Coastal Protection and Restoration Authority
150 Terrace Avenue, Baton Rouge, LA 70802 | coastal@la.gov | www.coastal.la.gov

2017 Coastal Master Plan

Appendix C: Modeling

Chapter 2 - Future Scenarios

Report: Final

Date: April 2017

Prepared By: The Water Institute of the Gulf

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.

Suggested Citation:

Meselhe, E., White, E. D., and Reed, D. J., (2017). *2017 Coastal Master Plan: Appendix C: Modeling Chapter 2 – Future Scenarios.* Version Final. (p. 32). Baton Rouge, Louisiana: Coastal Protection and Restoration Authority.

Acknowledgements

The authors would like to thank the RAND team (Jordan Fischbach, David Johnson, and Kenneth Kuhn) for contributions from the CLARA storm analysis, the entire 2017 Coastal Master Plan modeling team (listed in Chapter 1), the Predictive Models Technical Advisory Committee (PM-TAC), external reviewers, and the Planning Tool team for their contributions to this effort. Thanks also go to Jennifer Butler, Jeff Heaton, Marla Muse-Morris, and Mark Legendre for contractual support and management, and to Taylor Kimball for editorial support. Lastly, the authors would like to thank Natalie Peyronnin, Mark Leadon, and Ed Haywood for contributions during early phases of the model improvement planning effort and Brian Harper for his contributions to early phases of the PM-TAC.

This effort was funded by the Coastal Protection and Restoration Authority (CPRA) of Louisiana under Cooperative Endeavor Agreement Number 2503-12-58, Task Order No. 03.

Executive Summary

Coastal Louisiana has experienced dramatic land loss since at least the 1930's. A combination of natural processes and human activities has resulted in the loss of over 1,880 square miles since the 1930's and a current land loss rate of 16.6 square miles per year. Not only has this land loss resulted in increased environmental, economic, and social vulnerability, but these vulnerabilities have been compounded by multiple disasters, including hurricanes, river floods, and the 2010 Deepwater Horizon oil spill, all of which have had a significant impact on the coastal communities in Louisiana and other Gulf coast states. To address this crisis the 2007 Coastal Master Plan was developed under the direction of the Louisiana Legislature. 2012 marked the first five-year update to the plan, and the second update is scheduled for 2017.

A number of substantial revisions have been made in preparation for the 2017 Coastal Master Plan modeling effort. Chapter 2 describes why environmental scenarios are needed for the 2017 Coastal Master Plan, and how the scenarios were developed. It also provides details on selection of the environmental drivers, the plausible range of values for each driver, and the analysis and modeling used to support the selection of values for each scenario.

Additional details for the modeling components are provided in a series of attachments.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ADCIRC	Advanced Circulation
AVB	Atchafalaya-Vermillion Bay
BRT	Breton Sound
CAS	Calcasieu
CLARA	Coastal Louisiana Risk Assessment
CORS	Continuously Operating Reference Stations
CPRA	Coastal Protection And Restoration Authority
EAD	Expected Annual Damage
ECHAM	Max Planck Institute For Meteorology ECHAM5 General Circulation Model
ESLR	Eustatic Sea Level Rise
FWOA	Future Without Action
GCM	General Circulation Model
GENMOM	USGS and Portland State University GENMOM general circulation model
HSDRRS	Hurricane and Storm Damage Risk Reduction System
HURDAT	HURricane DATabases
ICM	Integrated Compartment Model
LBA	Lower Barataria
LO	Less Optimistic
LPO	Lower Pontchartrain
LTB	Lower Terrebonne
MD	Moderate
PDI	Power Dissipation Index
PM-TAC	Predictive Models Technical Advisory Committee

PR	Plausible Range
UBA	Upper Barataria
UPO	Upper Pontchartrain
USACE	U.S. Army Corp Of Engineers
UTB	Upper Terrebonne

Chapter 2: Future Scenarios

1.0 Introduction

1.1 The Need for Scenarios

The objective of Louisiana's Comprehensive Master Plan for a Sustainable Coast is to evaluate and select restoration and protection projects that build and sustain the landscape and reduce risk to communities from storm surge based flooding. Given the uncertainty associated with future environmental conditions, models that seek to predict future outcomes must incorporate some level of variability in their inputs to reflect such uncertainty. This is especially important to help in decision making when planning long-term (50-year), large-scale (coast wide) restoration and protection efforts for coastal Louisiana. There are many ways to consider unknown future conditions, and selecting a strategy to incorporate those conditions into a modeling effort depends on the types of information available and how the results will be used. Where there is no known likelihood associated with environmental conditions but rather a range of plausible future conditions, scenario analysis (e.g., Groves and Lempert, 2007; Mahmoud et al., 2009) provides a viable way for decision makers to explore the effects of different possible future conditions on the outcomes of interest. The primary role of scenarios in the master plan modeling is to provide insight into project performance into the future, across a range of plausible future conditions.

A scenario approach, evaluating model outcomes across different combinations of values for a set of environmental drivers, was used in the development of the 2012 Coastal Master Plan. This effort builds on the work conducted for the 2012 Coastal Master Plan and provides a foundation for the selection of scenario values for the 2017 Coastal Master Plan. The resulting representations of future environmental conditions captured in the scenarios are not intended to represent "what will happen into the future;" instead, they are a means of gaining insight into the uncertainty of the future and an acknowledgement that the past environmental conditions will not necessarily repeat into the future. Including future scenarios in master plan analyses allows for the consideration of a variety of plausible future conditions.

In preparation for the 2012 Coastal Master Plan, nine key environmental drivers were identified for which it was challenging to determine a more or less likely set of values to drive the modeling effort. Some of these environmental drivers are influenced by climate change or management decisions in the future (e.g., eustatic sea level rise [ESLR] and river nutrient concentrations, respectively), and some are based on processes that are not fully understood (e.g., subsidence, marsh collapse threshold). Such complexity made it challenging to identify values for the future scenarios to drive the models.

This report documents the procedures used to explore new data and literature regarding some of the environmental drivers and develop a set of analyses to explore model output response to different values for environmental drivers. These analyses are used to inform the selection of environmental drivers and values to be used in scenarios for the 2017 Coastal Master Plan modeling effort. Such analyses were not conducted prior to the selection of scenario values for use in the 2012 Coastal Master Plan. Consequently, while the values were thought to each contribute to change in model outputs, this hypothesis was not formally tested.

It is important to note that this report does not attempt to develop new science related to the environmental drivers or their temporal/spatial patterns. There is also no attempt to develop new forecasts or predictions of future conditions. Rather, this effort focuses on identifying the state of the science and applying that knowledge for coastal planning purposes. As such, the work is based on a combination of scientific literature, analysis of existing data, input from subject matter experts, and best professional judgment where necessary.

1.2 Developing Scenarios

Scenarios for use in planning can be derived in a number of ways. In some cases, they are developed by stakeholders and in others by using statistical methods to explore the possible range of future circumstances once plausible ranges for individual drivers have been identified. This report outlines options that were considered to explore model output response to changes in environmental drivers and procedure used. All approaches had to be feasible given the time and resource constraints of the planning process.

Once the nine key environmental drivers were identified for the 2012 Coastal Master Plan analysis, documentation was assembled to describe the plausible range of each driver over the 50-year planning horizon (Table 3). In some cases, this documentation was based on a review of the scientific literature. In other cases, ranges were generated using expert panels and/or inspection of available historical data. Once a plausible range for each driver is established, there are a number of ways scenario values can be selected. For 2012, expert opinion was used to select values from within each of the ranges. These selected values were then combined into a small set of future scenarios. One disadvantage of this approach is that while relatively simple to explain to stakeholders (especially compared to some of the statistical approaches used by others), the role of any individual driver in influencing model outcomes cannot be determined. Stakeholders may assume all the drivers are equally important; this may or may not be the case. Model outputs may be more sensitive to some environmental drivers than others. If that is the case, scenario analyses could be focused on fewer drivers to enable decision makers to better understand how future conditions influence master plan outcomes. A smaller number of drivers in each scenario also reduces the complexity of communication with stakeholders.

The approaches described in this report involve testing the effects of different values selected from the plausible ranges of several environmental drivers on key model outputs. The results of the model runs can then be explored to show which values across the plausible range of the environmental drivers produce change in model outputs. This information can then be used to inform the selection of a small set of scenario values for use in the 2017 Coastal Master Plan and makes it more likely that the different scenarios will produce a change in master plan model outputs. Not only do the experimental analyses described below facilitate the development of the future scenarios, they also provide valuable insight into overall model sensitivity which can be highly important when interpreting model outputs.

Due to limited time and resources, the experimental analyses described herein to identify scenario values were not applied to the surge and wave modeling component (incorporated using ADCIRC (Advanced CIRCulation Model)), but the surge and wave analyses are responsive to the values chosen for environmental drivers. Future storm surge and wave conditions will be predicted based on landscape conditions where landscape change will be driven by different values of environmental driver associated with each scenario. Some testing of candidate scenario values for storm intensity and frequency in the Coastal Louisiana Risk Assessment (CLARA) model was conducted prior to finalizing the values for the environmental scenarios. Further discussion of scenario values to be used in the risk analysis (e.g., fragility, population growth) can be found in Attachment C3-25.

