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2017 Coastal Master Plan

Appendix C: Modeling

Chapter 4 – Model Outcomes and Interpretations

Report: Final

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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

This chapter focuses on how the models described in previous chapters were used to predict future changes to the landscape, ecosystem, and risk characteristics of the Louisiana coast. Example outputs are provided from the models for the 50-year simulations for various environmental and risk scenarios. For landscape and ecosystem modeling, the Integrated Compartment Model (ICM) and the Ecopath with Ecosim (EwE) models were used. The ICM is made up of the following subroutines: hydrology, morphology, barrier islands, vegetation, and habitat suitability indices. The EwE model predicts fish and shellfish biomass. In terms of storm surge and risk, the Advanced CIRCulation (ADCIRC) model was used to predict storm surge, the Simulating Waves Nearshore (SWAN) model was used to predict waves, and the Coastal Louisiana Risk Assessment (CLARA) model was used to predict risk/damage.

The models were used to assess change over 50 years without the implementation of additional restoration or risk reduction projects (Future Without Action – FWOA). Then, additional model runs were conducted to compare the effects of individual projects and groups of projects (alternatives) against the FWOA. How the project attributes were reflected in the models and how adjustments in inputs or model dynamics were adjusted are described in Section 1. The second section outlines the initial conditions for the landscape and ecosystem, which were for primarily defined by existing data as described below and in previous chapters. Section 2 also describes how the effects of storms and waves on flood depths and damages for the initial conditions were derived using modeling. FWOA output is described in Section 3 of this chapter. Project-level outputs and interpretations are provided in Section 4, and project interactions are discussed in Section 5. Lastly, outcomes and interpretations of the draft and final 2017 Coastal Master Plan model outputs are included in Section 6. Because the final Coastal Master Plan did not change substantively from the draft version, model outcomes from the draft plan also serve as those for the final version of the plan.

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List of Abbreviations

AA	Atchafalaya/Terrebonne
ADCIRC	Advanced Circulation (model)
AEP	Annual Exceedance Probability
BIMODE	Barrier Island Model
CLARA	Coastal Louisiana Risk Assessment (model)
CP	Chenier Plain
CPRA	Coastal Protection and Restoration Authority
DEM	Digital Elevation Model
EAD	Expected Annual Damage
ESLR	eustatic sea level rise
EwE	Ecopath with Ecosim (model)
FEMA	Federal Emergency Management Agency
FWOA	Future Without Action
FWP	Future With Project
GIWW	Gulf Intracoastal Waterway
GOHSEP	Governor's Office of Homeland Security and Emergency Preparedness
HSDRRS	Hurricane and Storm Damage Risk Reduction System
HSI	Habitat Suitability Index
HUD	Department of Housing and Urban Development
ICM	Integrated Compartment Model

IP	Implementation Period
IPET	Interagency Performance Evaluation Taskforce
JPM-OS	Joint-Probability Method—Optimal Sampling
KMZ	Keyhole Markup Language
LaVegMod v2	Louisiana Vegetation Model (version 2)
LMI	low to moderate income
MTTG	Morganza to the Gulf
NAVD88	North American Vertical Datum of 1988
PB	Pontchartrain/Barataria
RL	Repetitive Loss
RSLR	Relative Sea Level Rise
SRL	Severe Repetitive Loss
SWAN	Simulating Waves Nearshore
TKN	Total Kjeldahl Nitrogen
TRG	Tidal Ranges

1.0 Project Implementation

The initial conditions for the 2017 Coastal Master Plan analysis were derived from existing data for topography, bathymetry, and vegetation cover (see Attachment C3 -27), with projects added to the landscape that were not represented in the initial data sets but are assumed to be in existence for the 2017 Coastal Master Plan FWOA condition. The FWOA landscape included all projects, even if they were very small features (i.e., smaller than project selected for consideration in the 2017 Coastal Master Plan). This was considered important to ensure that the performance of candidate projects was based on as realistic a landscape as possible. Refer to Appendix A: Project Definition for a list of projects included in the FWOA landscape. The modeling of individual candidate projects was based on a 50-year simulation.

This section describes how the candidate projects were added to the ICM, ADCIRC, and/or CLARA models, either through direct modification of topography/bathymetry (e.g., marsh creation), changes in how the model modifies land-water character (e.g., buffer behind a shoreline protection project to reduce marsh edge erosion), or through changes in model links that determine hydrologic exchanges (e.g., structure used for hydrologic restoration). Projects were incorporated as part of the model run "set-up" phase and were put into the landscape based on the specific attributes, including the implementation year, provided by CPRA. For project-level analysis, some model runs contained more than one project, yet care was taken to assure these were sufficiently separated in the model domain to avoid project interactions. The set-up for each type of project is described below. Appendix A: Project Definition provides more information on the project types and assumptions used to develop the project attributes provided to the modeling teams.

1.1 Hydrologic Restoration

Hydrologic restoration projects include the introduction of culverts, tide gates, locks, plugs, weirs, siphons, and pump stations into the model domain. These projects are primarily used to convey fresh water to proposed outfall areas or to improve water circulation and reduce saltwater intrusion within a hydrologic system. In most cases, the implementation of a hydrologic restoration project required the adjustment of existing model links or the addition of new links. The link type added or modified (channel, weir, lock, tide gate, orifice, culvert, or pump station) depends on the project specifics stated in the project attributes. In some cases, a project will include a plug, which requires blocking an existing channel link. To implement these projects, the modeler determines if a channel link is entirely blocked due to the plug, or if the channel link (whether representative of a single channel or composite channel) has a reduction in width due to the plug. For pump stations, tide gates, and other link types which feature control operations, it should be noted that the operation rules remain the same overall years of implementation within the model (i.e., the structure operation rules remain static over time even though actual operation can vary in response to conditions). For instance, it is not possible to implement a project in the ICM at year five with a prescribed operational trigger of 2.2 m stage in year 10 and switch to a trigger of 3 m stage in year 22. In cases with complex operational rules (such as operation at specific stage *and* salinity criteria), the hydrology code used in that model run was specifically modified to ensure correct operation of the project. However, this was only necessary for a few projects.

If at all possible, subdividing model compartments was avoided during project implementation. In some cases, this meant "projecting" the structure location near the boundary of the compartment for the establishment of link attributes. However, this procedure was only used if the hydraulic conveyance between the compartments was identical at the project location and at the compartment face. Effects of projects located within the interior of a compartment that do not affect exchange between two compartments were not captured within the ICM. Examples are provided in Figure 1a and 1b.

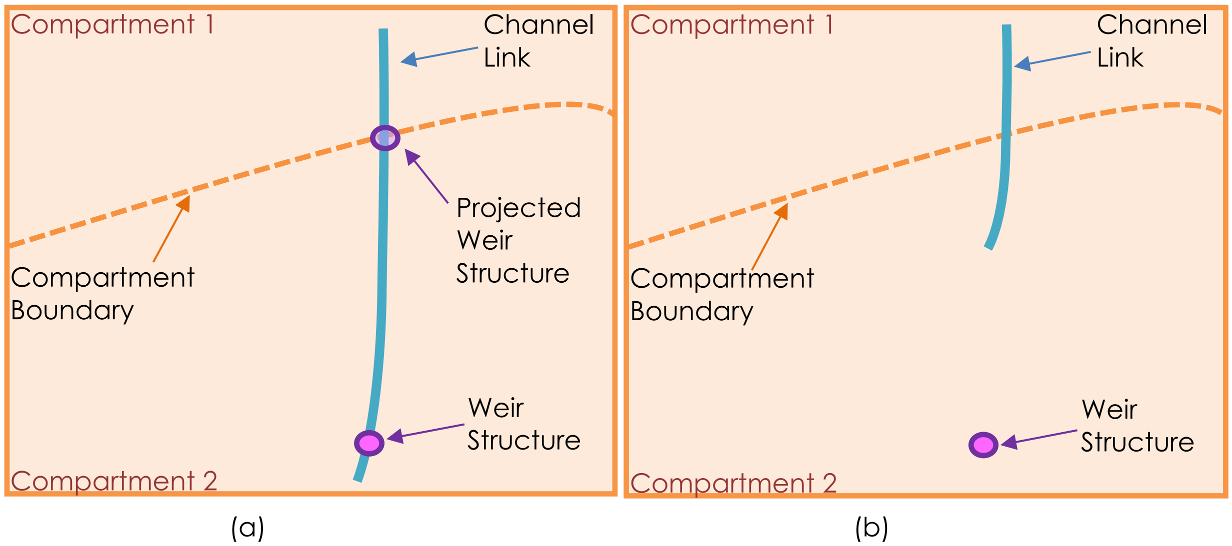


Figure 1: (a) Project is Able to be Projected to the Compartment Boundary; (b) Project Cannot be Projected to the Compartment Boundary Due to Other Flow Considerations or Placement Within the Interior of a Compartment.

1.2 Shoreline Protection

Shoreline protection projects are defined as near shore segmented rock breakwaters and are primarily used to reduce wave energies on shorelines in open bays, lakes, and natural and manmade channels. The project footprints were not included in the landscape Digital Elevation Model (DEM) or incorporated into the hydrology subroutine. These projects were implemented by adjusting the marsh edge erosion rate for any part of the compartment within the influence area behind the structure. This influence area was defined by a 200 m buffer on the landward side of the structure. The project effect on marsh edge erosion rate was applied at the 30 m grid level in the morphology subroutine. The amount of eroded sediment to be added to the compartment sediment pool was also proportionally reduced to account for the length of marsh edge within a compartment that would be protected by the project.

The marsh edge retreat rate was reduced for compartments impacted by the 200 m buffer. Equation 1 was used to determine the revised marsh edge erosion rate for each compartment containing the shoreline protection project:

$$MEE_{new} = \left((MEE_{original}) \left(\frac{A_{project}}{A_{total}} \right) (F_r) \right) + \left(1 - \left(\frac{A_{project}}{A_{total}} \right) (MEE_{original}) \right) \quad (1)$$

where

MEE_{new} = the compartment's marsh edge erosion rate, as reduced by the project
$A_{project}$ = project edge area = shoreline protection project length * assumed marsh edge width of one 30 meter land/water pixel in morphology subroutine
A_{total} = total marsh edge area

F_r = project reduction factor = wave (erosion) attenuation rate/100%

The project attributes included the designated wave (erosion) attenuation rate, which (as shown in Equation 1) was used as the percent reduction in the historic marsh edge erosion rate for each compartment containing the project. The new marsh edge erosion rate was then included in the revised compartment attribute input file.

1.3 Bank Stabilization

Bank stabilization projects are defined as the on shore placement of earthen fill and vegetative plantings and are primarily used to maintain shorelines in open bays, lakes, and natural and manmade channels. The procedure for modeling bank stabilization projects followed the guidelines outlined above for shoreline protection projects. The project footprints were not included in the landscape (DEM) or incorporated into the hydrology subroutine, but a 200 m buffer was used to determine the influence area of the project. Wave attenuation rates, as specified in the project attributes, were used to determine the new marsh edge erosion rate to be used in the compartment attribute input file.

1.4 Ridge Restoration

Ridge restoration projects are intended to re-establish historical ridges through sediment placement and vegetative plantings to provide additional storm surge attenuation and to restore forested maritime habitats. Ridge restoration projects were implemented in the ICM using the same procedure and approach used for levee projects. Ridge restoration projects were modeled via implementation in the landscape by adjusting the DEM as well as through modification/addition of hydrology links. The project was incorporated into the DEM based on the footprint shapefile provided by CPRA and the project elevation specified in the project attributes. If a ridge was added to the landscape, existing links were inspected, additional links were added if needed, and the existing marsh or channel links were adjusted to reflect the dimensions after the ridge project was in place. Attributes such as ridge crest elevation and base width (per the project attributes) were carried over into the link attributes specified in the links input file. These links allowed for overtopping of the ridge in the ICM. They blocked the flow between compartments where a ridge was present if the stage was less than the ridge crest elevation. If the stage was greater than the ridge crest elevation, the ridge link allowed conveyance as a channel link would, until the stage dropped below that of the ridge crest elevation.

1.5 Levees

When levee features were implemented in the ICM as a component of structural protection projects, the approach described above for ridge restoration projects was used. In addition to the link deactivation as described in Section 1.4, a large number of hydraulic control structures were included with the structural protection projects. These newly activated control structures were implemented in the ICM in the same manner that was used for activating new control structures in the hydrologic restoration projects (Section 1.1)

1.6 Oyster Reefs

Oyster reef restoration projects construct bioengineered reefs with shell cultch or engineered/artificial substrate that promotes oyster colonization. Continued oyster recruitment and growth is expected to augment the constructed reef to enhance protection and coastal restoration benefits, including protecting shorelines from erosive forces, reducing saline intrusion, and reducing open water fetches. The oyster reef candidate projects for the 2017 Coastal Master Plan are landscape-scale projects with features and effects large enough to be resolved by the ICM.

Within the model, an oyster restoration project affected the landscape evolution with a reduction in the marsh edge erosion rate. The project footprints were not included in the landscape (DEM) or incorporated into the hydrology subroutine. Instead, a polygon shapefile bounded by the oyster reef crest and a 1 km inland buffer delineated the affected shoreline areas. The marsh edge erosion rates and the eroded sediment within the compartment were then updated in a manner identical to the implementation of shoreline protection projects.

Oyster reef restoration projects also directly impacted the Attachment C3 -12: Oyster Habitat Suitability Index Model (HSI), where the HSI is a function of the computed salinity and the percent of the water bottom covered in oyster cultch. For model runs that incorporated oyster reef projects, separate HSI initial condition rasters were developed that increased the cultch bottom cover percentage within the oyster reef project footprint.

1.7 Marsh Creation

Marsh creation projects created wetlands in open water areas and re-graded existing marsh land through placement of dredged material and vegetative plantings. Marsh creation projects were incorporated into the ICM via the DEM and hydrology links. The footprint shapefile of the marsh creation project was used to insert the project into the DEM, using the attributes (such as marsh elevation) specified. It was specified in the code that marsh creation projects were not implemented in locations where the water depth was greater than 0.76 m North American Vertical Datum of 1988 (NAVD88) at the year the project was implemented. This was done to avoid inadvertent filling of channels on the landscape. As the implementation year varied per project, the fill volume was calculated at the time of implementation to more accurately determine the fill volume required to reach the desired marsh elevation.

The hydrology links in the ICM were also adjusted to implement the marsh creation projects. Marsh links were added at compartment faces as needed and existing were modified or removed due to the placement of the project. All channel links within the marsh creation polygons were converted to “maintained channel” links with a constant bottom elevation if they were intended to remain channel links following project implementation. Channel links were converted to “composite channel” links if they represented non-channelized flow in marsh areas. The cross-sectional area of these composite channel links was updated via the marsh creation project implementation code to adjust exchange as the composite link fills in with sediment.

1.8 Diversions

Diversion projects create new conveyance channels to divert fresh water and sediment from coastal Louisiana’s rivers into adjacent basins. Diversion projects were modeled within the ICM in multiple ways, depending upon the upstream source of water to be diverted. Many of the modeled diversions involved diverting flow from the Mississippi River into the wetland areas adjacent to the river. The Mississippi River is not included within the ICM model domain, though its influence on the estuarine basins is modeled as a series of flow distributaries; a fixed amount of the Mississippi River flow is modeled as direct flow input into specific model compartments adjacent to the channel. For example, the model compartment representing West Bay in the Bird's Foot Delta received an influx of flow (with suspended sediment and water quality constituents) that is equal to a defined portion of the river flow. This same approach was used to implement all of the diversion projects that propose to divert the Mississippi River water into the adjacent wetland areas.

Some diversion projects were modeled at a relatively small but constant design flowrate, such as the 5,000 cubic foot per second (cfs) Central Wetlands diversion (001.DI.18). For these projects, the design flowrate was added as a direct, constant flowrate input into the receiving model compartment. However, the majority of the diversion projects were modeled with an assumed operation regime dependent upon the flowrate within the river. The flowrate of diverted waters were calculated from linear rating curves based upon the design flowrate defined by CPRA. Many diversions were operated such that during low river flow periods, the diversion was inactive. Once the Mississippi River was flowing at a rate greater than the low flow threshold, the diversion flowrate would increase linearly based upon the rating curve assigned. The design capacity of each diversion project, as well as the river flowrates used to define the design flowrate, and the low flow thresholds are provided in Appendix A: Project Definition.

For all Mississippi River diversion projects, the flowrate within the river immediately downstream of the diversion intake was updated to account for the diverted flow. This residual flow was then used for the next diversion point downstream (either proposed or an existing distributary). While the Mississippi River was not included within the hydrodynamic subroutine, a mass/flow balance was conducted on the inflow boundary conditions, a priori, in order to accurately calculate the river flow available to be diverted at each location.

All sediment diversion projects along the Mississippi River used the 50-year time series of suspended sediment concentration in the Mississippi River developed for FWOA, and described in Attachment C3-26: Hydrology and Water Quality Boundary Conditions. All sediment diversions were implemented based upon the assumption that they would be designed such that a sediment-water-ratio of 1.0 was attained. The sediment-water-ratio is the ratio of suspended sediment concentration in the diverted outflow as compared to the channel-averaged suspended sediment concentration in the main channel of the river immediately upstream of the diversion intake structure. A sediment-water-ratio of 1.0 indicates that the river and diversion suspended concentrations are equal. A sediment-water-ratio less than 1.0 would indicate that the diversion structure is unable to convey all suspended material available in the river, and sediment-water-ratios greater than 1.0 may occur depending upon alignment and design of the intake structure (Meselhe et al., 2012).

The above procedure was used for modeling diversion projects along the Mississippi River. There were three other diversion projects that were implemented using a different methodology. One of these was the Manchac Landbridge Diversion (001.DI.100), a proposed diversion connecting the Bonnet Carre Spillway to the adjacent swamp forest area. This hydraulic connection was modeled by simply adding a new open channel link within the hydrology subroutine, connecting the model compartment representing the Spillway to the model compartment representing the adjacent swamp area. When water levels within the Spillway were high enough to enter this channel (either during Bonnet Carre gate openings or high water periods in Lake

Pontchartrain), the model would divert flow into the swamp area as a function of the differential water elevations represented in the model.

The other projects that utilized a different approach were the two diversion projects diverting water from the Atchafalaya River: Atchafalaya River Diversion (03a.DI.05) and Increase Atchafalaya Flow to Terrebonne (03b.DI.04). Unlike the Mississippi River, the Atchafalaya River is within the ICM domain; the model compartments and links automatically update the river flowrate downstream of the diversion locations based upon the hydrodynamics of the modeled system. To implement these two projects, a new open channel link was added to the model domain representing each diversion location. The flow within these diversion links was then assigned as directly proportional to the flow within the main stem of the Atchafalaya River immediately upstream of the diversion location. The portion of flow diverted for 03b.DI.04 was 11% of the Atchafalaya River flow, and 03a.DI.05 diverted 26%. If a simulation was required with both of these diversions active at the same time, the diverted flow reduced to 8% and 17% of the Atchafalaya River flow for 03b.DI.04 and 03a.DI.05, respectively. The proportion of river flow diverted was determined from a study of these two proposed projects (Moffatt & Nichol, 2016).

1.9 Barrier Islands

Barrier island restoration projects were implemented in the ICM by incorporating a project design template into the DEM that represents the cross-shore profiles (spaced at 100 m in the long-shore direction) within the Barrier Island Model (BIMODE) subroutine. The project design template specified a project footprint area and a cross-shore profile with defined elevations for beach, dune, and back barrier marsh zones. When implemented within the model, the pre-project elevation data were updated to meet the elevations prescribed in the design template. The amount of fill required to build to the design elevation varied based upon implementation year and scenario; therefore, the required fill volume was calculated to accurately determine the variation in project costs.

The design elevation and areal extent of the barrier island restoration projects were prescribed prior to model implementation. However, the exact location of the project was not predetermined due to different rates of island migration over time. The project location was determined by matching the template shoreline location with the FWOA shoreline location at the beginning of the implementation year. This was required because the fill volume calculation was performed by comparing the pre- and post-project elevations. If a static template location was used, fill volumes (and subsequent project costs) would be inaccurate due to the migration of barrier island shorelines over time.

The BIMODE subroutine has a model structure defined by cross-shore profiles; the spatial resolution is 2 m in the cross-shore direction with 100 m spacing of profiles in the long-shore direction. This resolution was sufficient to accurately represent the project design template, but the resolution was adjusted when BIMODE output was passed to the wetland morphology subroutine. The BIMODE cross-shore profiles are interpolated into a 30 x 30 m DEM that is stitched into the coast wide DEM used by the wetland morphology subroutine. This 30 m DEM is the elevation dataset that was provided to the ADCIRC+SWAN model; however, the barrier island portion of the ADCIRC+SWAN domain utilized the high resolution cross-shore profile data directly from the post-project BIMODE output.

1.10 Surge and Wave Modeling of Restoration Projects

The ADCIRC+SWAN model implemented restoration projects using the project properties as they were described by the ICM model outputs. The projects were applied to the ADCIRC+SWAN model in the form of changes to topographic/bathymetric elevation and changes to land use characteristics which were converted into frictional parameters. The same control volume averaging method used to implement future environmental scenarios was also applied here (Attachment C3-25.1; Appendix 3, Figure 53).

The exceptions to the control volume averaging method were for the treatment of ridge restoration and barrier island projects. Like other raised features, such as roadways and coastal ridges, which are not modeled as weirs but are still important for flood routing, ridge restoration projects and barrier islands had explicitly defined crown elevations. This approach avoided artificially lowering crown elevations due to smoothing associated with the control volume averaging technique. Ridge crown elevations were applied using the DEM processed from ICM model outputs. Barrier island crown elevations were similarly mapped from BIMODE outputs.

1.11 Structural Protection

1.11.1 ADCIRC/SWAN

Structural hurricane protection projects evaluated in the 2017 Coastal Master Plan include one or more of the following basic components: earthen levee, concrete T-wall, and floodgates. Floodgates are typically constructed at road, railroad, and water body crossings. Additionally, pump stations are included in the interior of ring levees. The ADCIRC+SWAN model was used to evaluate how structural protection projects affected water surface elevation (surge) and wave response throughout coastal Louisiana.

To maximize computational efficiency, structural protection projects were divided into six model mesh groupings. An example grouping is shown on Figure 2 and contains four projects. Groupings were chosen such that projects would not interact and, therefore, could be studied in isolation though they were simulated in the same model mesh.

Figure 2: Example Hurricane Protection Project Grouping for the Project Implementation Phase.

Project features (i.e., earthen levee, concrete T-wall, and floodgates) were implemented using ADCIRC's weir boundary condition. The ADCIRC weir boundary condition defines a feature that is too small to be captured accurately solely using finite elements in a particular model region. Overtopping volumes were computed using the formula for a broad crested weir when the computed stillwater elevation on either side of the boundary exceeds the specified crest elevation. Crest elevations are defined by the design elevations for each project feature. If the crest elevation is not exceeded, the feature appears numerically as a vertical wall.

The SWAN model also implements these features as vertical walls; however, wave heights are assumed to be reduced to zero when crossing the feature before being allowed to redevelop on the opposite side of the boundary. Overtopping volumes due to waves were not computed within ADCIRC+SWAN.

Many other such features are implemented in ADCIRC this way, including significant local levees and federal levees such as the Mississippi River levees, Greater New Orleans levees, and the levees encompassing Larose to Golden Meadow. For the purposes of this modeling effort, all structures were assumed to be in their closed position, and pumps were not operated.

1.11.2 CLARA

Structural risk reduction projects, including new or upgraded earthen levees, concrete T-walls, floodgates, and pumps were evaluated using the CLARA model to estimate their potential for flood depth and damage reduction. The structural features evaluated in the 2017 analysis are described in Appendix A of the 2017 Coastal Master Plan (McMann et al., 2017).

Structural projects are represented as elevated weir features in surge and wave hydrodynamic modeling. These projects are each incorporated into one of six coast wide groups that include sets of projects expected to provide independent utility and benefits, so that the effects of one project in a group do not interact or conflict with another. In the case of unenclosed protection projects (i.e., fronting barriers), storm surge and wave results from a sample of 60 simulated storms are used directly for statistical flood depth calculations in the CLARA model pre-processing module at each CLARA grid point (Fischbach et al., 2016).

For upgraded or newly enclosed protected systems, alternately, storm surge and wave results are provided with the project in place for a series of “surge and wave points” (SWPs) surrounding the protection system. In these cases, information about the new or upgraded system within the CLARA model flood depth module is also utilized to estimate flood depths in enclosed areas. The additional information includes structure heights, fill or armoring characteristics, geospatial alignment, and the location of transition features such as pumps or gates (see Appendix A). Enclosed protected systems are then evaluated using the CLARA model flood depth module using the same approach described in Fischbach et al. (2012 & 2016).

The CLARA model generates statistical estimates of flood depth annual exceedance probabilities at every CLARA grid point with both unenclosed and enclosed projects in place for each group to produce a final set of future with project (FWP) flood depths. This exercise is repeated for every combination of project group, environmental scenario, and fragility scenario in the 2017 analysis. All scenarios are evaluated in year 25 and year 50 future conditions. Note, however, that only the low environmental scenario is evaluated in year 10; CPRA assumes that these results can be used as a reasonable proxy for the year 10 medium and high scenario conditions to better conserve supercomputer resources for hydrodynamic modeling.

Next, a series of geospatial polygons are generated which indicate the zone of influence for each structural project within a group. These polygons are developed based on a combination of storm surge and wave results and expert judgment. These polygons are used to estimate the effects of the individual structural projects within each group, with the assumption that only grid points within the polygon for a given project will change from the FWOA to FWP. Flood depth changes outside of the project influence zone are disregarded. In this way, a coast wide project group can be divided into a series of individual, regionally focused project effects. Furthermore, when evaluating enclosed protected systems, only changes to SWPs within the project influence zones are considered in the flood depth module; if a portion of the system lies outside of any project influence zone, the FWOA surge and wave values are used instead. This is done to reduce the potential impact of noise in the ADCIRC and SWAN models.

Finally, the CLARA model damage module is used to estimate direct damage from flooding with the project in place and summarized using the expected annual damage (EAD) metric at each CLARA model grid point. Influence zone polygons are again used to assign FWP damage to individual projects. Results from the FWP and FWOA analysis are then summed and aggregated using the methods described in Fischbach et al. (2016), Sec. 5.3.4, to estimate the mean and standard deviation of the change in EAD (risk reduction project benefit) for each of the 54 summary risk regions across the Louisiana coast. Except for year 10, for reasons noted above, this process is repeated for every project group, environmental scenario, and fragility scenario evaluated in the CLARA model. The damage estimates also include three distinct population and asset growth scenarios (Fischbach et al., 2016), adding an additional layer of scenario uncertainty on the flood depth results using full factorial combination.

1.12 Nonstructural

Nonstructural projects are evaluated directly in the CLARA damage module according to the methods described in Fischbach et al. (2012 & 2016).[1] For the 2017 analysis, these projects consider different levels of investment in flood hazard mitigation in different coastal communities, all compared to the FWOA flood damage level as a baseline. The CLARA model uses a set of decision rules to determine where and how much investment would be made. Specifically, "project variants" describe how decisions are made regarding which 1) locations and 2) structures are eligible for elevation, floodproofing, or acquisition.

Project variants are defined by the standards for mitigation heights used to determine which structures should be elevated, floodproofed, or acquired. The standards are determined by median estimates of the 100-year flood depths at each CLARA model grid point under a specified landscape scenario and year, plus two feet of "freeboard" above the median 100-year depth. Project variants differ in which landscape scenario and year these depths are drawn from; grid point locations with no 100-year flood depths are not considered for investment in a given variant. More detail on the iterative process used to identify project variants can be found in Groves et al. (2016).

The CLARA team developed and provided an initial set of analysis results to the Planning Tool Team to support CPRA's identification of nonstructural project variants. These data were provided for each proposed variant and CLARA model grid point under each of the future scenarios under consideration. Specific data provided include:

- Counts of the structures elevated, floodproofed, and acquired;
- Costs of elevations, floodproofing, and acquisitions; and
- Benefits of nonstructural risk reduction (reduction in EAD compared to FWOA).

The CLARA team also provided data summarizing other relevant characteristics of areas considered for nonstructural risk reduction investment to help support the identification of project variants. These include the percentage of households categorized as low to moderate income (LMI), the number of properties that have suffered repetitive loss (RL) or severe repetitive loss (SRL) from flood events in the past, and estimates of median 100-year flood depths under initial conditions and in selected future scenarios. Estimates of the percentage of LMI households and the number of RL and SRL properties by grid point were derived from the Department of Housing and Urban Development (HUD) FY 2014 low to moderate income summary data (HUD, 2015), as well as data provided by CPRA originally provided by the Federal Emergency Management Agency (FEMA) and the Louisiana Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP), respectively.

Key assumptions related to nonstructural project implementation in the CLARA model include:

- Following the 2012 analysis, this analysis assumes 70% participation when voluntary nonstructural mitigation incentives are offered. This means that 70% of eligible structures are mitigated in targeted CLARA model grid points.
- Residential structures can be elevated up to a maximum of 4.3 m above existing adjacent grade. If the standard exceeds this level, the structure is acquired instead.

[1] Note that a version of this discussion also appears in Fischbach et al. (2016), Sec. 8.4.

- Commercial, industrial, and public buildings can receive dry floodproofing if the foundation is three feet or less below the reference standard. Residential dry floodproofing is not considered in this analysis.

The parameter values for the seven project variants chosen for evaluation by CPRA are summarized in Table 1. The mitigation standards determined by each variant were run through the CLARA economic module for every combination of flood depth and economic scenario. Separate decisions are made in the Planning Tool for each of 54 "nonstructural project areas," which correspond directly to the CLARA model risk regions but only include geographic regions that have assets identified as eligible for nonstructural investment (see Fischbach et al., 2016). The seven variants were run through each of the 54 nonstructural project areas, yielding a total of 7 X 54 = 378 separate nonstructural projects for consideration in the 2017 Coastal Master Plan analysis.

Table 1: Selected Nonstructural Project Variants.

Project variant	Landscape scenario	Year	Additional filters
1	-	1 (initial conditions)	-
2	Low	10	-
3	Medium	10	-
4	High	10	-
5	Medium	10	Only grid points where LMI > 30%
6	Medium	25	-
7	High	25	-

Using the final set of nonstructural project variants identified, the CLARA team provides data to the Planning Tool Team describing results from the analysis for each variant in each future year and scenario condition. One data set describes the characteristics of the project variants, including their construction costs, the numbers of structures mitigated by structure type, and nonstructural project duration. Duration is calculated as a function of the total number of structures mitigated in each risk region using a crosswalk provided by CPRA (Table 2).

Table 2: Nonstructural Project Duration Assumptions.

Structures mitigated (risk region)	Assumed duration (years)
0-30	1
31-200	2

Structures mitigated (risk region)	**Assumed duration (years)**
201-500	3
501-1000	4
1,001-2,000	5
2,001+	7

Another dataset describes the summary characteristics of the areas where nonstructural mitigation is implemented, including percent LMI, count of RL and SRL properties, and number of structures eligible for mitigation. As with the structural projects, all of these results are summarized by risk region. Finally, a third set details the estimated EAD reduction benefits from each nonstructural project, comparing the with-project and FWOA damage values using the same methods described above for structural projects. The final results are summarized by nonstructural project variant, risk region, scenario, and year.

2.0 Initial Conditions

2.1 Landscape and Ecosystem

The initial characteristics of landscape and ecosystem are, for the most part, derived from existing data sources. Information about these initial conditions datasets, data sources, and data preparation is provided in Attachment C3-27: Landscape Data. Some adjustments were made to account for projects recently constructed or that are expected to be constructed in the near future (Appendix A). The graphics below show the initial conditions for the 2017 Coastal Master Plan modeling effort. Figure 3 shows starting elevations across the coast, Figure 4 shows coast wide land-water configuration, and Figure 5 shows initial vegetation cover.

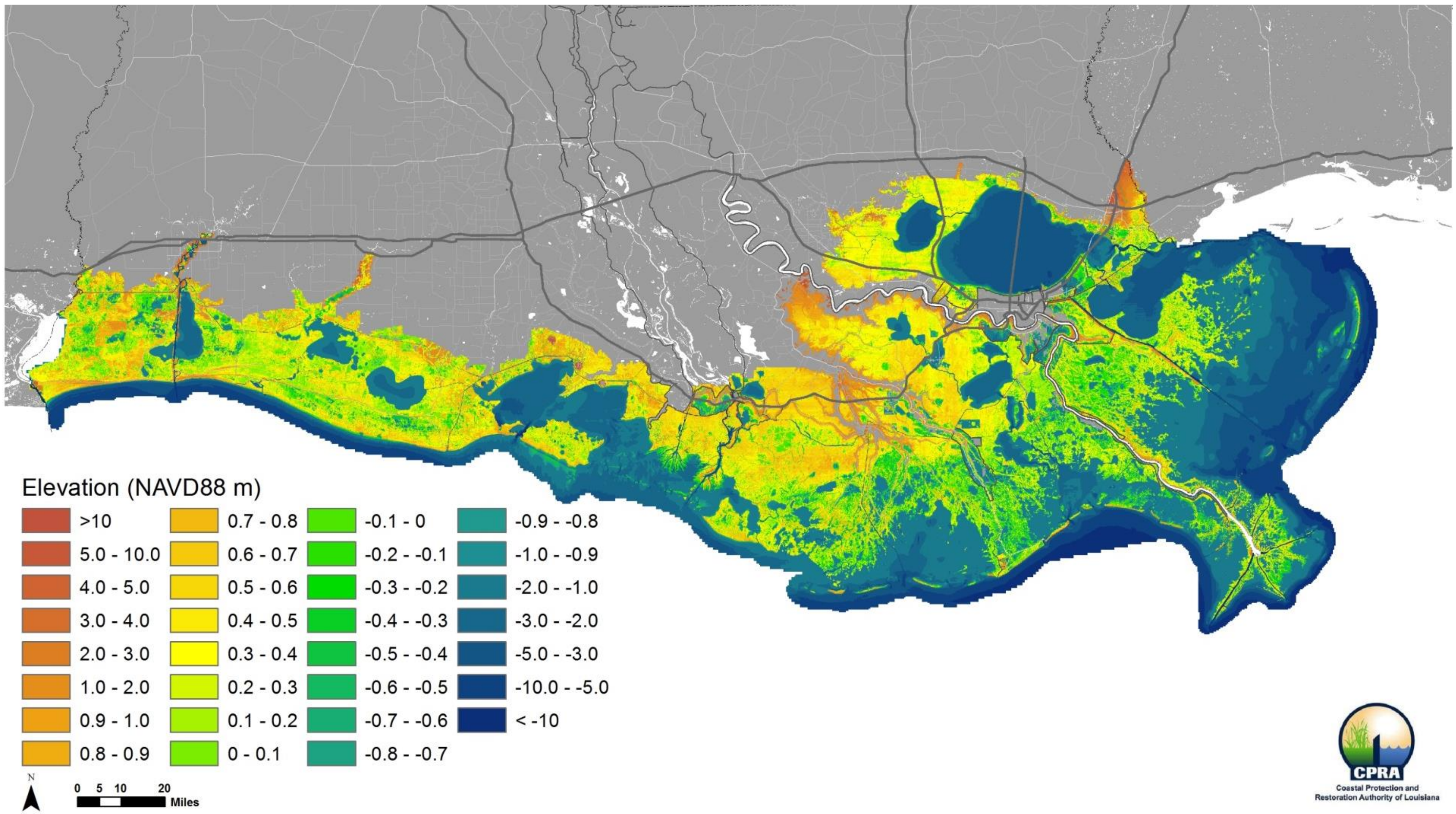


Figure 3: Initial Topography and Bathymetry for the 2017 Coastal Master Plan Modeling Effort.

