2023 COASTAL MASTER PLAN

SCENARIO DEVELOPMENT AND FUTURE CONDITIONS

APPENDIX B

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COASTAL PROTECTION AND
RESTORATION AUTHORITY
150 TERRACE AVENUE
BATON ROUGE, LA 70802
WWW.COASTAL.LA.GOV

COASTAL PROTECTION AND RESTORATION AUTHORITY

This document was developed in support of the 2023 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 six years) and annual plans. CPRA's mandate is to develop, implement, and enforce a comprehensive coastal protection and restoration master plan.

CITATION

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- Coastal Protection and Restoration Authority (CPRA) of Louisiana – Stuart Brown, Ashley C. Cobb, Madeline Leblanc Hatfield, Valencia Henderson, Krista L. Jankowski, David Lindquist, Sam Martin, and Eric D. White
- University of New Orleans – Denise Reed

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EXECUTIVE SUMMARY

Uncertainty in future environmental conditions presents a challenge for long-term, large scale planning efforts like the development of the 2023 Coastal Master Plan. As in previous plans, this is addressed through the use of a scenario approach to define environmental drivers that are used as inputs to predictive modeling the plan development process. Building on efforts in 2012 and 2017, the development of environmental scenarios for this plan involved the identification of key variables, definition of variable value plausible ranges, and selection of variable values. For the first time, the 2023 Coastal Master Plan approach to environmental scenarios is grounded in creating suites of climate-driven variables that co-vary consistent with representative concentration pathways (RCPs) associated with the lower and higher environmental scenario. Importantly, these scenarios do not represent forecasts of future climate conditions, but rather have been developed for the express purpose of evaluating restoration and risk reduction projects within the master plan process. This appendix is intended to provide a high level description of the 2023 Coastal Master Plan environmental scenarios used for project selection. Technical details supporting the development of each variable will be available in attachments to this appendix.

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LIST OF ABBREVIATIONS

ADCIRC .... ADVANCED CIRCULATION MODEL
AR5 .... FIFTH ASSESSMENT REPORT
CAT .... COASTAL ADVISORY TEAM
CLARA .... COASTAL LOUISIANA RISK ASSESSMENT
CMIP .... COUPLED MODEL INTERCOMPARISON PROJECT
CORS .... CONTINUOUSLY OPERATING REFERENCE STATIONS
CPRA .... COASTAL PROTECTION AND RESTORATION AUTHORITY
CRMS .... COASTWIDE REFERENCE MONITORING SYSTEM
DS .... DEEP SUBSIDENCE
ICM .... INTEGRATED COMPARTMENT MODEL
IPCC .... INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
NCA .... NATIONAL CLIMATE ASSESSMENT
NGS .... NATIONAL GEODETIC SURVEY
NOAA .... NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
PM-TAC .... PREDICTIVE MODELING TECHNICAL ADVISORY COMMITTEE
RCPS .... REPRESENTATIVE CONCENTRATION PATHWAYS
RSET-MH .... ROD SURFACE ELEVATION TABLE-MARKER HORIZON
SS .... SHALLOW SUBSIDENCE
SWAN .... SIMULATING WAVES NEARSHORE
TS .... TOTAL SUBSIDENCE

1.0 INTRODUCTION

1.1 THE NEED FOR SCENARIOS

One of the main objectives of the 2023 Coastal Master Plan is to evaluate and select restoration and risk reduction projects that reduce land loss and reduce storm surge-based flood risk to communities. Given the uncertainty associated with future environmental conditions due to climate and environmental change, 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; Mohammed 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 both the 2012 and 2017 Coastal Master Plans. This was an acknowledgement that it is not expected that past environmental conditions will repeat into the future, and that there is uncertainty about exactly how and to what degree future environmental conditions will differ from those of the past. For the 2023 Coastal Master Plan, a scenario approach was again used, though the approach to selecting scenario values was refined and modified from past efforts. Importantly, the representations of future environmental conditions captured in the environmental scenarios are not intended to represent with certainty what exactly will happen into the future. Instead, they represent a range of plausible future outcomes that can be used as tools in the broader master plan decision-making process.

1.2 UPDATING SCENARIO DEVELOPMENT

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 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. A detailed accounting of the environmental scenarios used in the 2012 Coastal Master Plan is available in Appendix C: Environmental Scenarios (CPRA, 2012).