There are four primary steps in developing scenarios for use in the 2017 Coastal Master Plan:

1. Revisit the 2012 Coastal Master Plan work on future scenarios, select drivers that are relevant to the 2017 analyses, and identify whether plausible ranges for the relevant environmental drivers should be modified, using recent literature, data, and other information;
2. Assess the response of key model outputs to changes in value of the environmental drivers
    a. Design focused numerical experiments and perform analysis to assess the response of key outputs of the 2017 Coastal Master Plan Integrated Compartment Model (ICM)
    b. Sensitivity testing, using 2012 data, with CLARA to ensure that variation in storm frequency and intensity would influence the performance of risk reduction projects;
3. Conduct ICM model runs on a range of candidate scenario values to confirm outputs based on combinations of driver values; and
4. Identify three scenarios (combination of values of environmental drivers) to be used in the 2017 Coastal Master Plan modeling effort.

Because scientific understanding of environmental conditions continues to grow and evolve, fall 2014 (time this report was written) was used as the 'stopping point' for new information to be included/considered in the identification of plausible ranges, as time is needed for the technical team to implement the experimental model runs and design the scenarios that will be used in the 2017 Coastal Master Plan modeling. New information and data made available after fall 2014 will be included in future master plan updates.

2.0 Selection of Drivers and Identification of Ranges

2.1 Revisiting the 2012 Coastal Master Plan

Nine key environmental drivers considered to have uncertain outcomes over the next 50 years were used to develop future scenarios for the 2012 Coastal Master Plan technical analysis. Appendix C: Environmental Scenarios (CPRA, 2012) provides an overview of each of the environmental drivers included, plausible ranges for those drivers across a 50-year planning horizon, and a rationale for selecting values from within those ranges to formulate the future scenarios. Table 3 provides an overview of the drivers, plausible ranges considered, and the values used to define two future scenarios – 'moderate' and 'less optimistic' – for the 2012 Coastal Master Plan. A third scenario was also incorporated in the final 2012 analysis; this scenario was identical to the 'moderate' scenario but had a eustatic sea level rise (ESLR) value of 0.78 m over 50 years.

Table 1: Overview of the Environmental Uncertainties ('drivers' in 2017 analyses) and Values used to Define Two Future Scenarios for the 2012 Coastal Master Plan.

Environmental Uncertainty	Plausible Range	Moderate Future Value	Less Optimistic Future Value
Eustatic Sea Level Rise	0.16 to 0.65 m over 50 years (a higher value of 0.78 m over 50 yrs was eventually considered for 'alternative' modeling)	0.27 m / 50 yr	0.45 m / 50 yr
Subsidence	0 to 35 mm/yr; varies spatially	0 to 19 mm / yr (values vary spatially)	0 to 25 mm / yr (values vary spatially)
Tropical Storm Intensity	Current intensities to +30% of current intensities	+10% of current intensities	+20% of current intensities
Tropical Storm Frequency	-20% to +10% of current frequency	Current frequency; (one Category 3 or greater storm every 19 yr)	+2.5% of current frequency; (one Category 3 or greater storm every 18 yr)
Mississippi River Discharge	-7% to +14% of annual mean discharge; adjusted for seasonality	Mean annual discharge (534,000 cfs)	-5% of mean annual discharge (509,000 cfs)
Rainfall	Historical monthly accumulations (+/- 1 SD); varies spatially (8 points from gridded data field)	Historical monthly averages	25th percentile of historical monthly averages
Evapotranspiration	Historical monthly averages (+/- 1 SD); varies spatially (10 interpolated points from North American Regional Reanalysis dataset)	Historical monthly averages	+0.4 SD from historical monthly averages
Mississippi River Nutrient Concentration	- 45% to +20% of current nitrogen & phosphorus concentrations	-12% of current concentrations (mg/L) Phosphorus = 0.19 Nitrite + Nitrate = 1.1 Ammonium = 0.038 Org. Nitrogen = 0.67	Current concentrations (mg/L) Phosphorus = 0.22 Nitrite + Nitrate = 1.3 Ammonium = 0.044 Org. Nitrogen = 0.77
Marsh Collapse Threshold	Salinity (ppt) Swamp: 4-7 Fresh Marsh: 6-8 Inundation (water depth, cm) Intermediate Marsh: 31-38 Brackish Marsh: 20-26 Saline Marsh: 16-23	Mid-range values of salinity and/or inundation result in collapse Salinity (ppt) Swamp: 6 Fresh Marsh: 7 Inundation (water depth, cm) Intermediate Marsh: 34 Brackish Marsh: 23 Saline Marsh: 21	Lower 25th percentile values of salinity and/or inundation ranges result in collapse Salinity (ppt) Swamp: 5 Fresh Marsh: 7 Inundation (water depth, cm) Intermediate Marsh: 33 Brackish Marsh: 21 Saline Marsh: 18

2.2 Why Fewer Drivers are considered for 2017

Early in the model improvement work for the 2017 Coastal Master Plan, model team leaders were asked to identify the most important drivers that should be considered in the scenario analysis. Their recommendation was to begin with the same drivers used in 2012 with the exception of the marsh collapse threshold; it is proposed to explore the influence of uncertainty in this environmental driver during the planned model uncertainty analysis. This is recommended because marsh collapse threshold is not an uncertainty in terms of unknown future environmental conditions; rather, it is an uncertainty of our understanding of the current conditions and processes at work.

A literature and data review was conducted to update the plausible range of each remaining driver by incorporating the latest available information. The list of drivers was later reconsidered, as the ICM began to take shape, in terms of each driver's likely impact on model outcomes. Removing non-critical drivers from the scenario analysis results in a more robust experimental design for testing model response to the remaining environmental drivers – those drivers likely to have a more substantial impact on model outputs. It also reduced the time and resources needed to complete the analysis.

The following is an explanation of the changes made to the list of drivers for 2017 compared to 2012; changes to the ranges are provided in Table 4:

- Mississippi River Discharge – this is being **removed** from the 2017 future scenarios analysis. Based on the literature review conducted, including a review of the literature that was used to identify the range used in the 2012 effort, the recommendation is to remove Mississippi River discharge from the scenario analysis, as there is little evidence to support a change in discharge in the future, and instead use the historical hydrograph without adjustments.

- Precipitation – this is a **change in terminology** from Rainfall in the 2012 effort to indicate inclusion of all forms of precipitation.

- Mississippi River Nutrient Concentration – this is being **removed** from the 2017 future scenarios analysis. The 2017 Coastal Master Plan will model nutrients in the water quality subroutine and with a nitrogen uptake subroutine; however, model outputs that depend on these water quality calculations are not expected to be primary decision drivers in planning efforts. Therefore, future uncertainty of nutrient concentrations is unlikely to alter planning decisions made for the 2017 Coastal Master Plan; this driver will no longer vary across future scenarios.

2.3 Summary of Ranges for 2017 Drivers

This section provides an overview of each environmental driver that is included in the 2017 Coastal Master Plan future scenarios analysis. Overviews include a brief statement regarding the values used in the 2012 Coastal Master Plan and the rationale for setting the plausible 50-year ranges (2015 – 2065) for use in the 2017 Coastal Master Plan. Table 4 compares the 2017 ranges to those used in 2012, including the values used in the 2012 moderate and less optimistic scenarios. Additional details on each of the drivers are provided in Attachments C2-1- C2-4.

Eustatic Sea Level Rise (ESLR)

The 2012 plausible range for ESLR was established on the basis of a data and literature review. The low end of the range assumed no acceleration of the current rate beyond a recent observed linear rate, and the high end of the range assumed acceleration consistent with the National Research Council (NRC, 1987) scenario used to define the high sea level rise scenario for the U.S. Army Corps of Engineers Circular #1165-2-211 (USACE, 2009). For the final 2012 analysis, a 'very high' ESLR rate was incorporated, based on Vermeer and Rahmstorf (2009).

Although the full breadth of historical work on this topic was considered for updating the 2017 range, emphasis was placed on new observations and predictive modeling generated between the 2010 completion of the review that informed the 2012 Coastal Master Plan models and fall 2014. Specifically, input for setting the new range included altimetry data, western Florida tide gauge stations, an updated U.S. Army Corps of Engineers Circular #1165-2-212 (USACE, 2011), National Research Council 2012 sea level rise estimates and regional modifications (NRC, 2012), as well as a set of sea level rise scenarios and regional modifications included in the 2013 5th Assessment Report of the Intergovernmental Panel on Climate Change. To establish the full plausible range of future sea level rise, this review equally evaluated results from both process-based and semi-empirical predictive models. The result is a slightly wider plausible range of values compared to 2012.

Note: only eustatic (global) or regional sea level rise rates were used, as the subsidence component of locally specific relative sea level rise is accounted for separately in the 2017 modeling effort.

For more information on eustatic sea level rise, see Attachment C2-1.

Subsidence

Subsidence, as applied in the 2012 Coastal Master Plan scenarios was derived from a map of plausible subsidence rates (ranging from 0 to 35 mm yr^{-1}) across coastal Louisiana that were differentiated into 17 geographical regions. Recent technical literature, information, and data were identified and reviewed to determine if the accuracy and spatial variability of the 2012 subsidence rates or spatial coverage could be improved. No new definitive studies on subsidence were found to provide coast wide predictions of future rates, and there are issues of concern with the two new data sources considered. For example, the tide gauge data analysis likely better reflects relative sea level rise not enabling the specific identification of subsidence, and the Continuously Operating Reference Stations (CORS) data are largely derived from instrumentation mounted on buildings which may not reflect the open estuary rates.