Figure 4: Initial Land/Water for the 2017 Coastal Master Plan Modeling Effort.

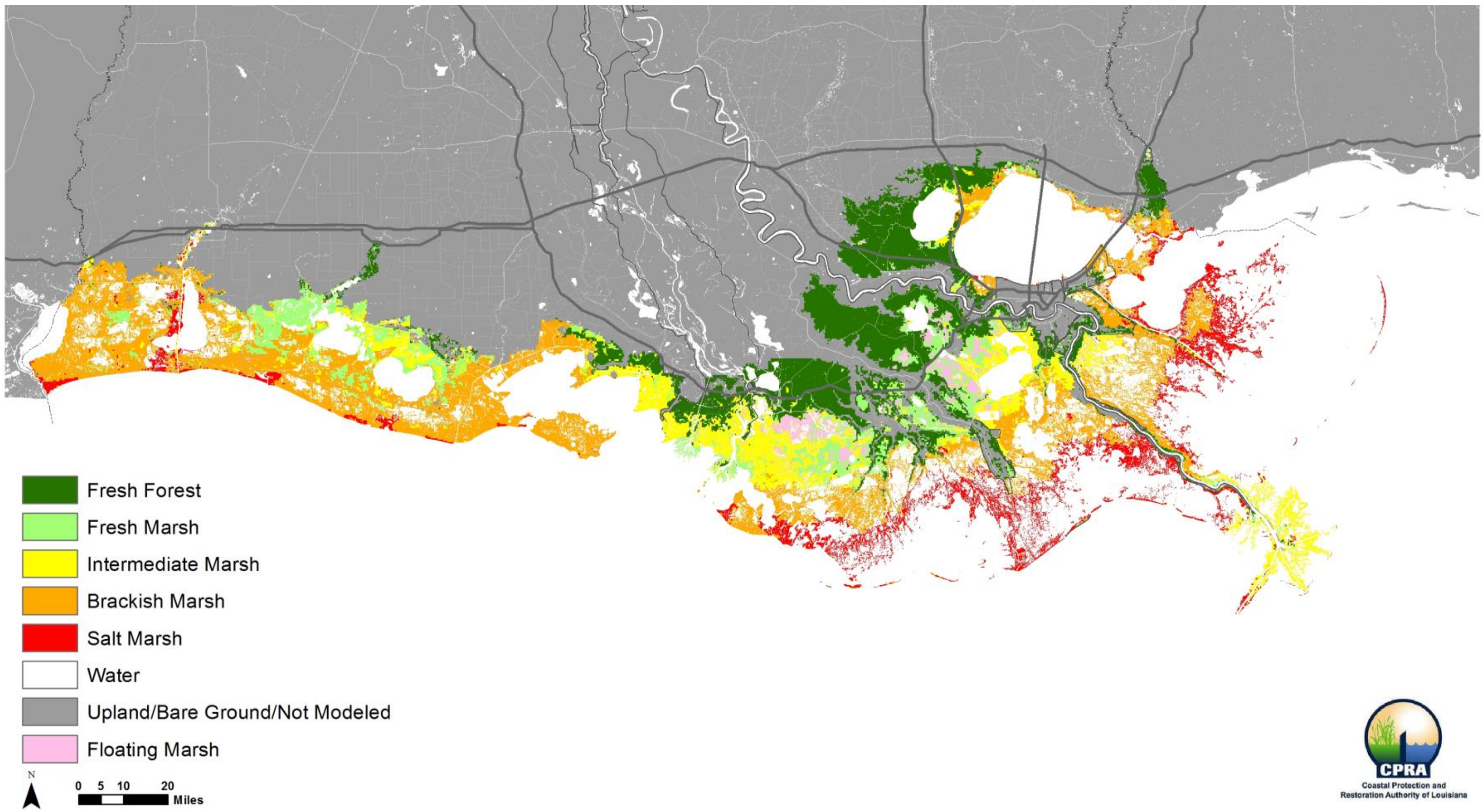


Figure 5: Initial Vegetation Cover for the 2017 Coastal Master Plan Modeling Effort.

2.2 Flood Depth

ADCIRC and SWAN simulations were conducted on the initial conditions model geometry to ensure model stability and performance, validate the model, and establish surge and wave responses for comparison to future scenarios. The mesh was created using the best available data sources for present-day bathymetry, topography, levee crest elevations, and other raised-feature elevations (e.g., roadways and coastal ridges; CPRA, 2015). In addition to the landscape information described above, land cover data that included the distribution of vegetation species was also used (see Attachment C3-27: Landscape Data). Model parameters, including Manning's *n* (frictional resistance to flow) and directional roughness length (applied as a wind velocity reduction factor), were assigned using the initial conditions land cover. Figure 6 through Figure 8 show the elevation, Manning's *n*, and directional roughness length model inputs used for the initial conditions simulations for surge and waves.

Maximum surge, maximum significant wave height, peak wave period and wave direction were examined for initial conditions simulations. For the purposes of illustration, images of maximum surge, maximum wave height, wave period, and time series surges are shown for two storms. The wave period and directions shown are those that occurred at the same time as the maximum wave height. Figure 9 through Figure 12 show storm 014, which makes landfall in the eastern side of the state. Figure 13 through Figure 16 show storm 218, which makes landfall in the western side of the state.

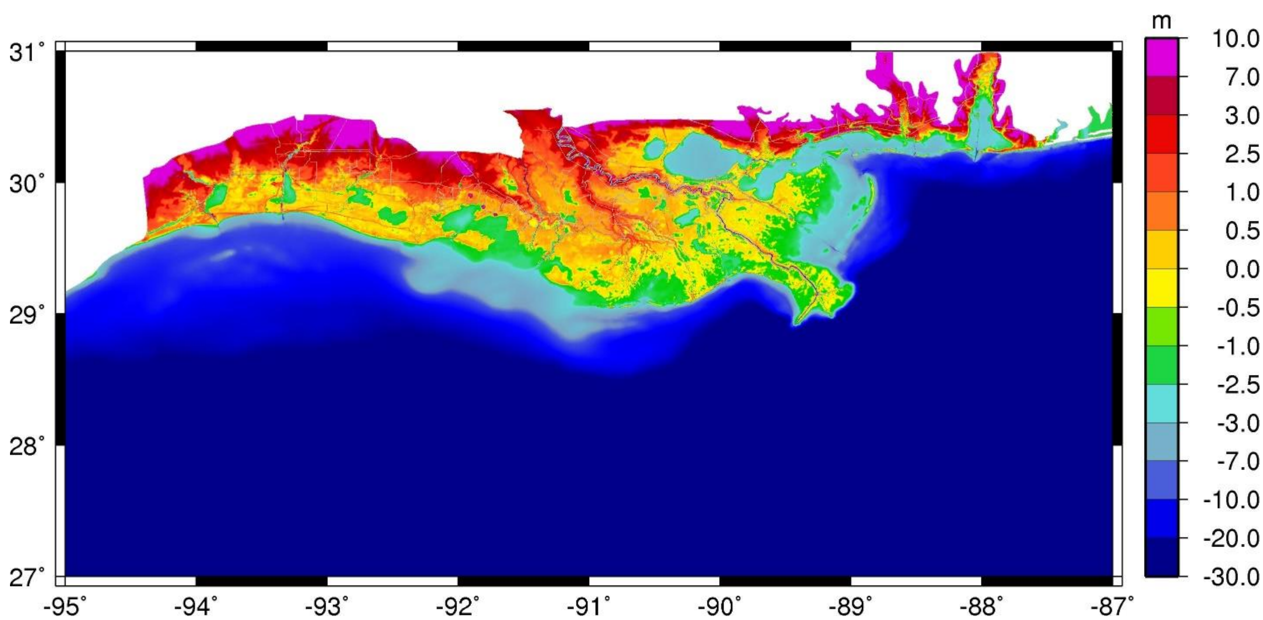


Figure 6: Topography and Bathymetry (meters, NAVD88 2009.55) Used for Simulation of the Initial Conditions.

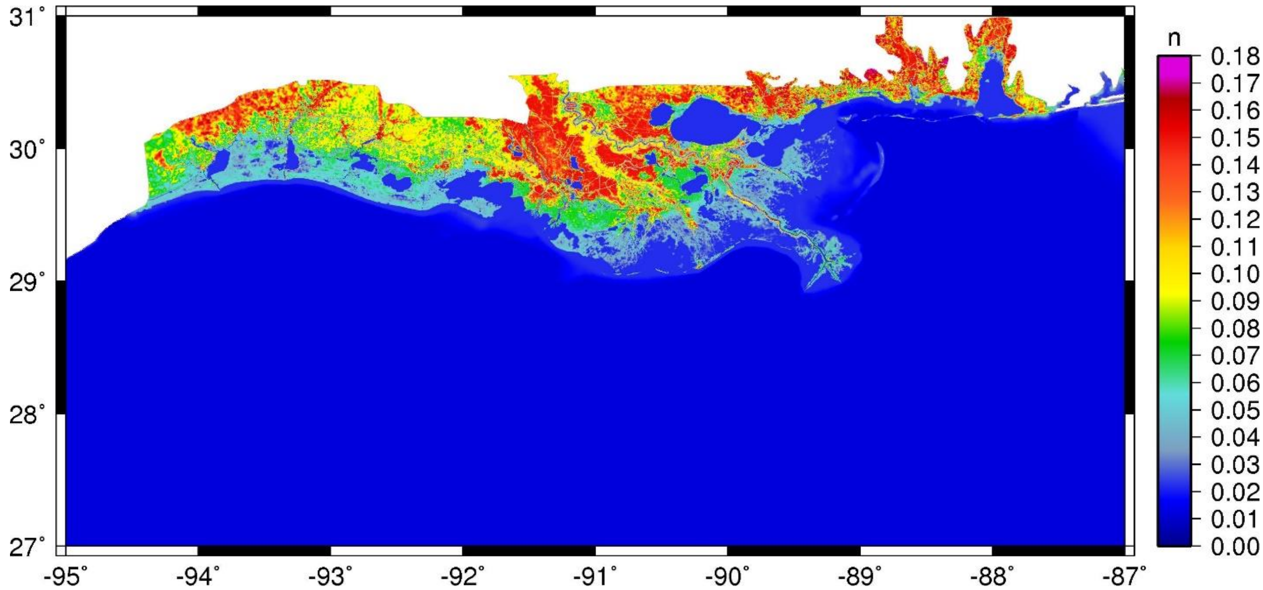


Figure 7: Manning's n Values Used for Simulation of the Initial Conditions.

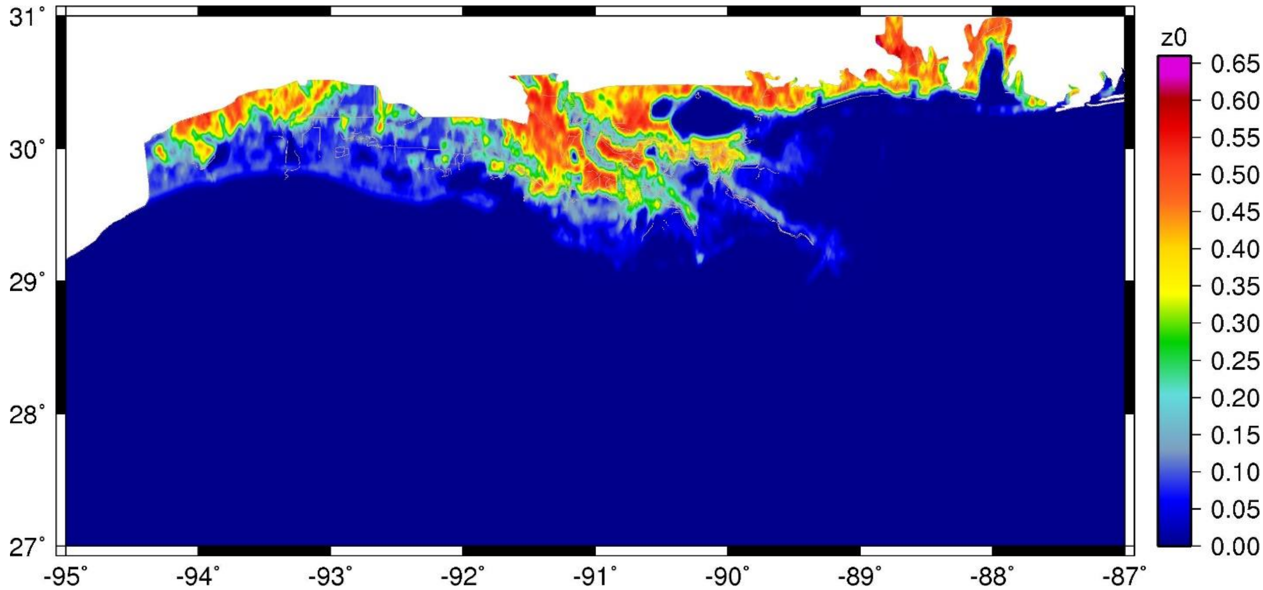


Figure 8: Directional Roughness Length Used for Simulation of the Initial Conditions. Values shown are for wind blowing from south to north.

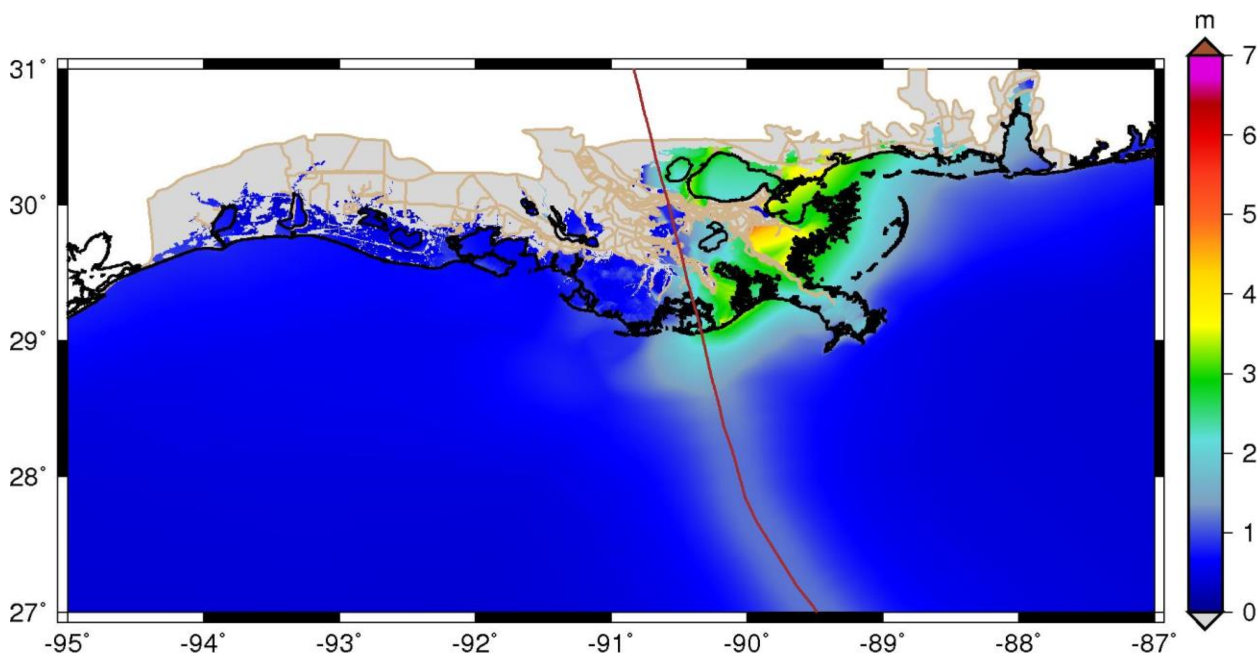


Figure 9: Maximum Surge Elevations (meters, NAVD88 2009.55) During the Initial Conditions Simulation of Storm 014.

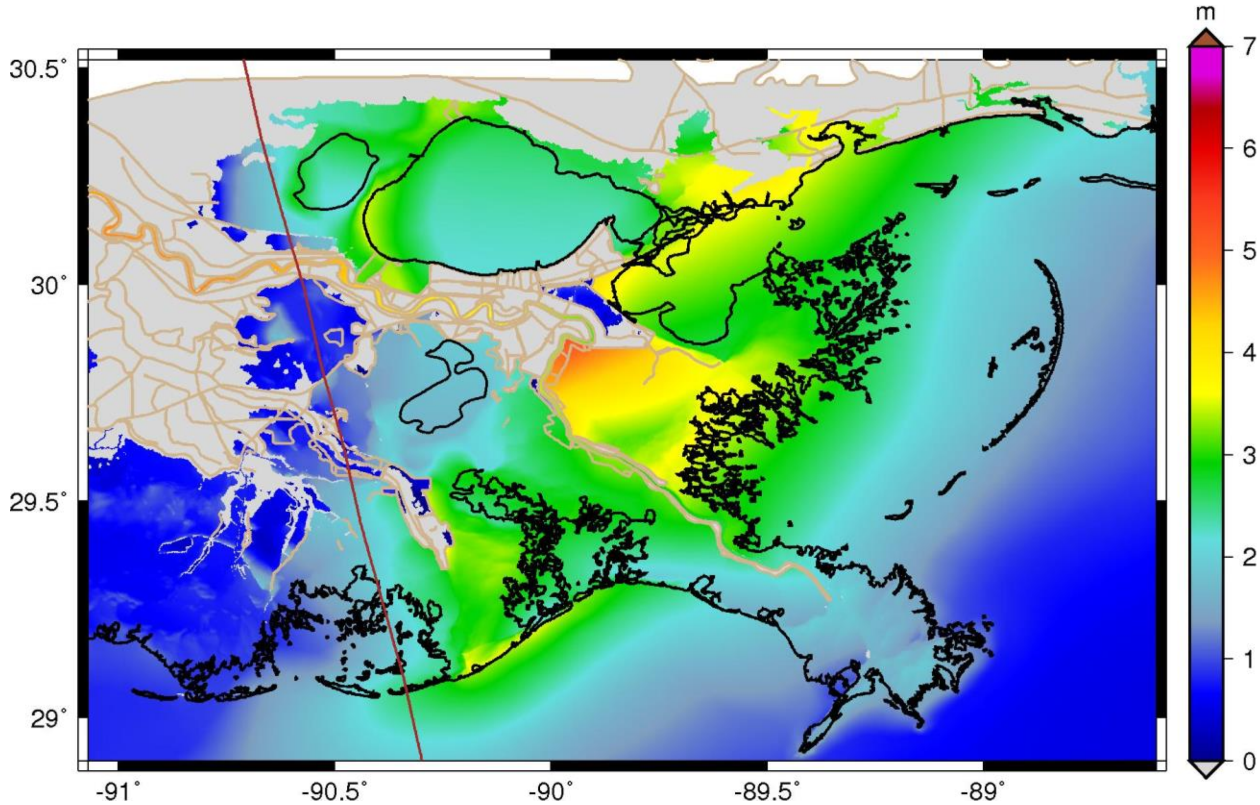


Figure 10: Maximum Surge Elevations (meters, NAVD88 2009.55) During the Initial Conditions Simulation of Storm 014.

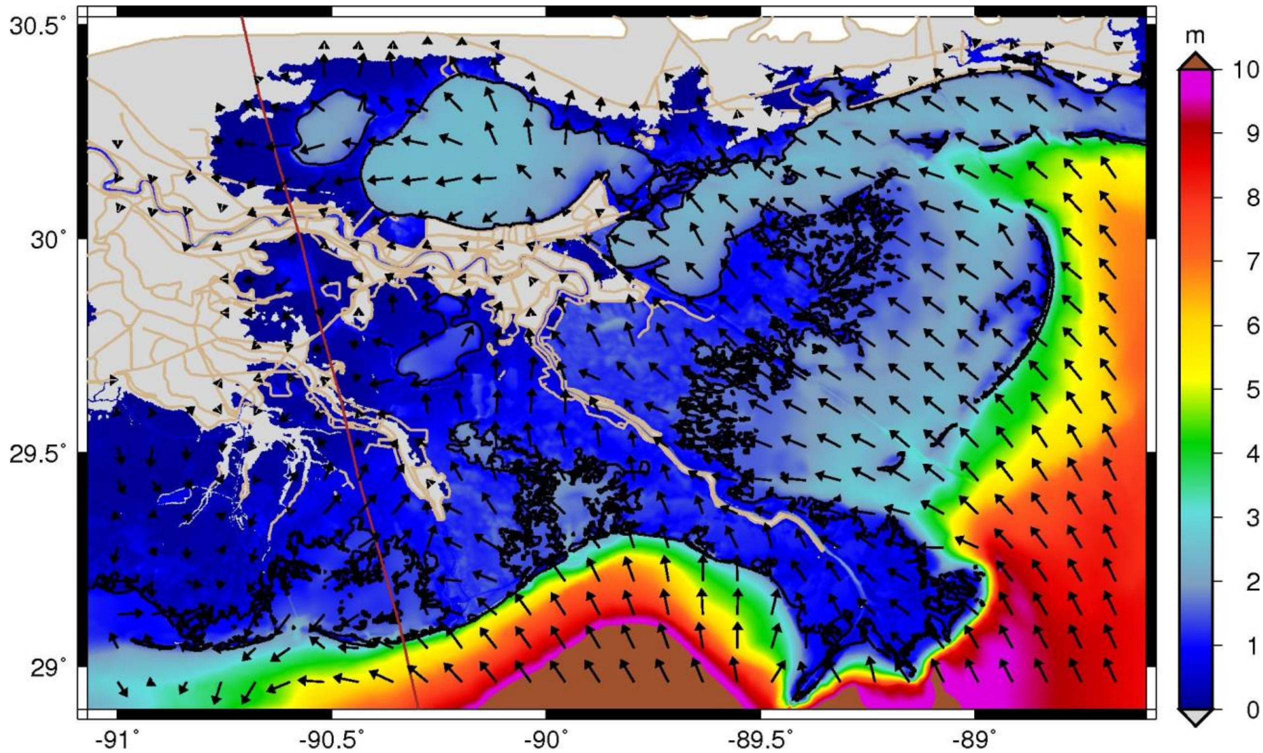


Figure 11: Maximum Significant Wave Heights (meters) and Associated Directions During the Initial Conditions Simulation of Storm 014.

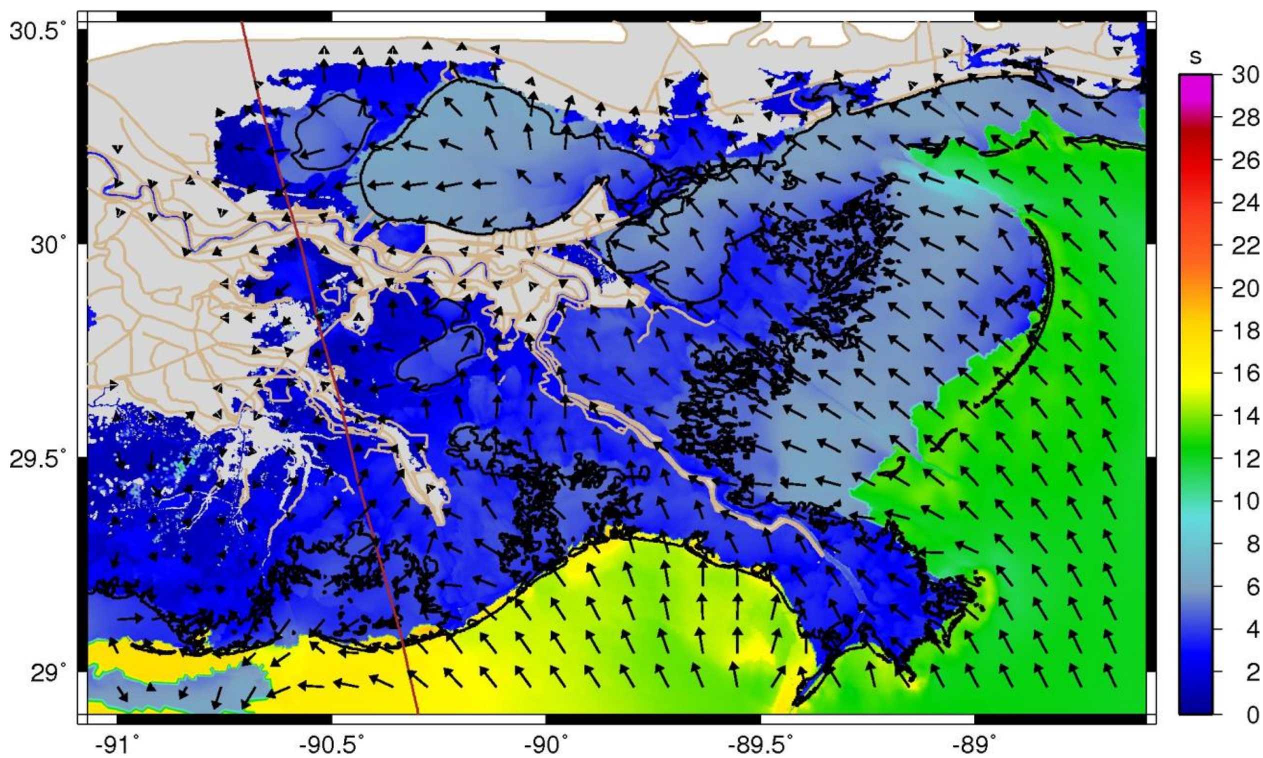


Figure 12: Peak Wave Periods (seconds) and Associated Directions During the Initial Conditions Simulation of Storm 014.

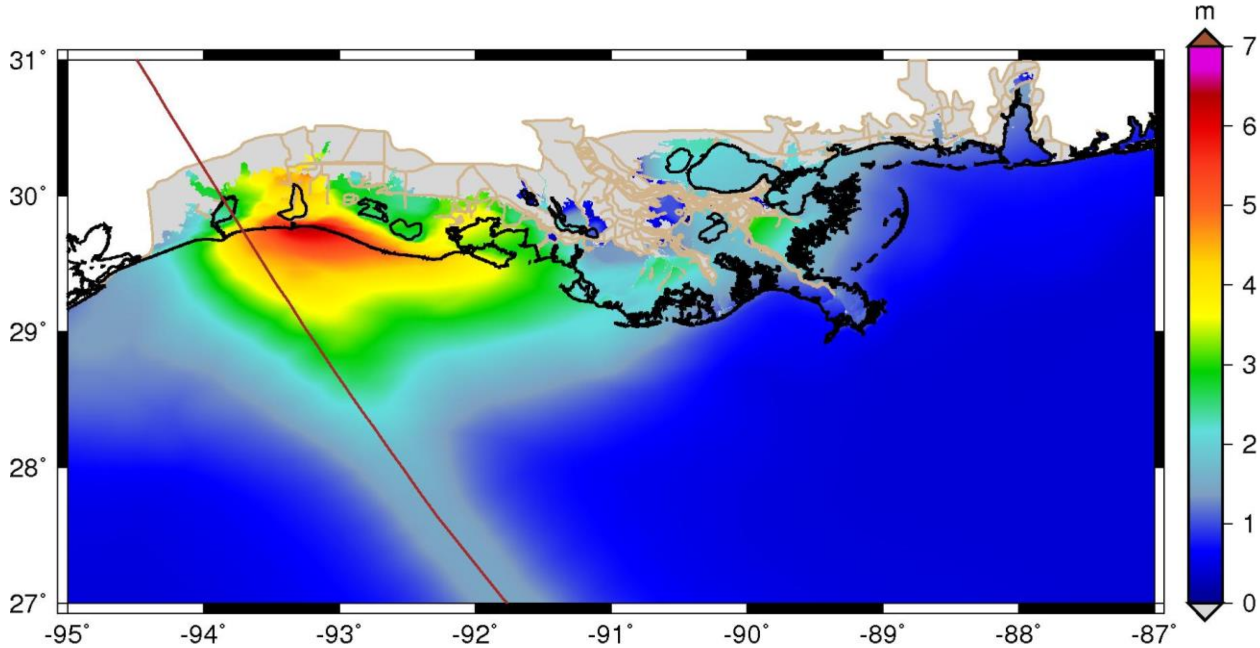


Figure 13: Maximum Surge Elevations (meters, NAVD88 2009.55) During the Initial Conditions Simulation of Storm 218.

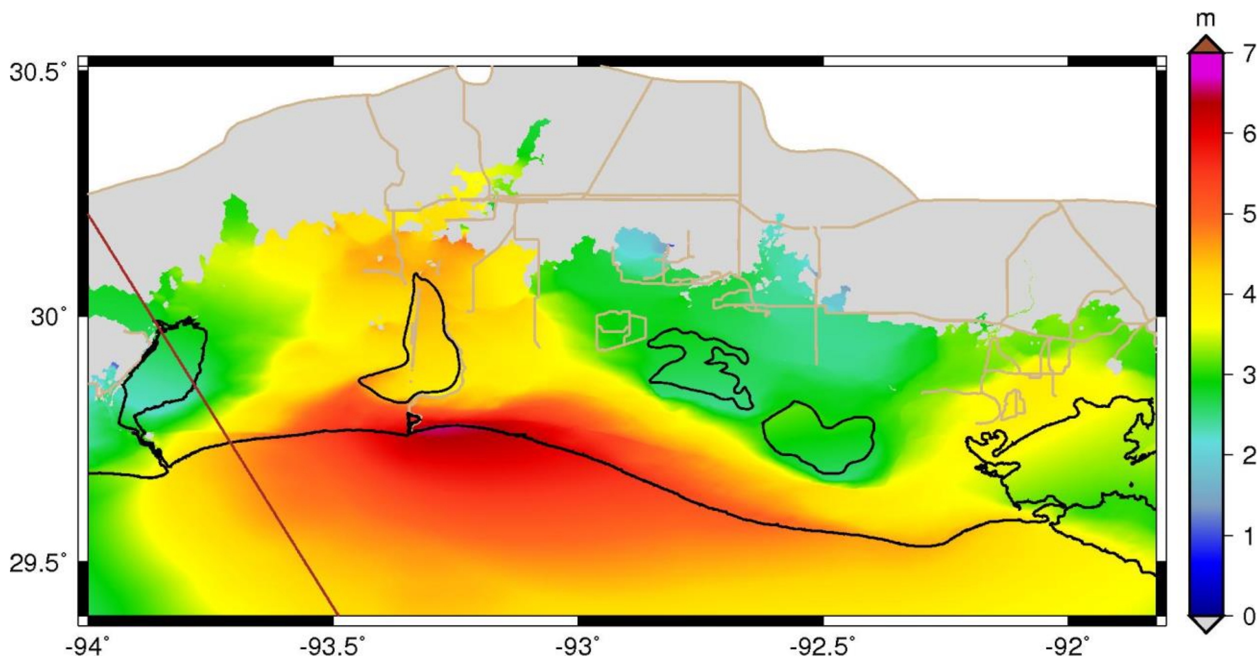


Figure 14: Maximum Surge Elevations (meters, NAVD88 2009.55) During the Initial Conditions Simulation of Storm 218.

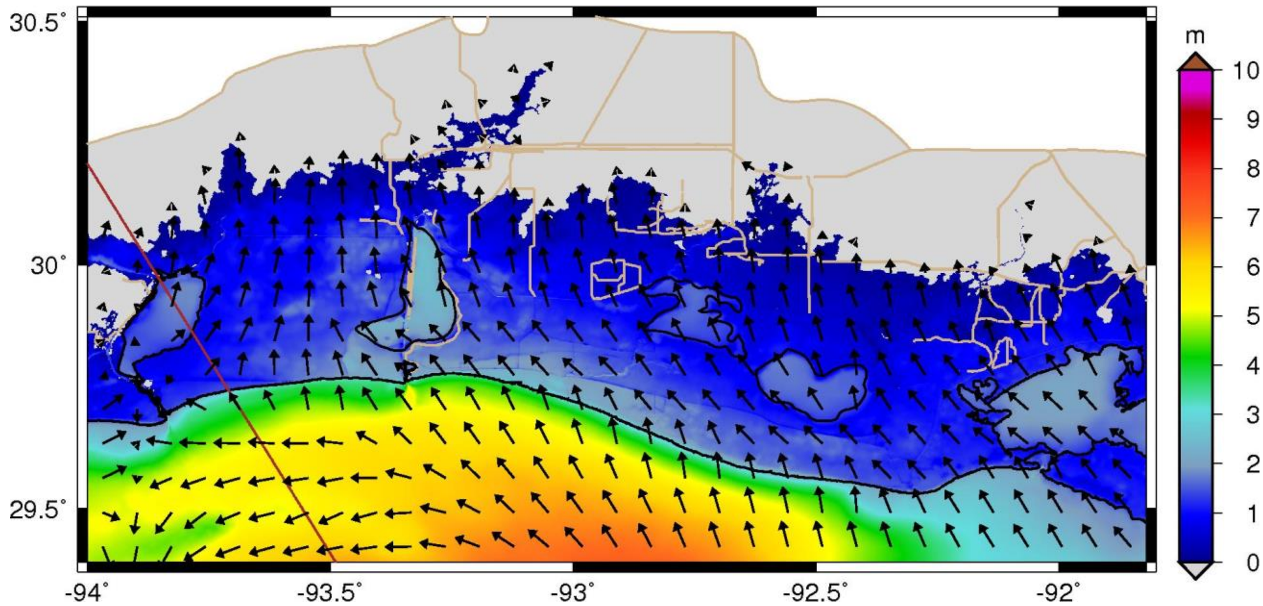


Figure 15: Maximum Significant Wave Heights (meters) and Associated Directions During the Initial Conditions Simulation of Storm 218.

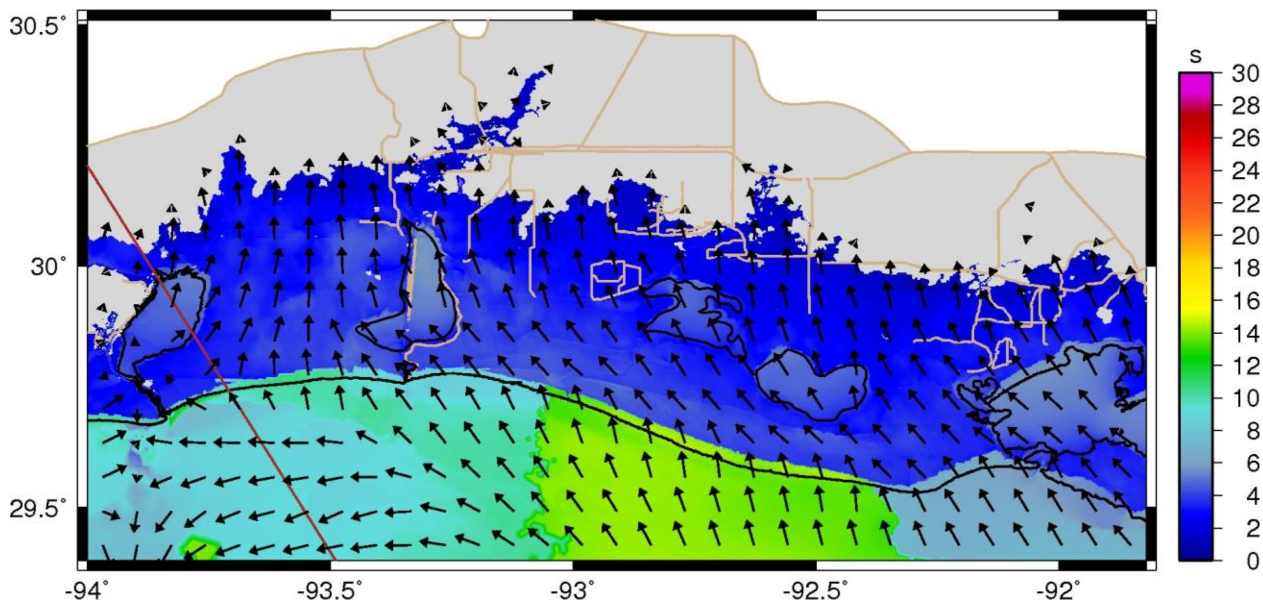


Figure 16: Peak Wave Periods (seconds) and Associated Directions During the Initial Conditions Simulation of Storm 218.