For the 2017 Coastal Master Plan, new data and literature regarding some of the environmental drivers was available and a set of analyses was developed to explore model output response to different values for environmental drivers. These analyses were then used to inform the selection of environmental drivers and values to be used in scenarios for the 2017 Coastal Master Plan modeling effort, including the removal of some variables used in the 2017 analyses. A detailed accounting of the environmental scenarios used in the 2017 Coastal Master Plan is available in Appendix C, Chapter 2 (Meselhe et al., 2017).

For the 2023 Coastal Master Plan, a thorough review of the process used to develop the environmental scenarios used in past master plans was conducted along with consideration of new data and literature available since the development of the 2017 plan. Through this process it was recognized that several prominent and consequential climate change-related synthesis reports had been released since the development of the previous plan. These include the Fifth Assessment Report (AR5) released by the Intergovernmental Panel on Climate Change (IPCC) in 2014, the Global and Regional SLR Scenarios for the U.S. Technical Report released by the National Oceanic and Atmospheric Administration (NOAA) in 2017, and both the Third and Fourth National Climate Assessment (NCA) released in 2014 and 2018, respectively. For each of these reports, authors have grounded their assessments in the widely-used representative concentration pathways (RCPs) that form the foundation for the majority of recent coordinated global climate model experiments.

The selection of environmental scenario variable values for the 2023 Coastal Master Plan leveraged these substantial bodies of work on climate change-related environmental drivers and their impacts on coastal landscapes. A common thread through these works is the recognition that climate related variables will co-vary depending on the concentration of greenhouse gases like CO2 in the atmosphere. It is also recognized that greatest amount of uncertainty about future environmental conditions stems from not knowing what decisions will be made in the near and long-term that will determine what those concentrations will be, thus the use of scenarios and projections built from assumed RCPs to define a range of possible outcomes. These principles were similarly adopted for the development of environmental scenarios used for project selection in the 2023 Coastal Master Plan. 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 understanding the state of the science and leveraging that knowledge for coastal planning purposes.

The Integrated Compartment Model (ICM), Storm Surge and Waves models (ADCIRC and SWAN), and Coastal Louisiana Risk Assessment model (CLARA) are used to understand future landscape change and changing vulnerability under various future environmental scenarios. In the master plan process, one goal of modeling landscape change and storm surge-based flood risk is to explore the effects of different possible future conditions on the performance of restoration and risk reduction projects and inform decision-making processes. A second goal is to allow for communication with coastal residents about possible future coastal conditions. Model inputs, such as the current landscape and existing hydrologic connections, provide a starting point for these predictive models. Environmental variables such as temperature, precipitation, and sea level rise serve and inputs to the numerical models and, by changing them over time, provide projections of the impact of climate change through the model period. The future is uncertain with regard to climate-related environmental conditions and, therefore, assumptions about how climate will change must be made in order to model future conditions for planning.

For 2012 and 2017, the environmental scenarios were developed through the identification of key variables, identification of plausible ranges for each individual variable, and then selection of variable values for each scenario independent of the other variable values selected for the particular scenario. This approach met several of the key criteria for defining variable values for the scenario approach to environmental drivers in the master plan process, such as

- Identifying and including key environmental drivers as necessary within landscape and risk assessment modeling processes.
- Assigning plausible values for each environmental variable value according to the best available data and scientific literature at the time scenarios are being developed.
- Developing environmental scenarios including variable values that are unique (i.e., different enough from the value for the same variable in another scenario) so as to result in distinct responses within the predictive models used.

However, one limitation of this approach was in the independent selection of variable values. Over the past several years there has been an emerging scientific consensus around the relationships between radiative forcing and environmental change. Climate change-related projections from entities such as the IPCC, NOAA, and the U.S. Global Change Research Program have been based on the understanding that when there is additional energy retained in the Earth's atmosphere, climate-driven environmental variables such as temperature, precipitation, sea level rise, and intensity of storms can be impacted. Therefore, consideration of climate-driven variables as a related suite that co-varies depending on the assumed future environmental conditions is an improvement to the development of environmental scenarios for use in coastal planning. For the 2023 Coastal Master Plan, this approach of developing and cohesive environmental scenarios with co-varying climate-related variable values was adopted.