Considering the lack of definitive data or new studies on which to justify modifying the spatial polygon boundaries, the recommendation is for the 2017 Coastal Master Plan to use the same geographic regions and subsidence rates therein as the 2012 Coastal Master Plan.

For more information on subsidence, see Attachment C2-2.

Precipitation

In the 2012 Coastal Master Plan modeling effort, the plausible range of precipitation (referred to in 2012 as Rainfall) was based on historical monthly accumulations (+/- 1 SD) using records from 1990-2010. Eight precipitation gauges were used to provide the spatial variability of the rainfall pattern across the Louisiana coast.

However, general circulation models (GCMs) are now available and provide information on the impact of greenhouse gas emissions on future climate and are increasingly used to develop regional models of future climate. The availability of both these GCM and regional climate datasets have resulted in the recent incorporation of climate projections in numerous large-scale water resource planning efforts (Hagemann et al., 2012; Huntington et al., 2014; Sankovich et al., 2013).

Three regional climate projections (developed from GFDL, ECHAM, and GENMOM GCM climate projections and dynamically downscaled via the RegCM3 regional climate model; Hostetler et al., 2011) were used to determine a range of future precipitation conditions across coastal Louisiana for use in the 2017 Coastal Master Plan. In addition to these three future projections of climate, historic records of precipitation were considered when developing the plausible range. The low end of the 2017 precipitation range is set by GENMOM data and represents an approximate 5% decrease in 50-year cumulative precipitation compared to historical data. The high end of the range is set by the ECHAM data and represents an approximate 14% increase in 50-year cumulative precipitation compared to historical data.

For more information on precipitation, see Attachment C2-3.

Evapotranspiration

In the 2012 Coastal Master Plan modeling effort, the plausible range of evapotranspiration was based on historical (calculated via Penman-Monteith) monthly accumulations (+/- 1 SD). These monthly values did not vary temporally (e.g., all 50 January evapotranspiration values were the same for each simulated year); however, the data varied spatially across the coast per 10 points extracted from existing datasets derived from climatic data.

The same three regional climate projections used to develop precipitation scenarios (as discussed in the previous section of this report) were also used to determine a range of future evapotranspiration conditions across coastal Louisiana. In addition to these future projections of climate, the historic monthly mean potential evapotranspiration rates (calculated via Penman-Monteith) were considered in developing the plausible range. The low end of the 2017 evapotranspiration range is set by GENMOM data and represents a 30% decrease in 50-year cumulative evapotranspiration compared to historical (Penman-Monteith). The high end of the ranges is set by the Penman-Monteith data and represents historic monthly mean potential evapotranspiration.

For more information on precipitation, see Attachment C2-3.

Tropical Storm Intensity

In 2012, the plausible range tropical storm intensity was based on a suite of literature, including global and regional models and expert input from the 2012 Coastal Master Plan risk assessment modeling team.

Future hurricane intensity was revisited for the 2017 effort and the revised plausible range of future change builds off an updated literature review with expert input from the risk assessment modeling team. The range was drawn from several robust modeling efforts that projected potential changes in tropical storm intensity using central pressure deficit, wind speed, and power dissipation index (PDI). Recommended plausible ranges are based on projections of Atlantic Ocean Basin changes only, although studies analyzing potential changes in the Pacific and global basins have been noted. Both the literature reviewed and the historical record (since 1980) provide evidence to suggest an increasing trend in tropical storm intensity; therefore an increase in overall intensity compared to existing conditions is suggested for the 50-year period of analysis.

Note: due to the nature of the storms in the synthetic storm suite being used for the 2017 Coastal Master Plan modeling effort, there are limitations in the possible adjustments of storm intensity for the landscape analyses. Therefore tropical storm intensity will not be included in the ICM future scenarios; rather, it will be reserved for use in the risk assessment modeling (ADCIRC and CLARA).

For more information on tropical storm intensity, see Attachment C2-4.

Tropical Storm Frequency

In 2012, the plausible range of tropical storm frequency was based on a suite of literature, including global and regional models and expert input from the 2012 Coastal Master Plan risk assessment modeling team. During this effort, only the frequency of Category 3 hurricanes or higher was considered.

Based on a literature review including projections of recent modeling efforts and expert input from the risk assessment modeling team, several adjustments are suggested. The 2017 Coastal Master Plan will consider all tropical storms and major hurricanes separately, with a decrease in the frequency of all tropical storms and an increase in major hurricanes. Specifically, the 2017 revision proposes a slight reduction in the frequency of all tropical storms compared to what was used in the 2012 Coastal Master Plan but a higher frequency of major hurricanes. Recommended plausible ranges are based on projections of Atlantic Ocean Basin changes only, although studies analyzing potential changes in the Pacific and global basins have been noted.

For more information on tropical storm frequency, see Attachment C2-4.

2.4 Comparison of 2012 and 2017 Values

For ease of comparison, Table 4 provides a summary of the 2012 Coastal Master Plan plausible range and moderate and less optimistic scenario values as well as the plausible range proposed for the 2017 effort.

Table 2: 2017 Coastal Master Plan Environmental Driver Ranges, Compared to those Used in 2012.

Environmental Driver	**2012 Coastal Master Plan** **Plausible Range (PR)** **Moderate (Md) future scenario** **Less Optimistic (LO) future scenario**	**2017 Coastal Master Plan** **Plausible Range**
Eustatic Sea Level Rise	PR: 0.16 to 0.65 m over 50 years Md: 0.27 m / 50 yr LO: 0.45 m / 50 yr High SLR: 0.78 m / 50 yr	0.14 to 0.83 m over 50 years
Subsidence	PR: 0 to 35 mm/yr; varies spatially (See Page 2)	Same as 2012

Environmental Driver	**2012 Coastal Master Plan** **Plausible Range (PR)** **Moderate (Md) future scenario** **Less Optimistic (LO) future scenario**	**2017 Coastal Master Plan** **Plausible Range**
Subsidence (cont.)	Md: 20% into the range (0 to 19 mm / yr) LO: 50% into the range (0 to 25 mm / yr)	Same as 2012
Tropical Storm Intensity	PR: Current intensities to +30% of current intensities Md: +10% of current intensities LO: +20% of current intensities	+4 to +23% of current central pressure deficit
Tropical Storm Frequency	PR: -20% to +10% of current frequency Md: Current frequency; (one Category 3 or greater storm every 19 yr) LO: +2.5% of current frequency; (one Category 3 or greater storm every 18 yr)	All tropical storms: -28% to 0% change of current frequency Major storms: +13% to +83% change of current frequency
Precipitation	PR: Historical monthly accumulations (+/-1 SD), 1961-1990; varies spatially (8 points taken from gridded data field) Md: Historical monthly average LO: 25th percentile of historical monthly	Low: -5% of 50-yr observed cumulative High: +14% of 50-yr observed cumulative
Evapotranspiration	PR: Historical monthly average (+/-1 SD); varies spatially (10 points taken from existing data) Md: Historical monthly average LO: +0.4 SD from historical monthly average	Low: -30% of 50-yr cumulative Penman-Monteith evapotranspiration High: Historic Penman-Monteith evapotranspiration record

3.0 Analysis to Support Selection of Scenario Values

This section describes the analysis options considered to select the scenario values and the results of the analysis that was used in the selection of the values. The final scenario values for the 2017 Coastal Master Plan and the process used to arrive at these decisions is also presented.

3.1 Suggested Approaches for Value Selection

There are a number of approaches that can be used to select the values used in scenarios. This section outlines two options considered to assess the effects of changing environmental driver values on model output and a description of the 'hybrid' analytical approach used to select the values for scenarios for the 2017 Coastal Master Plan. Land area is a primary decision driver for the 2017 Coastal Master Plan; these options were developed for consideration of the effect of scenario values on coast wide land. The effect of changing storm intensity and frequency on CLARA damage estimates is assessed separately (section 3.2.3).

3.1.1 Option 1 – Baseline Comparison Multi-Phased Approach

This approach is grounded in having a 'baseline' model run intended to represent historical or moderate conditions for comparison to previous outputs or other known conditions. Additional model runs with specific changes to environmental drivers can be performed and compared to the baseline simulation. The intent of this comparison is to determine the effects of change in individual environmental drivers as well as several interactive driver combinations on model outcomes. The first phase of simulations indicates the changes to specific environmental drivers; all other drivers would assume the same values used in the baseline model run. Later phases would change combinations of drivers based on the findings from the first phase and understanding of how environmental factors interact to influence coastal change.

The phased approach provides flexibility to design simulations to examine specific spatial considerations (e.g., some drivers may be expected to have a greater effect on certain regions of the coast), while other simulations would focus on temporal considerations (e.g., some drivers require a full 50-year model run to assess the full breadth of their impacts, but others may not).

In addition, testing drivers individually and collectively in different phases allows environmental drivers that do not show strong influence on the model outputs across their range in the first phase of runs to be eliminated unless there is a reasonable hypotheses that they may have more influence when interacting with a non-baseline value of another driver. A second phase of the analysis could consider values between those used in the first phase and/or could consider hypothesized interactions among changes in drivers (e.g., the effect of changing precipitation/evapotranspiration when SLR is at its highest). The phased approach would allow for testing of key questions or concerns that may arise from the first phase of model simulations in a subsequent phase of simulations.

