email correspondence was sufficient to keep team members informed and the modeling effort moving forward. By completing thorough documentation of the modeling components and processes early in the 2017 modeling effort, the team was able to focus on production runs.

Engagement with the PM-TAC helped reaffirm challenging topics and provided guidance directly to the modeling team through the duration of the modeling effort. They provided external input from the scientific community. The number of in-person meetings, the use of focused questions to guide the meetings, and the process for meeting report-outs was considered useful and sufficient (Attachment C5-1).

The modeling team also prepared for and participated in an in-person outreach meeting with the local technical community and two technical outreach webinars. These webinars were recorded and are available to the public on the CPRA website. Per feedback received, these efforts were considered useful for transparency of the modeling process and for keeping the local technical community engaged.

Lastly, members of the modeling team presented the collective work of the 2017 Coastal Master Plan modeling effort at the State of the Coast (2014 and 2016), National Conference on Ecosystem Restoration (2015), and Coastal and Estuarine Research Federation 2015 conferences. These conferences were successful in reaching out to both regional and national technical audiences.

3.0 Predictive Models Technical Advisory Committee

The role of the PM-TAC is outlined in Chapter 1 of this Appendix. The PM-TAC met six times with the Modeling Decision Team (MDT) and the modeling team between December 2013 and March 2016. For each meeting, the MDT provided a series of questions for the PM-TAC to address, and brief meeting summary reports were required from the PM-TAC to recap comments and evaluations made verbally during the in-person meetings. The PM-TAC also met in September 2016 to develop their final report. The PM-TAC meeting reports and final report are available as Attachment C5–1.

In their final report, the PM-TAC identified as series of key recommendations (Table1) as well as a number of more detailed recommendations regarding specific aspects of the modeling. In many cases, the issues identified by the PM-TAC directly mesh with lessons learned articulated by the modeling team (see section 4 below) and the numbering used in Table 1 is used to cross reference between the PM-TAC observations and those of the modeling team. In addition, model specific recommendations of the PM-TAC are also referenced in later sections of this report. Note that in addition to “key” and “specific” recommendations, the PM-TAC also noted: “the modeling effort for the 2017 Coastal Master Plan substantially improved the 2012 approach. The modeling team made good progress in integrating model components, addressing uncertainty, incorporating scenarios, and more.”

Table 1: Key Recommendations from the PM-TAC Final Report. Numbering is provided for Reference Purposes Only.

	PM-TAC Key Recommendations - November 2016
1	The models developed for the 2017 Coastal Master Plan should be expected to continue to evolve with a long-range goal of a fully integrated modeling system.
2	Immediate future development should focus on sections of the models that were identified as most important in the 2017 model sensitivity and uncertainty analysis or where current model dynamics appear to be overly simple.
3	The modeling team needs to closely examine the quality and quantity of data that are used to configure and calibrate the models and identify which emerging types of data would be most useful for further improvement or testing of the models.
4	Considering both spatial and temporal variability in future scenarios is critical.
5	Future work should investigate the robustness of some of the Habitat Suitability Index (HSI) models to alternative formulations and to areas of uncertainty in data. Future planning should consider a long-term effort to develop species-specific population models as an alternative or a complement to EwE and HSIs.
6	Rainfall and runoff processes need to be more fully integrated into the tide, wind-wave, and surge model, and sensitivity of project evaluations to the impact of individual storms compared to other factors (e.g., sea level, subsidence) needs to be undertaken.

4.0 Modeling Limitations and Possible Improvements

The assumption made as the modeling team considered lessons learned and recommendations for the future was that for the 2022 Coastal Master Plan there will be a need for modeling tools to be used in a similar way as they were in 2017 (i.e., simulating the effects of both individual projects and project interactions) with possibly less focus on individual projects and more regional analysis of different areas of the coast and project interactions.

4.1 Landscape Modeling

4.1.1 Marsh collapse thresholds

The land collapse and gain criteria utilized within the ICM morphology subroutine are applied per vegetation type (e.g., fresh marsh, intermediate marsh, etc.), and comprise either a salinity or depth threshold. While spatial variability in collapsed marshes is modeled as a function of the topobathymetric and water level data, the inundation depth thresholds are global parameters set during ICM morphology calibration. The collapse criteria were chosen based on the prevalence of different wetland types at varying heights above and below the annual mean water levels (Couvillion & Beck, 2013). Based upon the uncertainty analysis performed (Attachment C3-24), minor changes in water levels and accretion rates indicate that the ICM is quite sensitive to small changes in inundation depth calculations (PM-TAC #2). This indicates strong sensitivity to these collapse criteria. It is recommended that analysis be conducted to thoroughly analyze the ICM's sensitivity to these collapse criteria and to develop the ability to vary these collapse criteria spatially throughout the model domain. To develop strong marsh collapse threshold spatial relationships, it may prove beneficial to develop a set of landscape data to simulate a hindcast of historic land change in coastal Louisiana. This would allow a more rigorous calibration and validation of these key parameters used within the ICM morphology subroutine.