2.0 2023 SCENARIOS

2.1 ENVIRONMENTAL SCENARIO VALUES

As a starting point, the environmental scenario variables used in the 2017 Coastal Master Plan were reviewed and considered for inclusion in the 2023 Coastal Master Plan. All but one variable were carried forward for 2023 as they continue to be recognized as important components of master plan modeling. The variable that was removed from the environmental scenarios, storm frequency, was removed due to decreased confidence in the direction and magnitude of change in the variable as a result of changing climate conditions. Additional research and literature may allow for the re-inclusion of this variable in future master plan scenarios. The list of variables included in the 2017 and 2023 Coastal Master Plan environmental scenarios can be found below.

Table 1. Variables included in Environmental Scenarios

Variable	2017	2023	Climate-driven?
SUBSIDENCE	X	X	
SEA LEVEL RISE	X	X	X
TEMPERATURE	X	X	X
EVAPOTRANSPIRATION	X	X	X
PRECIPITATION	X	X	X
TRIBUTARY HYDROGRAPHS	X	X	X
STORM INTENSITY	X	X	X
STORM FREQUENCY	X		X

Variable values were determined in a step-wise fashion, as follows:

1. Subsidence scenario values were determined through a stand-alone process (detailed in Fitzpatrick et al., 2020)
2. Sea level rise curves were selected for use in two project selection scenarios, with the Lower scenario representing a more moderate future sea level rise outcome and associated with CMIP5 model ensemble outputs based on RCP 4.5 and the higher scenario representing a more severe future sea level rise outcome and associated with CMIP5 model ensemble outputs based on RCP 8.5
3. Values for precipitation and temperature were then developed for the Lower and higher scenario based on median CMIP5 model ensemble outputs for RCP 4.5 and RCP 8.5, respectively
4. The resulting precipitation values were used to develop Lower and higher scenario synthetic tributary hydrographs to be used in the environmental scenarios
5. The resulting temperature values were used to develop Lower and higher

scenario values for evapotranspiration using the temperature projections as an input

6. Increases in storm intensity were adjusted from 2017 following an updated literature review

The environmental scenarios used for project selection in the 2023 Coastal Master Plan are described in Figure 1 below. Additional information on determining the values for each scenario variable follows.

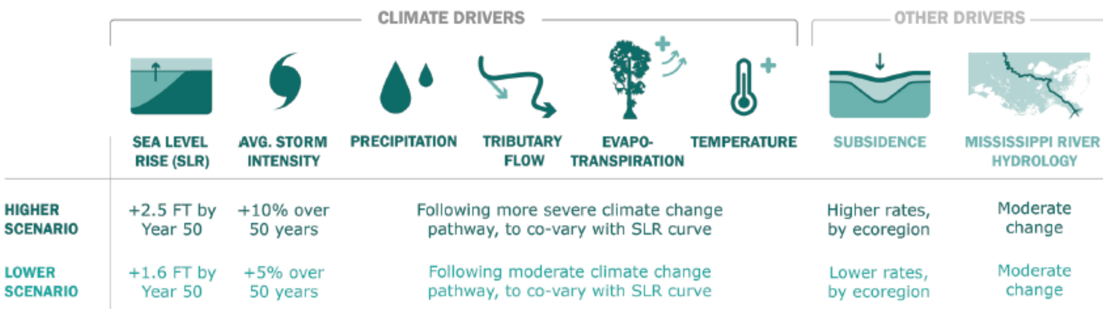

Figure 1. Environmental scenario variable values.

2.2 SUBSIDENCE

Through analysis completed for 2017 (Meselhe et al., 2017), it was confirmed that subsidence and sea level rise were the two environmental scenario values that had the greatest impact on landscape outcomes in the ICM. Subsidence is different than the other environmental scenario variables included in the 2023 Coastal Master Plan in that variability in subsidence rates across coastal Louisiana is not directly climate-driven. Subsidence is, however, very important to the predictive modeling used to develop the master plan. The ICM uses subsidence to lower the land surface, while additional components of the model separately account for surface sediment deposition and wetland soil development, both of which can offset the effects of subsidence on surface elevation. Subsidence is also applied in risk modeling using CLARA. Refining subsidence rates for use as model inputs for the ICM is an important part of updating predictive models for the 2023 Coastal Master Plan.