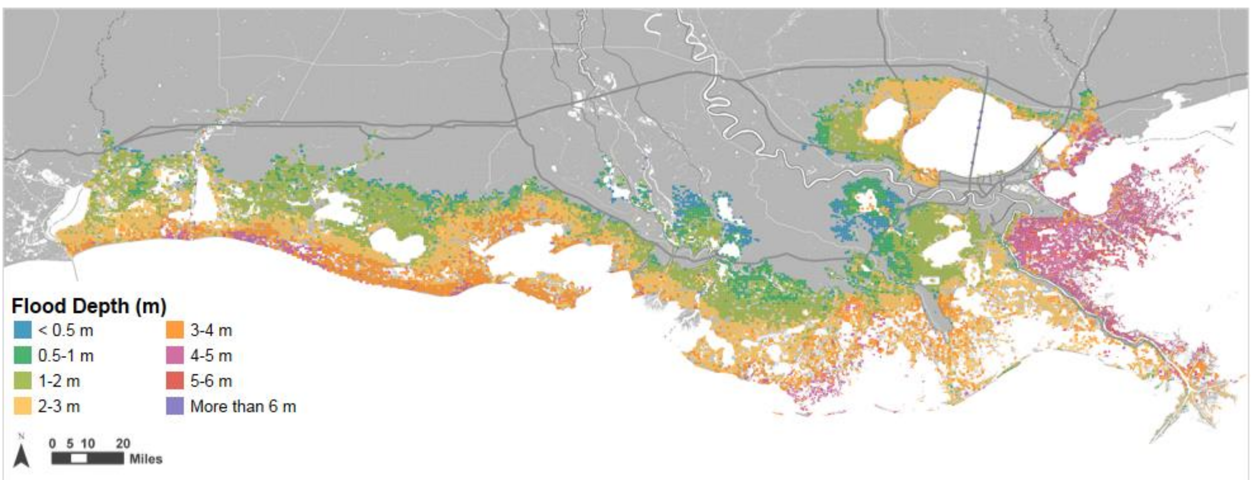
Statistical results for initial conditions were generated using an adapted Joint-Probability Method-Optimal Sampling (JPM-OS) approach from a set of 92 hypothetical storms simulated using the ADCIRC and SWAN storm surge and wave models (see Attachment C3-25, Sec. 6.5). Flood depth recurrence was estimated for unenclosed areas and enclosed areas, respectively, from the 10-year (10% chance) to the 2,000-year (0.005% chance) annual exceedance probability (AEP) interval.

For enclosed protected areas, three scenarios were included to represent alternative assumptions about the fragility of protection structures when overtopped:

- **No Fragility**: Storm surge and wave overtopping can occur, but no structure failure or breach flows occur;
- **IPET**: Fragility assumptions adapted from the Interagency Performance Evaluation Taskforce (IPET) Risk and Reliability Model (IPET, 2009); and
- **MTTG**: Fragility assumptions adapted from the U.S. Army Corps of Engineers Morganza to the Gulf (MTTG) Reformulation Study (USACE, 2013).

The possibility of levee failure was considered for all coastal levee, floodwall, and gate structures surrounding enclosed protected systems in the study region. Protection structures along the Mississippi River (Mississippi River and tributaries projects), by contrast, were assumed to have no probability of failure even when overtopped. For more information on the fragility scenarios and key related assumptions, see Attachment C3-25, Sec. 4.

Results for the 100-year AEP interval flood depths in the IPET fragility scenario are shown in Figure 17 for unenclosed areas of the coast. Many areas of the coast face more than 2 m of flooding at the 100-year interval in the initial conditions, while areas further upland show 1-2 m of depth for much of the remaining study area domain. Portions of the southeastern coast, including Lake Borgne and the east bank of Plaquemines Parish, face 100-year depths of 4-6 m in this analysis.

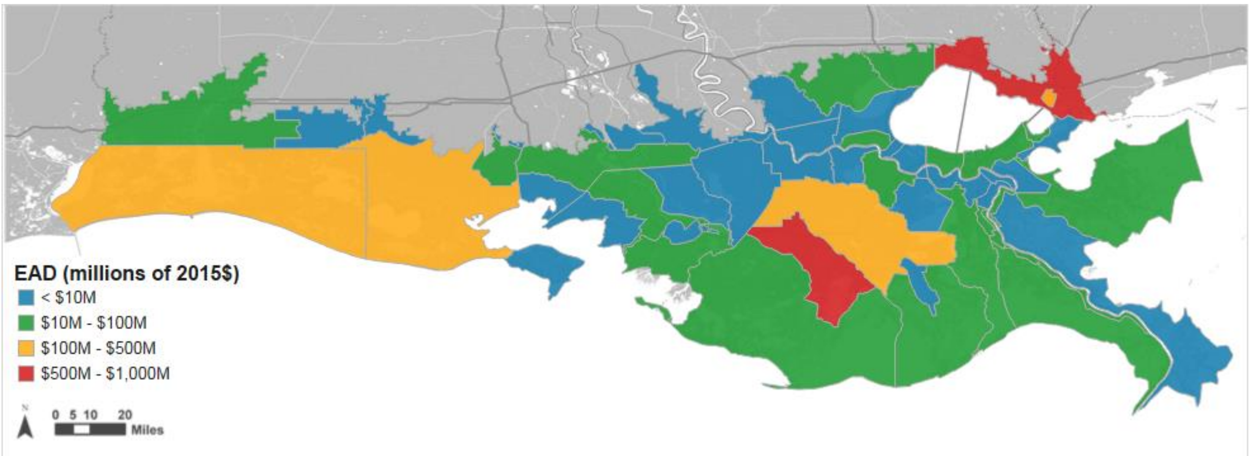


Note: 50th percentile 100-year flood depths of at least 0.2 m shown.

Figure 17: Initial Conditions 100-Year Coast Wide Flood Depths – IPET Fragility Scenario.

2.3 Damage

Direct damage from coastal flooding was also estimated with the CLARA model for initial conditions. Damage is summarized coast wide using the EAD metric, which represents an average of annual damage or loss for coastal Louisiana from Atlantic storms attaining a minimum central pressure deficit of 985 millibars (mb) or lower. Results are summed for each of 54 unique "risk regions" identified across the study area to support the 2017 Coastal Master Plan analysis (see Attachment C3-25, Sec. 8.3). Overall, coast wide EAD in the initial conditions is estimated at $2.7 billion (2015 constant dollars) in the IPET fragility scenario, with similar results observed in the No Fragility and MTTG scenarios (not shown). Levels of EAD in initial conditions vary by risk region (Figure 18). Regions with the highest initial EAD, exceeding $100 million, include Cameron and Vermilion parishes, developed areas in and around Houma (Terrebonne Parish) and Raceland (Lafourche Parish), and Slidell and other developed areas of St. Tammany Parish.



Note: Map shows mean expected annual damage for each risk region in the IPET fragility scenario.

Figure 18: Initial Conditions Expected Annual Damage by Risk Region – IPET Fragility Scenario.

3.0 Future Without Action

This section presents example outputs from the models for the 50-year FWOA simulations. Example outputs are included for key outputs for each of the models for each scenario. For the landscape and ecosystem outputs, the ICM was run for 50 years for each environmental scenario (Appendix C: Chapter 2). Storm surge, wave and risk models were run across landscape/land cover conditions generated by the ICM for year 10, year 25 and year 50.

3.1 Stage

Stage is generated for over 900 different locations across the coast. To reflect aspects of the variation, the coast was divided into three hydrologic regions: PB: Pontchartrain/Barataria (including Bird's Foot Delta), AA: Atchafalaya/Terrebonne, and CP: Chenier Plain. To assess the coast-landward gradients in each region, inland, intermediate, and coastal compartments were selected as shown in Table 3.

Table 3: Compartments of Interest within Each Region.

Region	Compartment of interest	Descriptive location	Location relative to the Gulf of Mexico coast
PB	248	East Lake Salvador	Inland
PB	278	Mud Lake/North Barataria Bay	Intermediate
PB	284	Northeast of Grand Isle	Near coast
AA	481	Lake Palourde	Inland

Region	Compartment of interest	Descriptive location	Location relative to the Gulf of Mexico coast
AA	512	Lake de Cade	Intermediate
AA	649	Caillou Bay	Near coast
CP	796	Northwest Grand Lake	Inland
CP	844	East Calcasieu Lake	Intermediate
CP	893	Holly Beach	Near coast

Figure 19 through Figure 21 show the 50-year time series for mean daily stage for PB (Barataria) for the low scenario for the inland, intermediate, and near coast compartments, respectively. Averaging has filtered the diurnal tides; the resulting stage record reflects the seasonal changes in the Gulf stage and the effect of wind. Sea level rise is evident in all these time series. The spikes in the record are due to storm surge events that are averaged in the daily stage and consequently, the spikes are much lower than the maximum surge level.

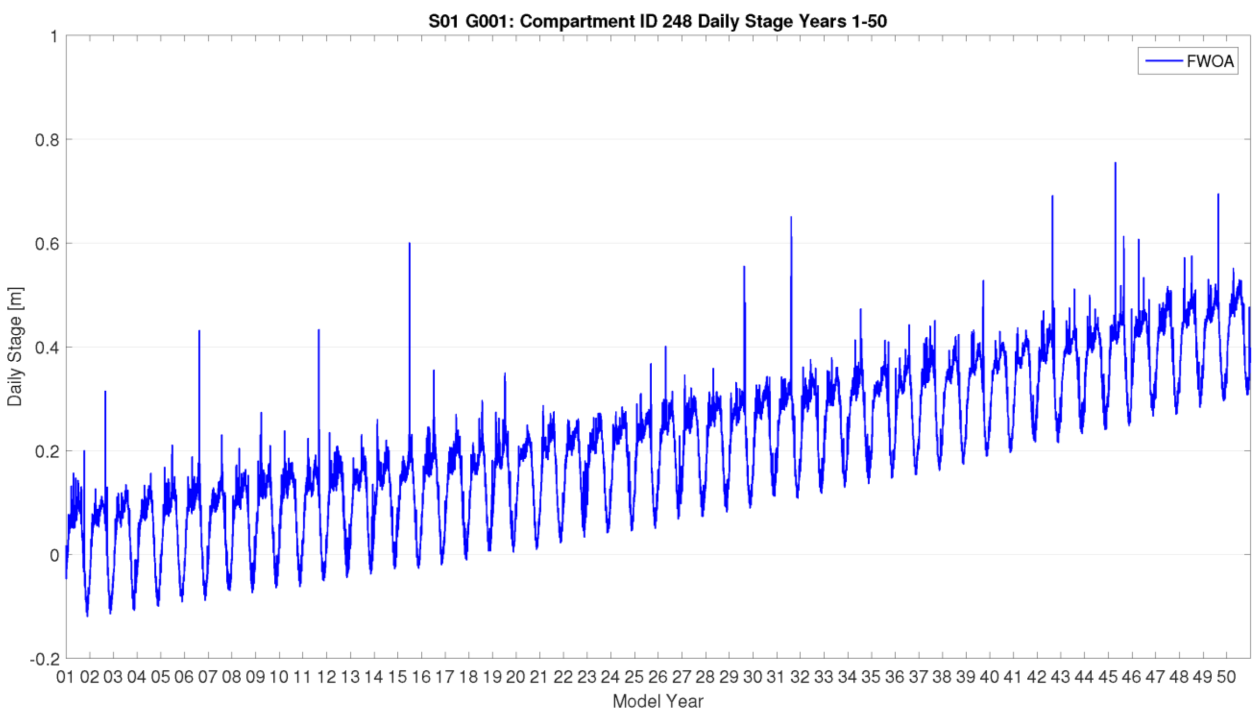


Figure 19: Mean Daily Stage in Compartment 248 - East Lake Salvador in PB for the Low Scenario (Representative of Inland Compartment Results).

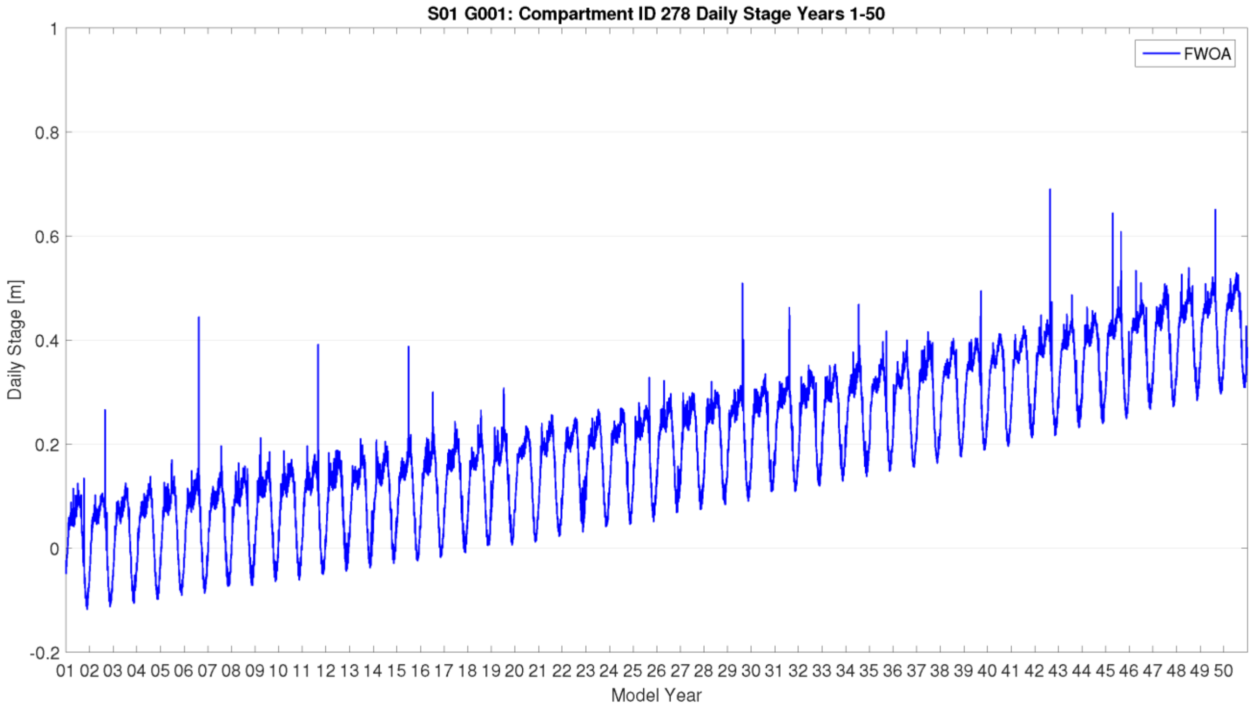


Figure 20: Mean Daily Stage in Compartment 278 - Mud Lake/Upper Barataria Bay in PB for the Low Scenario (Representative of Intermediate Compartment Results).

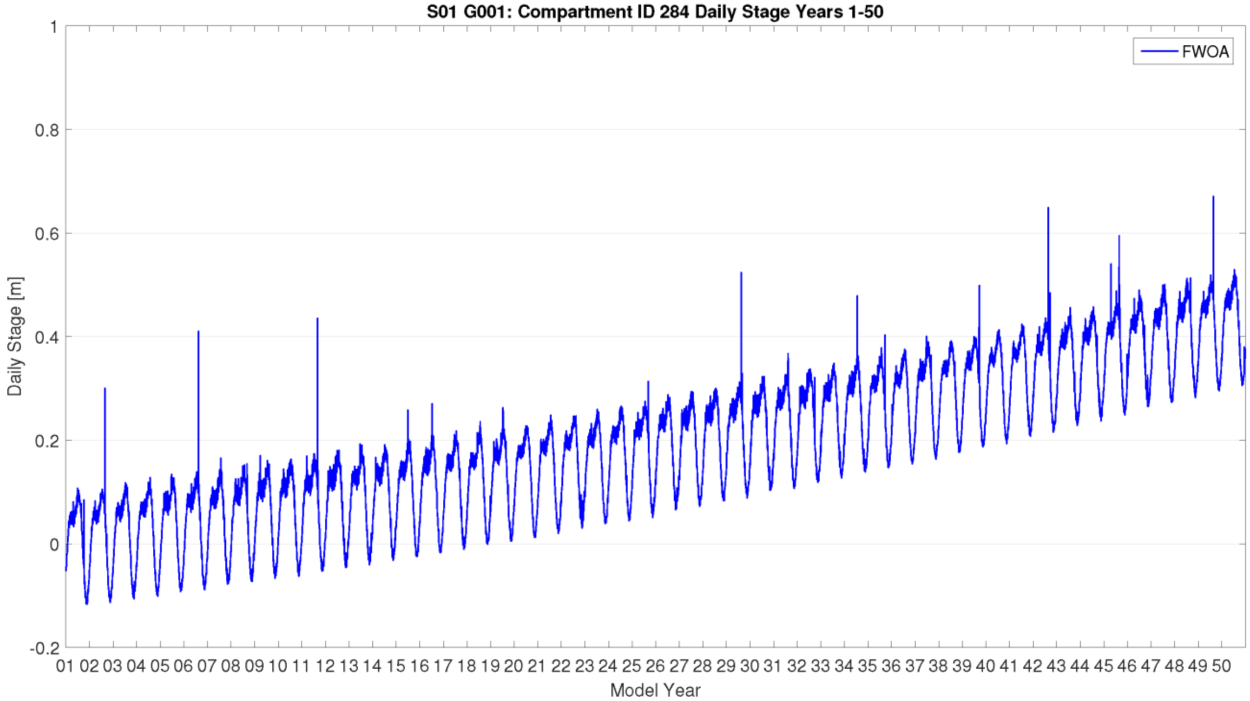


Figure 21: Mean Daily Stage in Compartment 284 - Northeast of Grand Isle in PB for the Low Scenario (Representative of Near Coast Compartment Results).

Figure 22 through Figure 24 show the 50-year time series for mean daily stage for PB (Barataria) for the high scenario for the inland, intermediate, and near coast compartments, respectively. The format of the data is the same as for the figures above. Excluding hurricanes, the mean daily stage for the high scenario is approximately 0.4 m higher than for the low and 0.2 m higher than the medium scenario.

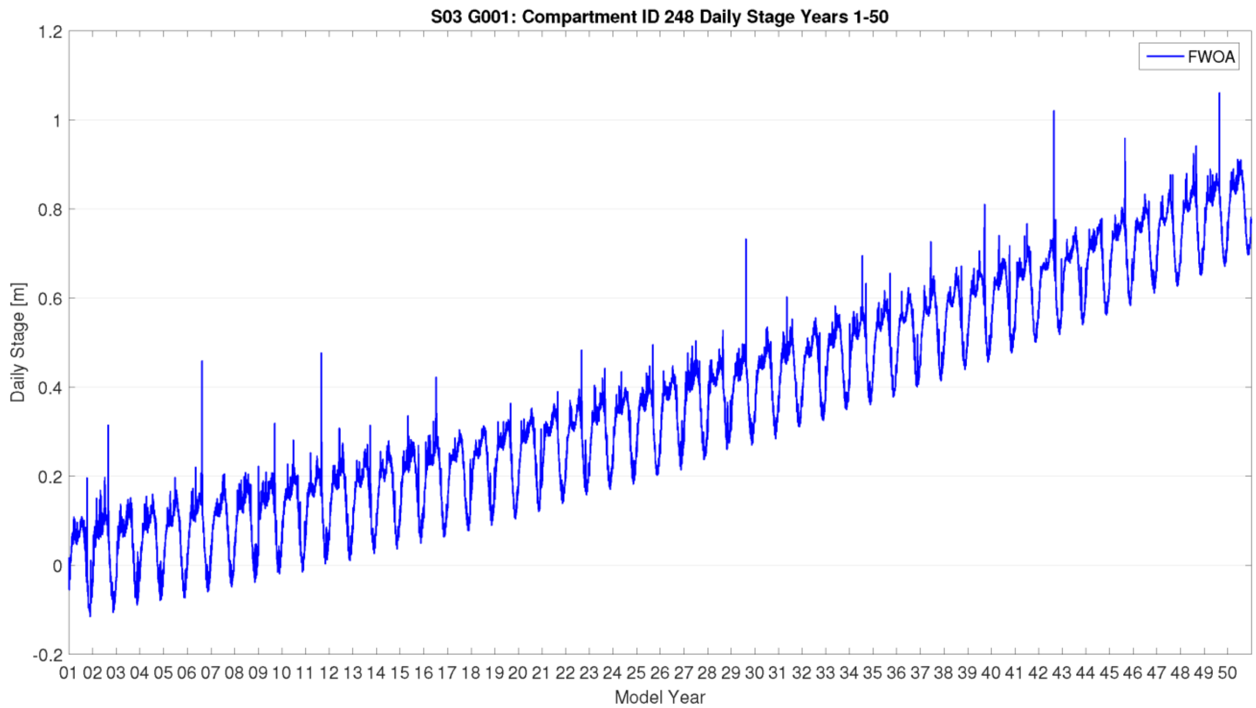


Figure 22: Mean Daily Stage in Compartment 248 - East Lake Salvador in PB for the High Scenario (Representative of Inland Compartment Results).

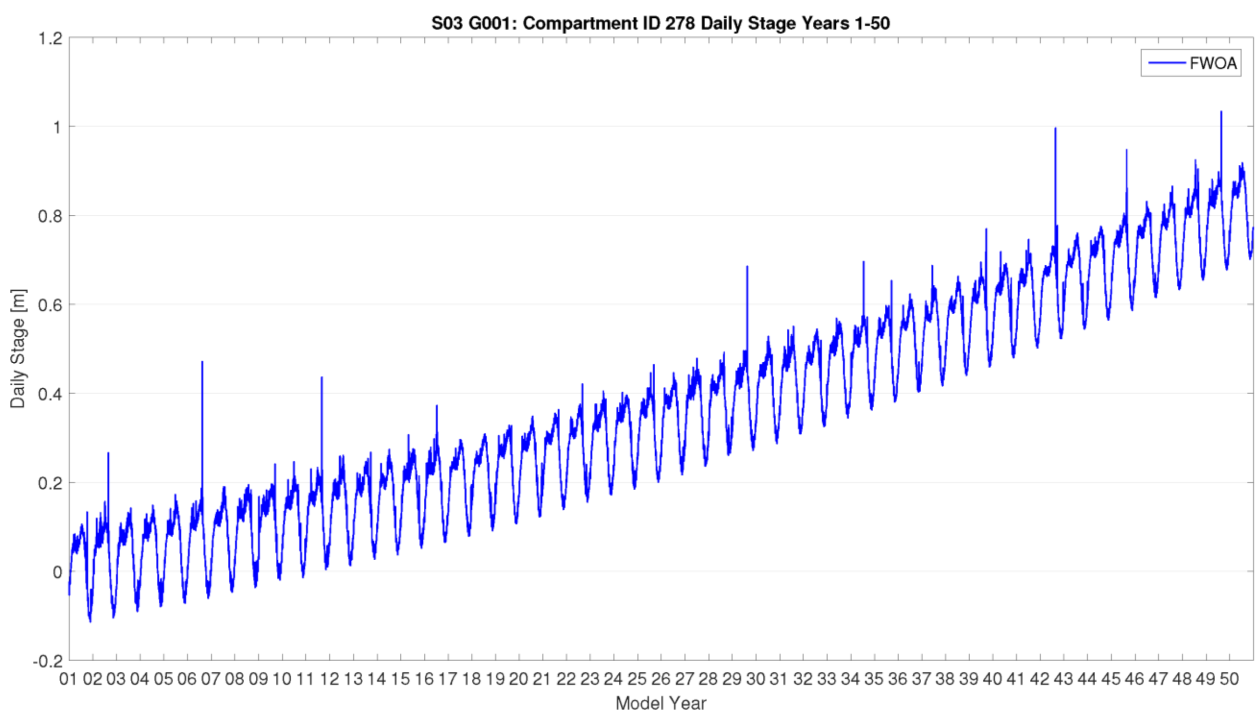


Figure 23: Mean Daily Stage in Compartment 278 - Mud Lake/Upper Barataria Bay in PB for the High Scenario (Representative of Intermediate Compartment Results).

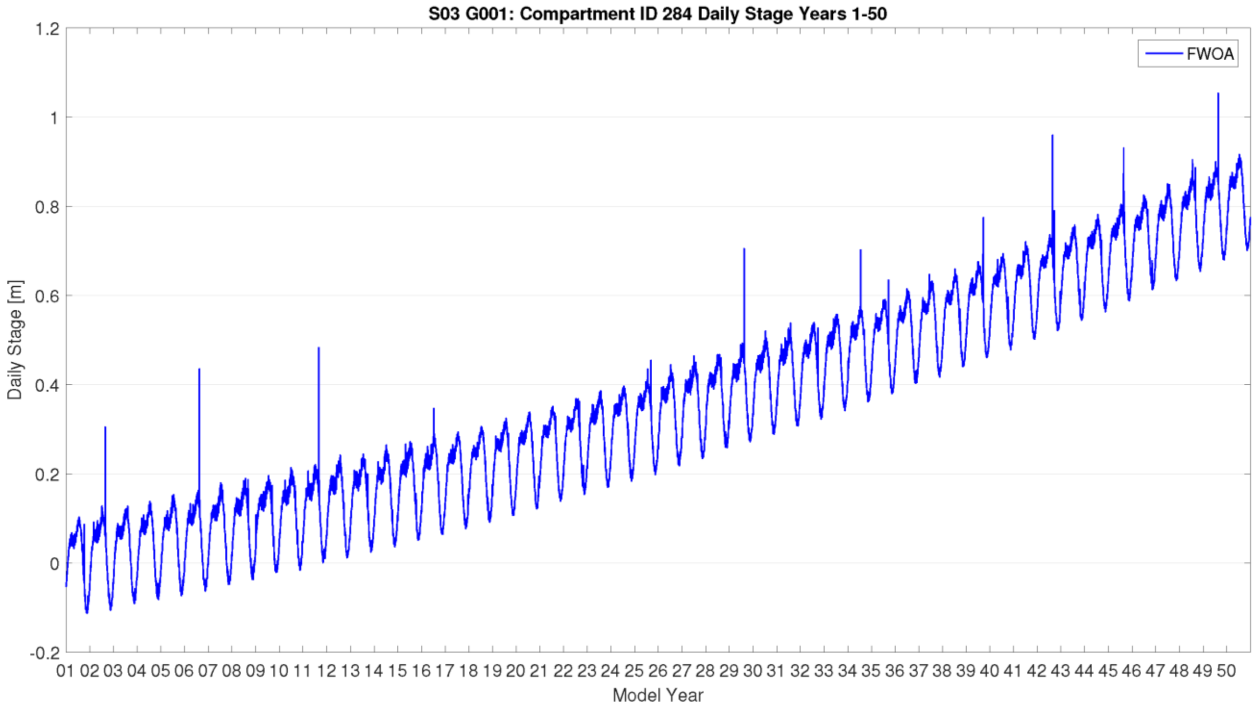


Figure 24: Mean Daily Stage in Compartment 284 - Northeast of Grand Isle in PB for the High Scenario (Representative of Near Coast Compartment Results).

Figure 25 through Figure 27 show the 50-year time series for mean daily stage for the AA (Atchafalaya/Terrebonne) region for the low scenario for the inland, intermediate, and near coast compartments, respectively.

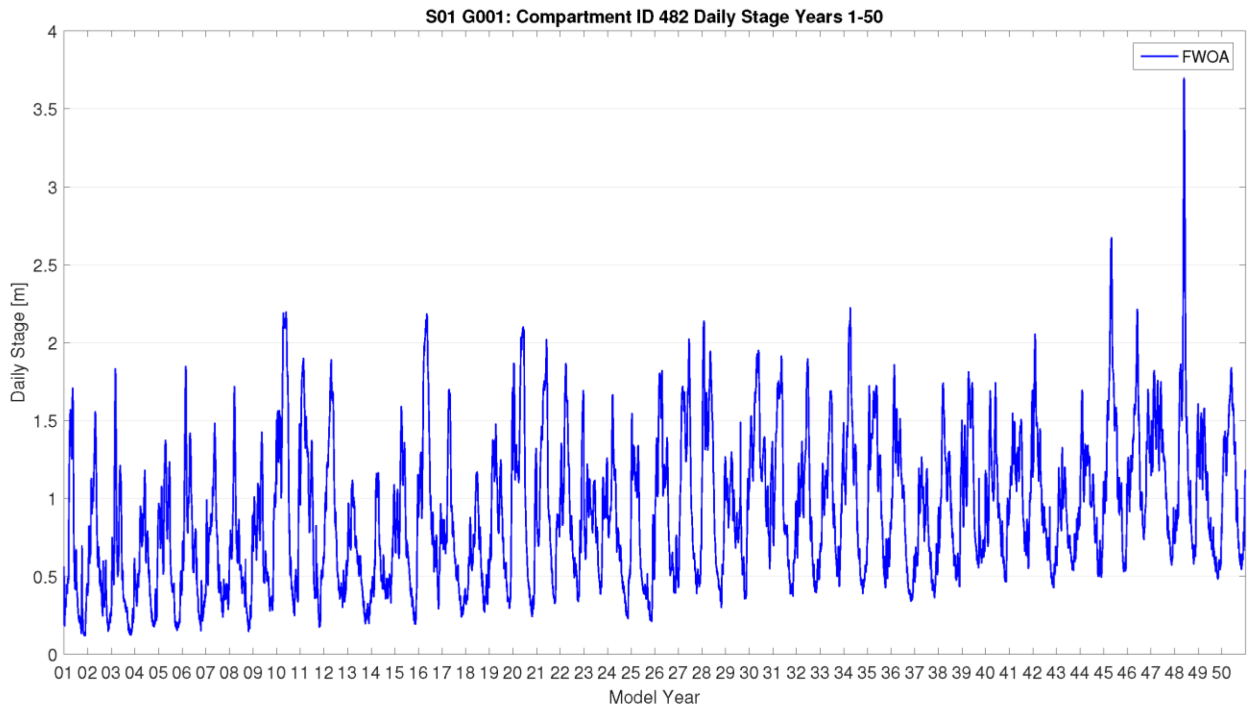


Figure 25: Mean Daily Stage in Compartment 482 – Lake Palourde in AA for the Low Scenario (Representative of Inland Compartment Results).

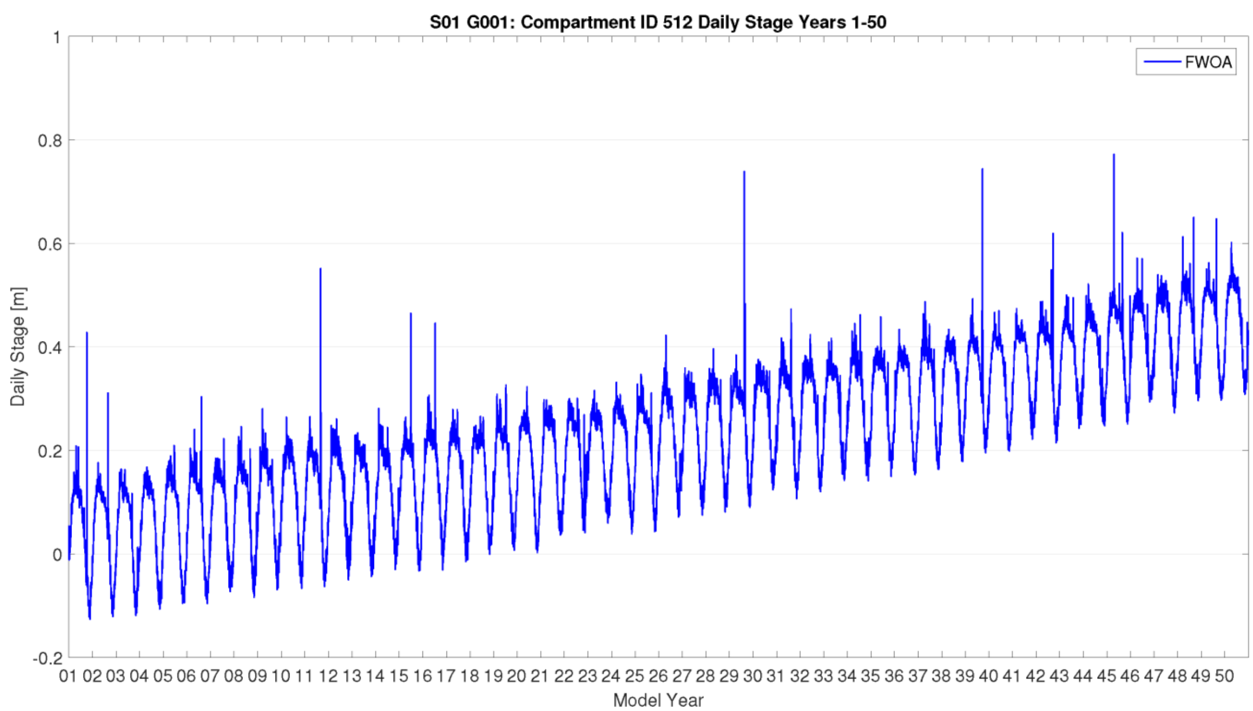


Figure 26: Mean Daily Stage in Compartment 512 – Lake de Cade in AA for the Low Scenario (Representative of Intermediate Compartment Results).

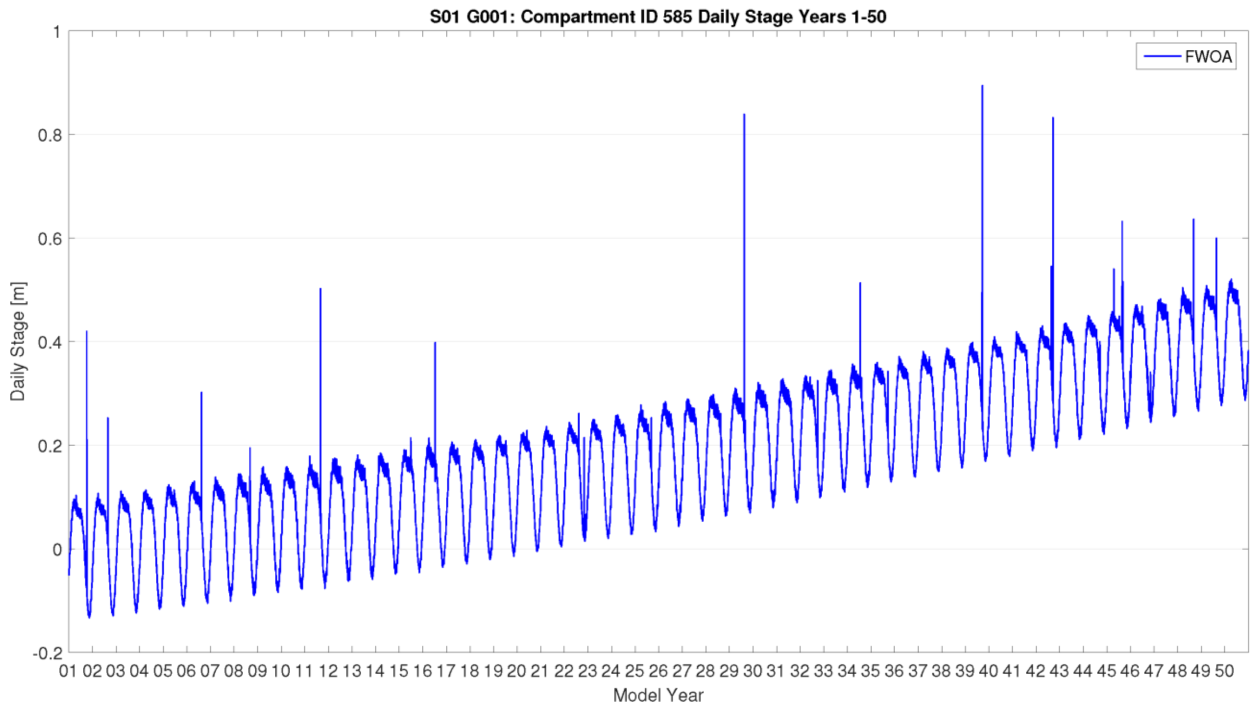


Figure 27: Mean Daily Stage in Compartment 585 – Caillou Bay in AA for the Low Scenario (Representative of Near Coast Compartment Results).