An example design of the first phase of analysis for this approach is provided in Attachment C2-5: Options for Sensitivity Analyses Table 1. Reference to "moderate" and "less optimistic" refers to the 2012 Coastal Master Plan scenario values.

3.1.2 Option 2 – Statistically Based Approach

This option includes a matrix of targeted model runs to examine the combined impact of changes in the environmental drivers on the model output as well as to explore the interaction among the environmental drivers. In option 2, the key environmental drivers are organized into three groups. The 64 runs represent each possible mixture of the four combinations for each grouping of drivers (i.e., 4 combinations ^ 3 driver groups = 64), and the intent would be to perform all simulations in a single phase (Table 5). The full set of model runs are listed in Attachment C2-5: Options for Sensitivity Analyses Table 2. In some cases, the combinations enable exploration of drivers within a group and in other cases spatial variation in outputs may be used to tease out the effects, for instance, of subsidence (which varies spatially) from ESLR (which is a single value coast wide) for each combination. In comparison to option 1, this approach is faster because it does not require iterations. However, it can only explore a specific set of values that must be defined before the analysis begins. Given this, it may be difficult to determine scenario values for each driver since only three values for each driver will be included in the analysis given the limited time available for the analysis. As such, decisions for selecting values for inclusion in the three future scenarios would be drawn from insights gained from these 64 model runs.

Table 3: Experimental Matrix Design of Environmental Drivers and Four Combinations. Low = the lowest value of the range to be tested; mid = a value in the mid area of the range; high = the highest value of the range to be tested.

Environmental Driver	Combination 1	Combination 2	Combination 3	Combination 4
Precipitation/Evapotranspiration				
Precipitation Evapotranspiration	Historical (mid) IWMI - historical (high)	GENMOM (low) GENMOM (low)	ECHAM (high) ECHAM (mid)	GENMOM (low) IWMI - historical (high)
Relative Sea Level Rise				
Subsidence ESLR	20% into range (low) 0.22m (low)	20% into range (low) 0.43m (mid)	50% into range (mid) 0.43m (mid)	75% into range (high) 0.83m (high)
Tropical Storms				
Frequency (all storms) Frequency (major hurricanes)	-28% (low); 17 storms +13% (low); 8 major	-14% (mid); 20 storms +13% (low); 10 major	-14% (mid); 20 storms +50% (mid); 13 major	0% (high); 23 storms +83% (high); 18 major

3.2 Modeling to Identify Scenario Values

The analysis used as a basis for the selection of scenario values was ultimately a hybrid of the approaches described above. It was conducted in two phases in order to first explore the response of land area in the ICM to various combination of environmental driver values, and second to ensure that the scenarios selected represented a spread of landscape changes under Future Without Action Conditions (FWOA). Both phases were necessary as the options described above and the lists of combinations of values shown in the appendices do not necessarily represent combinations of values for use in actual scenarios. Rather, they are designed to explore the sensitivity of model outputs to individual drivers or combinations of drivers. Once candidate values for scenarios were selected, an additional set of analyses was conducted to explore trends over time and to support the selection of three sets of scenario values to move forward.

3.2.1 Sensitivity Analyses

Table 4 shows the values tested with model runs. Run S20 is the 'baseline' model run intended to represent historical conditions. The number of model runs and the values tested were identified based on the time and resources available to conduct the analysis, professional judgment of the potential role of different drivers, and the need to test sensitivity to changes in storm intensity and frequency given that these factors did not influence landscape change in the 2012 Coastal Master Plan modeling.

Table 4: List of the Sensitivity Runs Conducted to Assess Changes in Model Outputs of Land Area in Association with Changing Environmental Drivers.

Run ID	Precipitation	Evapotranspiration	Eustatic Sea Level Rise	Subsidence	Number of Storms	Number Of Major Storms
S20	Historical (mid)	Historical (high)	.22m (low)	20% of range (low)	23 (High)	11 (Low)
S21	Historical (mid)	Historical (high)	0.43m (mid)	20% of range (low)	23 (High)	11 (Low)
S22	Historical (mid)	Historical (high)	0.43m (mid)	50% of range (mid)	23 (High)	11 (Low)
S24	Historical (mid)	Historical (high)	.83m (high)	50% of range (mid)	23 (High)	11 (Low)
S26	Historical (mid)	Historical (high)	.22m (low)	50% of range (mid)	23 (High)	11 (Low)
S27	Historical (mid)	Historical (high)	.22m (low)	75% of range (high)	23 (High)	11 (Low)
S30	GENMOM (low)	Historical (high)	.22m (low)	20% of range (low)	23 (High)	11 (Low)
S33	ECHAM (high)	GENMOM (low)	.22m (low)	20% of range (low)	23 (High)	11 (Low)
S36	Historical (mid)	Historical (high)	.22m (low)	20% of range (low)	17 (Low)	8 (Low)
S39	Historical (mid)	Historical (high)	.22m (low)	20% of range (low)	23 (High)	18 (High)
S62	GENMOM (low)	Historical (high)	0.43m (mid)	20% into range (low)	23 (High)	18 (High)
S65	GENMOM (low)	Historical (high)	0.43m (mid)	50% into range (mid)	23 (High)	18 (High)
S68	GENMOM (low)	Historical (high)	0.83m (high)	75% into range (high)	23 (High)	18 (High)
S76	Historical (mid)	Historical (high)	0.43m (mid)	75% into range (high)	23 (High)	11 (Low)
S77	Historical (mid)	Historical (high)	0.83m (high)	20% into range (low)	23 (High)	11 (Low)

Line graphs showing comparisons of land change for several runs including S20 – the 'baseline' run approximating historical conditions – enabled direct evaluation of the sensitivity of the land output to specific changes in values of the environmental drivers. For example, comparison of

S20 and S21 (where the environmental drivers other than ESLR are held constant) shows that land area predicted by the model is sensitive to increasing ESLR from the low (S20) to the mid (S21) value (Figure 3).

3.2.1.1 Subsidence and ESLR

Differences in land outputs associated with changing subsidence and eustatic sea level rise were also evaluated (Figure 4). For S22, S26 and S27 in Figure 4 only values for ESLR and subsidence change relative to S20 values. For S68 values for precipation (lower) and storm intensity and frequency (both higher) also change in relation to S20. This accounts for the higher land in S68 in early years of the model run compared to S20.

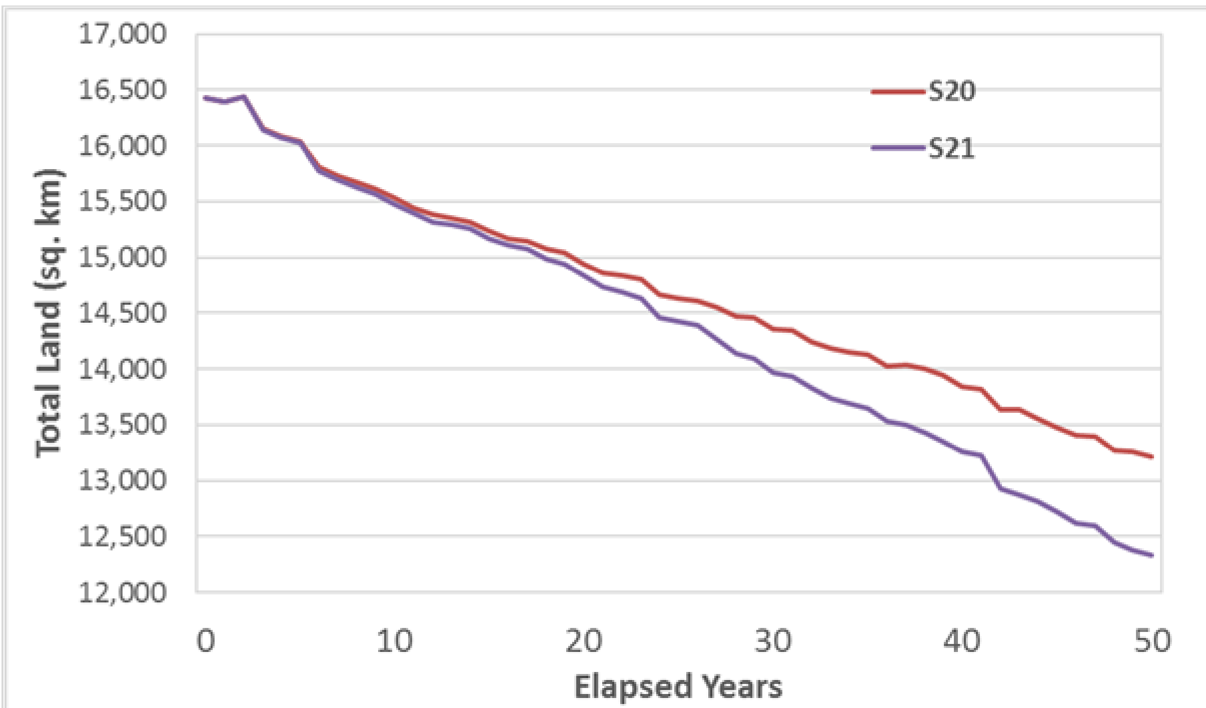

Figure 1: Comparison of Coast Wide Land Outputs for S20 (baseline) and S21 (baseline with mid value for ESLR).