4.1.2 Nutrients and Vegetation Biomass

While the vegetation subroutine has been substantially improved for the 2017 Coastal Master Plan modeling effort, there are still some ecological processes that have not yet been included. The most notable of these is the omission of the role of nutrients. Nutrients play an important role in plant ecology, influencing rates of growth, shaping competition between species, and governing the spatial and temporal distribution of plants on the landscape. The omission of nutrient effects from the model reflects the limitations of empirical information needed to derive and parameterize algorithms. While nutrient effects have been documented for several of the species included in the model, most of the 41 plant species have not been studied in sufficient detail to produce a biologically sound model. For example, the Coastwide Reference Monitoring System (CRMS) stations and data, that were the basis for parameterizing the effects of salinity and hydrology data on plants, do not include records of nutrient levels. Missing from our understanding are details about the physiological effects of nutrients, such as the rate of growth for various species under different levels of nutrient availability, the rate of nutrient uptake by species, minimum nutrient levels required to sustain growth (on a per species basis), and the way nutrients interact with salinity and wave amplitude. Without this information, it is not possible to produce an ecologically sound model of plant community dynamics that reflects the effects of nutrients. Attempting to add nutrient effects without this information would only serve to increase uncertainty in the model results. Unless additional detailed information becomes available in time, it is unlikely that this limitation will be addressed in time to inform the 2022 Coastal Master Plan.

4.1.3 Organic Accretion

Within the ICM, wetland soils include both organic and mineral components which drive accretion of the wetland surface. The mineral component (mass per unit area per year) is derived from the hydrology subroutine (Attachment C3-1). The organic content of the soil in the current model is not responsive directly to hydrologic forcing. Rather annual organic mass loading to the soil is derived from a regional data set for Louisiana coastal wetland soils by wetland type. For example, there are different values for fresh marsh and saline marsh and these vary regionally across the coast. The organic soil component is therefore dependent on location and vegetation type and does not reflect future influences of hydrologic change, other than when they cause a change in vegetation type. Nor, as described above, are they responsive to nutrient loading which is widely recognized as a factor that can influence root/shoot allocations of plant biomass and thus influences organic accretion. The uncertainty analysis (Attachment C3-24) indicated that land loss is highly sensitive to organic accretion in the ICM (PM-TAC #2). Ongoing studies and monitoring of wetland soils may provide additional information that can be used to improve this component of the ICM prior to the 2022 Coastal Master Plan, and this key element of the morphology subroutine should be revisited accordingly.

4.1.4 Storm Deposition Mapping

The current version of the ICM used for the 2017 Coastal Master Plan includes hurricane storm surge, wind fields, and rainfall data to assess the impact of hurricanes on landscape evolution. While important dynamics occur during major storm events, the ability of the ICM to accurately simulate these dynamics is currently limited by the temporal resolution of the various ICM subroutines. For instance, the ICM hydrology subroutine simulates hydrologic changes at a sub-minute time step, a temporal resolution that could reasonably capture important storm dynamics such as wave energies and subsequent sediment resuspension and deposition patterns. However, when the sediment distribution patterns and water level impacts are translated into landscape morphology within the ICM morphology subroutine, average annual values are utilized. All sediment deposition upon the marsh surface is mapped by distributing the annual sediment deposition mass upon the portion of the marsh surface that had been inundated at any point during the previous year. The open water deposition (or erosion) is similarly mapped by integrating the entire deposition/erosion mass across the entire open water bed area. Refinements to the interaction between the ICM hydrology and morphology representations of sediment deposition/erosion could result in a more realistic representation of sediment deposition upon the marsh surface, potentially increasing the ability to assess storm impacts upon the landscape with the ICM framework.