Recently published studies provided new information on subsidence rates in coastal Louisiana. These include small and large-scale observational studies, as well as data re-analyses and data syntheses. The 2023 subsidence approach relies on the development of several subsidence maps for coastal Louisiana. The first is a deep subsidence (DS) map derived from data from geodetic survey benchmarks, both primary (Continuously Operating Reference Stations or CORS) and secondary (CPRA/National Geodetic Survey (NGS) benchmarks). The resulting map shows variation in DS rates across the coast, with broad spatial patterns related to underlying geology and past depositional processes. In addition, two shallow subsidence (SS) maps were created using data derived from the most up-to-date rod surface elevation table-marker horizon (RSET-MH) measurements taken at Coastwide Reference Monitoring System (CRMS) sites. CRMS-derived SS rates were aggregated by ICM ecoregions (i.e., at a sub-regional scale). For each ICM ecoregion, first quartile and median SS values were calculated due to variability in the SS data. Total subsidence (TS) rates (i.e., the sum of SS and DS) are determined by creating composite maps. As there are two SS maps, two maps for TS result – one representing a lower total subsidence rate scenario and the other a higher subsidence rate scenario (Figure 2, below).

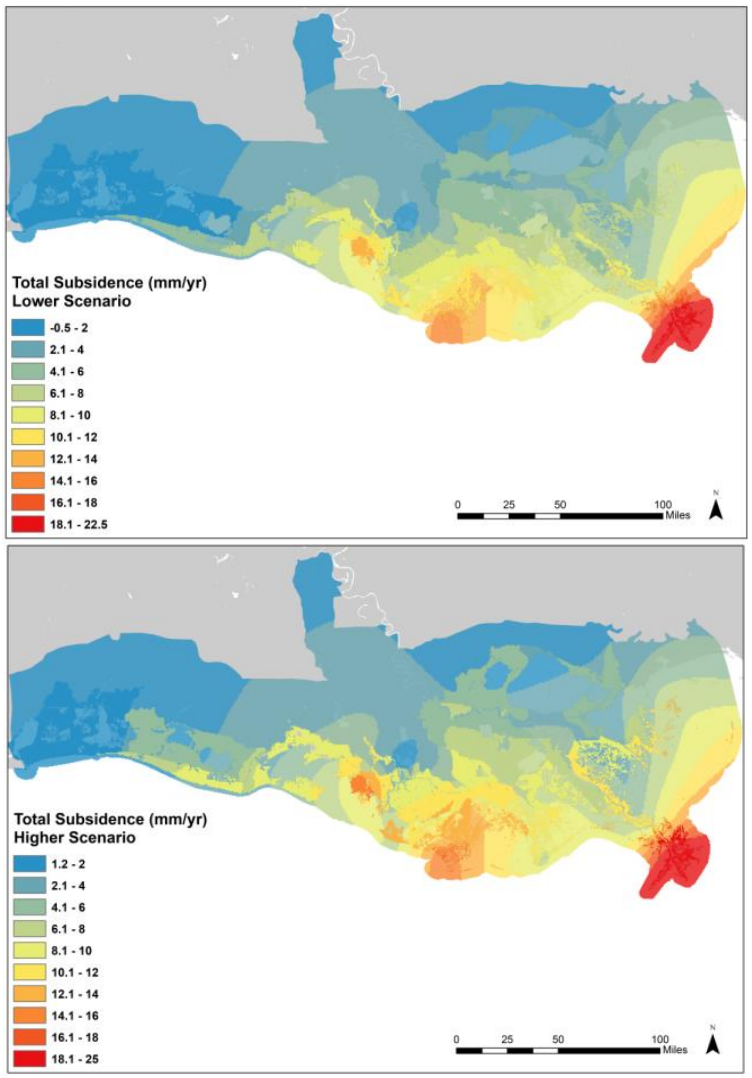

Figure 2. Total subsidence scenario maps.

Details of the approach used for the 2023 Coastal Master Plan, including the assumptions and limitations of the 2023 approach and the consistency of derived rates with recent studies are available in Attachment B3: Determining Subsidence Rates for Use in Predictive Modeling.