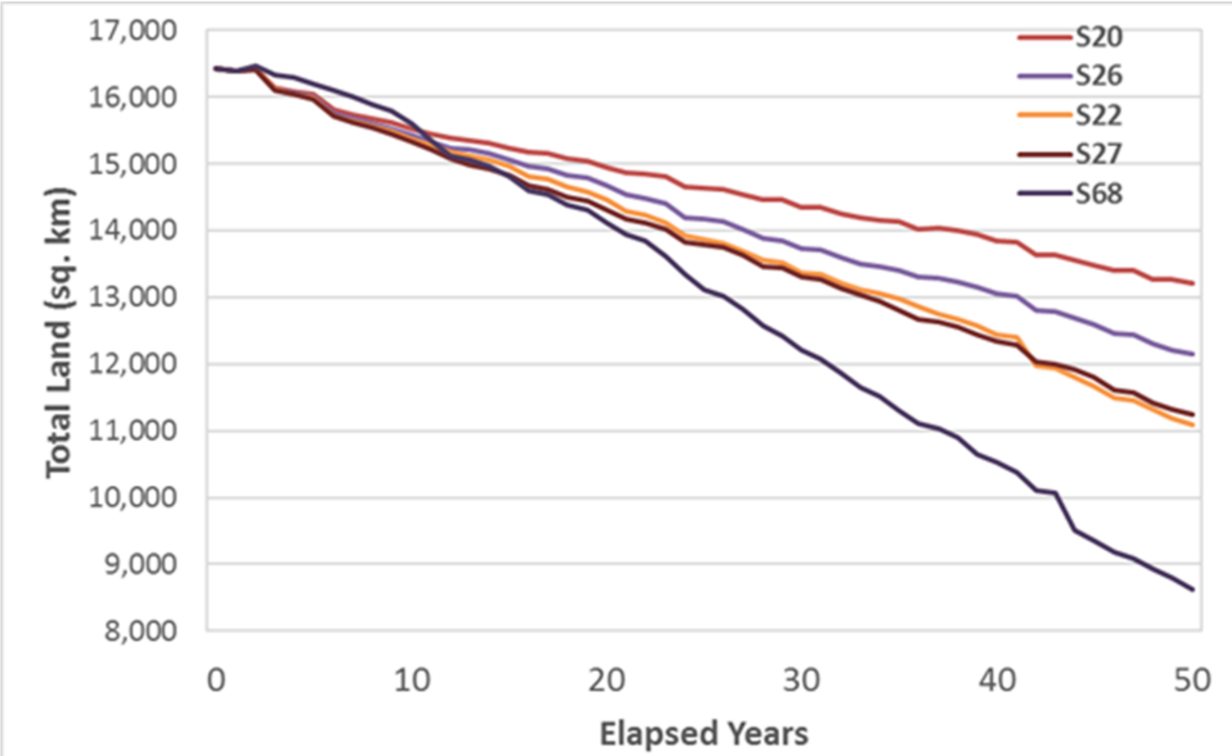

Figure 2: Comparison of Coast Wide Land Outputs for Model Runs with Varying Subsidence and Eustatic Sea Level Rise Rates (see text for details). Note extended y-axis compared to Figure 3.

As a result of these analyses, the following combinations of ESLR and subsidence values were selected for further testing in candidate scenarios:

ESLR (m/50yr)	Subsidence
0.43	20% of range
0.63	50% of range
0.83	50% of range
0.63	20% of range
0.63	35% of range

All three values of ESLR tested in the sensitivity runs were selected for inclusion in further analysis. These values are based on extensive literature on future rates of ESLR (Attachment C2-1) and represent the range of conditions considered by the National Climate Assessment (Parris et al., 2012). While the sensitivty runs showed an even higher amount of land loss over 50 years for S68, which included both high ESLR and high subsidence, in general there is less of a consensus regarding future subsidence rates. The plausible range described in Attachment C2-2 is based on expert opinion and while no new coast wide information was available to update the ranges used in the 2012 Coastal Master Plan, some evidence suggests that subsidence rates may decrease over time (Kolker et al., 2011) making the rates toward the high end of the range perhaps less likely to occur. Rather, the subsidence rates selected for further examination span the range considered in the 2012 Coastal Master Plan.

3.2.1.2 Precipitation and Evapotranspiration

While variations in subsidence and ESLR lead to differences in total land area over time, the sensitivity runs demonstrated a much smaller difference in coast wide land when precipitation and evapotranspiration were varied. Figure 5 shows the baseline S20 run against S30 (decreased preciptation relative to S20) and S33 (increased precipation and decreased evapotranspiration relative to S20). Both S30, the drier scenario, and S33, the wetter scenario show less land loss over time than S20. The difference between S30 and S33 at the coast wide scale however is small.

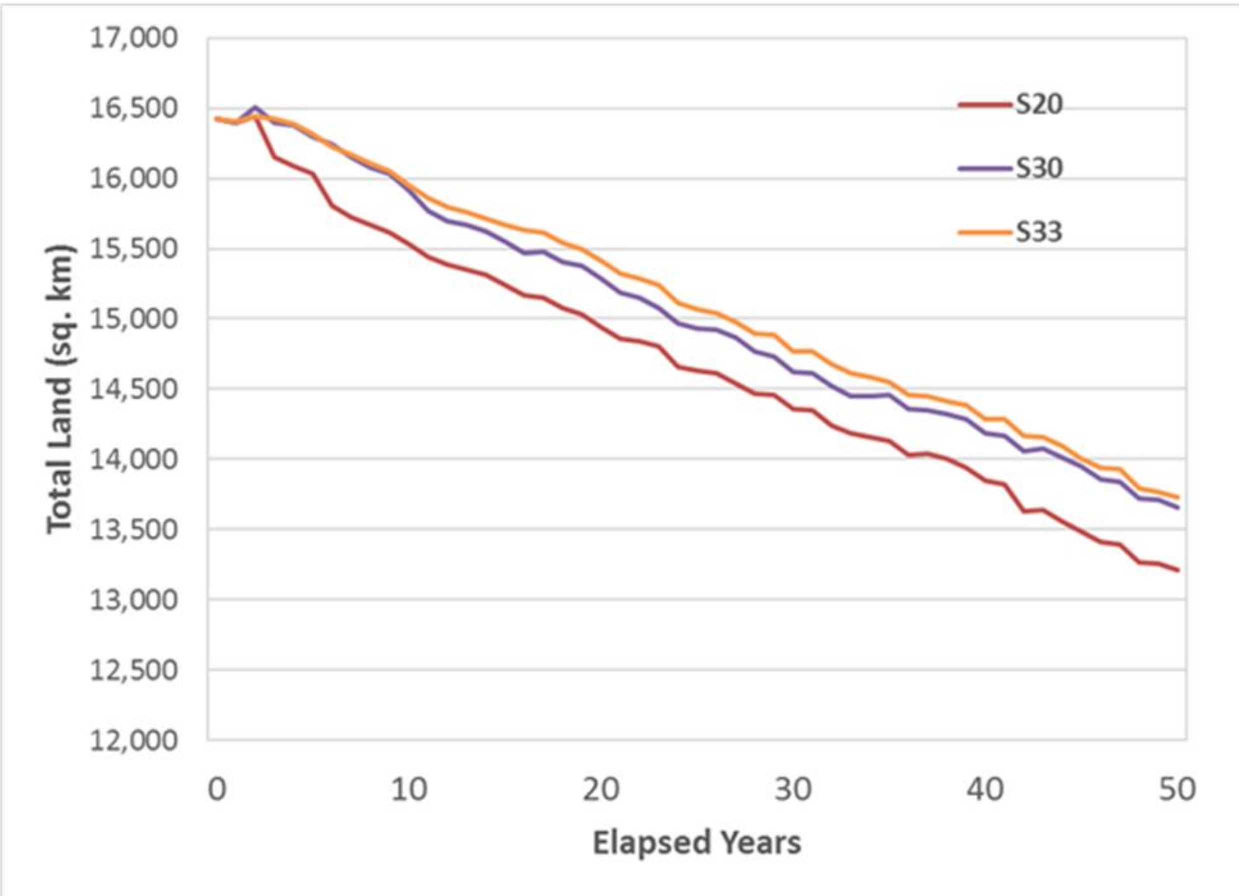

Figure 3: Comparison of Coast Wide Land Area for Model Runs with Varying Precipitation and Evapotranspiration Rates. S30 is 'drier' than S20 and S33 is 'wetter' than S20.

To further explore the regional effects of changes in precipation and evapotranspiration, variations over time were examined for selected ecoregions.[1] In addition to assessing long-term trends differences from the baseline run were calculated. Figure 6 shows an example of the differences between S20 and S33. This graph shows a complex response, that varies by location

[1] The coast has been dived into 11 ecoregions, defined by hydrologic boundaries, to facilitate regional comparison of model outputs.

and over time, to changes in precipitation/evapotranspiration compared to the baseline. While the effect in any individual ecoregion is generally less than 30 km², differences in land area can be positive or negative. Note that these are differences from the baseline trend (shown in Figure 3) rather than changes in absolute area within an ecoregion.