4.1.5 ICM Sensitivity to Storm Tracks

The inclusion of hurricane effects on estuarine/landscape dynamics was a new development for the 2017 Coastal Master Plan. Despite improvements in run time for the current ICM compared to the models used to predict landscape change for the 2012 Coastal Master Plan, it is not possible to produce probabilistic assessments of storm impacts for each project level and alternative analysis. Dialog among the MDT, the modeling team, and the PM-TAC preceded the decision to include storm effects in the 50-year simulations in accordance with the historical pattern of impacts on the coast (Attachment C3-3). As noted by the PM-TAC (#6) this means that some projects could be impacted by storms because of their location and other similar projects in a different location would not be subject to the same effects. Future exploration of how to reflect the influence of tropical storms and hurricanes on the landscape and ecosystem need to consider this sensitivity, and how improvements can be made to address storm dynamics (see section 4.1.5 above) will be an important factor in addressing how to reflect storm tracks and intensity in the 50 year simulations.

4.1.6 Sediment Grain Size

The ICM currently tracks three different grain sizes for entrained, suspended, and deposited sediments as well as flocs. The assumptions used in these algorithms are described in Attachment C3-1 and are based on established literature and data where it is available. A major limitation of this approach is the lack of data on bed sediment grain size in Louisiana estuaries. The grain size of suspended sediment is taken into account in the ICM in terms of how the sediment is spatially distributed across the marsh surface. Sensitivity analysis would be a useful approach to understanding the effect of different assumptions about bed sediment character so that the ICM can appropriately represent these entrainment, suspension, and depositional processes.

4.1.7 Incorporating Open Channel Hydraulics

Currently, compartments in the ICM are connected through hydraulic links or marsh links. Flow exchange among the compartments takes place through these connections and flow exchange is governed by the capacity of these connections. Flow through the standard links resembles flow through channels but it assumes that the flow is exchanged instantaneously (i.e., it is not realistically routed through the channel nor does it experience the appropriate lag and attenuation that actually occurs in channels as a result of their length and resistance to the flow). Flow through marsh links resembles sheet flow that occurs at flood stage.

An improvement would be to incorporate an explicit representation of channel flow compartments to capture the larger rivers and channels, both within and those entering the coastal zone. The formulation and modeling techniques to capture channel flow are quite mature and can be coded into the ICM. Care should be taken, however, to ensure that a stable and robust numerical algorithm is chosen to represent channel hydraulics. A one-dimensional (1D) representation would be the most realistic approach that is consistent with the remainder of the ICM in terms of simplicity and computational efficiency.

Including 1D channel hydraulics would better capture flow distribution and connectivity among the open water areas in coastal areas. It would also broaden the applicability of the ICM to coastal and deltaic systems. For example, it would allow for a more robust flow and sediment distribution and routing through the Mississippi and Atchafalaya rivers, capture the flow transfer among the various basins along the Gulf Intracoastal Waterway, and provide a more realistic representation of riverine systems such as the Vermilion, Mermentau, Calcasieu, Sabine, and Neches.

The added computational burden to explicitly represent these 1D features would not be significant. It is difficult to quantify the exact computation impact, but simple testing can be done in a pilot location to quantify the added computational needs across the coast.

4.1.8 Refinements to ICM Compartments

The ICM contains multiple subroutines, each applied at a different spatial resolution. For example, the vegetation subroutine uses a 500 m X 500 m uniform grid, the morphology routine uses a 30 m X 30 m uniform grid, and the hydrology subroutine is applied to variable size compartments. Hydrologic parameters, specifically water level, salinity, and sediment, are mapped onto the vegetation and morphology routines. If the hydrology compartments are too large, they span over large variations of vegetation and morphology environments. This discrepancy in spatial resolution could potentially cause errors and unrealistic patterns and could be revised by unifying the spatial scale of the hydrology compartments with the scale(s) used by other subroutines.

One model improvement that would simplify spatial processing routines is to revise the vegetation model grid to a resolution that is a multiple of the morphology subroutine grid resolution. The current 500 m grid used by the ICM vegetation subroutine does not align with the 30 m grid resolution of the morphology subroutine, which results in inconsistent reclassification across grid boundaries in the current model. Future versions of the ICM should be initialized such that the two grids align.