Figure 28 through Figure 30 show the 50-year time series for mean daily stage for the AA (Atchafalaya/Terrebonne) region for the high scenario for the inland, intermediate, and near coast compartments, respectively.

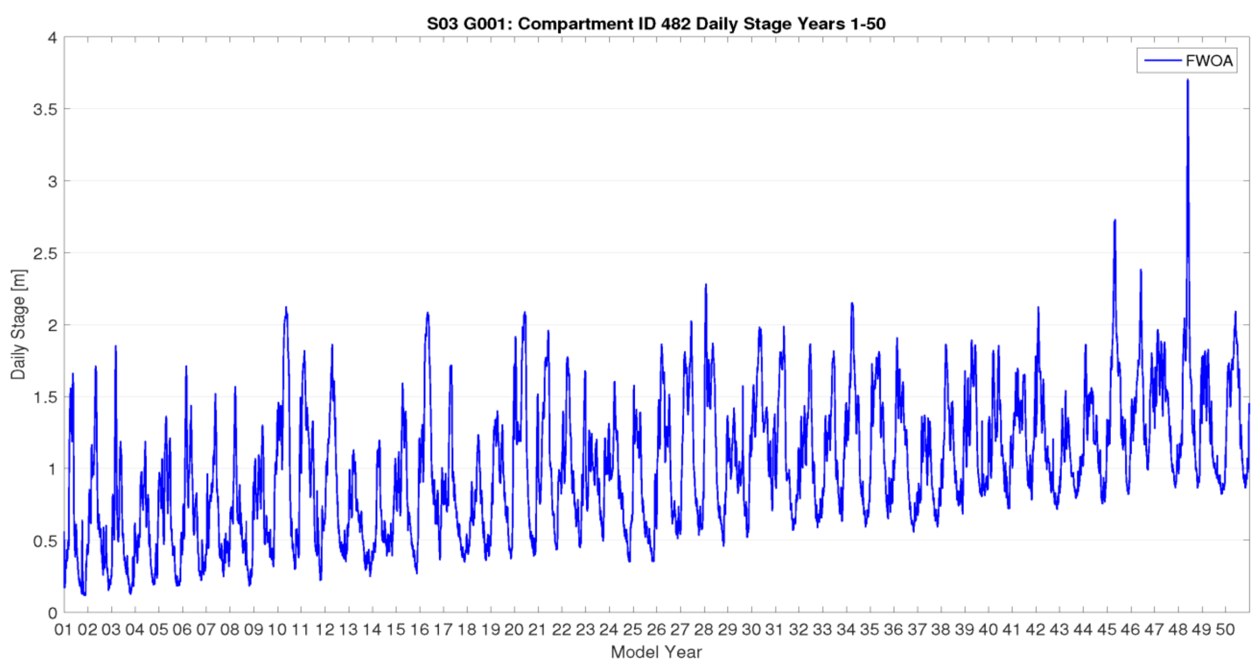


Figure 28: Mean Daily Stage in Compartment 482 – Lake Palourde in AA for the High Scenario (Representative of Inland Compartment Results).

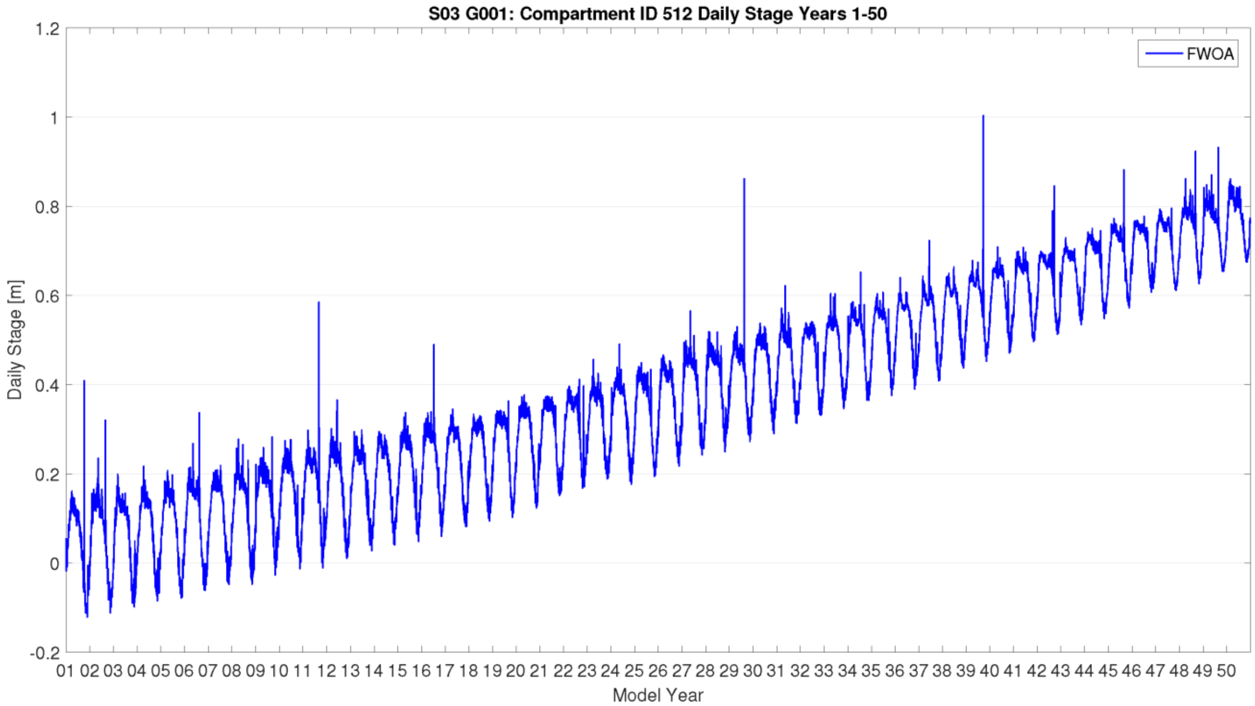


Figure 29: Mean Daily Stage in Compartment 512 – Lake de Cade in AA for the High Scenario (Representative of Intermediate Compartment Results).

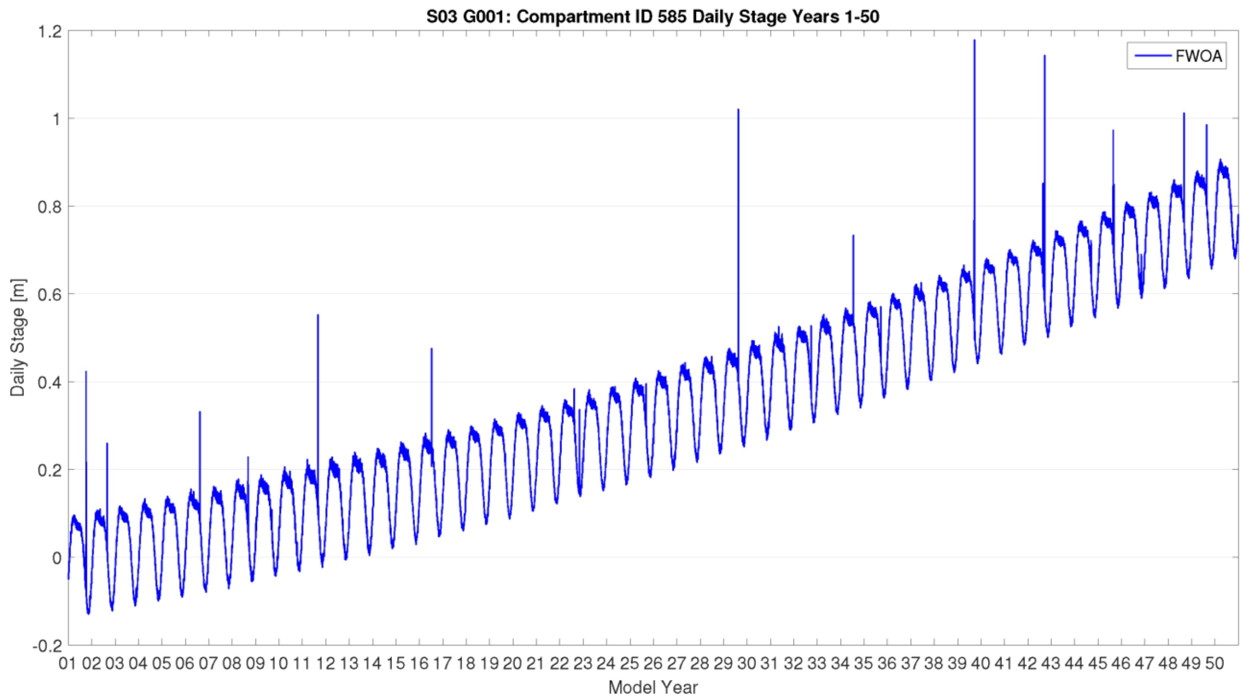


Figure 30: Mean Daily Stage in Compartment 585 – Caillou Bay in AA for the High Scenario (Representative of Near Coast Compartment Results).

Figure 31 through Figure 33 show the 50-year time series for mean daily stage for the Chenier Plain (CP) for the low scenario for the inland, intermediate, and near coast compartments, respectively. All of the CP stations showed indications of local hydrologic inputs due to rainfall or tributary inflows; this effect decreases from the inland compartment towards the coast.

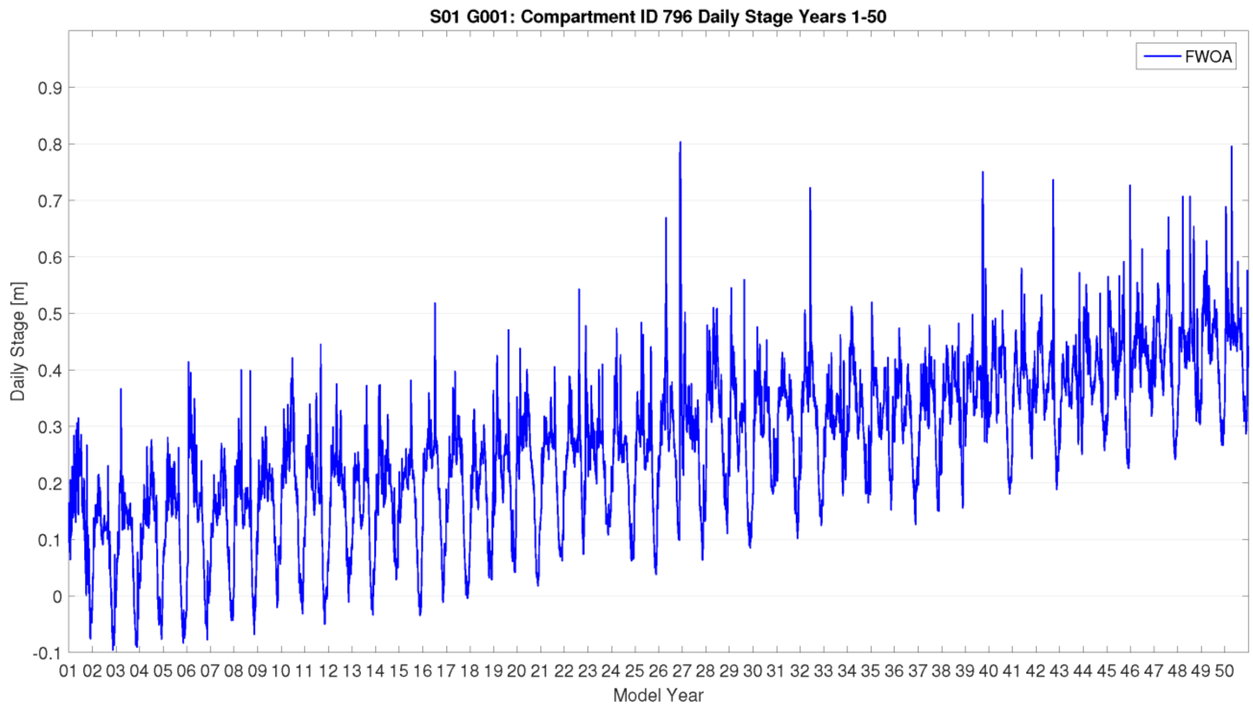


Figure 31: Mean Daily Stage in Compartment 796 – Northwest Grand Lake in CP for the Low Scenario (Representative of Inland Compartment Results).

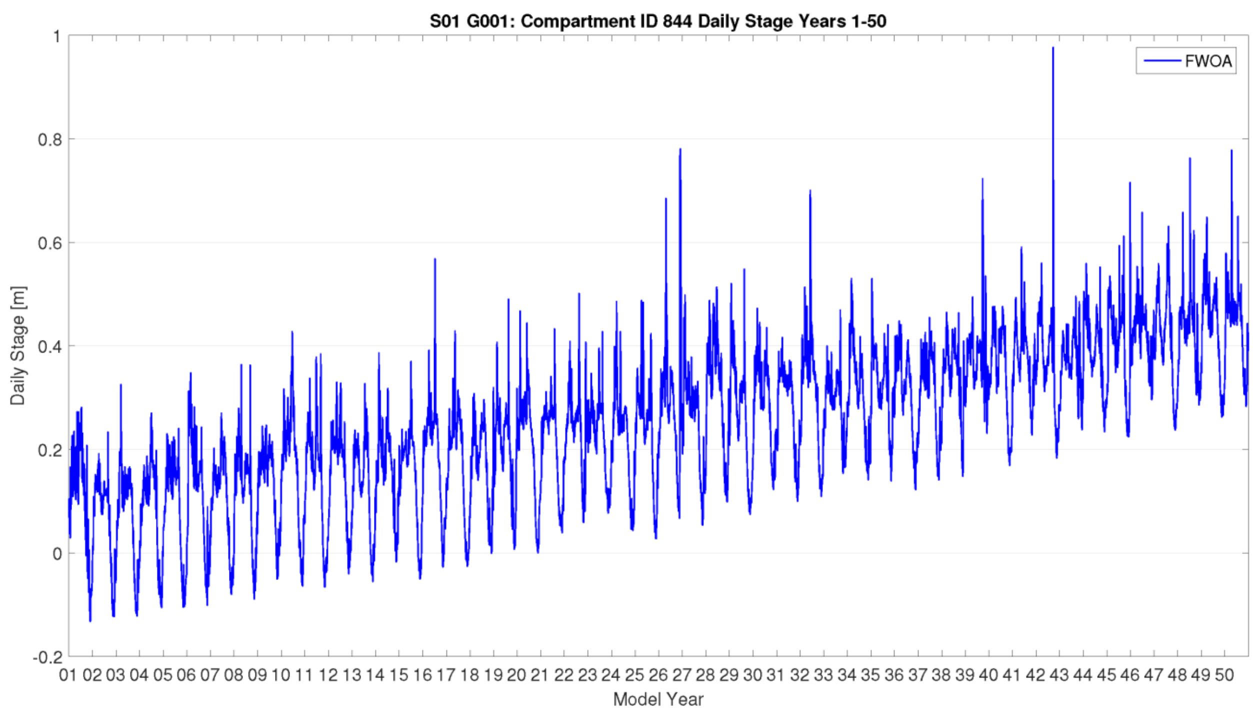


Figure 32: Mean Daily Stage in Compartment 844 – East Calcasieu Lake in CP for the Low Scenario (Representative of Intermediate Compartment Results).

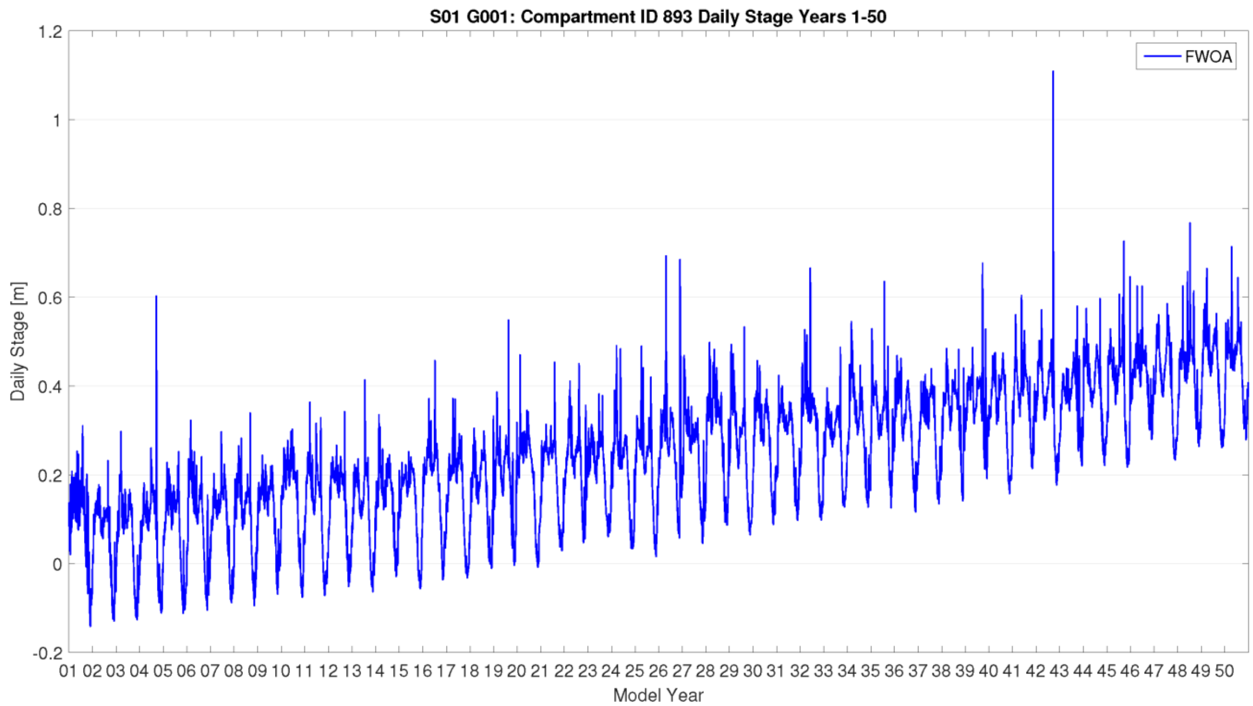


Figure 33: Mean Daily Stage in Compartment 893 – Holly Beach in CP for the Low Scenario (Representative of Near Coast Compartment Results).

Figure 34 through Figure 36 show the 50-year time series for mean daily stage for the Chenier Plain (CP) for high scenario for the inland, intermediate, and near coast compartments, respectively. The hydrologic signal noted in the low scenario is also present in the high scenario, but it is more subdued possibly because of the higher stage and increased tidal prism.

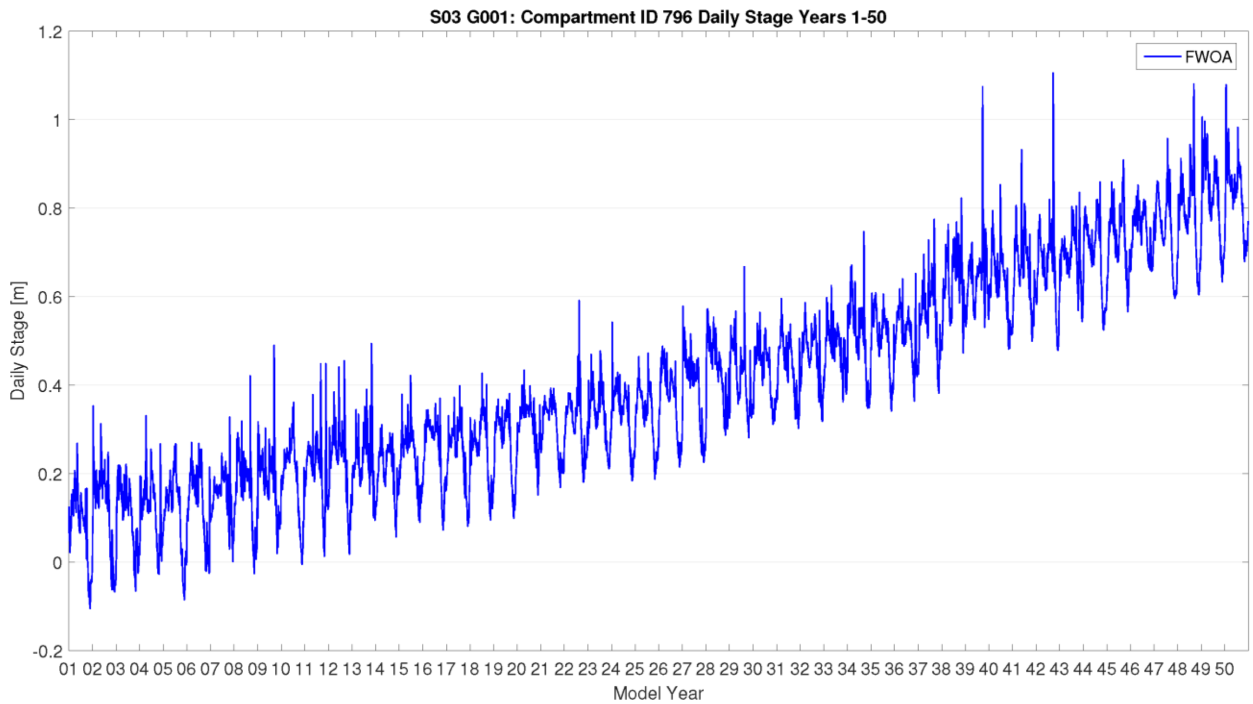


Figure 34: Mean Daily Stage in Compartment 796 – Northwest Grand Lake in CP for the High Scenario (Representative of Inland Compartment Results).

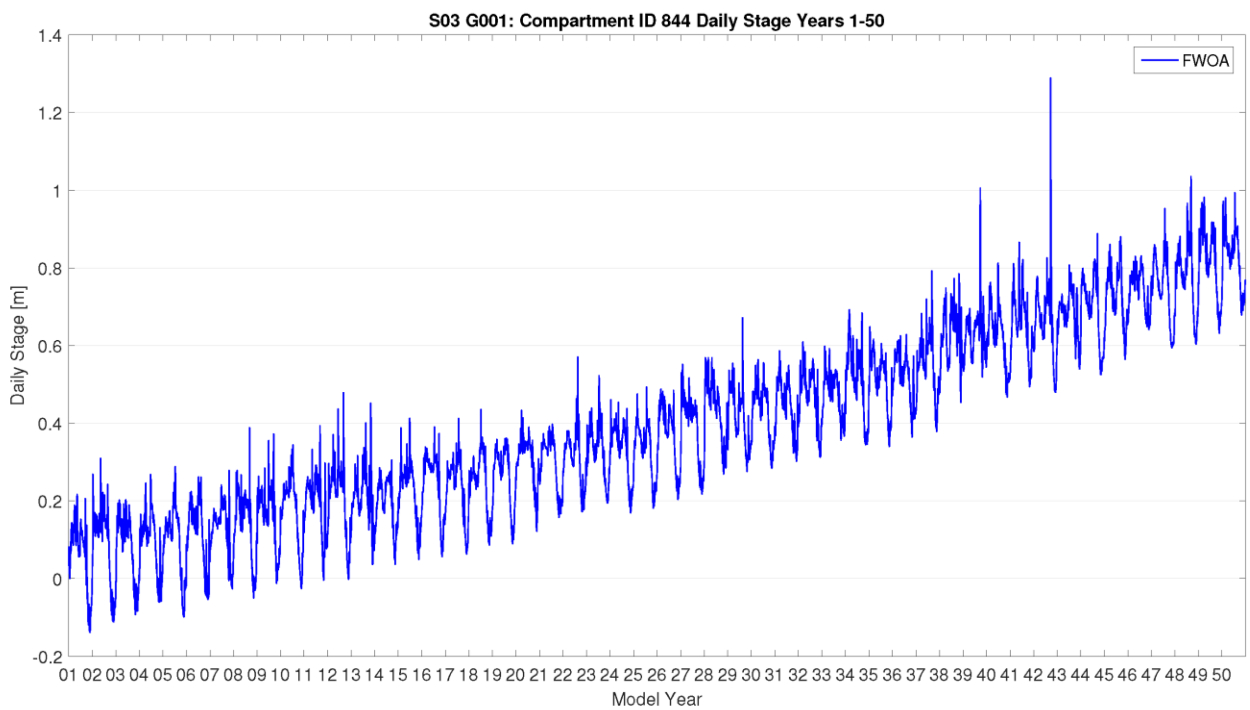


Figure 35: Mean Daily Stage in Compartment 844 – East Calcasieu Lake in CP for the High Scenario (Representative of Intermediate Compartment Results).

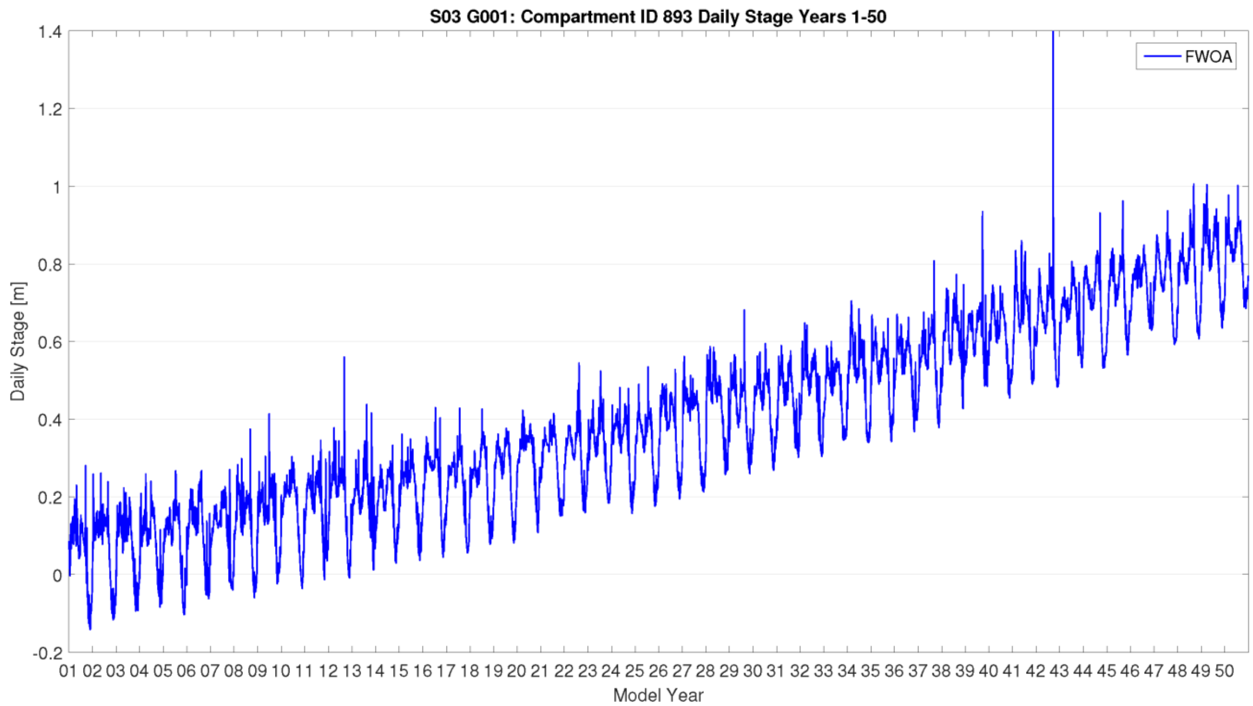
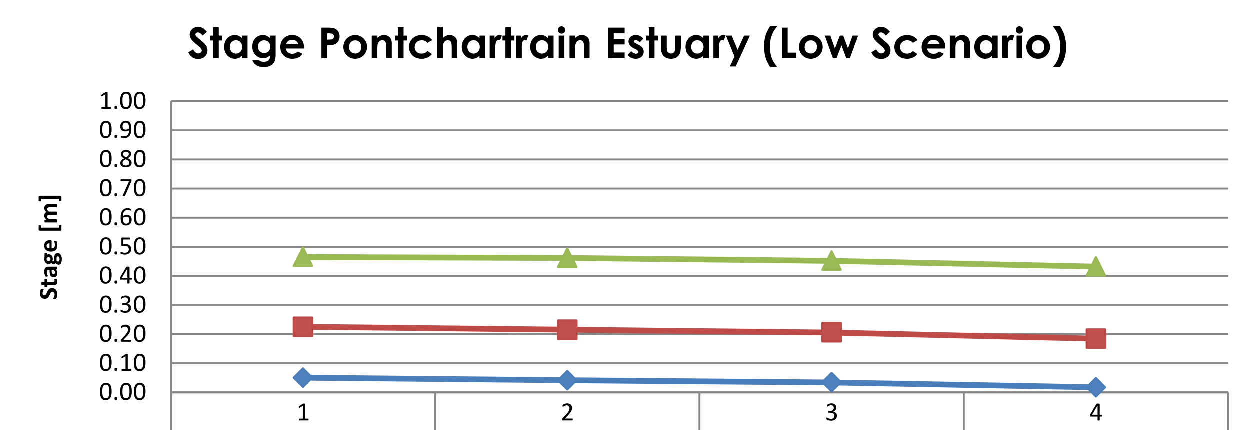


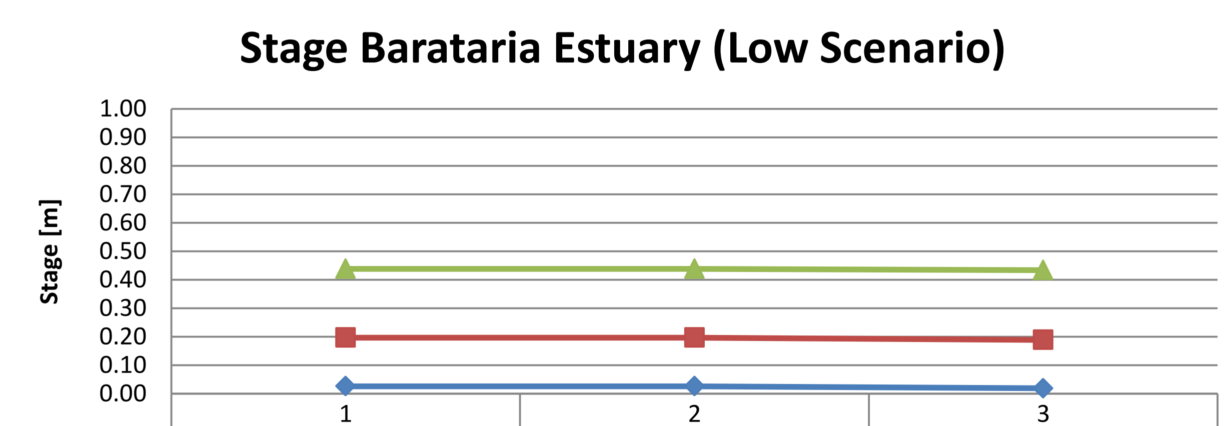
Figure 36: Mean Daily Stage in Compartment 893 – Holly Beach in CP for the High Scenario (Representative of Near Coast Compartment Results).

Figure 37 through Figure 42 present the temporal changes in the stage profile for the low, medium, and high scenarios for Pontchartrain Estuary and Barataria Estuary, respectively. Here, the stage profile references the stage versus position inland from the coast. These profiles show how the stage is very similar between the two estuaries for each scenario. Based on these relationships, the proximity to the Gulf is not a large driver in the stage values.



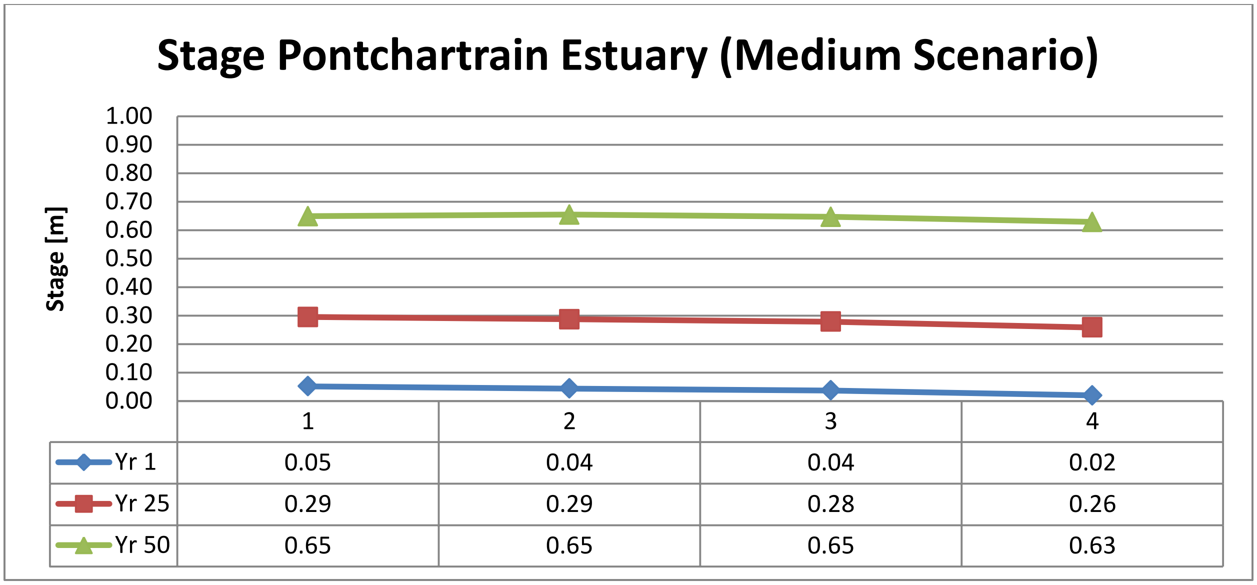
	1	2	3	4
Yr 1	0.05	0.04	0.03	0.02
Yr 25	0.22	0.21	0.21	0.18
Yr 50	0.46	0.46	0.45	0.43

Figure 37: Temporal Changes in the Stage Profiles for the Pontchartrain Estuary for the Low Scenario (1 = Inland; 2 = Intermediate; 3 = Near Coast; and 4 = Offshore).



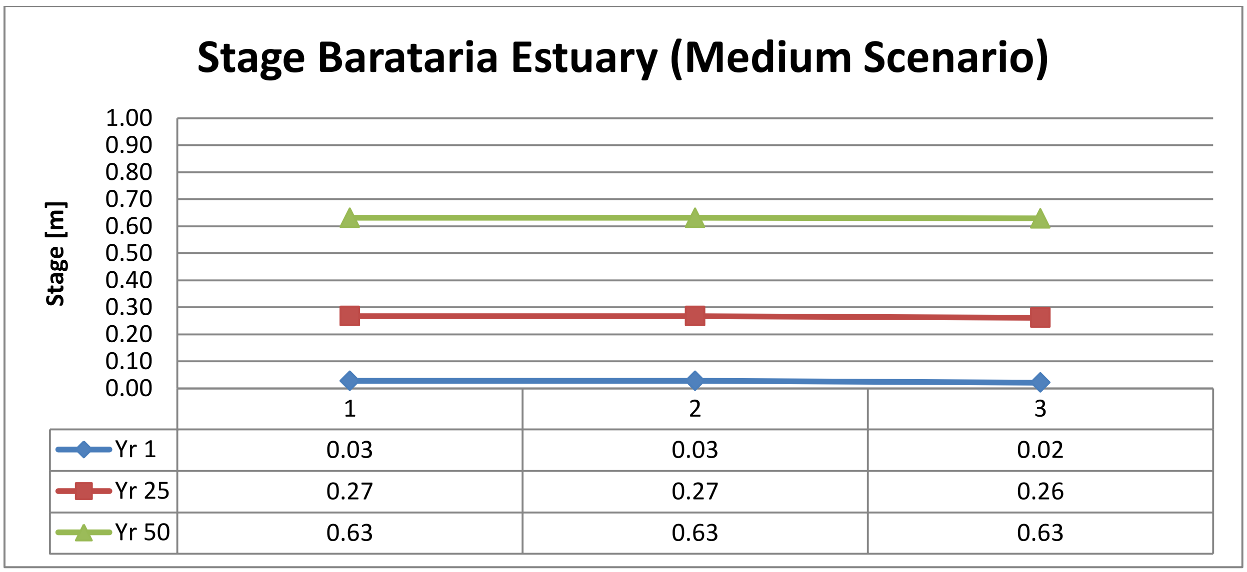
	1	2	3
Yr 1	0.03	0.03	0.02
Yr 25	0.20	0.20	0.19
Yr 50	0.44	0.44	0.43

Figure 38: Temporal Changes in the Stage Profiles for the Barataria Estuary for the Low Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).