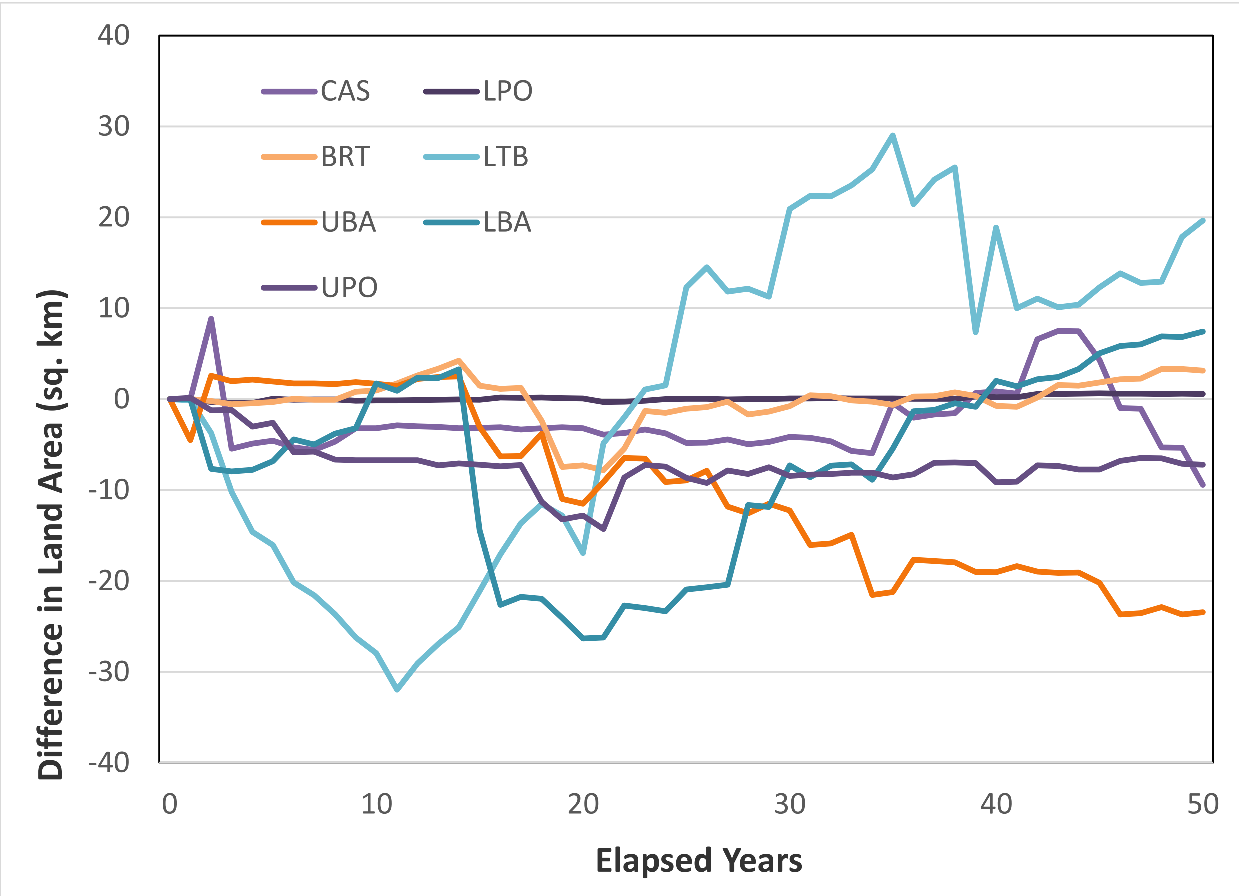

Figure 4: Differences in Land Area between the Baseline Run (S20) and a Wetter Set of Conditions (S33) for Selected Ecoregions. Negative values indicate more land at a time interval in S33 compared to S20. CAS – Calcasieu, LPO – Lower Pontchartrain, BRT – Breton Sound, LTB – Lower Terrebonne, UBA – Upper Barataria, LBA – Lower Barataria, UPO Upper Pontchartrain

After consideration of these and other results of the sensitivity runs, the following values of preciptation and evapotranspiration were selected for further testing using candidate scenarios:

Precipitation	Evapotranspiration
>Historical (ECHAM)	<Historical (GENMOM)
>Historical (ECHAM)	Historical
Historical	Historical

Even though the land change effects at the coast wide scale shown in Figure 5 are small, the change away from land loss associated with the 'historical condition' indicates a complex interaction between precipitation and evapotranspiration and landscape change (Figure 6).

The values used are derived from global climate modeling, itself the result of the efforts of a broad scientific community (Attachment C2-3). Thus, while the effects of varying precipitation and evapotranspiration may not be large, the inclusion of these variations enables consideration of complex climate-landscape interactions that may occur in the future.

3.2.1.3 Storm Frequency and Intensity

Storm intensity and frequency were also adjusted as part of the sensitivity analysis. In Figure 7, S36 and S39 are identical to S20 except for the storm frequency/intensity – S36 has the lowest storm frequency/intensity, and S39 has the highest frequency of major storms. S36 results in slightly less land loss, and the difference between S20 and S39 is imperceptible at the coast wide scale.

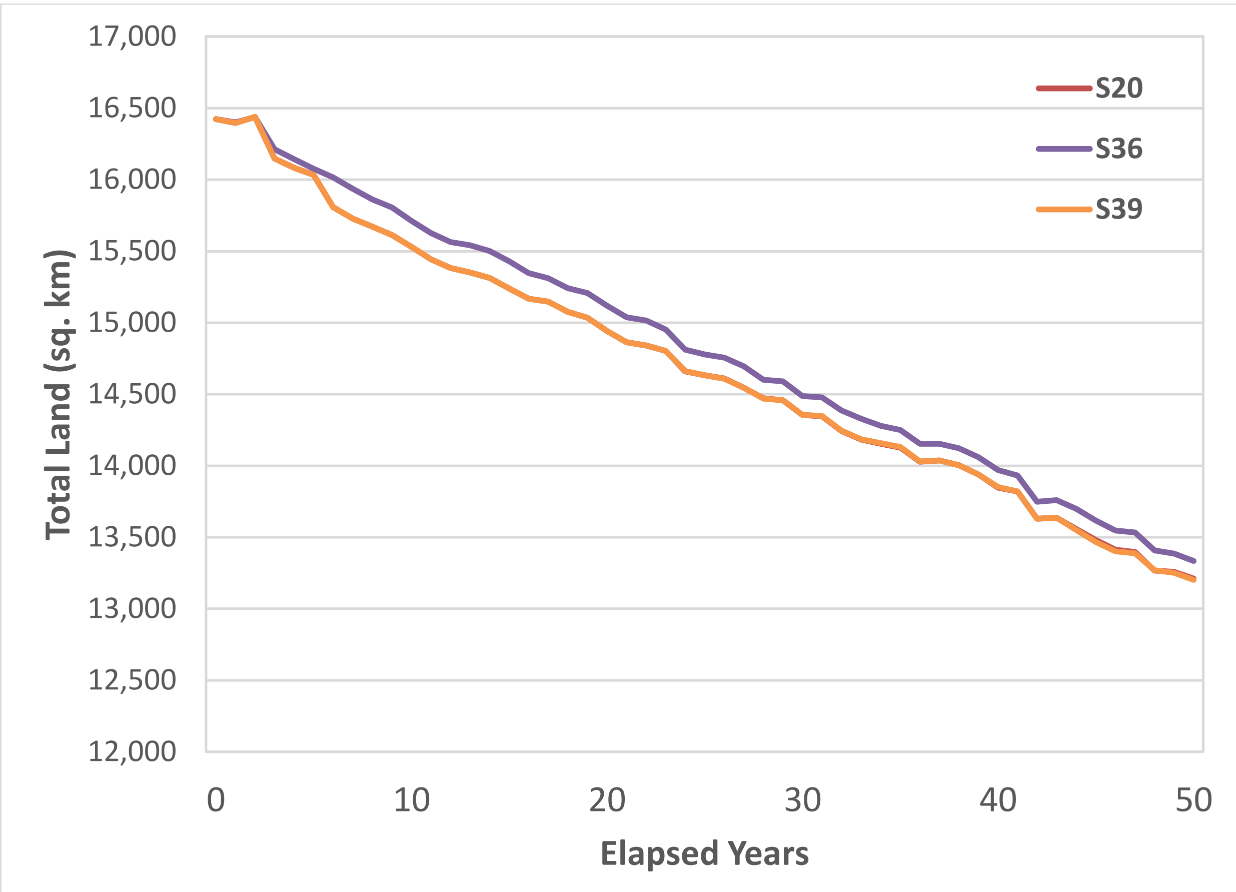

Figure 5: Comparison of Coast Wide Land Area for Model Runs with Varying Storm Frequency and Intensity. S36 has fewer total storms and fewer major storms than S20, and S39 has an increased frequency of major storms compared to S20. Note: S20 and S39 total land values are very similar.

The slight changes in coast wide land area associated with increased storms were further explored by comparing S20 and S39 for select ecoregions. Figure 8 shows how there is no difference in land area response until year 21of the analysis when there is a change in the character of the storms included in the runs. In that year a storm in S20 is replaced with a different synthetic storm[2] to represent an increase in the frequency of major storms. Changes in S39 compared to S20 result in more land loss in some ecoregions (e.g., AVB) and less land loss in others (e.g., UTB). In the ICM, storms can erode barrier islands, introduce sediments to marshes, and alter salinity and inundation patterns – effects which can be positive or negative for land area depending on the antecedent conditions. In addition the consequences of the change in storm are not limited to the year in which the storm occurs as changes in land loss alter hydrologic exchange in later years. The next change in storm character occurs in year 34 which triggers a change in land area between S20 and S39 in LTB. Over the 50-year period there are both positive and negative changes in different areas of the coast resulting in very little change at the coast wide scale shown in Figure 7, but a substantial change in some areas.