2.3 SEA LEVEL RISE

Analysis completed for 2017 (Meselhe et al., 2017) confirmed that, in addition to subsidence, sea level rise was one of the environmental variables that had the most impact on landscape outcomes in the ICM. Due to the importance of sea level rise rates to projections of landscape change within the ICM, development of environmental scenarios for the 2023 Coastal Master Plan began with the selection of sea level rise curves.

As in previous plans, a thorough review of available literature was conducted in order to understand the state of the science regarding plausible ranges for sea level rise over 50 years. From this review, an initial suite of possible sea level rise curves was identified, including

- The three sea level rise curves used in the 2017 Coastal Master Plan, but shifted along the trajectory to account for the 5 years of time elapsed between plans
- The six sea level rise curves developed by NOAA for the “Global and Regional Sea Level Rise Scenarios for the United States” report issued in 2017
- An additional 18 curves derived from CMIP5 analyses representing the 5th, 17th, 50th, 83rd, 95th and 99th percentile values for RCPs 2.6, 4.5, and 8.5

As in the 2017 Coastal Master Plan, sea level rise curves used in the environmental scenarios were regionally adjusted from global climate model data to refine projections based on local conditions. Sea level rise curves were also normalized to year 2020 in order for each to be comparable despite data source. Further technical details about the regional adjustment of the curves and related analyses will be available in a forthcoming attachment to this appendix.

It was recognized that several of the curves under consideration had similar sea level rise values at 2070. Therefore 10 equifinal groups (A – J) were made and each group was retained for further consideration (Figure 3). Through discussion with the Coastal Advisory Team (CAT) and the Predictive Modeling Technical Advisory Committee (PM-TAC), it was determined that selection of sea level rise curves for the environmental scenarios used in project selection should take into account consideration of

- A wide range of sea level rise curves to account for uncertainty around future outcomes
- A plausible, mid-range value for the Lower scenario to represent a more likely possible future outcome to provide a moderate projection of future landscape change and project impacts
- A plausible, upper-range value for the higher scenario to represent a less likely but

potentially more consequential possible future outcome to test the robustness of projects

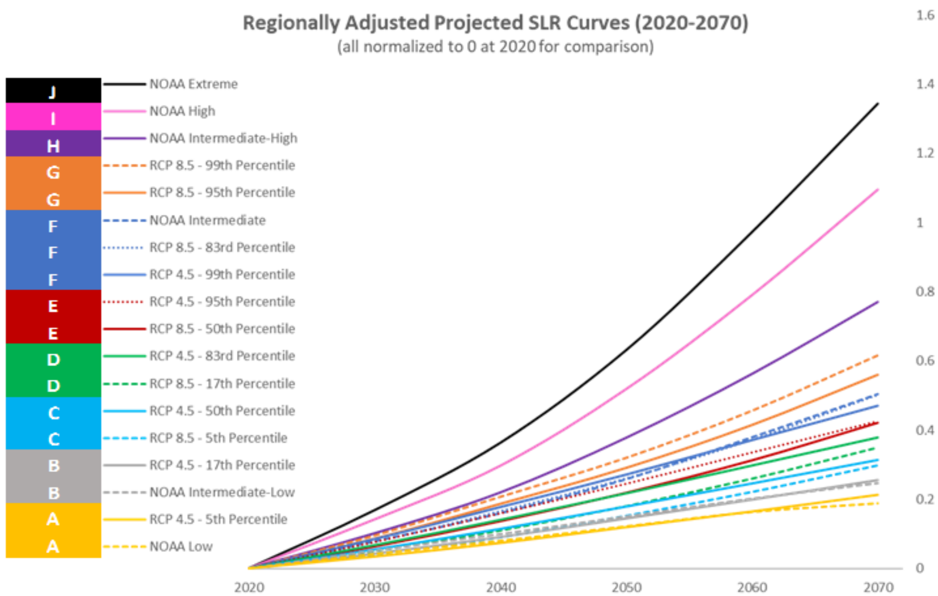

Figure 3. Equifinal groups of considered sea level rise curves.