	1	2	3	4
Yr 1	0.05	0.04	0.04	0.02
Yr 25	0.29	0.29	0.28	0.26
Yr 50	0.65	0.65	0.65	0.63

Figure 39: Temporal Changes in the Stage Profiles for the Pontchartrain Estuary for the Medium Scenario (1 = Inland; 2 = Intermediate; 3 = Near Coast; and 4 = Offshore).



	1	2	3
Yr 1	0.03	0.03	0.02
Yr 25	0.27	0.27	0.26
Yr 50	0.63	0.63	0.63

Figure 40: Temporal Changes in the Stage Profiles for the Barataria Estuary for the Medium Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).

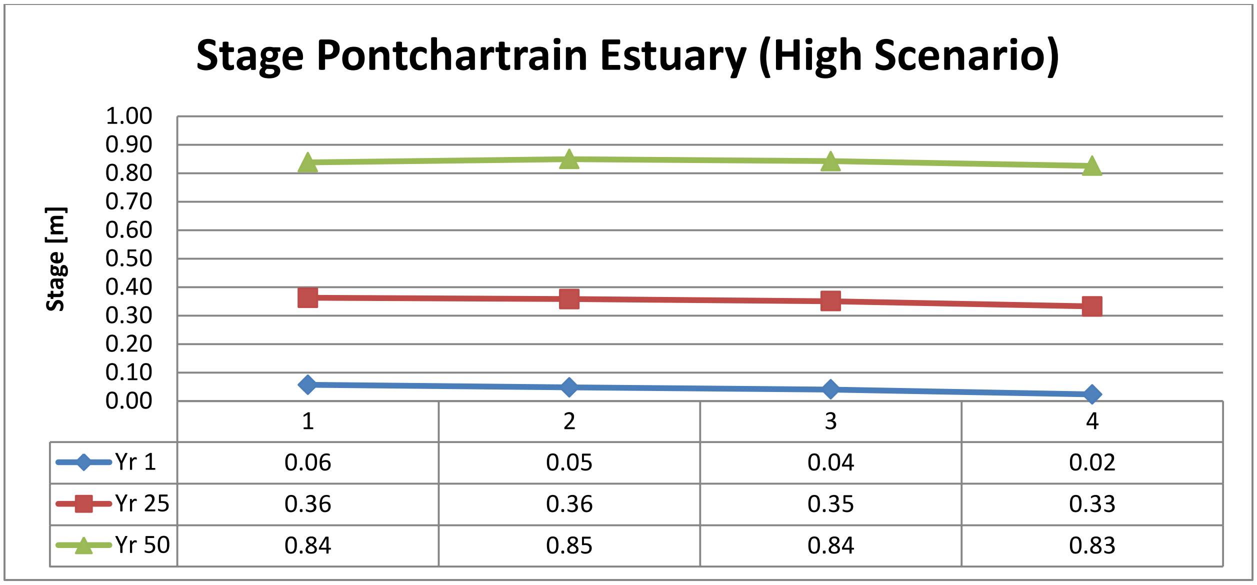


Figure 41: Temporal Changes in the Stage Profiles for the Pontchartrain Estuary for the High Scenario (1 = Inland; 2 = Intermediate; 3 = Near Coast; and 4 = Offshore).

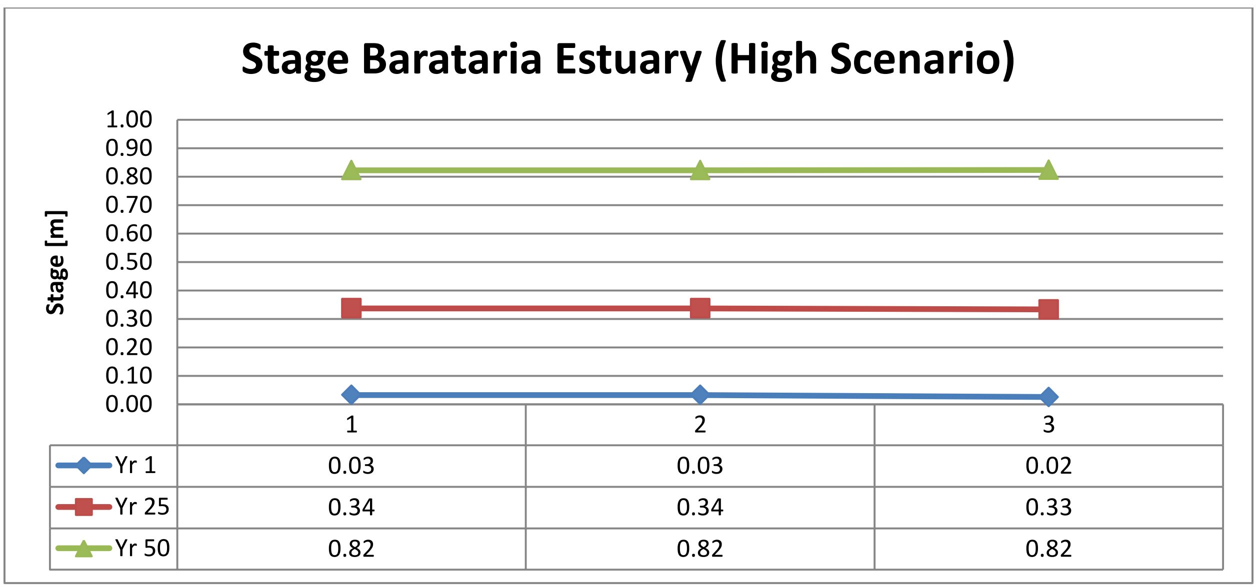
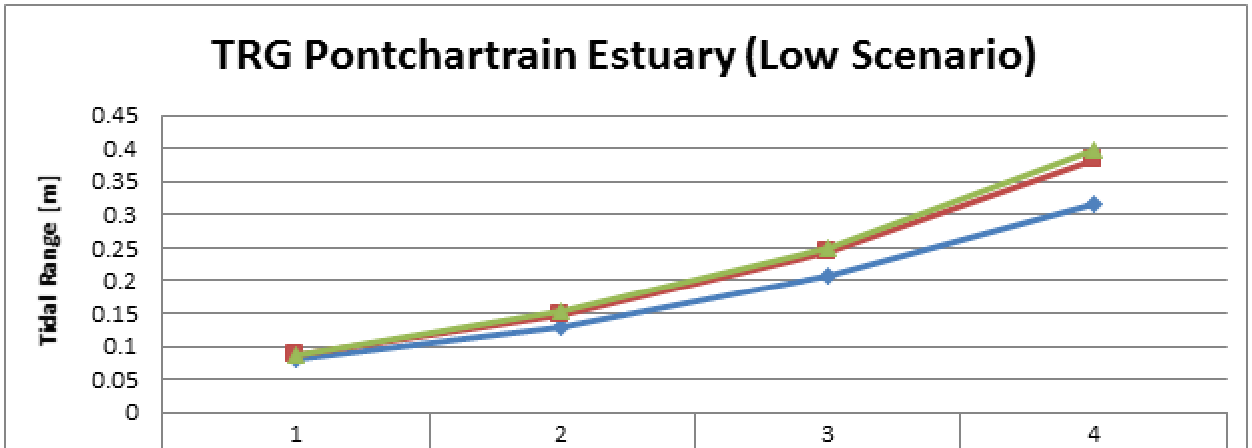


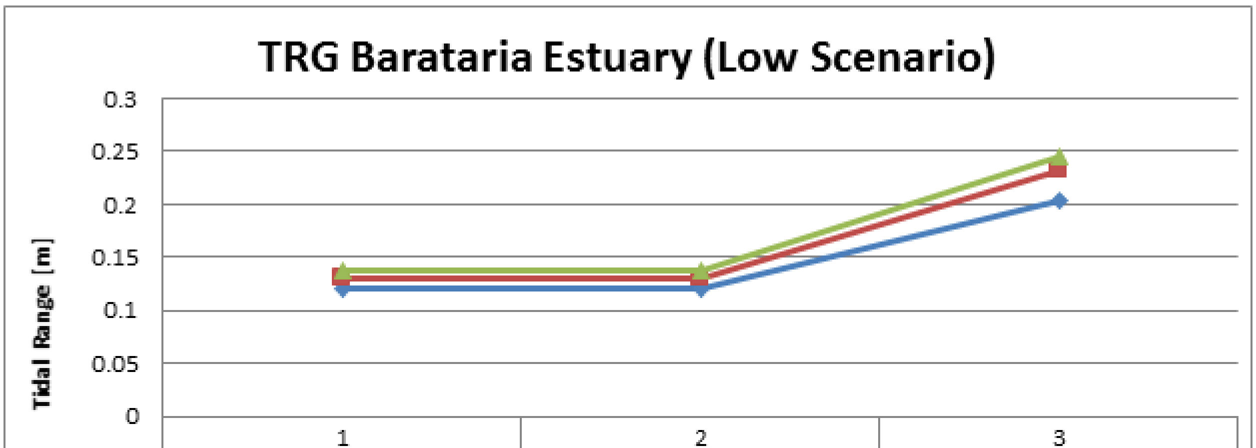
Figure 42: Temporal Changes in the Stage Profiles for the Barataria Estuary for the High Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).

In addition to the mean daily stage, the tidal range (TRG) was considered. Figure 43 and Figure 44 show the tidal range for the low scenario for Pontchartrain and Barataria (1 denotes the inland compartment; 2 refers to an intermediate compartment while 3 and 4 are the coastal areas). The TRG have been averaged for year 1, year 25 and year 50. In the Pontchartrain Estuary, there is a gradual attenuation of the tide going from the coast towards Lake Maurepas for all years. After 50 years, there is approximately 10% increase in the TRG. The coastal compartment in Barataria shows a similar increase in the TRG; however, the two inland locations experience slightly less increase. This is consistent with the progressive land loss within the basin and the associated deepening of the hydraulic conveyance links. The tidal prism is increased due to this increased TRG and the increased open water area.



	1	2	3	4
Yr 1	0.080	0.128	0.208	0.317
Yr 25	0.086	0.146	0.245	0.382
Yr 50	0.086	0.153	0.249	0.397

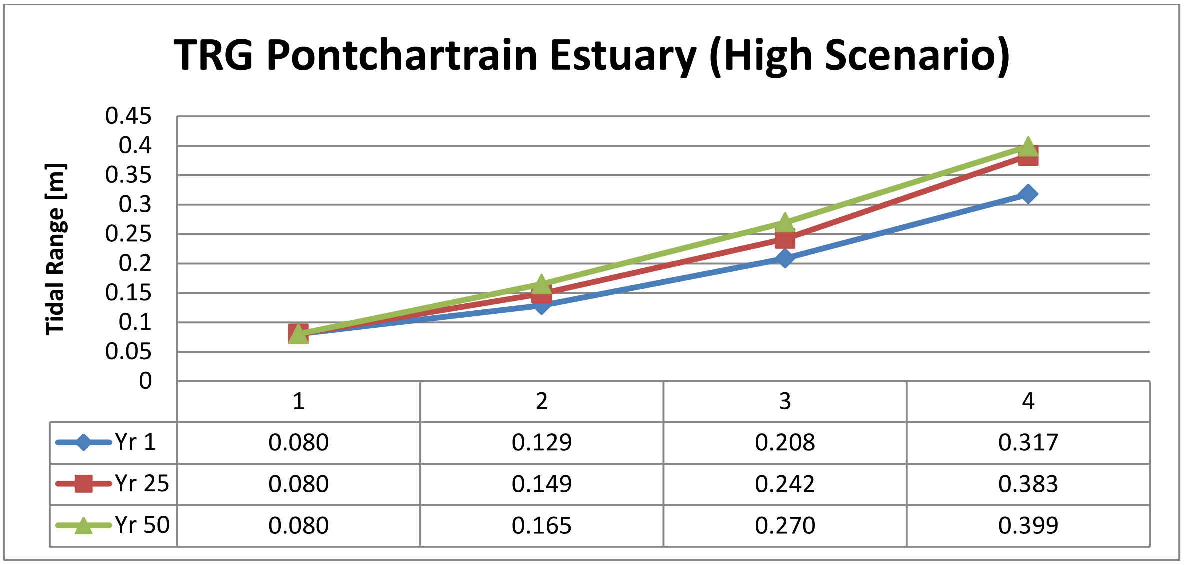
Figure 43: Mean Tidal Range as a Function of Location and Time for the Pontchartrain Estuary for the Low Scenario (1 = Inland; 2 = Intermediate; 3 = Near Coast; and 4 = Offshore).



	1	2	3
Yr 1	0.120	0.120	0.204
Yr 25	0.129	0.129	0.232
Yr 50	0.138	0.138	0.246

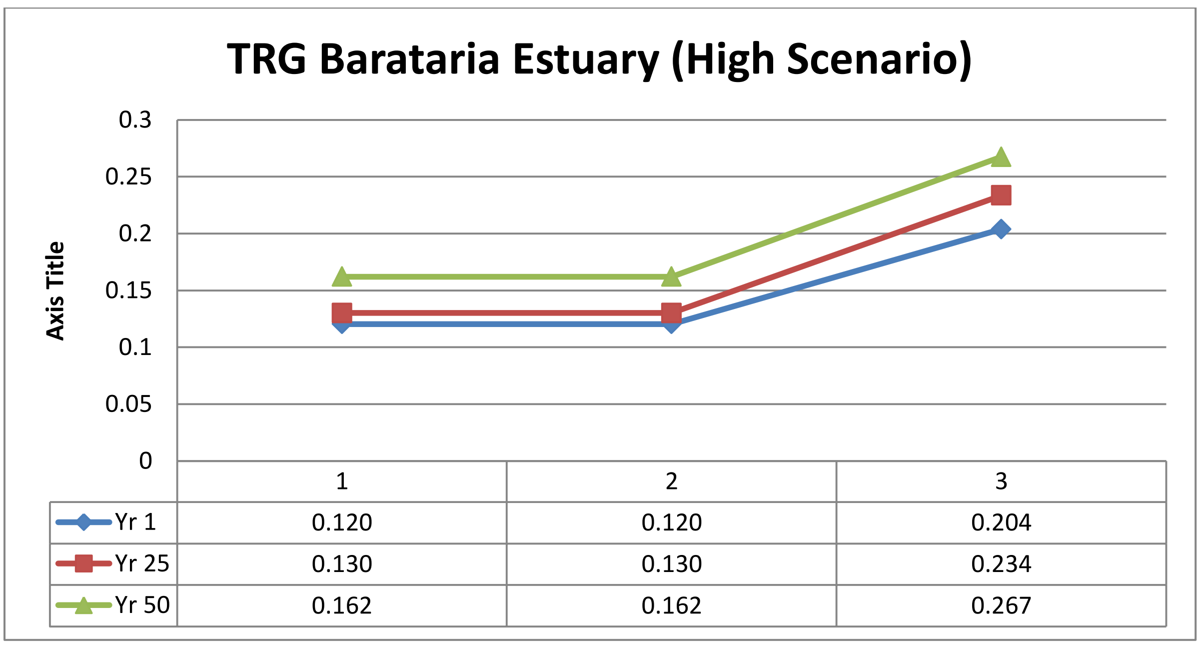
Figure 44: Mean Tidal Range as a Function of Location and Time for the Barataria Estuary for the Low Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).

Similarly, Figure 45 and Figure 46 show the TRG for the high scenario for PB (1 denotes the inland compartment; 2 refers to an intermediate compartment while 3 and 4 are the coastal areas). The TRG have been averaged for year 1, year 25 and year 50. In the Pontchartrain Estuary, there is a gradual attenuation of the tide going from the coast towards Lake Maurepas for all years. After 50 years, there is approximately 10% increase in the TRG. The coastal compartment in Barataria shows a similar increase in the TRG; however, the two inland locations experience slightly less increase. This is consistent with the progressive land loss within the basin and the associated deepening of the hydraulic conveyance links. The tidal prism is increased due to this increased TRG and the increased open water area. The difference between the low and high scenario is approximately 10%, which can be attributed to the increased sea level rise in the high scenario.



	1	2	3	4
Yr 1	0.080	0.129	0.208	0.317
Yr 25	0.080	0.149	0.242	0.383
Yr 50	0.080	0.165	0.270	0.399

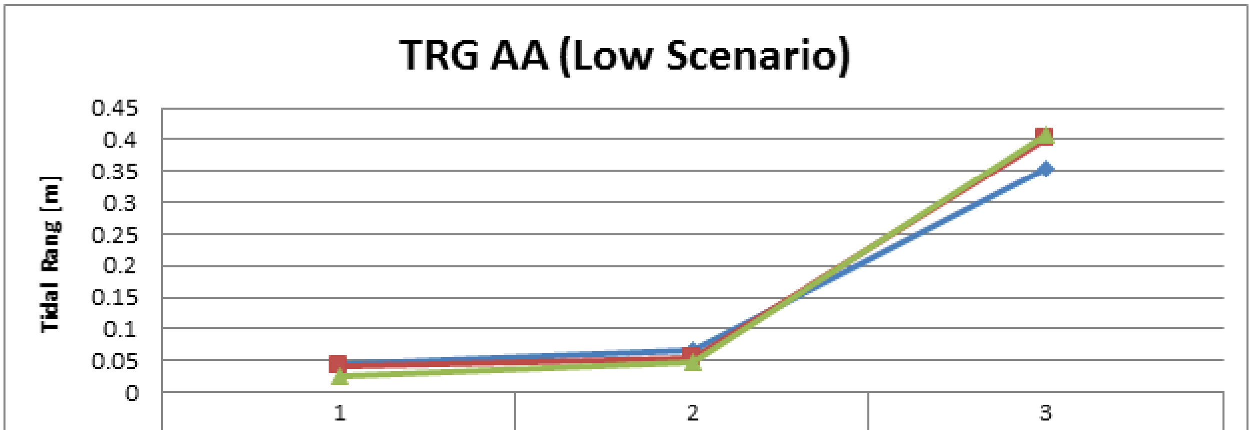
Figure 45: Mean Tidal Range as a Function of Location and Time for the Pontchartrain Estuary for the High Scenario (1 = Inland; 2 = Intermediate; 3 = Near Coast; and 4 = Offshore).



	1	2	3
Yr 1	0.120	0.120	0.204
Yr 25	0.130	0.130	0.234
Yr 50	0.162	0.162	0.267

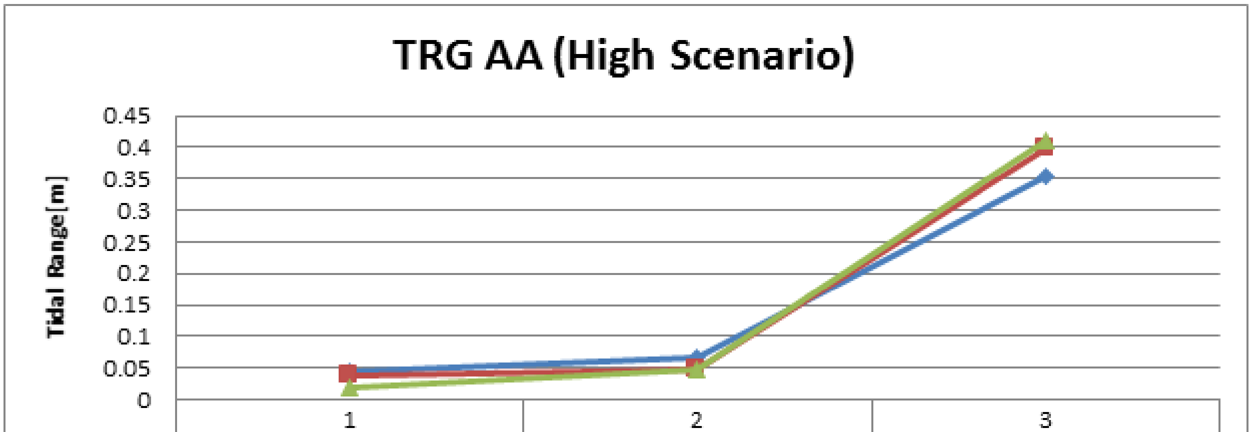
Figure 46: Mean Tidal Range as a Function of Location and Time for the Barataria Estuary for the High Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).

In the AA region, TRG is overwhelmed by the influence of the Atchafalaya River. Figure 47and Figure 48 show the large riverine related tidal attenuation at the interior cells for the low scenario and high scenario. Similar results occurred for the medium scenario, indicating that (regardless of scenario) there is a strong riverine influence in the AA region.



	1	2	3
Yr 1	0.043	0.067	0.354
Yr 25	0.040	0.054	0.400
Yr 50	0.027	0.047	0.408

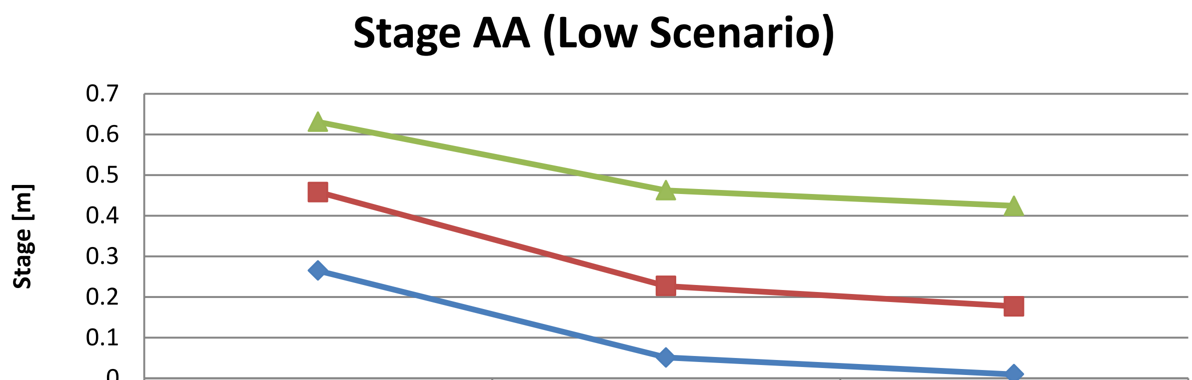
Figure 47: Temporal Changes in the Tidal Range Profile for AA for the Low Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).



	1	2	3
Yr 1	0.045	0.068	0.354
Yr 25	0.037	0.047	0.400
Yr 50	0.019	0.046	0.410

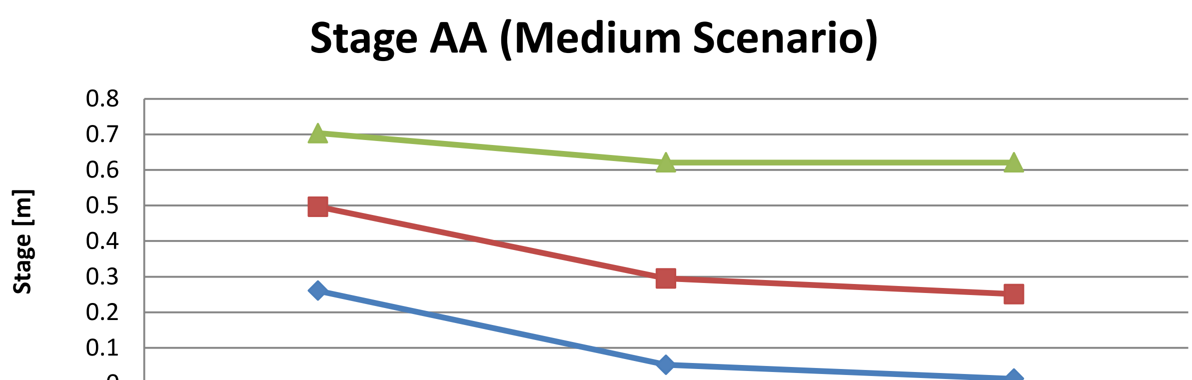
Figure 48: Temporal Changes in the Tidal Range Profile for AA for the High Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).

Figure 49 through Figure 51 present the temporal changes in the stage profile for the low, medium, and high scenarios, respectively. Here, the stage profile references the stage versus position inland from the coast. These profiles show how the backwater from the Gulf affects the river stages.



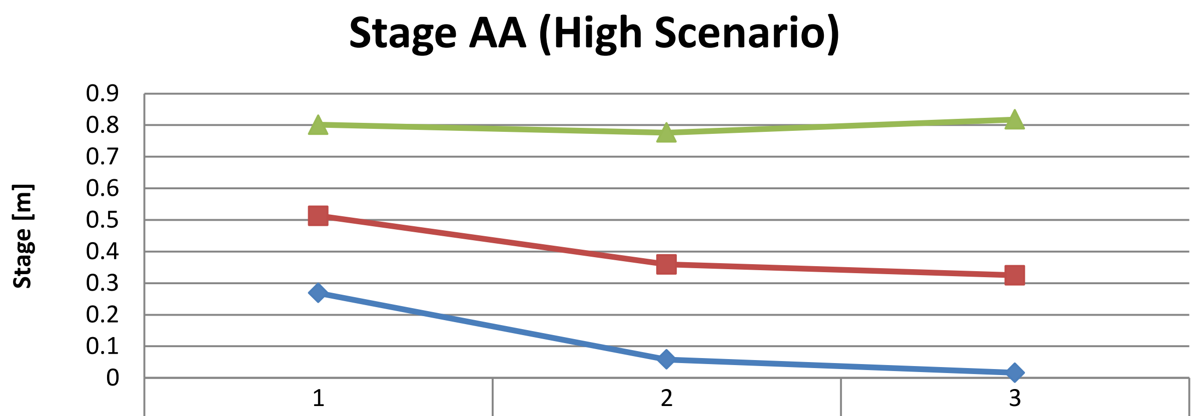
	1	2	3
Yr 1	0.26	0.05	0.01
Yr 25	0.46	0.23	0.18
Yr 50	0.63	0.46	0.42

Figure 49: Temporal Changes in the Stage Profiles for AA for the Low Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).



	1	2	3
Yr 1	0.26	0.05	0.01
Yr 25	0.50	0.30	0.25
Yr 50	0.70	0.62	0.62

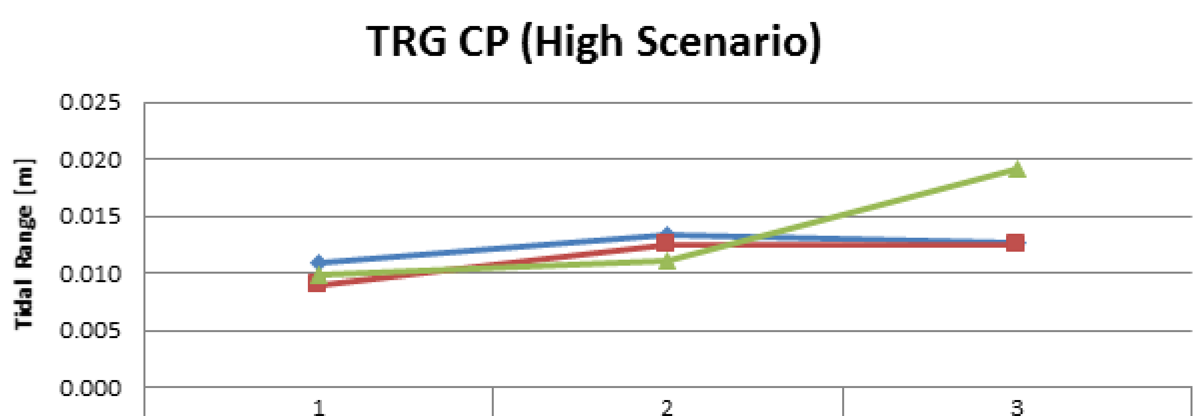
Figure 50: Temporal Changes in the Stage Profiles for AA for the Medium Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).



	1	2	3
Yr 1	0.27	0.06	0.02
Yr 25	0.51	0.36	0.32
Yr 50	0.80	0.78	0.82

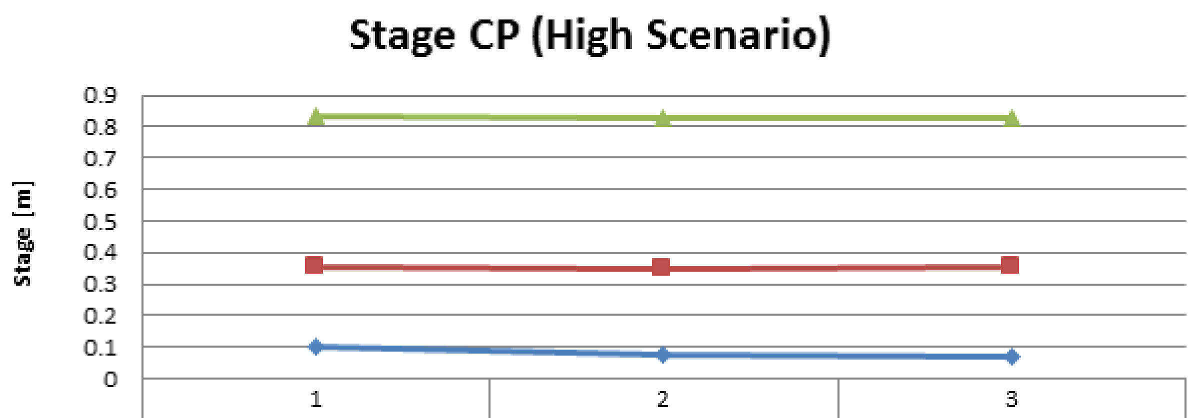
Figure 51: Temporal Changes in the Stage Profiles for AA for the High Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).

The mean TRG in CP at all three selected compartments is very small for the low and medium scenarios, and it remains low for 50 years. The higher relative sea level rise rate in the high scenario resulted in an increase in the mean TRG at the coastal compartment; however, it still remains quite small (Figure 52). The corresponding high scenario stage profiles essentially follow the Gulf stage as illustrated in Figure 53. The difference in mean stage between the coastal compartment and the inland compartment is about 8 cm in year 1 and 1 cm in year 50. It appears as though, in year 50 in the coastal compartment, the compartment is receiving more tidal influence, which may correspond with sea level rise and a subsequent increase overland flow.



	1	2	3
Yr 1	0.011	0.013	0.013
Yr 25	0.009	0.012	0.013
Yr 50	0.010	0.011	0.019

Figure 52: Temporal Changes in the Tidal Range Profile for CP for the High Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).



	1	2	3
Yr 1	0.10	0.08	0.07
Yr 25	0.35	0.35	0.36
Yr 50	0.83	0.83	0.83

Figure 53: Temporal Changes in the Stage Profiles for CP for the High Scenario (1= Inland; 2 = Intermediate; and 3 = Coastal).

3.2 Salinity

The temporal response of the cross-coast salinity gradient varies greatly from one region to another under all scenarios. Figure 54 shows the coast wide mean salinities for year 50 for the medium scenario. The mean annual system salinity for all of the compartments is 7.1 ppt in year 1. After 50 years, the mean system salinity increased to 10.7 ppt for the low scenario, 13.4 ppt for the medium scenario, and 15 ppt for the high scenario. This indicates a strong saltwater intrusion for all scenarios presumably with relative sea level rise as a major driver. There are a few anomalous compartments in each region that are possibly due to instabilities related to low hydraulic conveyance in the connecting links coupled with low open water areas; this can lead to intermittent activation of the marsh links as the sea level rises. This intermittent activation leads to false projections of flushing or stagnation of singular compartments. The issue was addressed in version 3 of the ICM code (ICM_v3; refer to Attachment C3-22: ICM Development).

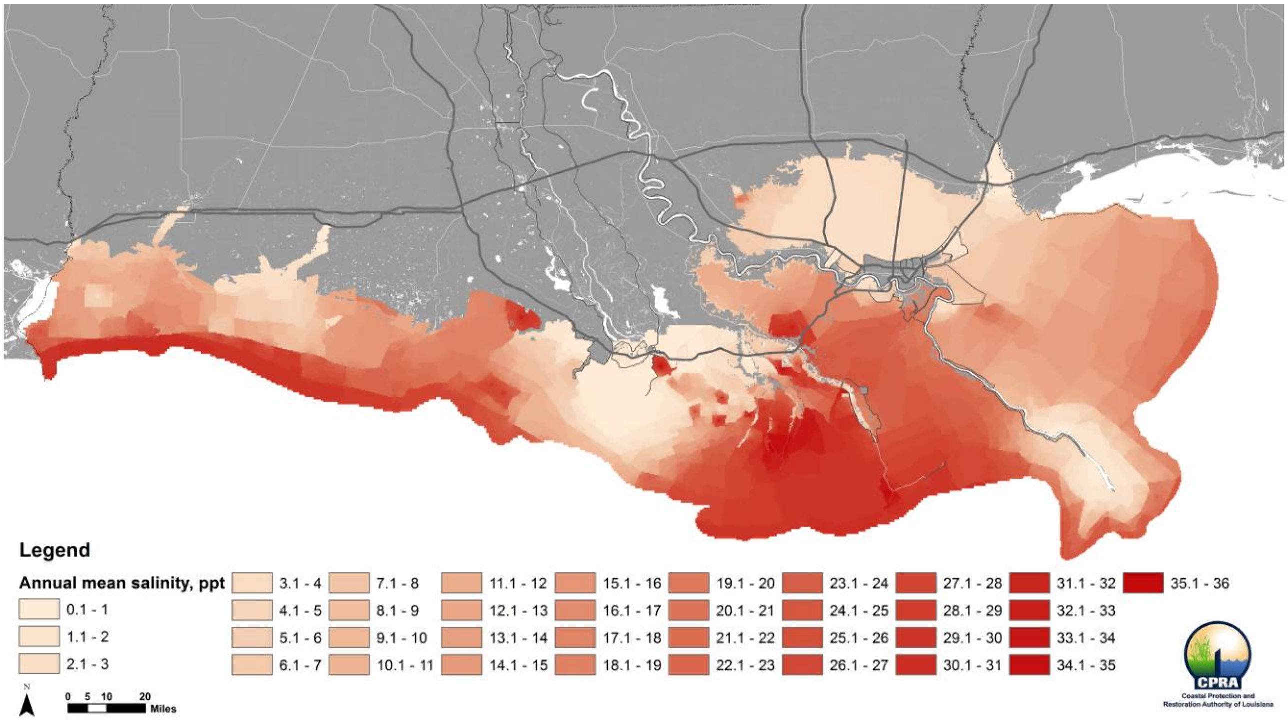


Figure 54: Mean Salinities (ppt) by Compartment for Year 50 for the Medium Scenario FWOA (G001).

Figure 55 through Figure 57 show the 50-year time series for mean monthly salinity for PB (Barataria Basin) for the low scenario for the inland, intermediate, and near coast compartments, respectively. The averaging has filtered the diurnal tide effects and most wind effects. Increasing salinity reaches the inland compartment at about year 33. An increase in salinity is noted in the intermediate compartment starting in year 30.