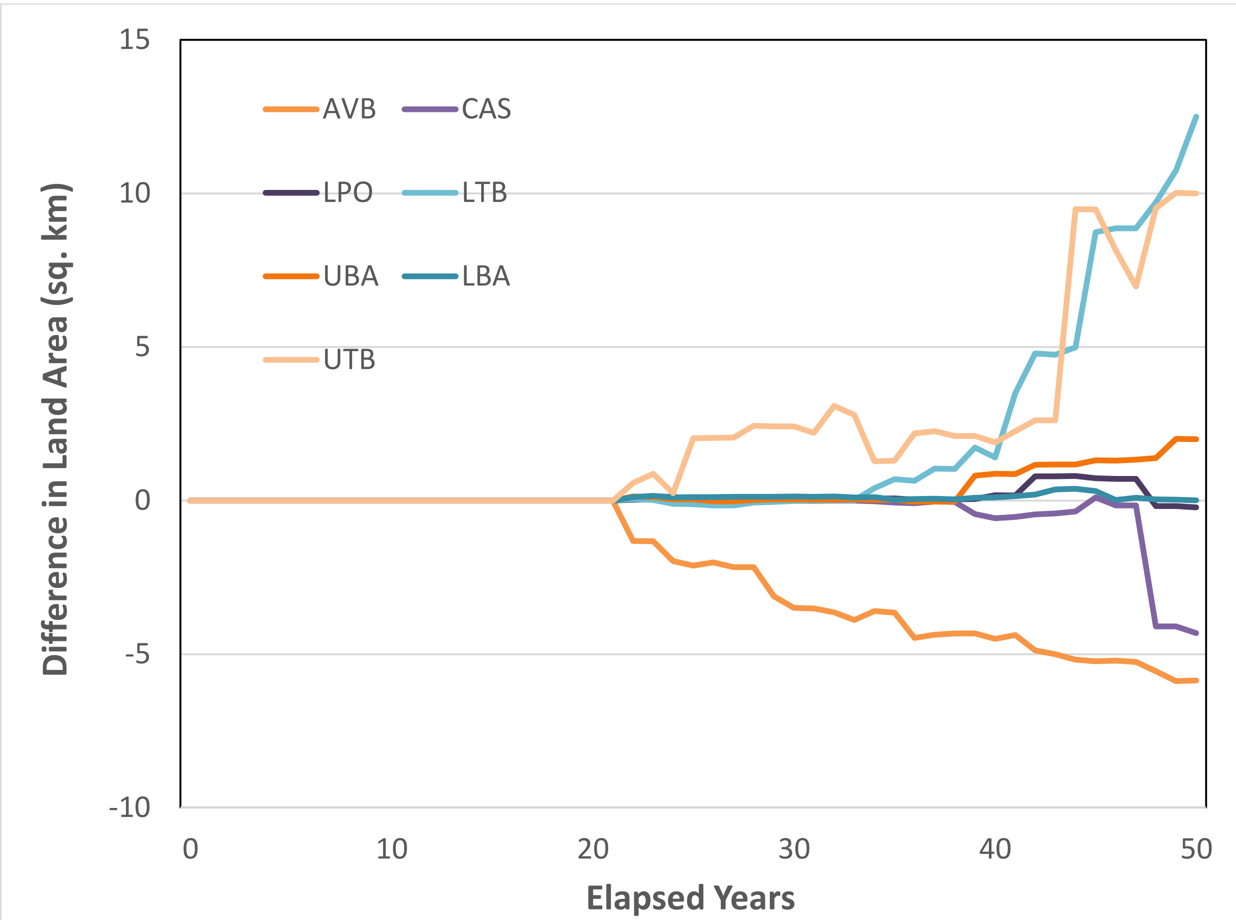

Figure 6: Differences in Land Area between the Baseline Run (S20) and an Increase in the Number of Total Storms and the Frequency of Major Storms (S39) for Selected Ecoregions. Negative values indicate more land at a time interval in S39 compared to S20. AVB – Atchafalaya/Vermilion Bay, CAS – Calcasieu, LPO – Lower Pontchartrain, LTB – Lower Terrebonne, UBA – Upper Barataria, LBA – Lower Barataria, UTB – Upper Terrebonne

[2] See Attachment C3-3 for more details on how synthetic storms were selected for inclusion in the modeling

Examination of the sensitivity of land area to changes in storm intensity and frequency showed that the inclusion (or exclusion) of individual storms over the 50-year period led to substantial local changes in land area but only to a small effect at the coast wide scale. Further inspection of land-water maps indicated that some of these local effects were compartment specific (e.g., the penetration of salt during a storm resulting in land loss). Because the effects are so localized and so sensitive to individual storms, it seems possible that varying the number and intensity of storms among scenarios could subject some projects (e.g., those located in the path of a storm that was included or excluded) to be impacted based on its location rather than its restoration characteristics. While this remains an issue to be carefully evaluated even if the storm set stays the same among the scenarios, varying storms by scenario could make the interpretation of project results challenging. Thus, the decision was made not to vary storm intensity and frequency in the landscape analysis.

3.2.2 Evaluation of Candidate Scenarios

Five candidate scenarios were selected for testing to inform the selection of the three environmental scenarios to be used in the 2017 Coastal Master Plan (Table 7). Due to the small variation on coast wide land associated with variation in precipitation and evapotranspiration, only three combinations were tested. These were combined with five combinations of values for eustatic sea level rise and subsidence.

Table 5: Values Used in the Five Candidate Environmental Scenarios.

Scenario	Precipitation	Evapotranspiration	ESLR (m/50yr)	Subsidence
1	>Historical (ECHAM)	<Historical (GENMOM)	0.43	20% of range
2	>Historical (ECHAM)	Historical	0.63	50% of range
3	Historical	Historical	0.83	50% of range
4	>Historical (ECHAM)	Historical	0.63	20% of range
5	>Historical (ECHAM)	Historical	0.63	35% of range

The results of the candidate scenario testing are shown in Figure 9. As expected based on the sensitivity analysis, S03, with the highest ESLR and the highest subsidence value, shows the greatest decrease in land area. S01 with the lowest ESLR and subsidence values shows the lowest coast wide land loss.

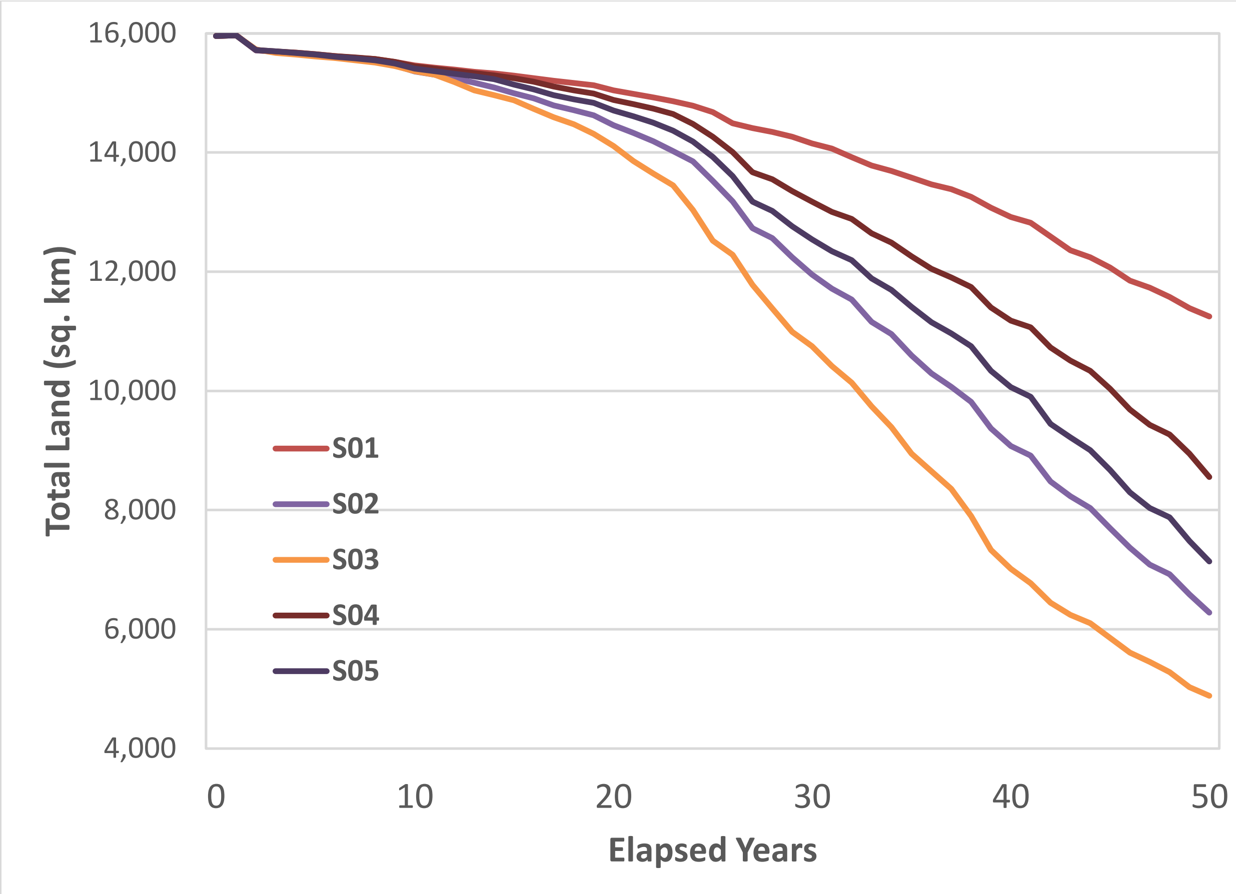

Figure 7: Coast Wide Land Area under Future Without Action for the Five Candidate Scenarios (see Table 7 for drivers included in each).