4.1.9 Marsh Links

Marsh links were a new addition to the 2017 Coastal Master Plan ICM. These links are activated when the subtending compartmental water levels exceed the link invert. Since, in general, these were not active for the historical calibration/validation periods, they were not completely calibrated and validated. In version 1 of the ICM (ICM_v1), these links passed water to the downstream compartment and then this flow was redistributed by the Kadlec-Knight equation to the marsh. Version 3 of the ICM (ICM_v3) accounted for direct transfer to storage on the marshes. The lack of calibration of these links is a model deficiency which may have affected the high water level computations and the model's response to sea level rise and subsidence. Since ADCIRC is used to model the marsh flows for hurricanes, it is possible to obtain the stage time series at all compartments for several storm tracks. These time series could then be used in the same manner as the CRMS stage data to calibrate the marsh links. The main calibration coefficient would be the Manning's *n*; however, the actual widths, lengths, and inverts assigned to these links is very approximate and some fine tuning of these dimensions would likely be needed. Storm tracks would have to be representative of all areas of the coast (e.g., a minimum of four tracks for calibration and four different tracks for validation). These links could be further validated with actual storms such as Katrina, Isaac, and Gustav. The potential benefits of this calibration are high in terms of improving the quality of ICM predictions (e.g., better prediction of the duration and depth of flood on a compartment basis and better prediction of the effect of subsidence and sea level rise on salinity and sediment distribution).

4.1.10 Marsh Edge Erosion and Fetch

Marsh retreat rates in the ICM were assigned to each compartment based on historical rates derived by the USGS (Attachment C3-2). This approach, while very robust, does not take into account the landscape changes that occur over time as reflected by processes such as edge retreat, marsh collapse, land building, and marsh creation. These landscape changes affect the annual wave power at the marsh edge. The wave power depends on wind speed and direction, fetch, and water depth. The ICM hydrology subroutine already contains wave computations and utilizes these inputs to obtain the wave power. Attempts to correlate wave power to marsh edge retreat on a single coast wide equation showed very high scatter related to observations (see Attachment C3-2). The PM-TAC noted in their specific recommendations that marsh edge erosion should be an area of future attention for the landscape models.

A potential improved approach is to calibrate a wave power equation for marsh retreat for every open water compartment; this would involve an equation with two or three parameters for each compartment (e.g., a two-parameter equation would have the form $R = a(P_w-b)$ where R is the annual retreat rate and is a calibration parameter; Pw is the wave power; and b is a threshold wave power below which no erosion occurs; $R = 0$ for $(P_w-b) <0$). To implement this, it would be necessary to “dynamically” track the open water fetch and depth at least on an annual basis. The coding effort needed to introduce this change is very low and simulation time would only increase slightly since the wave computations are already being performed. The fetch arrays would have to be re-computed in the ICM morphology subroutine on an annual basis when the digital elevation model (DEM) is updated. The benefits of this improvement are more realistic evaluation of the effects of large land loss processes (e.g., marsh collapse) and projects (e.g., marsh reaction).

This approach would be further enhanced by introducing a dynamic approach to fetch. As the landscape changes over the simulation period, the depth and fetch of the open water areas change and consequently the wave characteristics change. In the current version of the ICM hydrology subroutine, the fetch arrays (16 compass directions) are set as initial conditions in each compartment. The average depth along each fetch is also set as an initial condition. Resuspension of bed sediments and marsh edge retreat depend on the wave power which is a function of fetch, depth as well as wind speed, direction, and duration. The fetch and depth files could be updated when the DEM is updated. The coding effort needed to introduce a dynamic fetch is minimal, and simulation time would only increase slightly since the wave computations are already being performed. The fetch arrays and associated average depths would have to be re-computed in the ICM morphology subroutine on an annual basis when the DEM is updated. The payoff of improved wave computations would be reflected in more realistic sediment resuspension and sediment distribution computations. An addition benefit could come from the introduction of wave power in the marsh edge retreat estimates.

4.1.11 Barrier Island Modeling

The evolution of the barrier islands involves storm-driven cross-shore processes that include erosion of the shoreface, lowering of berm and dune elevations, and overwash of sediment onto backbarrier marsh platforms and/or into back bays, that produce barrier island migration and rollover. The SBEACH model was used to predict cross-shore morphologic changes in response to storm events based on measurement derived, empirical equations. The model was utilized outside the ICM to create a database of beach profile responses to representative storm conditions. Several recommendations are proposed to address the SBEACH model limitations and improve the Barrier Island Model (BIMODE) implementation. First, a more robust calibration effort of the SBEACH model coefficients should be conducted to yield more accurate predictions of storm-driven morphologic changes with an emphasis on overwash. Next, additional SBEACH model simulations should be performed to increase the database of beach profile responses and representative storm events. Or, if the timing of this approach could be employed, once the storm suite is chosen for the 50-year period of analysis, run SBEACH on representative profiles from each barrier island segment for the selected storm events to create the response database. Last, it is recommended that a sensitivity analysis should be performed to evaluate how the BIMODE model defines the pre-storm profile values and selects the representative profile from the database in which to read in its post-storm profile and overwrite the input profile.