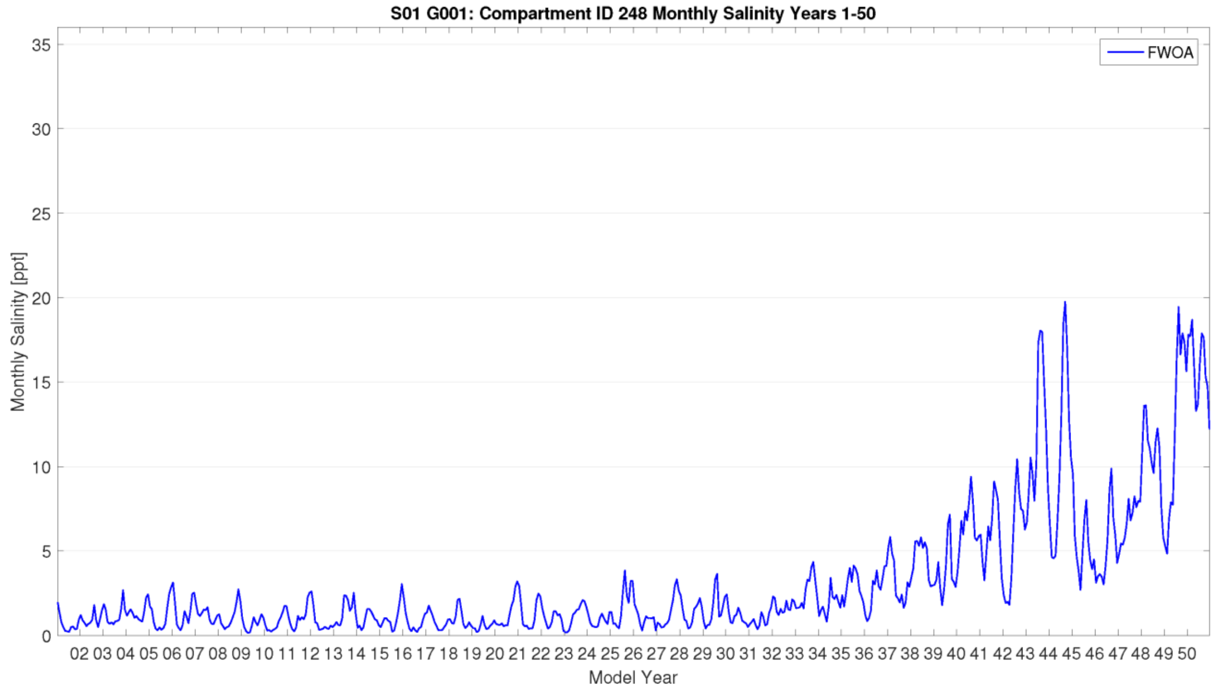


Figure 55: Mean Monthly Salinity in Compartment 248 - East Lake Salvador in PB for the Low Scenario (Representative of Inland Compartment Results).

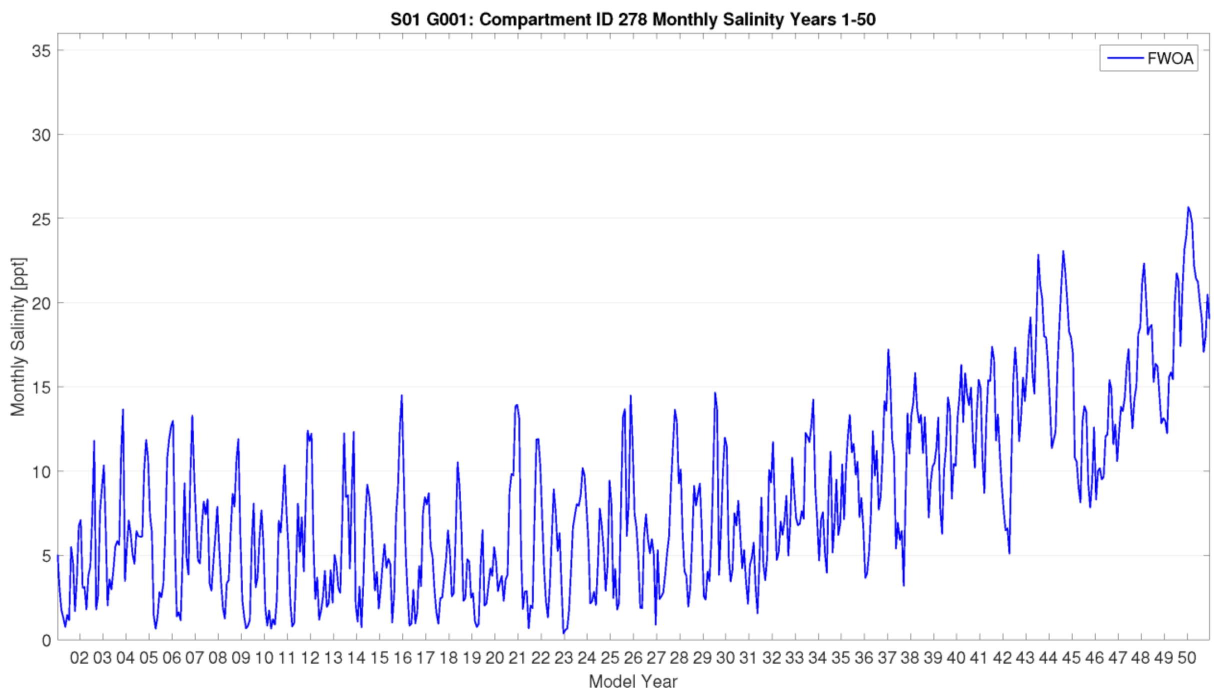


Figure 56: Mean Monthly Salinity in Compartment 278 - Mud Lake/Upper Barataria Bay in PB for the Low Scenario (Representative of Intermediate Compartment Results).

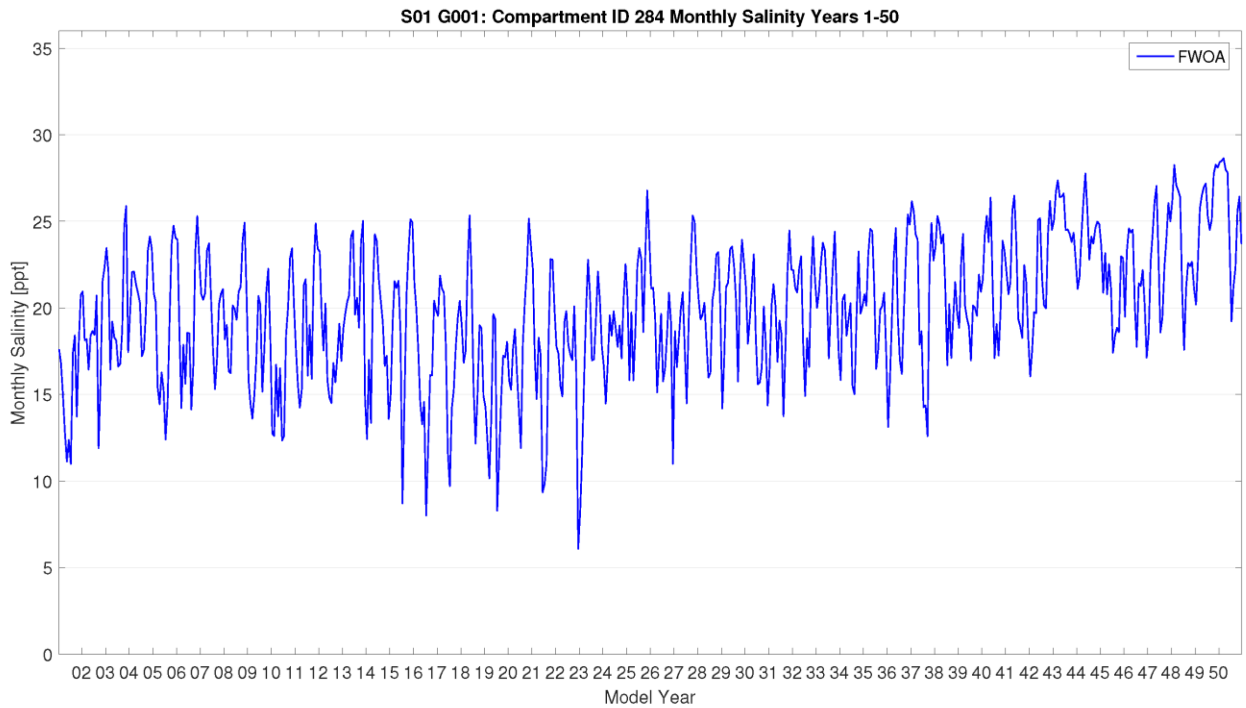


Figure 57: Mean Monthly Salinity in Compartment 284 -Northeast of Grand Isle in PB for the Low Scenario (Representative of Near Coast Compartment Results).

Figure 58 through Figure 60 show the 50-year time series for mean monthly salinity for PB (Barataria Basin) for the high scenario for the inland, intermediate, and near coast compartments, respectively. Salinity increases in the inland compartment in about year 18. An increase in salinity is noted in the intermediate compartment starting in year 10. After 50 years, the mean daily salinity for the high scenario is approximately 10 ppt higher than for the low scenario and 3 ppt higher than the medium scenario.

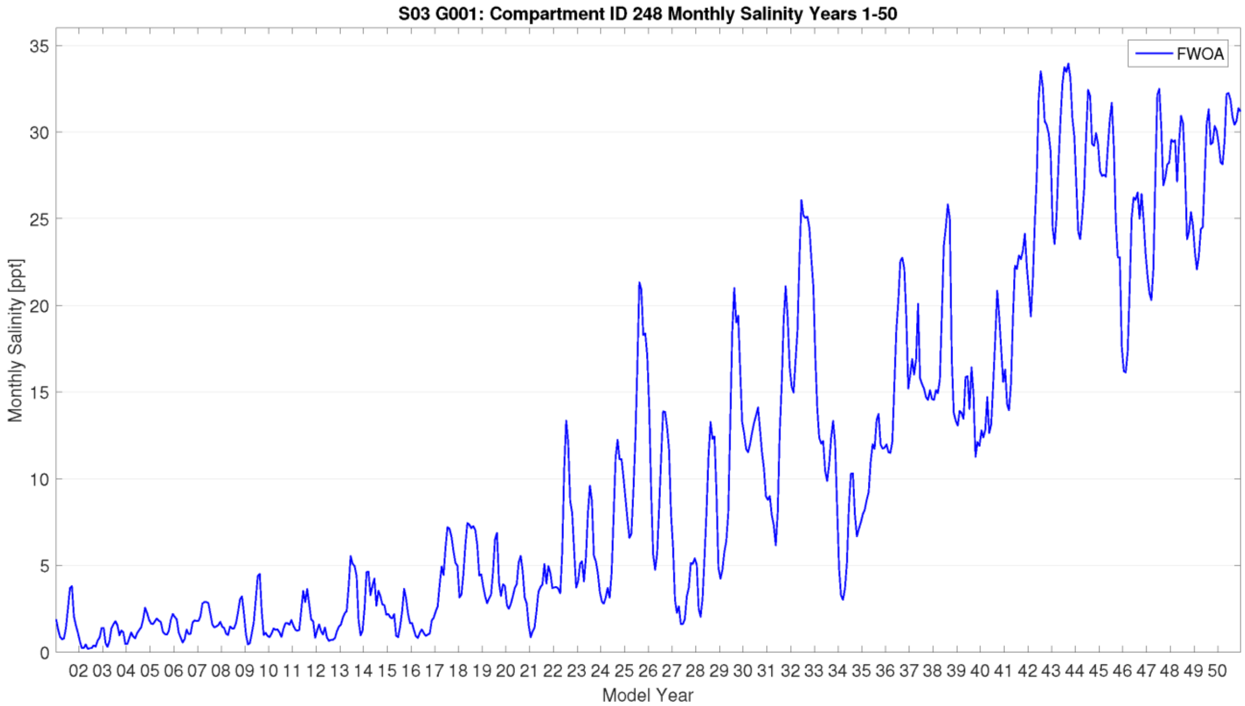


Figure 58: Mean Monthly Salinity in Compartment 248 - East Lake Salvador in PB for the High Scenario (Representative of Inland Compartment Results).

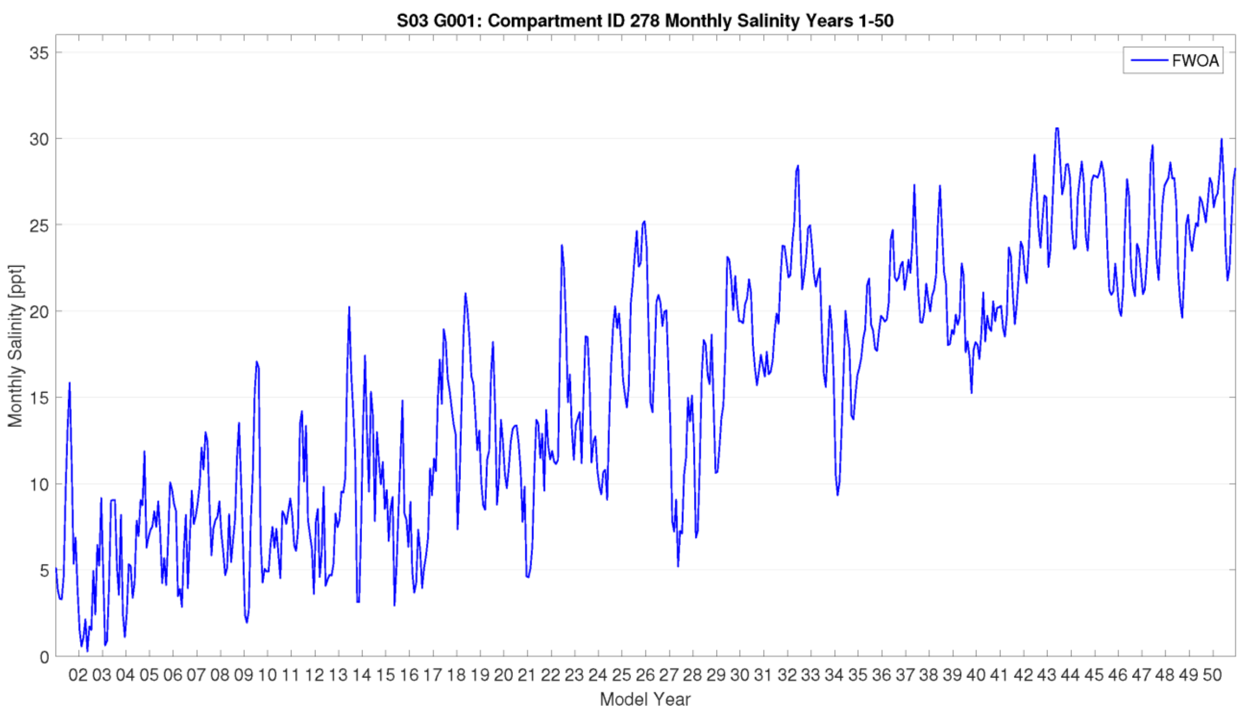


Figure 59: Mean Monthly Salinity in Compartment 278 - Mud Lake/Upper Barataria Bay in PB for the High Scenario (Representative of Intermediate Compartment Results).

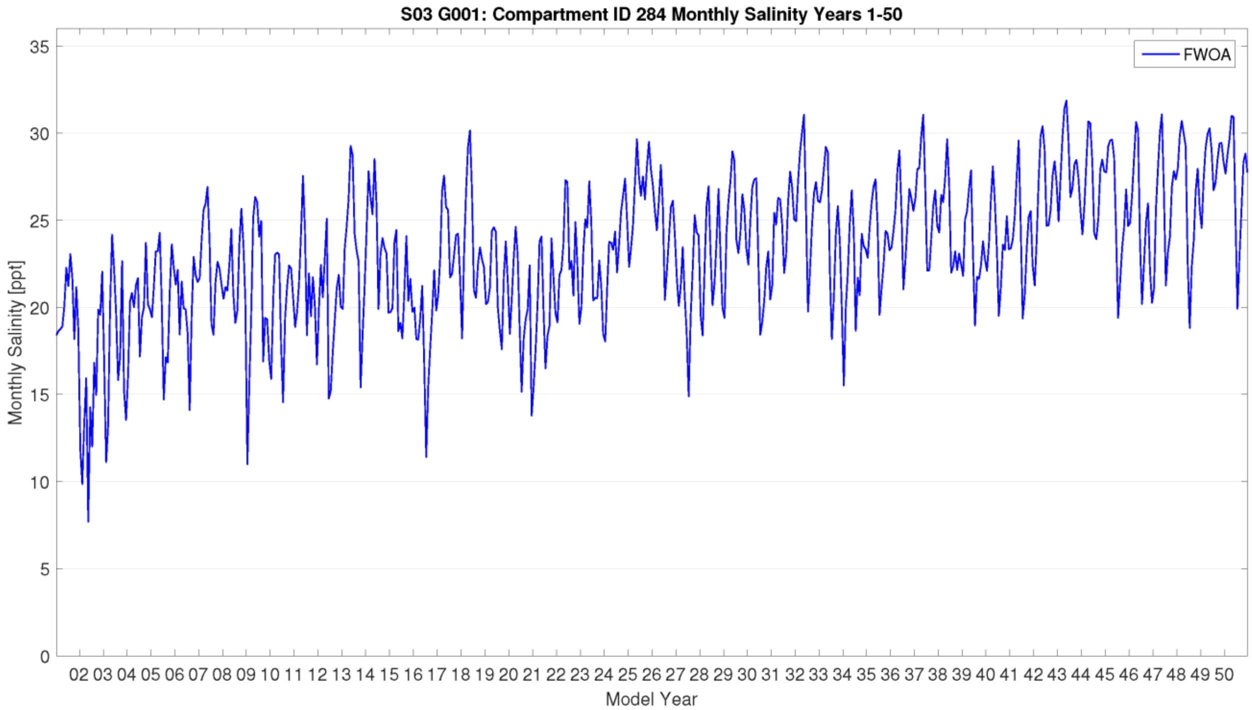


Figure 60: Mean Monthly Salinity in Compartment 284 - Northeast of Grand Isle in PB for the High Scenario (Representative of Near Coast Compartment Results).

Figure 61 through Figure 63 show the 50-year time series for mean monthly salinity for the AA region for the low scenario for the inland, intermediate, and near coast compartments, respectively. In this scenario, the inland compartment remains fresh water; this is reasonable since it is fed by river water. In the intermediate compartment, the salinity increase starts around year 40 and reaches approximately 10 ppt. The coastal compartment starts with a salinity of about 15 ppt and increases to around 22 ppt over 50 years.

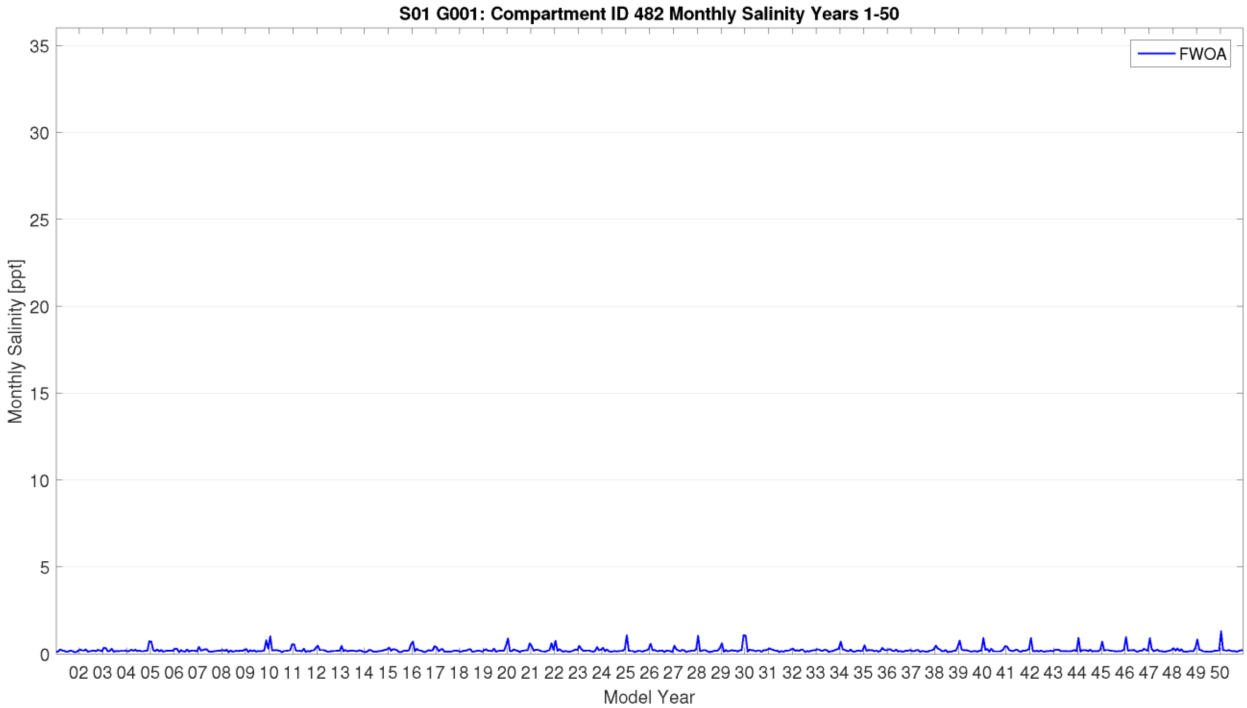


Figure 61: Mean Monthly Salinity in Compartment 482 – Lake Palourde in AA for the Low Scenario (Representative of Inland Compartment Results).

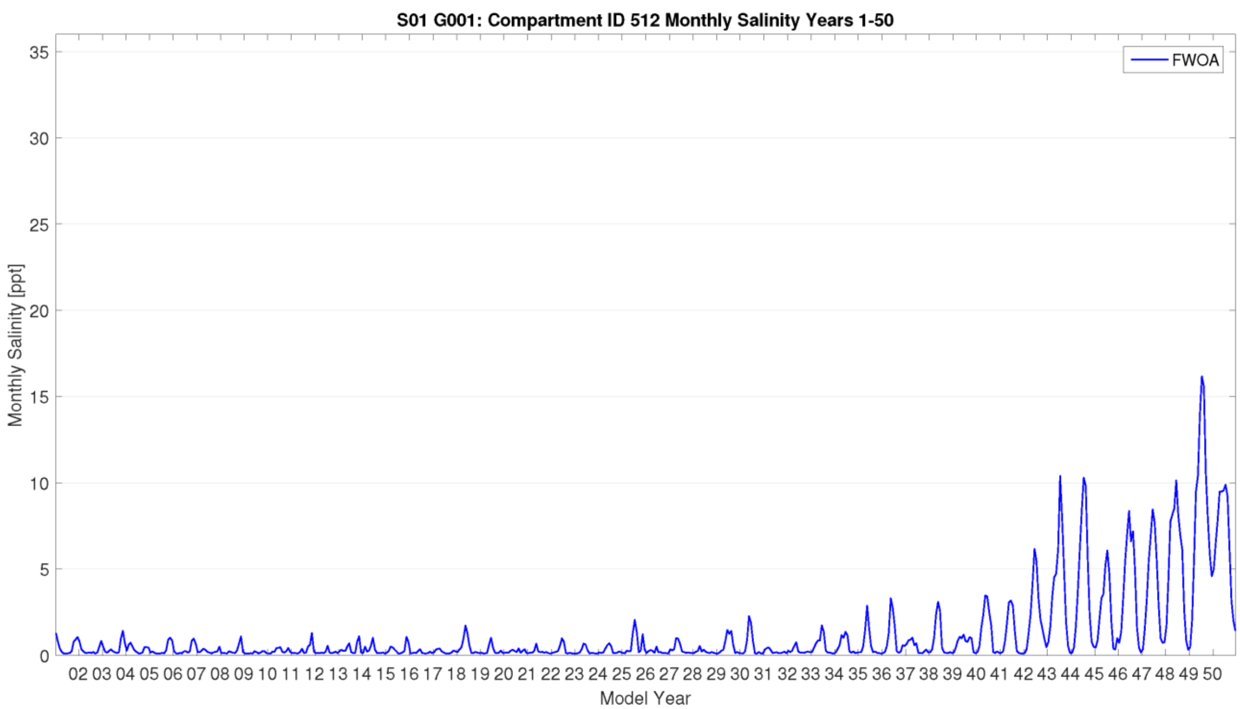


Figure 62: Mean Monthly Salinity in Compartment 512 – Lake de Cade in AA for the Low Scenario (Representative of Intermediate Compartment Results).

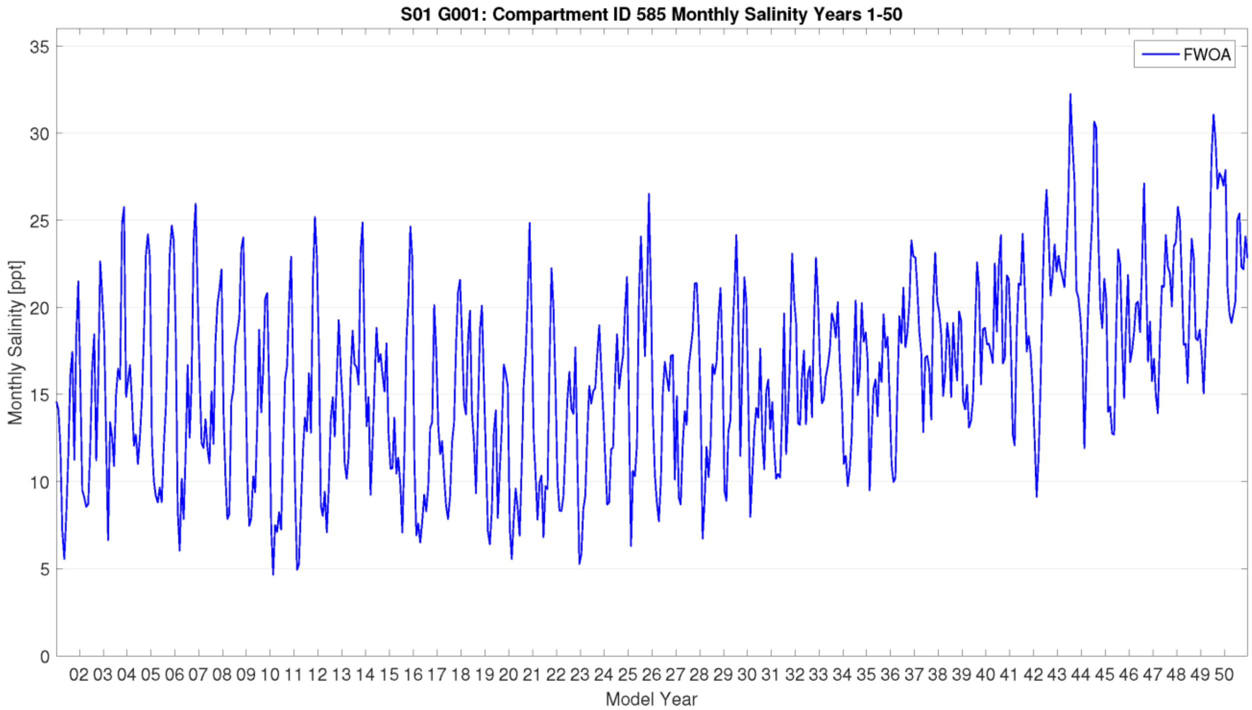


Figure 63: Mean Monthly Salinity in Compartment 585 – Caillou Bay in AA for the Low Scenario (Representative of Near Coast Compartment Results).

Figure 64 through Figure 66 show the 50-year time series for mean monthly salinity for the AA region for the high scenario for the inland, intermediate, and near coast compartments, respectively. In this scenario, the inland compartment remains fresh water; this is reasonable since it is fed by river water. In the intermediate compartment, salinity increase starts around year 12 and reaches approximately 22 ppt in 50 years. The coastal compartment starts with a salinity of about 15 ppt and increases to around 25 ppt over 50 years.

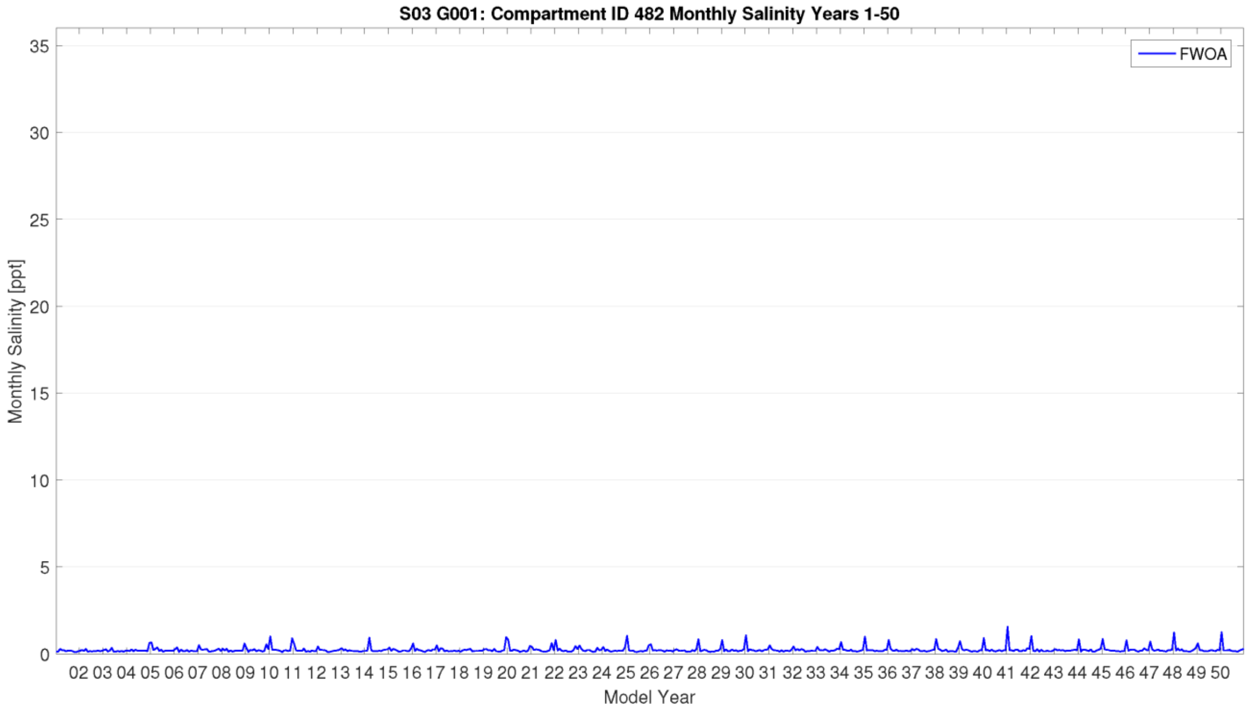


Figure 64: Mean Monthly Salinity in Compartment 482 – Lake Palourde in AA for the High Scenario (Representative of Inland Compartment Results).

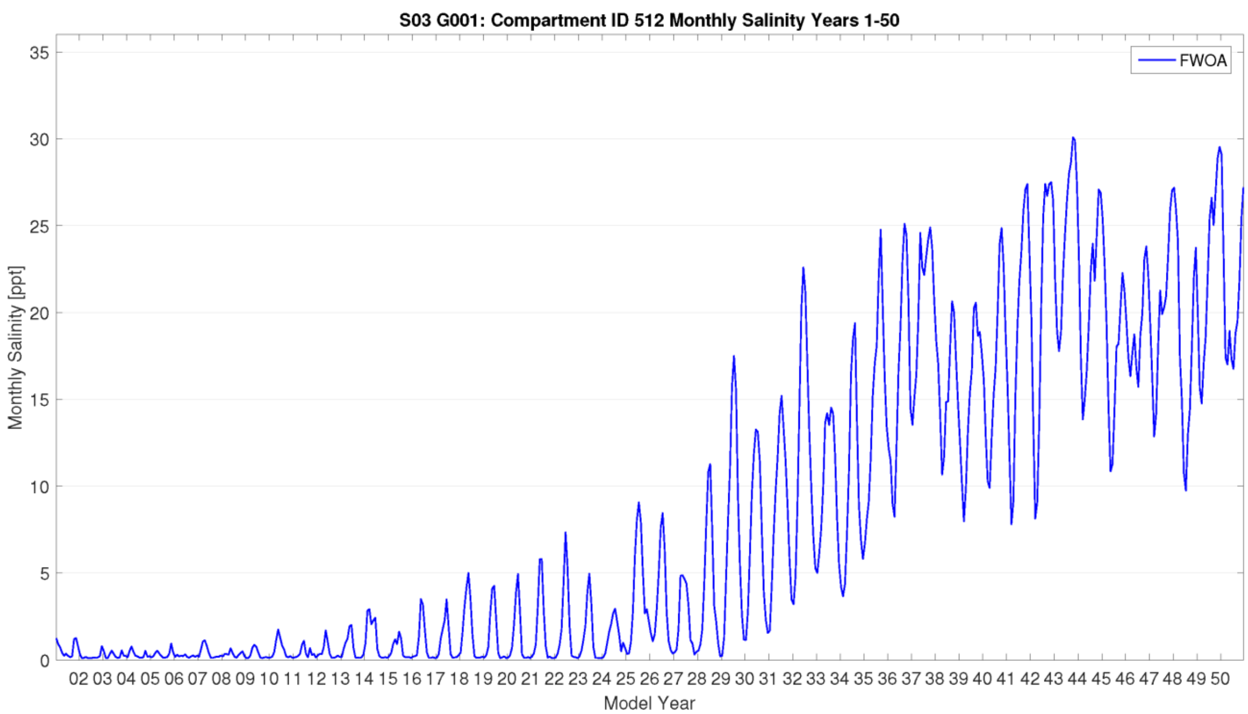


Figure 65: Mean Monthly Salinity in Compartment 512 – Lake de Cade in AA for the High Scenario (Representative of Intermediate Compartment Results).

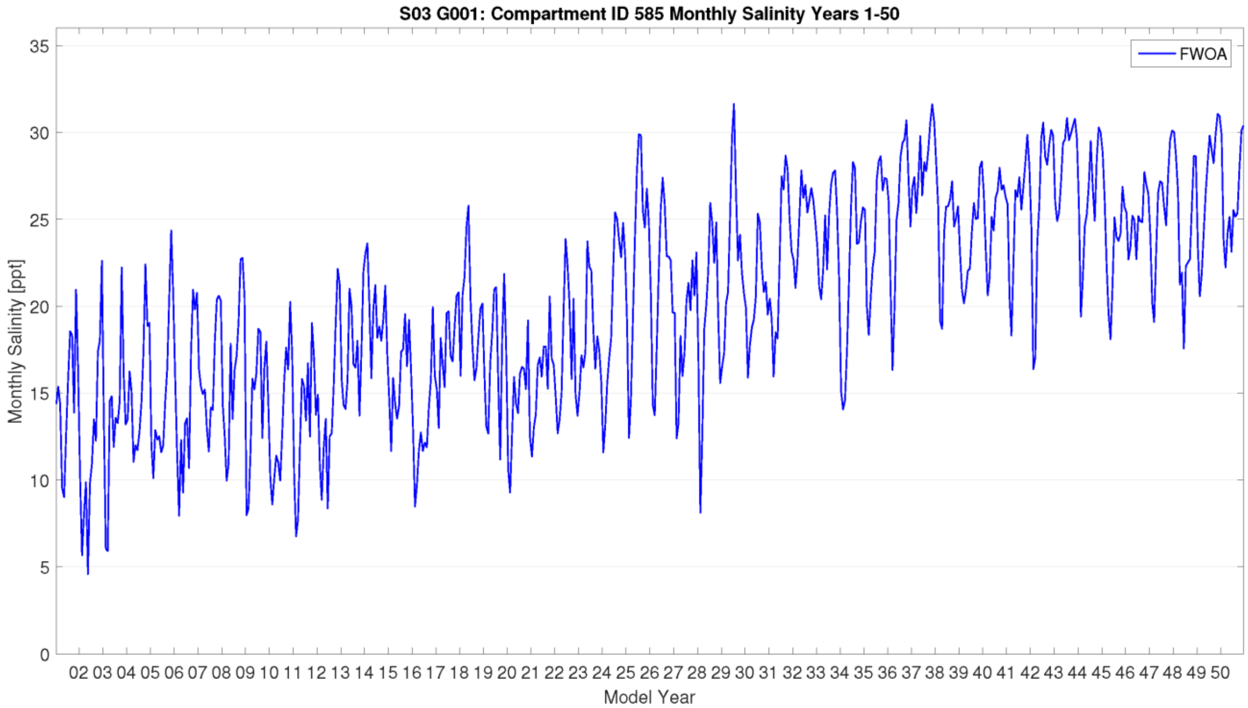


Figure 66: Mean Monthly Salinity in Compartment 585 – Caillou Bay in AA for the High Scenario (Representative of Near Coast Compartment Results).