3.2.3 Varying Storm Frequency and Intensity in CLARA

The CLARA model implements uncertainty in future storminess using environmental drivers, one representing the overall frequency of hurricanes impacting the study region and the other representing the average intensity of those storms. Future scenarios are defined by specifying changes in those two characteristics, relative to a baseline of current conditions. By contrast, the ICM models the overall frequency of hurricanes with no change from the historical record and specifies the frequency of major storms (those with sustained winds of greater than 100 knots). Separately varying the frequency of all storms and the frequency of major storms implies a change in the average intensity of storms included in the analysis.

As such, the implementations of future storminess in the CLARA and ICM models are related. Test runs of the ICM showed that a scenario assumption with the overall frequency of storms declining by 28% and the frequency of severe storms within the decreased total increasing by 13% over the 50-year simulation period showed little change in the net area of land across the coast (although there were local changes). Empirical analysis of the National Hurricane Center

Data set[3] indicates that this is equivalent in CLARA to a 28% decline in storm frequency combined with a 10% increase in average storm intensity.

Sensitivity testing suggests that modeling variation in both storm frequency and intensity is important for identifying potential variation in the performance of risk reduction projects. Coast wide estimates of expected annual damage (EAD) were generated using test data from the Year 50, 2012 Coastal Master Plan Less Optimistic landscape, varying storm frequency by -5%, 0%, and +5% relative to the historical frequency, and varying average storm intensity by 0%, 10%, and 20%. (Note that the 0%/0% case is equivalent to seeing no change in storminess compared to historical conditions, and the 5%/20% case is equivalent to the change in storminess assumed by the Less Optimistic scenario in 2012.)

Examining the elasticity of damage with respect to the parameters (i.e., the change in EAD resulting from a percentage change in storm frequency or average intensity) reveals some key differences:

1. Damage elasticity with respect to average storm intensity appears approximately constant, with a 10% increase in average intensity producing an 8% increase in EAD. The elasticity with respect to frequency varies, though; moving from -5% to 0% increases coast wide EAD by about 4.6%, but going from 0% to 5% increases EAD by about 8.7%.
2. Changes in storm intensity have a much more pronounced effect on EAD for areas within the Hurricane Storm Damage Risk Reduction System (HSDRRS), relative to other areas. A 10% increase in intensity increases EAD by about 15% for points on the East Bank of New Orleans, and 20% on the West Bank of New Orleans, compared to increases of 5.5% in other enclosed areas and 6.5% in unenclosed areas. Changes in storm frequency, on the other hand, produce approximately the same change in EAD for enclosed and unenclosed points.

T able 8 summarizes the above points by showing the EAD estimated by enclosed location and future storm frequency and average intensity for the nine cases analyzed. Coast wide totals are also provided In Table 9. Changing the frequency and intensity values for future scenarios will thus reveal differential performance in structural and nonstructural risk reduction projects, depending on what type of area they are designed to protect.

Table 6: EAD as a Function of Changes in Storminess.

		Future Average Storm		
Enclosed Status	**Future Storm Frequency**	**No**	**+10%**	**+20%**
East Bank HSDRRS	-5%	$1,996M	$2.298M	$2,641M
	No Change	$2,086M	$2.415M	$2,789M
	+5%	$2,262M	$2.589M	$2,986M

[3] The National Hurricane Center maintains HURricane DATabases (HURDAT)that contain details on tropical storms, that have occurred within the Atlantic Ocean since 1851.

		Future Average Storm		
Enclosed Status	**Future Storm Frequency**	**No**	**+10%**	**+20%**
West Bank HSDRRS	-5%	$111M	$131M	$162M
	No Change	$119M	$144M	$177M
	+5%	$126M	$148M	$189M
Enclosed, Non-HSDRRS	-5%	$1,550M	$1,637M	$1,724M
	No Change	$1,628M	$1,713M	$1,806M
	+5%	$1,759M	$1,870M	$1,996M
Unenclosed	-5%	$11,147M	$11,859M	$12,657M
	No Change	$11,645M	$12,400M	$13,208M
	+5%	$12,615M	$13,517M	$14,474M

Table 7: EAD as a Function of Changes in Storminess - Coast wide Summary.

	Future Average Storm Intensity		
Future Storm Frequency	**No**	**+10%**	**+20%**
-5%	$14,805M	$15,925M	$17,184M
No Change	$15,479M	$16,672M	$17,980M
+5%	$16,762M	$18,124M	$19,615M

4.0 Selection of Environmental Scenarios

Based on the analysis and testing described above, three environmental scenarios have been selected for use in the 2017 Coastal Master Plan. The values for these scenarios are shown in Table 10.

Table 8: Characteristics of the Environmental Scenarios to be used in the 2017 Coastal Master Plan.

Scenario	**Precipitation**	**Evapotranspiration**	**ESLR (m/ 50yr)**	**Subsidence**	**Overall Storm Frequency**	**Average Storm Intensity**
	Used in ICM				Used in CLARA	
Low	>Historical	<Historical	0.43	20% of range	-28%	+10.0%
Medium	>Historical	Historical	0.63	20% of range	-14%	+12.5%

Scenario	Precipitation	Evapotranspiration	ESLR (m/ 50yr)	Subsidence	Overall Storm Frequency	Average Storm Intensity
	Used in ICM				Used in CLARA	
High	Historical	Historical	0.83	50% of range	0%	+15.0%

The values for use in the ICM were selected to ensure that there was a range of consequences, in terms of coast wide land area, across the three scenarios. The Low, Medium, and High Scenarios correspond to S01, S04, and S03 in Figure 9. CLARA will model variability in the future storm frequency and average intensity to better explore the differential performance of projects under a range of future conditions. Values for each scenario used in CLARA were chosen to explore a range of plausible future changes in storm frequency and average intensity.

5.0 References

CPRA. (2012). 2012 Coastal Master Plan. Appendix C: Future Scenarios. http://www.lacpra.org/assets/docs/2012%20Master%20Plan/Final%20Plan/appendices/Appendix%20C%20-%20Environmental%20Scenarios-FINALv2wTpg%20%282%29.pdf

Groves, D. G. and Lempert, R. J. (2007). A new analytic method for finding policy-relevant scenarios. *Global Environmental Change, 17,* 73-85.

Hagemann, S., Chen, C., Clark, D. B., Folwell, S., Gosling, S. N., Haddeland, I., Hanasaki, N., . . . Wiltshire, A. J. (2012). Climate change impact on available water resources obtained using multiple global climate and hydrology models. *Earth Systems Dynamics Discussions, 3*, 1321-1345.

Hostetler, S.W., Alder, J.R. and Allan, A.M. (2011). Dynamically downscaled climate simulations over North America: Methods, evaluation and supporting documentation for users. *U.S. Geological Survey, Open-File Report 2011-1238*.

Huntington J., Gangopadhyay, S., King, D., Morton, C., Spears, M., Allen, R., . . . Joros, A. (2014).West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Irrigation Demand and Reservoir Evaporation Projections. DRAFT – Technical Memorandum No. 68-68210-2014-01. *U.S. Bureau of Reclamation, Technical Service Center*.

Kolker, A. S., Allison, M. A., and Hameed, S. (2011). An evaluation of subsidence rates and sea-level variability in the northern Gulf of Mexico. *Geophysical Research Letters, 38(21)*. DOI: 10.1029/2011GL049458.

Mohammed, M., Liu, Y., Hartmann, H., Stewart, S., Wagener, T., Semmens, D., Stewart, R., … Winter, L. (2009). A formal framework for scenario development in support of environmental decision-making. *Environmental Modelling and Software, (24),* 798-808.

NRC. (1987). Responding to Changes in Sea Level: Engineering Implications. National Academy Press, Washington, D.C.

NRC. (2012). Sea level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Academies Press, Washington, D.C.

Parris, A., Bromirski, P., Burkett, V., Cayan, D., Culver, M., Hall, J., Horton, R., . . . Weiss, J. (2012). Global Sea Level Rise Scenarios for the US National Climate Assessment. *NOAA Tech Memo OAR CPO-1*. 37 pp.

Sankovich, V., Gangopadhyay, S., Pruitt, T., and Caldwell, R.J. (2013). Los Angeles Basin Stormwater Conservation Study – Task 3.1 Development of Climate-Adjusted Hydrologic Model Inputs. U.S. Bureau of Reclamation - Technical Service Center. Denver, Colorado.

USACE. (2009). Water Resources Policies and Authorities Incorporating Sea-Level Change Considerations into Civil Works Programs (Circular No. 1165-2-211), July 1, 2009, expires July 1, 2011.

USACE. (2011). Sea-Level Change Considerations for Civil Works Programs (Circular No. 1165-2-212), October 1, 2011, expires September 30, 2013.

Vermeer, M. and Rahmstorf, S. (2009). Global Sea Level Linked to Global Temperature. PNAS 106:51 pp 21527-21532. Published online: http://www.pnas.org/content/106/51/21527.full.pdf+html