4.2 Storm Surge and Risk Modeling

4.2.1 Risk Metrics

The 2017 Coastal Master Plan analysis uses direct economic damage from flooding as a primary metric to assess future coastal flooding vulnerability and to estimate the benefits from proposed risk reduction projects. Economic damage is typically discussed in terms of expected annual damage (EAD) and is currently calculated as the average damage in a given year from coastal storms roughly Category 1 or greater on the Saffir-Simpson scale. Estimates of damage at different recurrence intervals (annual exceedance probabilities) are also considered, considering everything from the 10-year (10 percent annual chance) to the 2,000-year (0.05 percent annual chance) flood event (see Attachment C3-25 for more details).

These metrics have proven helpful to support planning and project prioritization, but future analysis could be improved by expanding upon the range of measurements used to evaluate flood risk. The metrics could be improved in several ways.

First, measurements of flood damage could be improved by directly including tidal flood events or higher-frequency non-tropical storms (e.g., winter storms), with associated recurrence probabilities, into the statistical estimates of flood depth and damage recurrence. As coastal subsidence progresses and sea levels continue to rise, these high-frequency, lower-damage events are likely to increasingly affect Louisiana's coastal communities, but are not yet accounted for in the formal damage estimates or project benefit comparisons. Incorporating high-frequency events into damage recurrence will improve the overall estimate of project benefits, and would provide a better understanding of how coastal restoration projects could help to offset tidal or other "nuisance" flooding. To fully account for high-frequency flood conditions in future master plan analyses, an evaluation of the known meteorological, hydrologic, and coastal hydraulic conditions that result in nuisance flooding must be evaluated, as well as future scenario environmental conditions (e.g., changes in precipitation patterns and sea level rise) that would lead to a change in expected flood conditions. Based on findings from such an evaluation, a methodology could be developed that provides the requisite levels of accuracy, calculation time, and outputs necessary to inform master plan decisions. Methodologies could be as simple as projecting current nuisance flood conditions forward, adjusting to account for future scenario environmental conditions, or as complex as expanding the current joint probability methodology to incorporate additional considerations such as winter storms and high tide.

Second, the risk metrics themselves could be expanded from a set of estimates of economic damage to a wider array of measures of different consequences of flooding. Flood damage recurrence is a useful proxy, but tends to be higher in areas with a greater concentration of assets and wealth. In particular, focusing on measures of economic damages will obscure the consequences of flooding in lower-density or lower-income coastal communities. A broader set of metrics is already included in the additional metrics for the 2017 Coastal Master Plan (Attachment C4-11), but EAD is the primary risk decision metric used to evaluate and compare projects. Future analyses could include metrics that quantify other concerns, such as population exposure to flooding, or disruption of critical services. Analysis of these metrics would allow planners to take a more holistic view of vulnerability and flood risk, and it would provide greater insight into equity considerations associated with the distribution of benefits from the master plan.

More holistic metrics may also better capture the disruptive impacts of high-frequency or "nuisance" flooding in future years. Such flooding may disrupt disadvantaged populations without producing very large amounts of economic damages. Rather than estimating the depth of flooding corresponding to specific return periods, it could also be helpful to calculate the return period of a particular level of flooding to estimate the frequency of nuisance floods with and without protection projects. Generating these additional metrics would enable overlays with population demographics and social vulnerability measures that could be helpful in supporting community resilience planning efforts (e.g., Groves et al., 2016).

Finally, an important step forward would allow for the consideration of future scenario "pathways." The current analysis approach considers each time period independently, calculating statistical flood damage in a given year (year 0, 10, 25, or 50) without accounting for how coastal storms can impact coastal communities and affect their development over time. An alternate approach would instead evaluate a wide range of different pathways representing the recurrence of storms over the 50-year simulation period in a broad range of plausible patterns, later combined in statistical summaries. This approach would provide several key benefits: 1) better capture how the population and development patterns might shift in response to multiple storm events over time; 2) consider risk reduction project benefits over time instead of snapshots of future time periods; and 3) allow the analysis to include adaptive components that could redirect investment or otherwise respond to changing conditions as different scenario pathways unfold.