This resulted in four groups (D, E, H and I) being identified for testing with two groups (E and H) ultimately being selected for use for project selection for the 2023 Coastal Master Plan. The sea level rise curve chosen for the lower scenario results in 1.65 ft (0.49 m) of sea level rise over 50 years which falls within the plausible range of sea level rise associated with RCP 4.5. The curve chosen for the higher scenario results in 2.50 ft (0.77 m) of rise over 50 years, which falls within the plausible range of sea level rise associated with RCP 8.5. For comparison, the sea level rise curves used in the 2017 analysis would range from 1.5 ft (0.46 m) to 2.9 ft (0.90 m) if adjusted for elapsed time and re-used in 2023. Additional technical details about the testing will be available in a forthcoming attachment to this appendix. Underlying data for the considered, tested, and selected sea level rise curves will be available in a forthcoming attachment to this appendix.

2.4 OBTAINING CO-VARYING VALUES FOR TEMPERATURE AND PRECIPITATION

Once the sea level rise curves were selected and an associated RCP was identified, it was necessary to obtain co-varying projections of precipitation and temperature to include in the two environmental scenarios for project selection. It was recognized early in the plan development process that independent climate modeling for the development of environmental scenarios around cohesive suites of variable values for use in the 2023 Coastal Master Plan would be cost, time, and computationally prohibitive. Instead, outputs from phase five of the Coupled Model Intercomparison Project (CMIP) were leveraged for this planning process. Established by the World Climate Research Program, the Coupled Model Intercomparison Project (CMIP) is a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models that provides a community-based infrastructure in support of climate model diagnosis, validation, intercomparison, documentation and data access CMIP has been widely adopted by the international climate modeling community since its inception in 1995.

At the time of scenario development for the 2023 Coastal Master Plan in 2020, CMIP5 outputs that informed efforts such as the fifth assessment report of the IPCC (AR5) were the best available climate change projection data. Because of this, CMIP5 outputs were leveraged to provide climate-related variable projections for environmental scenarios. Since that time, the sixth assessment report (AR6) has been released and data from the sixth phase of CMIP is beginning to be made available. Data from CMIP6 and other more recent studies will be considered in the development of environmental scenarios for future master plans.

The “Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" archive at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/ provided precipitation and temperature data sets for use in the 2023 Coastal Master Plan environmental scenarios for project selection. Both precipitation and temperature projections for RCP 4.5 and RCP 8.5 were obtained using a spatial selection tool to select data for coastal Louisiana. Historical precipitation and temperature records were used to establish baseline records which were then differenced from the CMIP5 projections in order to define anomalies for each variable and develop inputs for those variables for the environmental scenarios. For the Lower scenario, the 50th percentile outputs of RCP 4.5 were used to define the temperature and precipitation anomalies, while the 50th percentile outputs of RCP 8.5 were used in the case of the higher scenario.

Further technical details on the development of the precipitation and temperature projections for the 2023 Coastal Master Plan will be reported in a forthcoming attachment to this appendix.

2.5 TRIBUTARY HYDROGRAPHS, EVAPOTRANSPIRATION, AND STORM INTENSITY

Additional climate-driven variables are used within the predictive models drive hydrologic and morphologic processes. Variable values for tributary hydrographs and evapotranspiration are defined using the values for precipitation and temperature, respectively. The development of the synthetic tributary hydrographs will be discussed more in a forthcoming attachment to this appendix. For evapotranspiration, the Hargreaves-Samani 1985 equation was used and an adjustment for the temperature terms in that equation was applied consistent with the temperature projections described above. Supporting documentation for the calculation of evapotranspiration will be available as supplementary material to this appendix.

Storm intensity is another climate-driven variable that was updated for 2023. For 2023, storm intensity was increased by 5% over 50 years for the Lower scenario and by 10% over 50 years for the higher scenario. Since the 2017 Coastal Master Plan was developed, several new studies of the projected impacts of future climate change on tropical storms and hurricanes have been published. A synthesis report by Knutson et al. (2020) presented findings of projected storm parameters across several studies and it was recognized that there the trend across storms in the Atlantic basin was increased intensity over time, though reported mean and median values for the percentage increase in intensity led to lower values being selected for 2023 as comparted to those applied in the 2017 plan. The trends in storm frequency were less clear, and because of the limited confidence in how to apply an adjustment to storm frequency that variable was removed from the environmental scenarios for the 2023 Coastal Master Plan. Supporting documentation for the selection of storm intensity values will be available as supplementary material to this appendix.

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