Figure 67 through Figure 69 show the 50-year time series for mean monthly salinity for the Chenier Plain (CP) for the low scenario for the inland, intermediate, and near coast compartments, respectively. All of the CP stations showed indications of local hydrologic inputs due to rainfall or tributary inflows; this effect decreases from the inland compartment towards the coast. Salinity increase reaches the inland compartment around year 33 with salinities in the range of 2 -12 ppt. In the intermediate compartment, the salinity increase starts around year 37 and reaches approximately 17 ppt. The coastal compartment starts with a salinity of about 7 ppt and increases to around 17 ppt over 50 years.

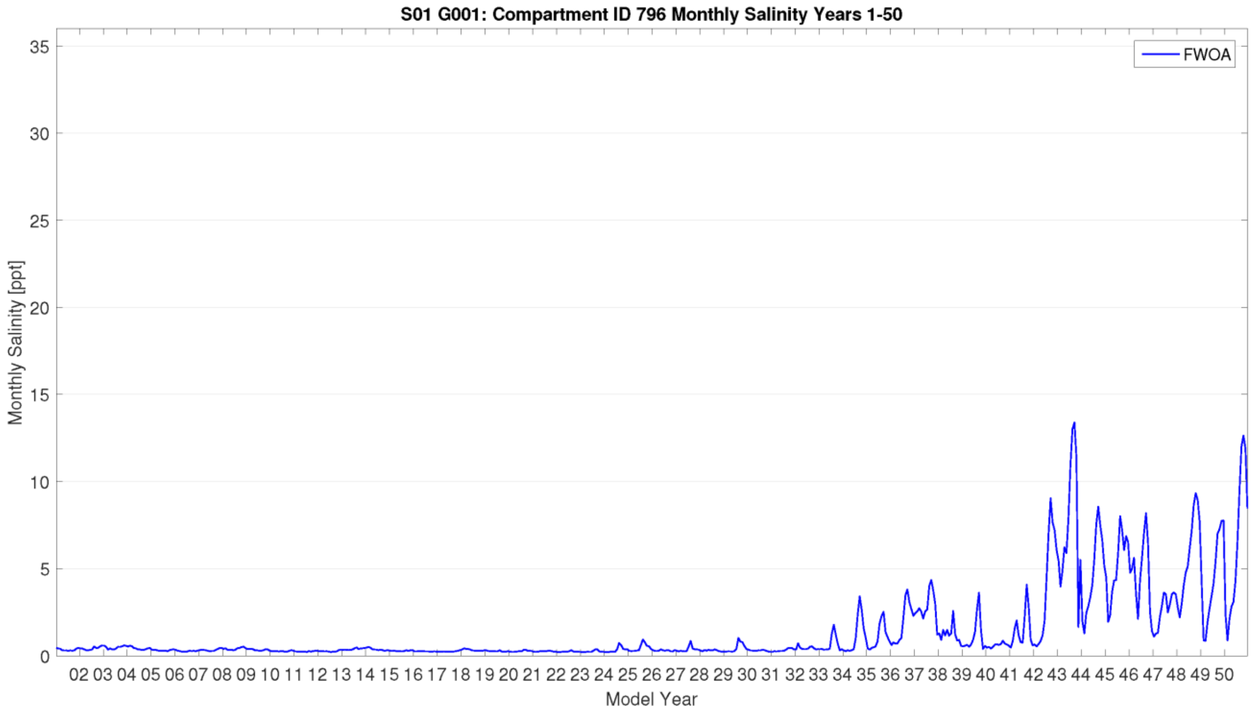


Figure 67: Mean Monthly Salinity in Compartment 796 – Northwest Grand Lake in CP for the Low Scenario (Representative of Inland Compartment Results).

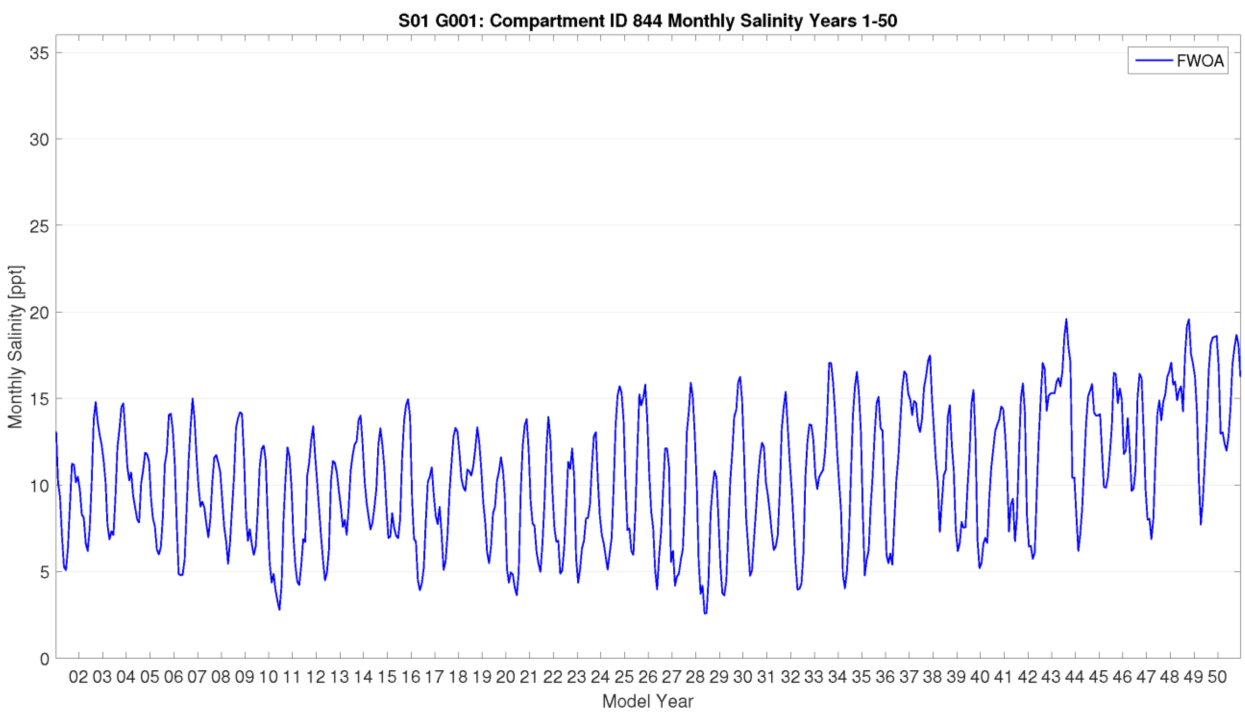


Figure 68: Mean Monthly Salinity in Compartment 844 – East Calcasieu Lake in CP for the Low Scenario (Representative of Intermediate Compartment Results).

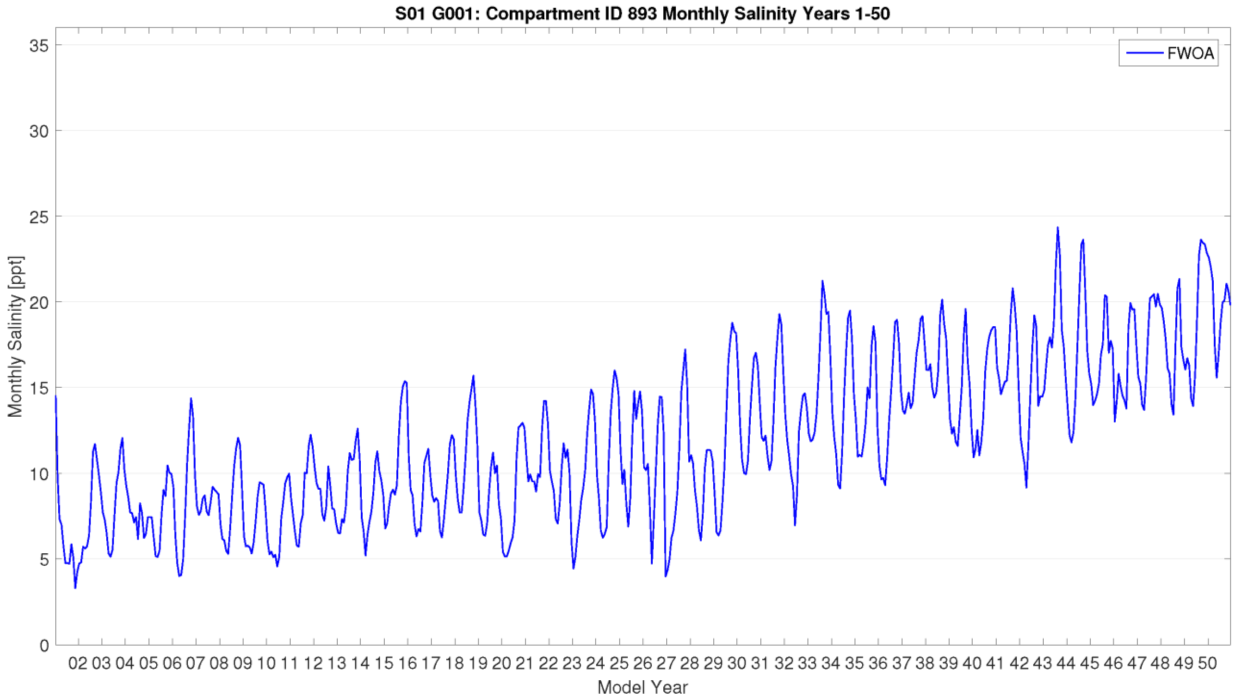


Figure 69: Mean Monthly Salinity in Compartment 893 – Holly Beach in CP for the Low Scenario (Representative of Near Coast Compartment Results).

Figure 70 through 72 show the 50-year time series for mean monthly salinity for the CP for the high scenario for the inland, intermediate, and near coast compartments, respectively. Salinity increase reaches the inland compartment around year 22 with salinities in the range of 2-20 ppt. The coastal cell increased from about 10 ppt to 20 ppt in 50 years. The spike in salinity at approximately year 37 (and subsequent drop in salinity) is due to an unstable interaction between the marsh links and the Kadlec-Knight marsh exchange equations. These issues are generally a result of the assumption that the salinity in the marsh is equal to the salinity in the open water areas – which was complicated by the marsh link network. In essence, this assumption was no longer valid in later simulation years when there were large masses of water being routed through the marsh link network (whether from accelerated sea level rise or some other mechanism) as well as via the Kadlec-Knight marsh exchange equation. This assumption effectively routed water from marsh links to the marsh surface but did not bring the salinity with it. Instead, it was routed to the open water area, resulting in these instability spikes. This only shows up in later years when marsh links that were not subjected to such large flows/salinities during the calibration period were 'activated'. This issue was corrected in a subsequent version of the model (used for simulation of alternatives).

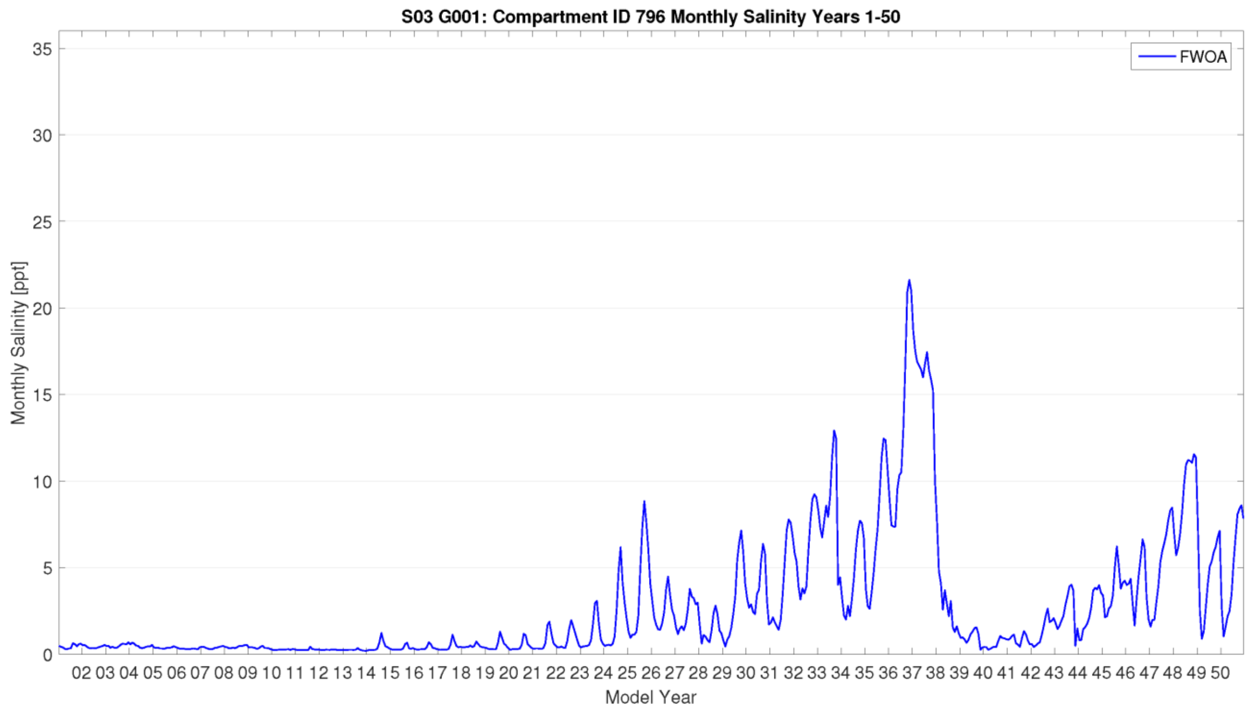


Figure 70: Mean Monthly Salinity in Compartment 796 – Northwest Grand Lake in CP for the High Scenario (Representative of Inland Compartment Results).

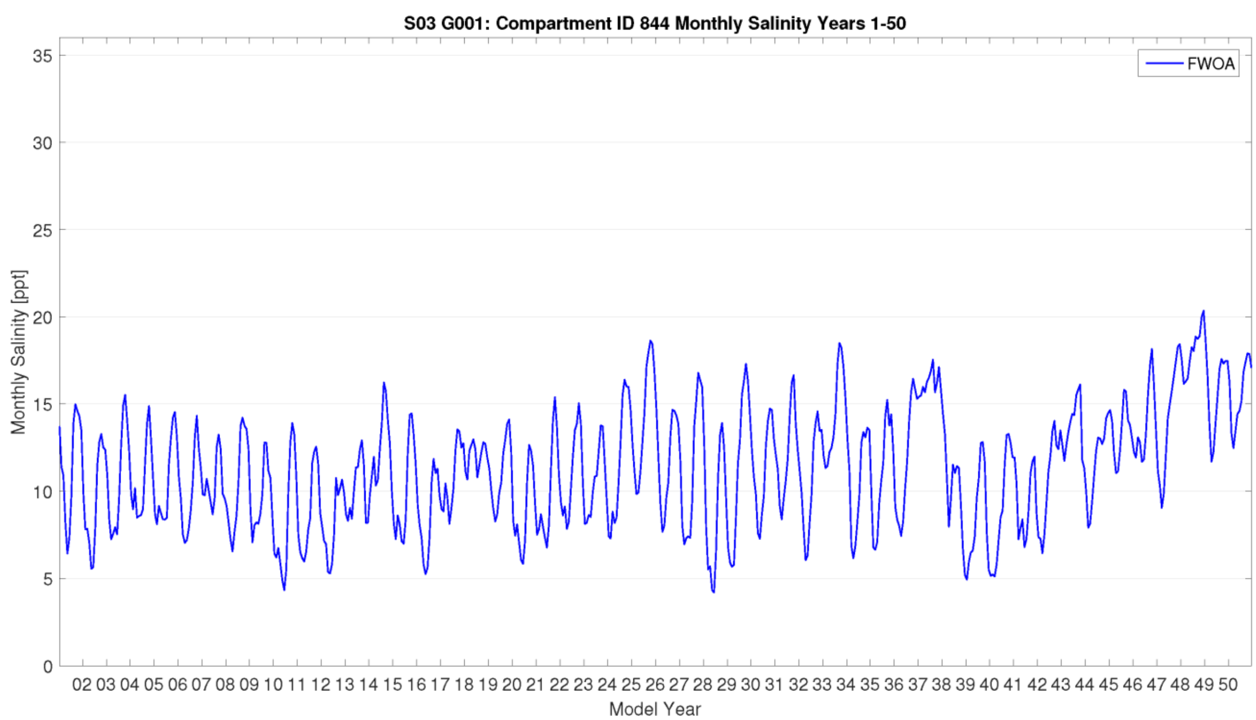


Figure 71: Mean monthly Salinity in Compartment 844 – East Calcasieu Lake in CP for the High Scenario (Representative of Intermediate Compartment Results).

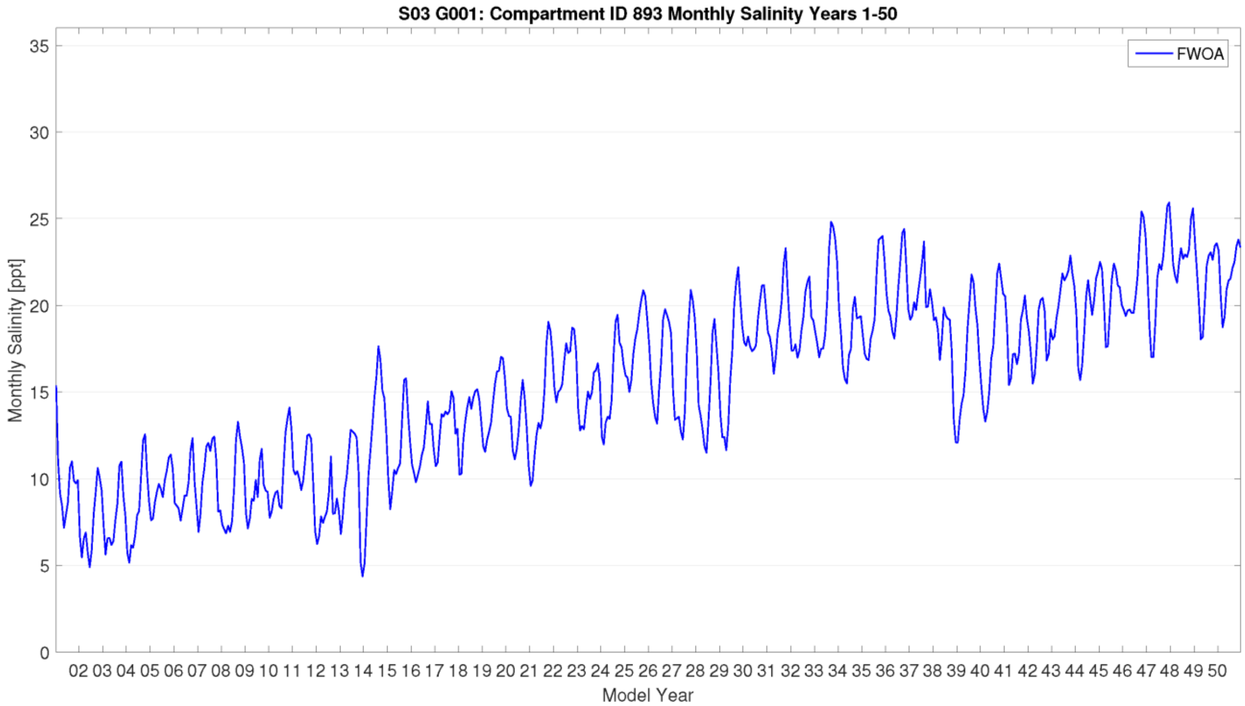


Figure 72: Mean Monthly Salinity in Compartment 893 – Holly Beach in CP for the High Scenario (Representative of Near Coast Compartment Results).

Figure 73 is a plot of the coast wide mean stage after 50 years and the predicted coast wide mean salinity after 50 years for all scenarios averaged across inland, intermediate, and near coast compartments. This plot shows a nearly linear relationship between mean stage and the mean system salinity, indicating that there is a nearly proportional increase of salinity with eustatic sea level rise (ESLR).

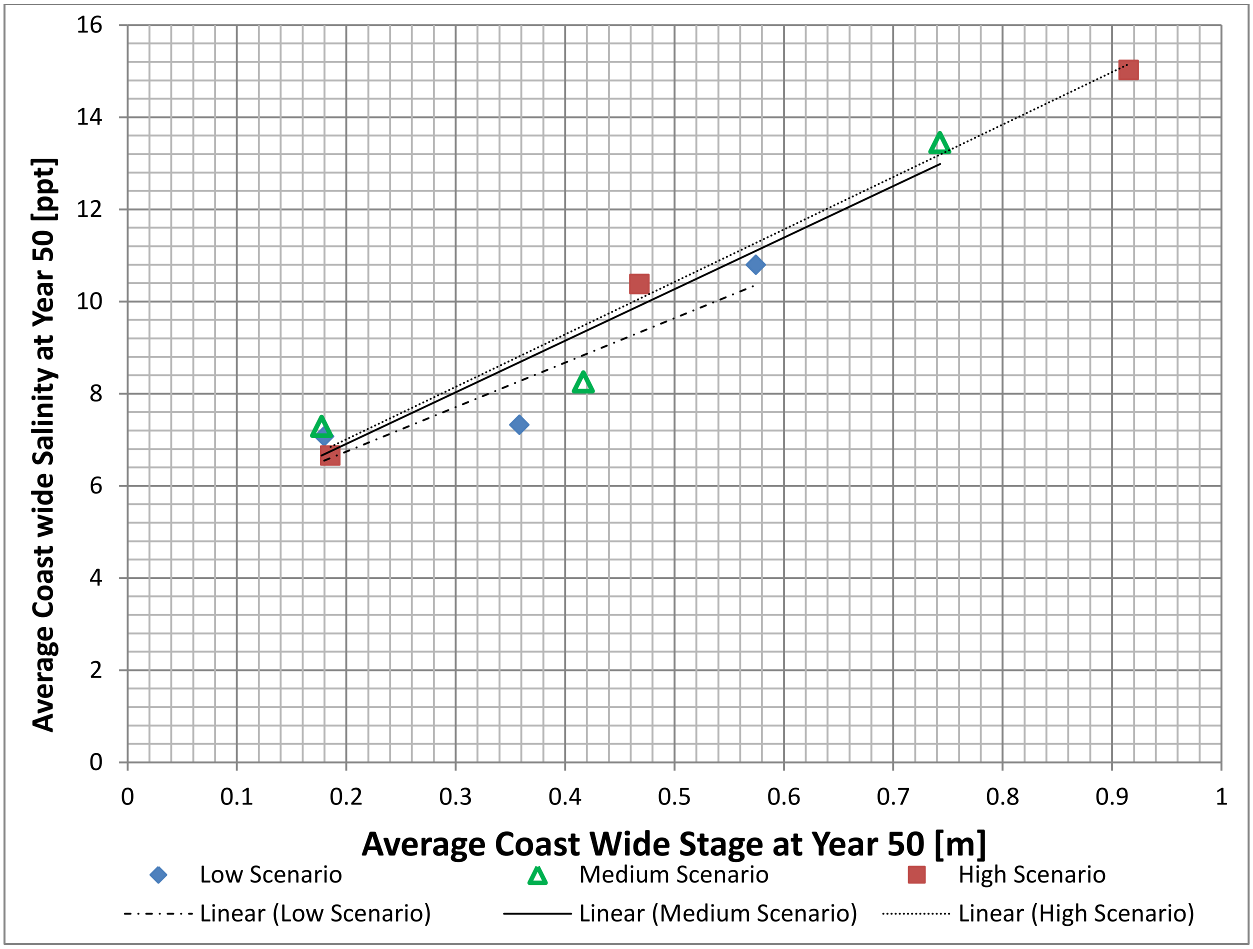


Figure 73: Response of Coast Wide Mean Year 50 Salinity (Averaged Over Inland, Intermediate, and Near Coast Locations) to the Mean Year 50 Stage (Averaged Over Inland, Intermediate, and Near Coast Locations) for All Three Scenarios (Low, Medium, and High).

3.3 Land Change

To facilitate the description of land change over time, ecoregions were used to define specific coastal areas (Figure 74). The curves of land area over time show trends that vary depending upon the collapse mechanism that triggers specific episodes of land loss (Figure 75-Figure 86). When large, abrupt shifts in land area appear in the land area time series, it is generally indicative of a salinity collapse threshold (see Table 4) being met during a specific model year. For example, the Bird's Foot Delta (BFD; Figure 77) and Upper Pontchartrain (UPO; Figure 75) ecoregions have very clear periods of abrupt land loss where substantial areas of coastal wetlands collapse during a single model year. Inspection of the vegetation maps indicate that the Bird's Foot Delta ecoregion experiences repeated periods of substantial fresh marsh collapse during years 24 and 25 under all three scenarios. This loss corresponds to low river years in the 50-year historic Mississippi River hydrograph (which is unchanged across all three scenarios). Under the high scenario, the Bird's Foot Delta ecoregion also experienced an episode of fresh marsh collapse during yet another low river year, year 43. The salinity stress collapse mechanism will only collapse fresh marsh areas that are inundated by the annual mean water level. Therefore, while the low river years are constant across scenarios, the amount of land inundated will change, particularly in the later years of scenarios with higher rates of sea level rise. These abrupt episodes of collapse due to salinity thresholds being met are evident primarily only in the eastern portion of the model domain where the influence of the Mississippi River fresh water supply is important to both vegetation cover (e.g., fresh marsh near the river) and the short-term salinity patterns that will impact collapse thresholds being met or not. However, areas remote from direct riverine influence in both the Atchafalaya/Vermilion/Teche (AVT; Figure 82) and Mermentau/Lakes (MEL; Figure 83) ecoregions have some areas of fresh wetland areas that collapse due to short-term periods of high salinity which may be caused by annual variation in precipitation and evapotranspiration.

The second trend visible in the land area over time curves is the continuous (e.g., non-piecewise) loss of coastal land area throughout all of the ecoregions. This non-abrupt, continuous loss of land is a function of the combined effects of subsidence and ESLR, both of which vary by scenario, on non-fresh wetlands; hence, the varying slopes and the modeled accretion of marsh elevation (a function of inorganic sediment deposition and organic loading) is unable to keep up with the relative sea level rise in each scenario, and as the rates of ESLR accelerate in later years, the rate of land loss increases as well. If only subsidence were resulting in land change through time, the coastal land area susceptible to inundation-derived collapse would be decreasing at a directly proportional rate with a constant slope, since modeled subsidence rates do not change through time. The addition of a non-constant rate of change in the eustatic sea level, however, results in an increasing negative slope over time. This increasingly negative slope is most evident in the high scenario than in the medium and low scenarios, a function of the fact that the high scenario has the largest acceleration of the three ESLR scenarios, followed by the medium scenario, and at last the low (see Appendix C: Chapter 2 and Attachment C2-1).

The exact depth of inundation resulting in collapse varies by vegetation type (see Table 4), and subsequently varies spatially across the coast; however, there are no clear spatial or temporal patterns evident that indicate a strong sensitivity to these different inundation depth thresholds. While no strong sensitivity to inundation depth threshold is evident, a sharp differentiation can be seen (both spatially and temporally) between collapse mechanisms. In other words, the loss pattern is driven by whether salinity is the driving force in collapse (e.g., fresh forested and fresh marsh areas) or whether inundation, regardless of threshold depth, will result in marsh collapse. If the modeled salinity values change gradually enough for an initially fresh land type to switch to a more salt-tolerant land type, a greater portion of the land will be able to be sustained through a short period of high salinities, reducing the number of abrupt losses through time (e.g., Figure 77) for a more consistent rate of change driven by sea level rise and subsidence rates (e.g., Figure 76).

In many of the ecoregions under the high scenario, it appears that the amount of land remaining at year 50 asymptotically approaches some non-zero number; these limits do not appear in all ecoregions, nor do they generally appear in the low and medium scenarios.

While there are many areas of land loss across the entire model domain, there are some specific areas where the ICM predicts land gain during 50 years of no action being taken. Areas within the model domain that are most evidently gaining land during the low scenario are: the Wax Lake Outlet and Atchafalaya deltas, the West Bay region of the Bird's Foot Delta, the Fort St. Phillip crevasse diversion on the east bank of the Mississippi River, the east bank of the Bird's Foot Delta in the vicinity of Quarantine, and portions of the Gulf Coast Intracoastal Waterway in the vicinity of Franklin. Less evident in the included figures are areas of land gain in the waterways immediately downstream of the Caernarvon diversion outfall. Similar gain is also occurring downstream of the Davis Pond diversion.

The areas of land gain are, intuitively, more evident at year 50 of the low and medium scenarios than at year 50 of the high scenario. At the end of the high scenario, the only areas indicating gain are in the three main active deltas: Wax Lake Outlet, Atchafalaya, and the West Bay portion of the Bird's Foot Delta (Figure 87-Figure 92).

In general terms, the land gain areas do not change much through time nor across scenario. The extent of land gain increases between years 25 and 50, and decreases from low to high scenarios (Figure 75 through Figure 86), but the locations that show this land gain do not change. That is, if land has been gained by year 50 at a location, the land gain was evident by year 25. Contrary to this, there are regions that experience loss *only* in the later years of the simulation when ESLR has risen dramatically and many areas that were not susceptible to collapse in year 25 are collapsed by year 50. This trend also holds when comparing across scenario; more land is susceptible to collapse under the high scenario; however, some regions (e.g., Wax Lake Outlet, Davis Pond, etc.), experience land gain regardless of scenario.

Coast wide over the 50-year FWOA (G001) there is a net change in land area within the model domain of -4,610 km^2, -7,320 km^2 and -10,990 km for the low, medium, and high scenarios, respectively (Figure 87-Figure 92).

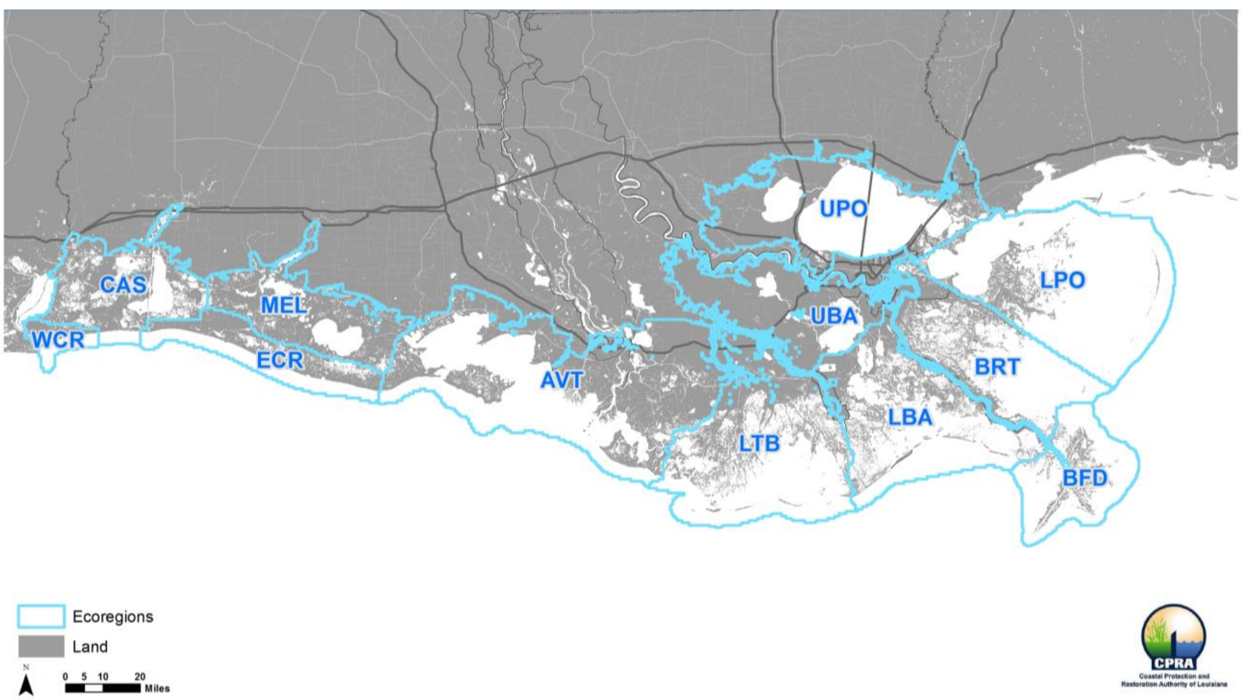


Figure 74: 2017 Coastal Master Plan Ecoregions.

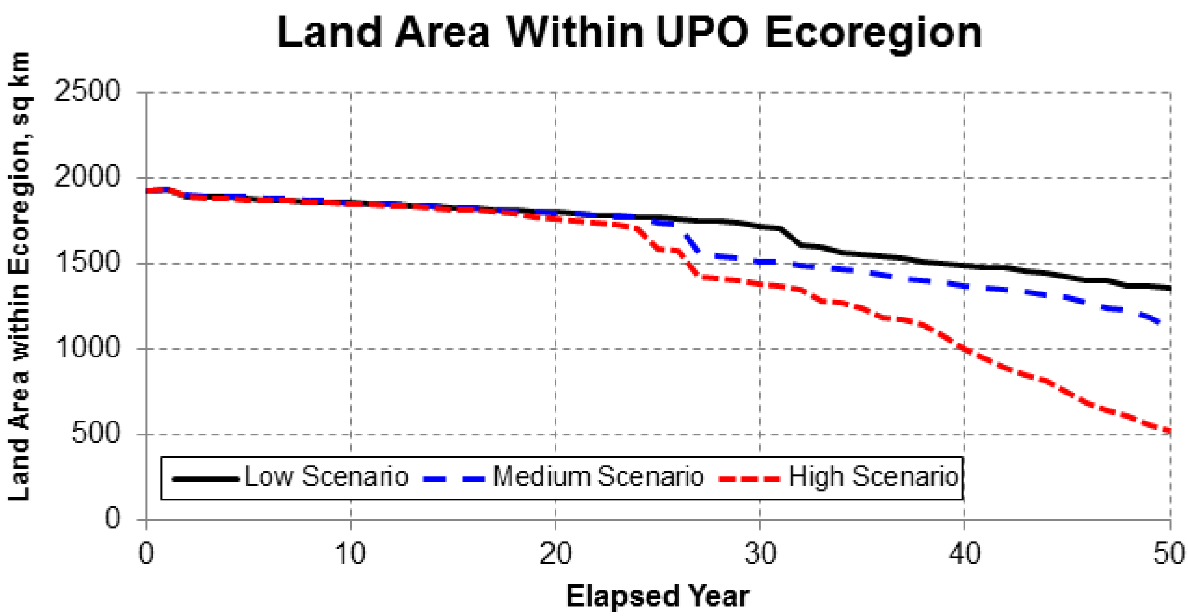


Figure 75: Land Area through Time within the Upper Pontchartrain Ecoregion.