However, such an approach could entail important tradeoffs between model resolution and high-performance computing needs, as it could require a large number of simulation runs to adequately capture the plausible range of futures. As such, lower resolution model emulators, or other tools suitable for screening analysis, could be considered to support this new approach. Applying a pathways approach would also require further research to develop suitable mechanisms for modeling how development is impacted by specific sequences of flood events.

4.2.2 Evaluating Additional Coastal Resilience Projects

The 2017 Coastal Master Plan considers nonstructural risk reduction investments intended to reduce the consequences of flooding to structures in the built environment. Specifically, the analysis includes elevating structures above ground level, floodproofing of nonresidential buildings, and acquisitions intended to remove structures from areas exposed to very high flood depths. There are other actions that communities might apply more broadly to collectively reduce risk or increase disaster resilience. For example, potential changes to building codes, zoning, or land use plans to promote structure hardening or prevent new development in high risk areas are not considered in the analysis. Similarly, investments in floodproofing or hardening of infrastructure that support critical services (e.g., transportation, energy supply, water, and sewer) are not currently considered, though these could be critical to ensuring that communities can recover quickly after a storm event.

Working through the Flood Risk and Resilience Program, CPRA could consider which resilience policy options are suitable for consideration for future master plan investment and those identified as relevant for CPRA could potentially be included in future master plan analysis. Changes in zoning or land use planning, for example, could be reflected as changes to the population and asset growth patterns that are considered during analysis. Further research is needed to identify precisely how such changes could impact future structure asset inventories. Additional investments in floodproofing and hardening would be reflected in adjustments to the depth-damage relationships applied to mitigated assets. When considering critical infrastructure elements, new risk metrics could be considered that relate to the probability of losing operational capacity with or without hardening measures.

The master plan also considers a limited number of mitigation standards for nonstructural risk reduction investments, based upon projected 100-year flood depths in specific future scenarios. Future efforts could consider performance of an expanded range of flood standards, considering both cost-effectiveness and the more holistic set of metrics described in the previous section.

In order to evaluate resilience policy options and to ensure economic damage estimates generated in the future reflect up-to-date assumptions, current and detailed structure inventory data should be collected and used to update the inventory data used in coastal master plan analysis. The current modeling effort is based on FEMA Hazus-MH MR2 and MR4 model data, relatively recent inventory estimates made available by the U.S. Army Corps of Engineers (USACE) New Orleans District, census data, and tax parcel-level data derived from three separate USACE investigations. Further details are provided in the 2017 Coastal Master Plan's Attachment C3-25 technical appendix. Any additional parcel-level data assembled by the USACE or otherwise made available from parish or local sources should be utilized to update the structure inventory considered during master plan analysis. Key characteristics would include structure location, type, building characteristics, and existing level of mitigation (e.g., elevated foundations for residential assets).

4.3 Water Quality, Fish, and Shellfish Modeling

4.3.1 Water Quality Subroutine

The current water quality modeling subroutine includes mass transfer equations for 14 water quality constituents (excluding suspended sediment, salinity, and temperature). These water quality parameters are coupled through source/sink terms for computing mass transfers due to kinetic processes. In addition, salinity, temperature, and suspended sediment also contribute to the distribution and concentration of water quality constituent predictions. The present approach allows the model to explore dynamics between constituents. However, due to the lack of observed water quality parameters for time-series data at model boundaries, model capability was greatly hindered. It is found that complexity of the water quality model is not consistent with other eco-hydro model components. Specifically, the impacts from missing individual input parameters compound model errors and inaccuracies due to the coupled source/sink terms within the algorithms; this results in a difficult calibration process for a coast wide model with limited input data.

For the 2017 modeling effort, the only utilization of the water quality output was to drive primary production levels for the fisheries biomass (EwE) model. If this is to be the only utilization of water quality modeling efforts in future master plans, it may be worthwhile to implement a simpler water quality model to simulate the required primary production data. This model could be designed with an appropriate level of complexity given the dearth of high quality boundary condition time series input data available across the entire coastal zone modeled within the ICM.

If the detailed water quality model is maintained within the ICM, it is highly recommended that a rigorous effort be undertaken to develop accurate representations of the boundary condition time series required to drive the coupled water quality algorithms. In addition, a more robust calibration effort should be undertaken for a subset of the model domain where high quality (both spatially and temporally) boundary and interior data has been collected. It is recommended that the Barataria region could be used as a pilot area, which would allow for the ICM calibration to benefit from other detailed water quality modeling efforts currently underway.

4.3.2 Ecopath with Ecosim

One particular area of improvement for future fish and shellfish modeling would be the inclusion of currently confidential fisheries landings data. Data from specific basins in Louisiana are kept confidential when catch is reported from three or less commercial fishermen. As fishing is an important driver of standing stock in coastal Louisiana (Chesney et al., 2000; De Mutsert et al., 2008), the ability to calibrate and validate the EwE model at a finer spatial resolution will likely improve the historical fits to survey and catch data, ultimately providing more confidence for future predictions. Lack of "responsiveness" of the model to inter-annual changes in biomass observations during the calibration phase, is likely largely due to changes in catch that are not captured well by the model due to a lack of information (related to PM-TAC #5).

Another challenge to the 2017 EwE modeling process is a low sample size and lack of a consistent time series of oyster monitoring data. The Louisiana Department of Wildlife and Fisheries is currently planning to expand their oyster monitoring program starting in 2017; inclusion of these data would improve the oyster biomass calibration and spatial distribution validation process. Additional improvements of the oyster modeling process could be found by adjusting the response curve of oysters to the presence of cultch. Since there is not a good empirical relationship between percent cultch and effective feeding rate, the 2017 effort made it very inclusive (i.e., presence of cultch makes the habitat fully suitable for oysters). Testing different response curves experimentally could provide a more accurate relationship between percent cultch and habitat capacity, placing a more conservative habitat restriction on the settlement of oysters.

Earlier described difficulties with the water quality modeling affected the Ecospace simulations, since especially Total Kjeldahl Nitrogen (TKN) has a significant bottom-up effect on distribution and amount of biomass of the higher trophic level species. A suggestion for future improvement would be to explicitly model chlorophyll a (Chl a) outside of the Ecospace model, and then drive the phytoplankton biomass with normalized changes in Chl a rather than using TKN as a primary productivity driver. Another advantage of this approach is that suspended sediment-related light limitations affecting algal production would then be captured, which is currently not the case. Direct simulation of Chl a changes during the production runs would have high pay-off for both the Ecospace modeling as well as the HSIs. If simulating Chl a turns out to not be practical, an alternative would be to develop a response curve for phytoplankton to total suspended solids, in addition to using nutrient output as a primary productivity driver (this driver can be the best performing nutrient; if not TKN, dissolved inorganic nitrogen (DIN) would work as well).

An alternative approach would be integration of the HSIs in the Ecospace model. The HSIs and the Ecospace biomass output currently serve as two independent assessments of potential effects of restoration and protection projects on different consumer groups. One by describing the suitability of the habitat, and the other by simulating the actual biomass changes of the different consumer groups throughout the years. The habitat capacity model in Ecospace also determines the suitability of the environment for each group in the model, every month of a simulation, by coupling the environmental driver value of a month (e.g., salinity) to a species-specific response curve (e.g., salinity tolerance) for every driver included in the model, and calculates the "habitat capacity" as an average suitability of each model cell based on all driver-response curve combinations (Christensen et al., 2014). These habitat capacity maps themselves do not undergo a separate calibration or validation process. Since the HSIs do undergo a validation and QA/QC process, directly using the HSI algorithms to derive habitat capacity maps may provide an improvement as well as a simplification. The Ecospace model would then just be linked to the HSI output of the ICM instead of environmental drivers and not utilize separate response curves. This approach would require aligning the HSI and Ecospace species list; all species of interest would need to be included in the HSI process, and data would need to be available to support that development. Conversely, the Ecopath food web can be simplified: species not selected for species-level interest can be grouped in functional groups (e.g., forage fish, non-fish predators).

5.0 Additional Comments

5.1 Science and Engineering Board

The Science and Engineering Board consisted of 10 members, and their role was to provide insight and guidance for the entire 2017 Coastal Master Plan effort. Appendix G provides more background on the SEB and includes summaries of their meetings. Although the SEB did not specifically focus on the modeling effort, as did the PM-TAC, they did have suggestions for model improvements. Specific recommendations on modeling are provided in Table 1 of Attachment C5-2: Additional Comments. Note that as these have been extracted from summary meeting reports, some slight changes in wording have been made to provide context for the individual obersvations.

5.2 External Reviewers

Early in the 2017 modeling effort, a group of subject matter experts were asked to review the model improvement reports. They were asked to focus on the following questions:

- Does the documentation clearly / adequately reflect the modeling process?
- Is the overall strategy appropriate for large scale (entire Louisiana coast), long-term (50 year) planning efforts?
- Are the technical assumptions and use of equations acceptable?
- Are there any fundamental flaws or otherwise that should be noted and/or revised for future coastal planning efforts?

Although many of their suggestions were incorporated in the 2017 modeling effort, there were a number of recommendations that were not able to be implemented due to time constraints. These were cataloged for future consideration and are included in Table 2 of Attachment C5-2: Additional Comments to provide additional ideas for the future modeling efforts. Note that as these have been extracted from direct comments on specific reports, some slight changes in wording have been made to provide context for the individual obersvations.

6.0 Common Issues

6.1 Data Needs

As with any effort of this nature, the continued improvement of input data is paramount (PM-TAC #3). Moving forward, additional and more complete datasets should be secured from regional sources such as Barrier Island Comprehensive Monitoring (BICM), CRMS, and System-wide Assessment and Monitoring Program (SWAMP), local project-level sources (e.g., bathymetry and topography), and national sources for precipitation and wind. Additional data for water quality (including total suspended sediment) has also been identified as a key current limitation and as more data becomes available the modeling approaches can be improved.

6.2 Quality Assurance and Quality Control

The 2017 modeling effort improved greatly on the QA/QC effort applied during the 2012 modeling effort (see Attachment C4-1), and it should be possible to further improve this important aspect by incorporating additional automation throughout the process. Subject matter experts will still be needed to interpret the outputs, but using more automated processes to analyze and visualize patterns will help ensure that QA/QC is accomplished in a timely manner and allow resolution of issues identified so as not to slow down the overall master plan process.

6.3 Spatial Scales

The challenge of modeling projects of all types and sizes across the coastal landscape remains. Specifically, evaluating the effects of small-scale projects, as well as those projects that provide basin-scale effects within the same coast wide 50-year modeling framework, needs careful consideration of the right approach. The spatial scale of the ICM compartments makes it difficult to reflect the local effects of ridges, shoreline protection, and bank stabilization projects, and in some cases, this is also true for smaller hydrologic restoration projects. The range of spatial scales of the projects is also an issue for the surge and risk analysis. This could be remedied through the use of more detailed models for some areas that are linked to the coast wide framework or by other approaches. Considering this issue early in the modeling phase for the 2022 Coastal Master Plan can better ensure the benefits of all projects evaluated are reflected in the outputs.

6.4 Detail vs. Application

A common theme throughout the suggested improvements and reviewer comments is the inclusion of additional detail into the models to better reflect the complex process interactions that govern landscape and ecosystem dynamics and exposure to risk from coastal storms. While improved data and understanding in the future can enable such developments, the ways in which the models are to be applied and the types of decisions they inform need to also be considered. The master plan is the first step in the analysis process for many projects. While the models should appropriately reflect coastal change, they also need to be sufficiently adjustable and computationally efficient to be applied in an even manner to many project types and locations. Having modeling tools that can be readily and consistently applied has advantages that in some instances might outweigh additional process details. In addition, once projects are included in the plan, as funds become available, they move into a process of refinement and more detailed evaluation that eventually leads to projects being built or implemented. At that stage, more detailed and tailored analysis is likely essential to ensure projects can be implmented to produce the expected results. This trade-off between detail and applicability to master plan-type decisions will be an important consideration as model improvements are considered for future master plans.

7.0 References

Chesney, E. J., Baltz D. M. and Thomas, R. G. (2000). Louisiana estuarine and coastal fisheries and habitats: perspectives from a fish's eye view. *Ecological Applications*, 10, pp. 350–366.

Christensen, V., Coll, M., Steenbeek, J., Buszowski, J., Chagaris, D. S. and Walters, C. J. (2014). Representing variable habitat quality in a spatial foodweb model. *Ecosystems* 17: pp. 1397-1412.

Couvillion, B., and Beck, H. (2013). Marsh collapse thresholds for coastal Louisiana estimated using elevation and vegetation index data. *Journal of Coastal Research*, 63, pp. 58-67.

De Mutsert, K., Cowan, J. H., Essington, T. E., and Hilborn, R. W. (2008). Reanalyses of Gulf of Mexico fisheries data: landings can be misleading in assessments of fisheries and fisheries ecosystems. *Proceedings of the National Academy of Sciences*, 105, pp. 2740-2744.

Groves, D. G., Kuhn, K., Fischbach, J., Johnson, D. R., and Syme, J. (2016). Analysis to Support Louisiana's Flood Risk and Resilience Program and Application to the National Disaster Resilience Competition. Santa Monica: RAND Corporation, RR-1449-CPRA.