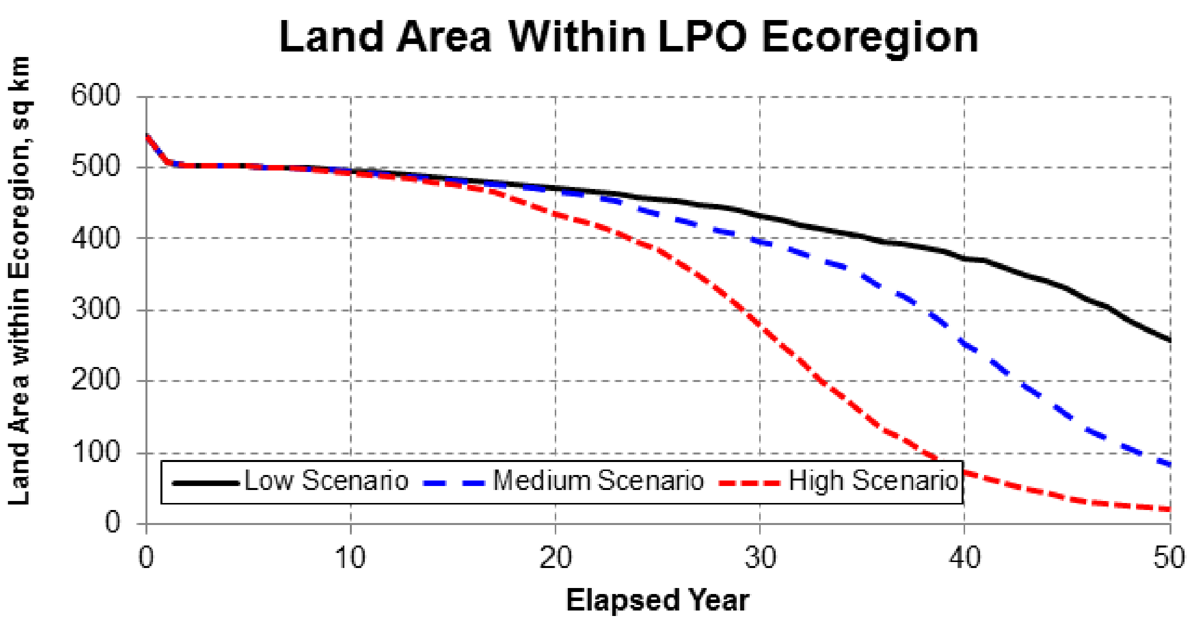


Figure 76: Land Area through Time within the Lower Pontchartrain Ecoregion.

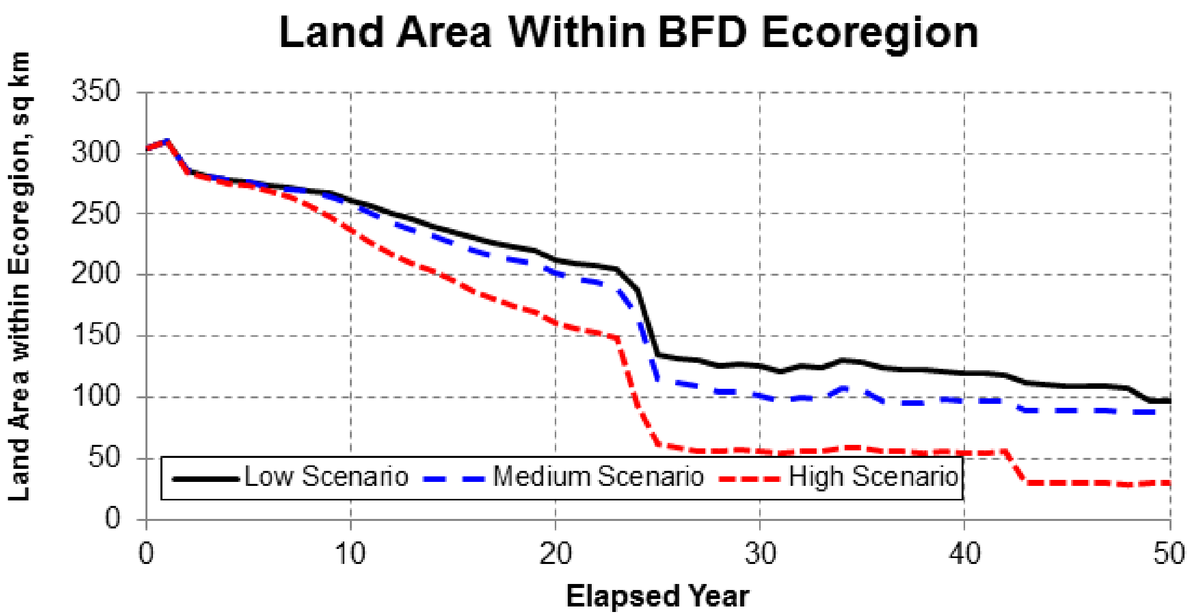


Figure 77: Land Area through Time within the Bird's Foot Delta Ecoregion.

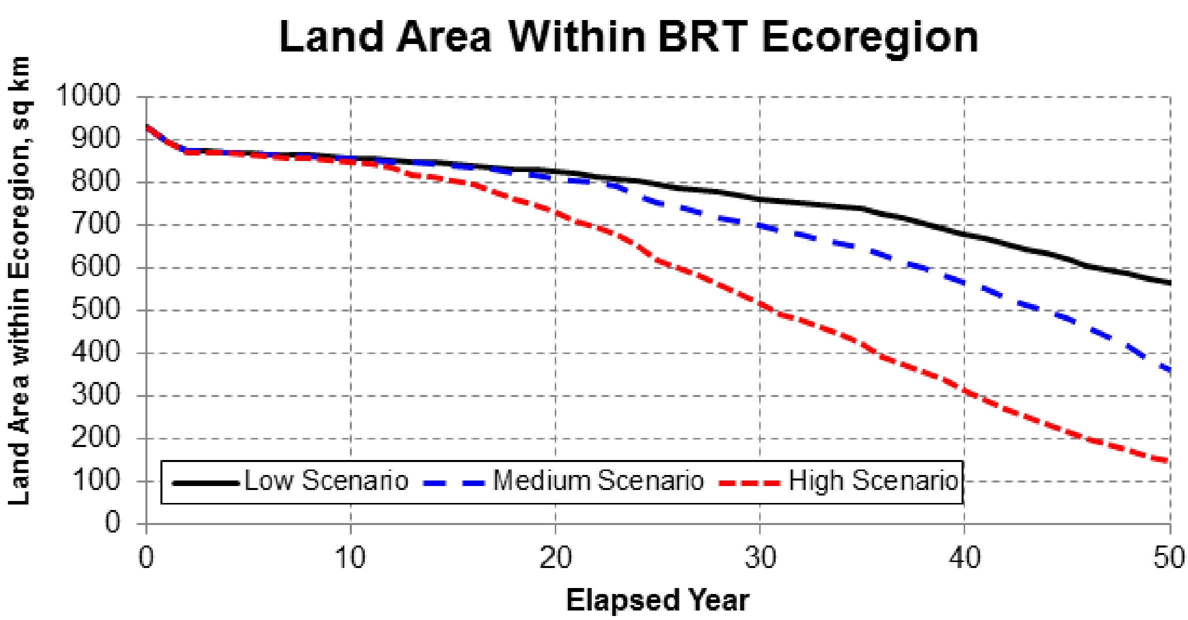


Figure 78: Land Area through Time within the Breton Ecoregion.

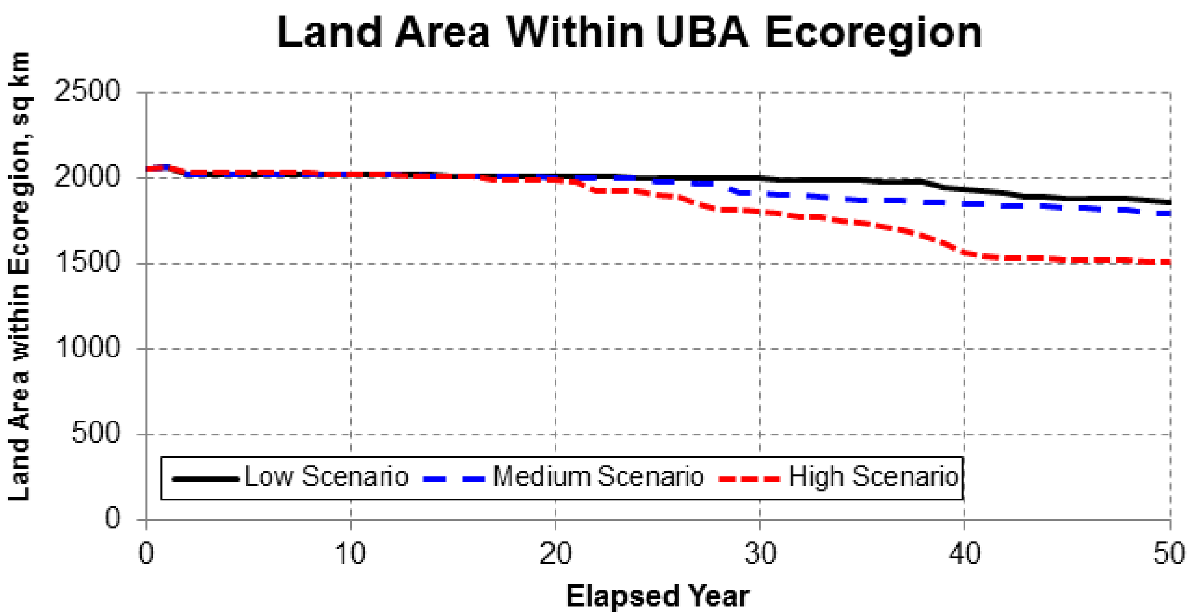


Figure 79: Land Area through Time within the Upper Barataria Ecoregion.

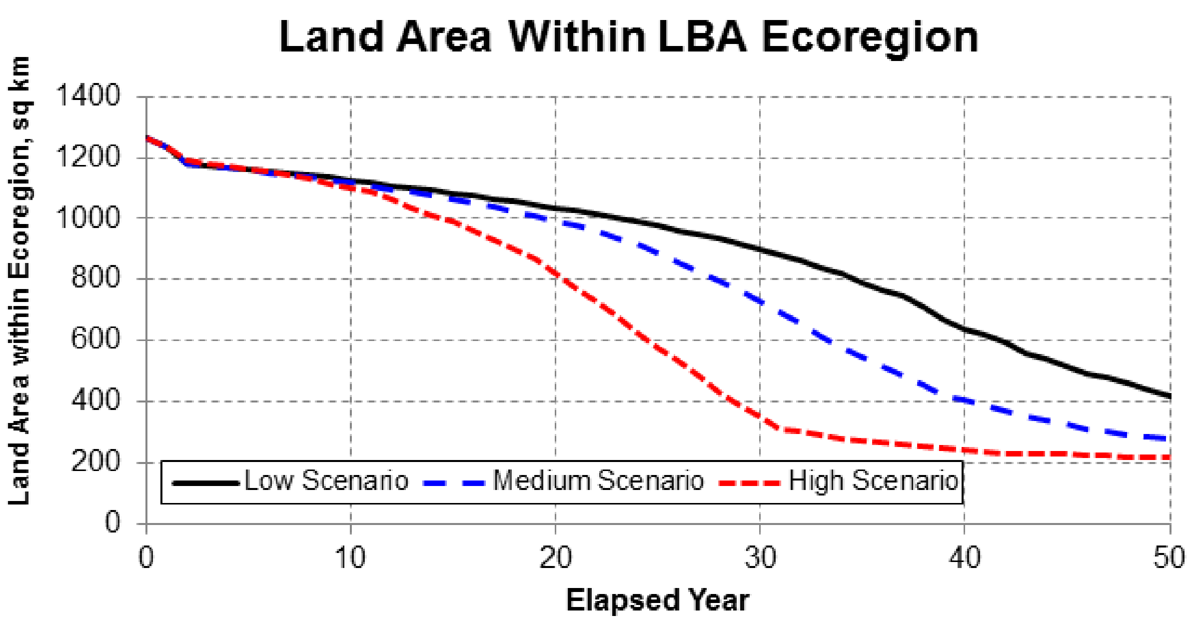


Figure 80: Land Area through Time within the Lower Barataria Ecoregion.

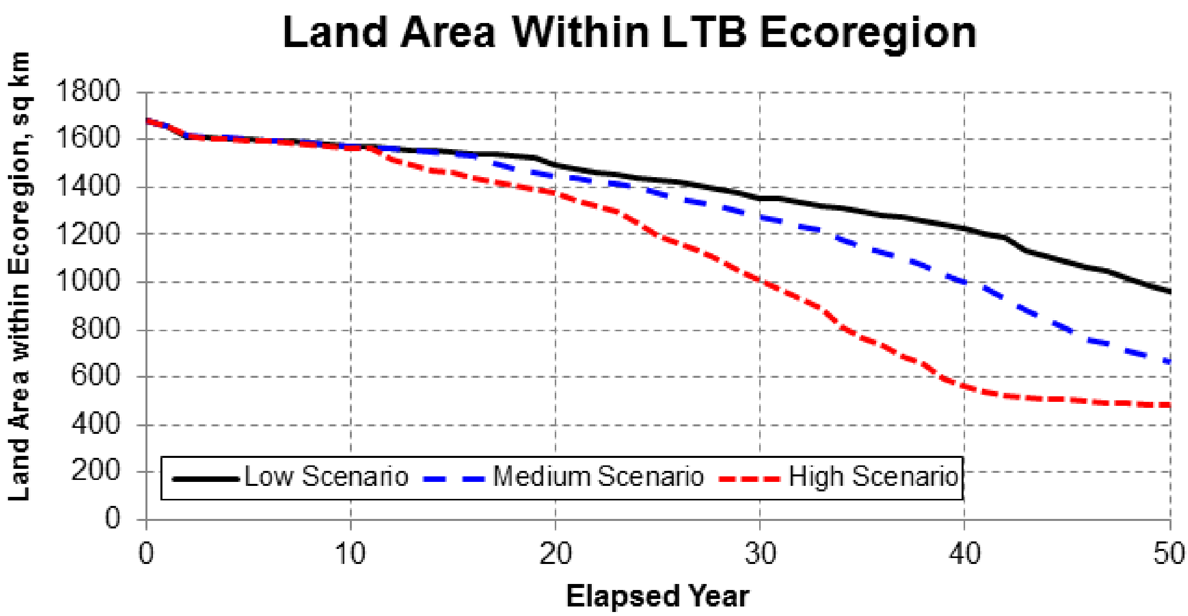


Figure 81: Land Area through Time within the Lower Terrebonne Ecoregion.

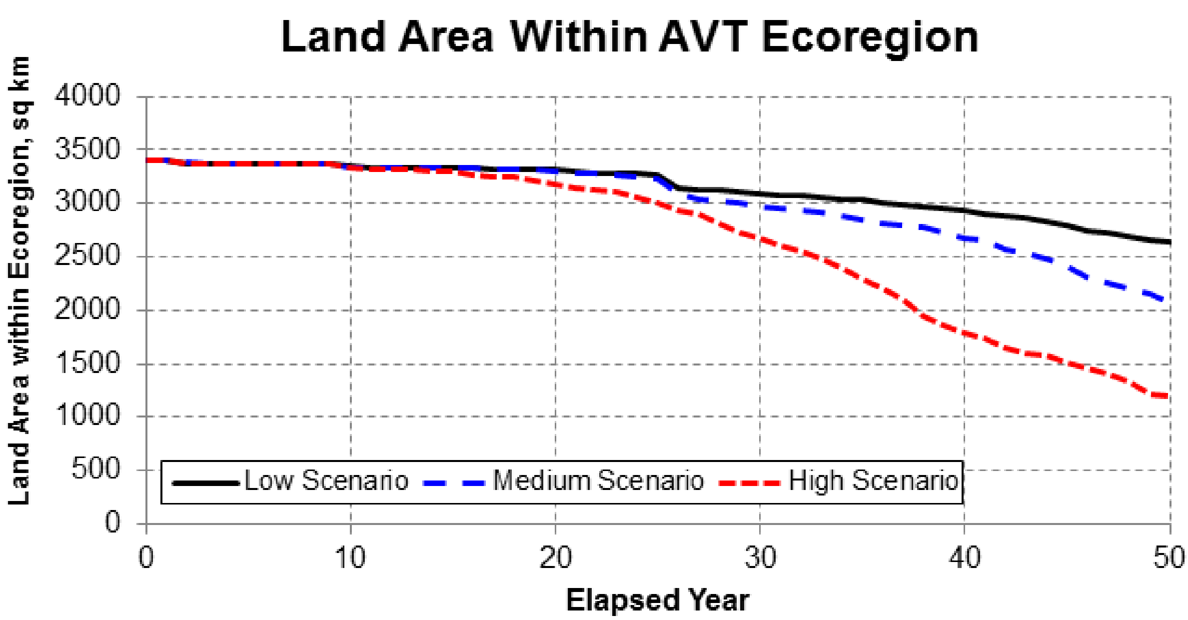


Figure 82: Land Area through Time within the Atchafalaya/Vermilion/Teche Ecoregion.

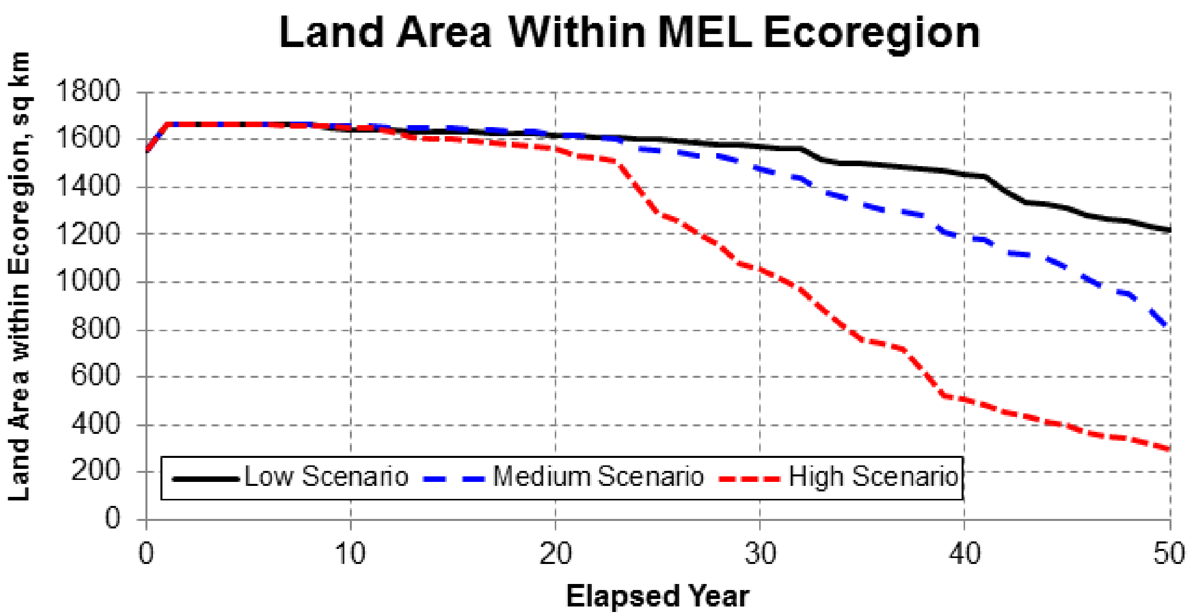


Figure 83: Land Area through Time within the Mermentau/Lakes Ecoregion.

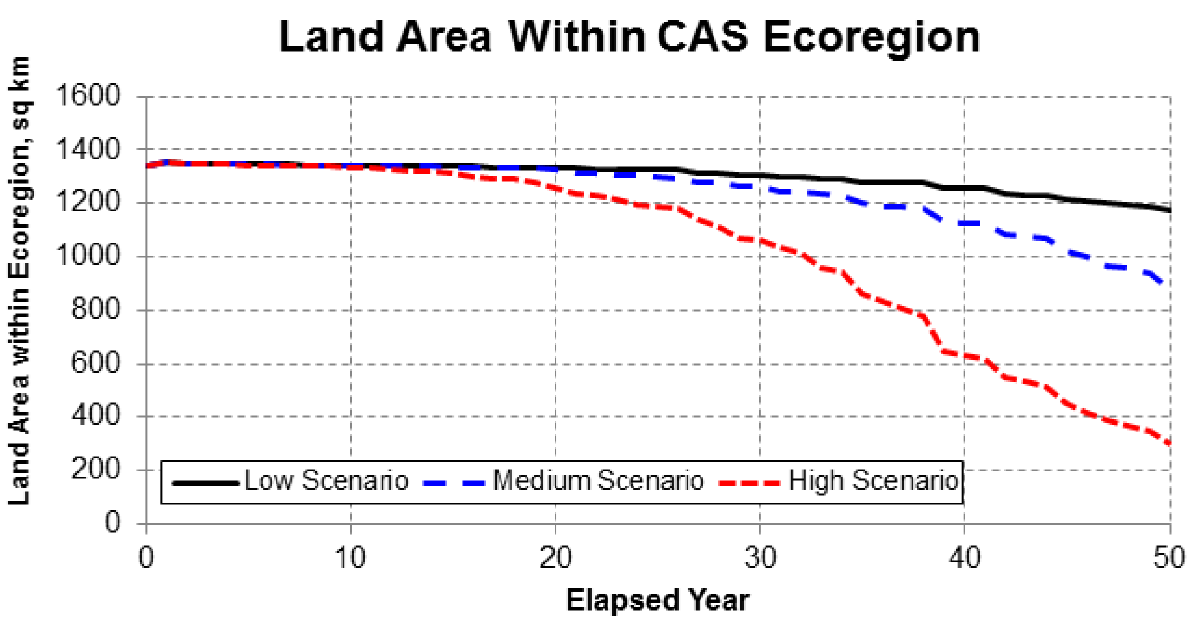


Figure 84: Land Area through Time within the Calcasieu/Sabine Ecoregion.

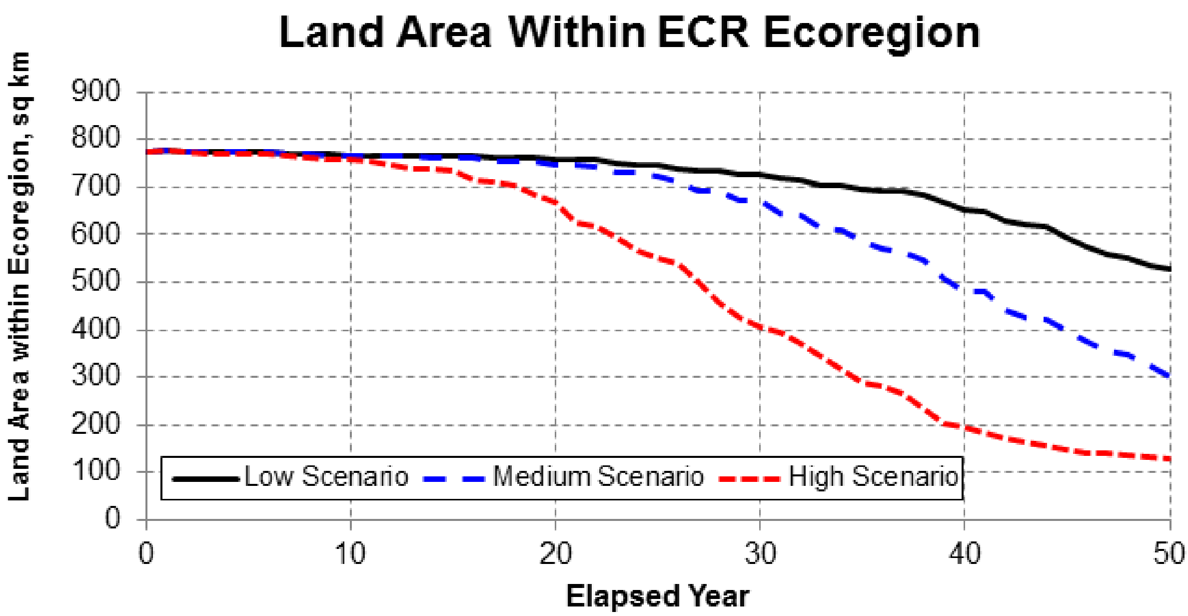


Figure 85: Land Area through Time within the Eastern Chenier Ridge Ecoregion.

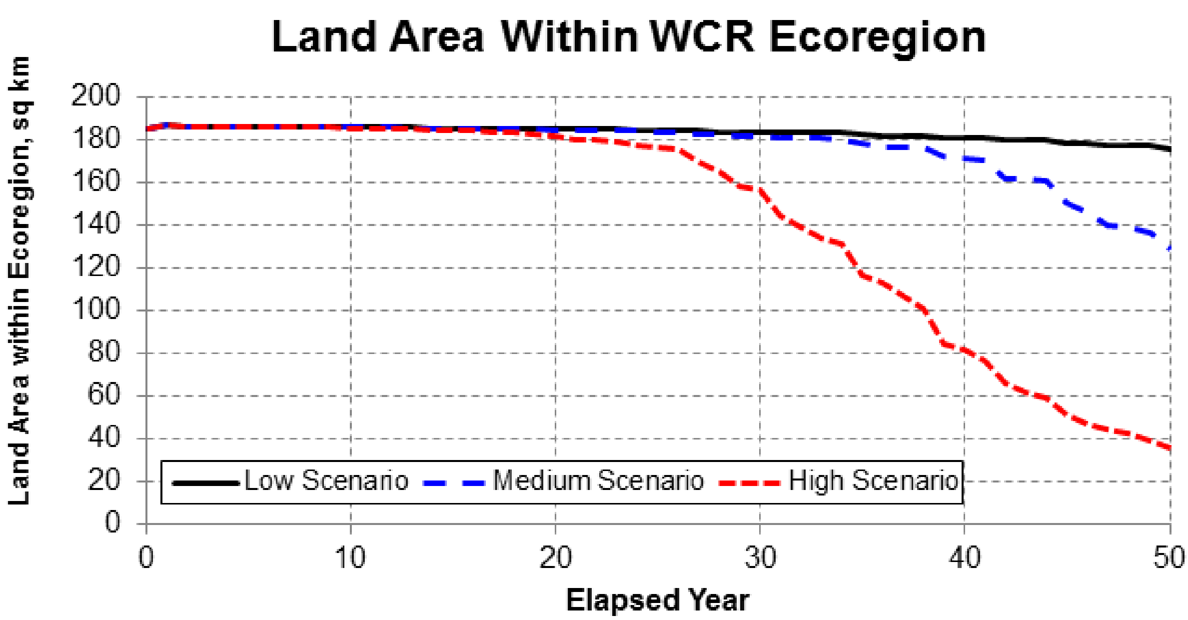


Figure 86: Land Area through Time within the Western Chenier Ridge Ecoregion.

Table 4: Mechanisms within ICM Driving Land Gain and Marsh Collapse.

Land Type	**Collapse/Gain threshold**
Fresh Forested Wetlands	Land will convert to water if it is at, or below, the annual mean water level for the year and the maximum two-week mean salinity during the year is above 7 ppt.
Fresh Marsh	Land will convert to water if it is at, or below, the annual mean water level for the year and the maximum two-week mean salinity during the year is above 5.5 ppt.
Intermediate Marsh	Land will convert to water if the annual mean water depth over the marsh for two consecutive years is greater than 0.358 m.
Brackish Marsh	Land will convert to water if the annual mean water depth over the marsh for two consecutive years is greater than 0.256 m.
Saline Marsh	Land will convert to water if the annual mean water depth over the marsh for two consecutive years is greater than 0.235 m.
Water	Water will be converted to land if the mean water level for two consecutive years is at least 0.2 m lower than the bed elevation of the water area.

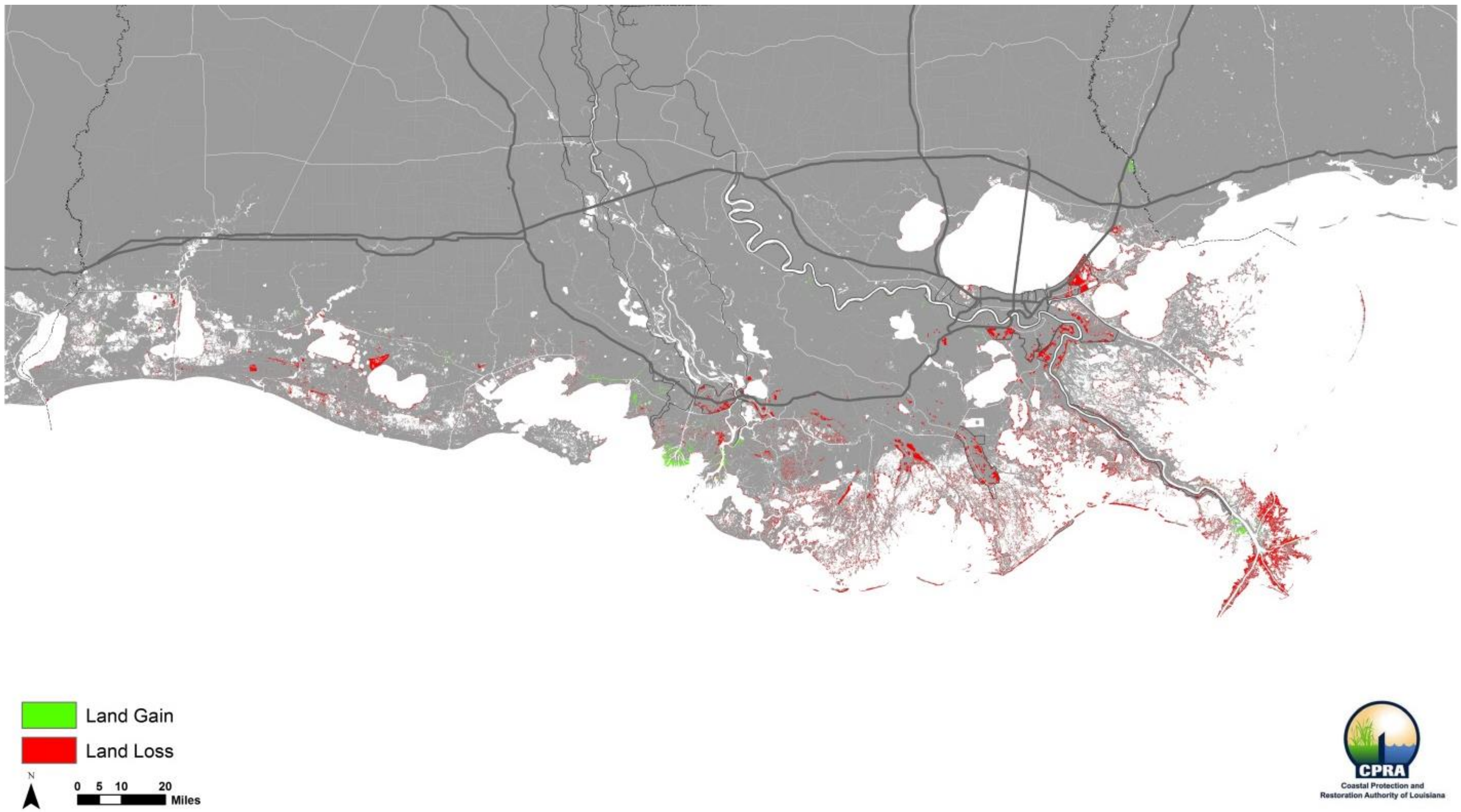


Figure 87: Land Change from Initial Conditions after 25 Years of Low Scenario – FWOA. Net Land Change (Land Gain-Land Loss) at Year 25 is -1,170 km^2 for the Low Scenario.

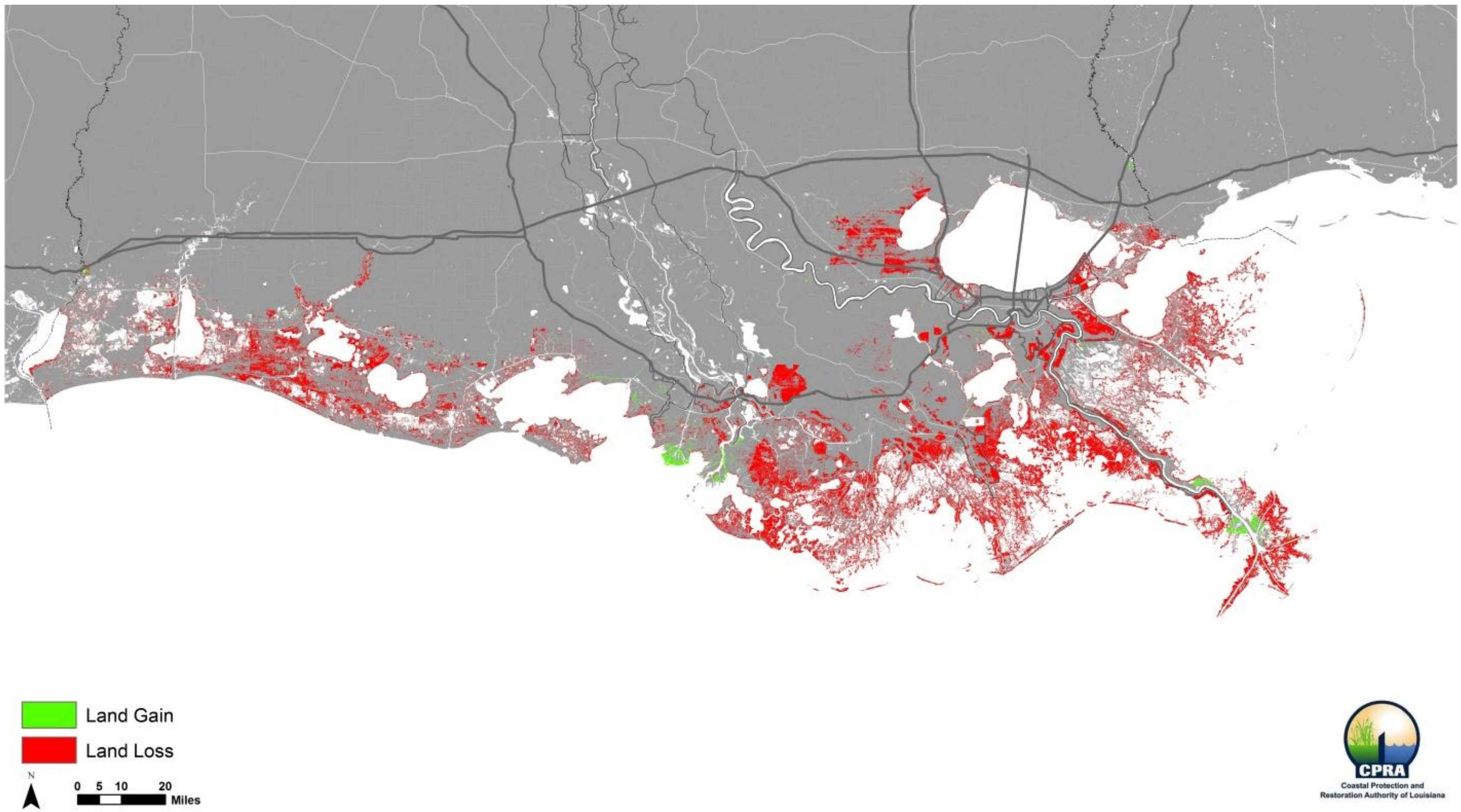


Figure 88: Land Change from Initial Conditions after 50 Years of Low Scenario – FWOA. Net Land Change (Land Gain-Land Loss) at Year 50 is -4,610 km^2 for the Low Scenario.

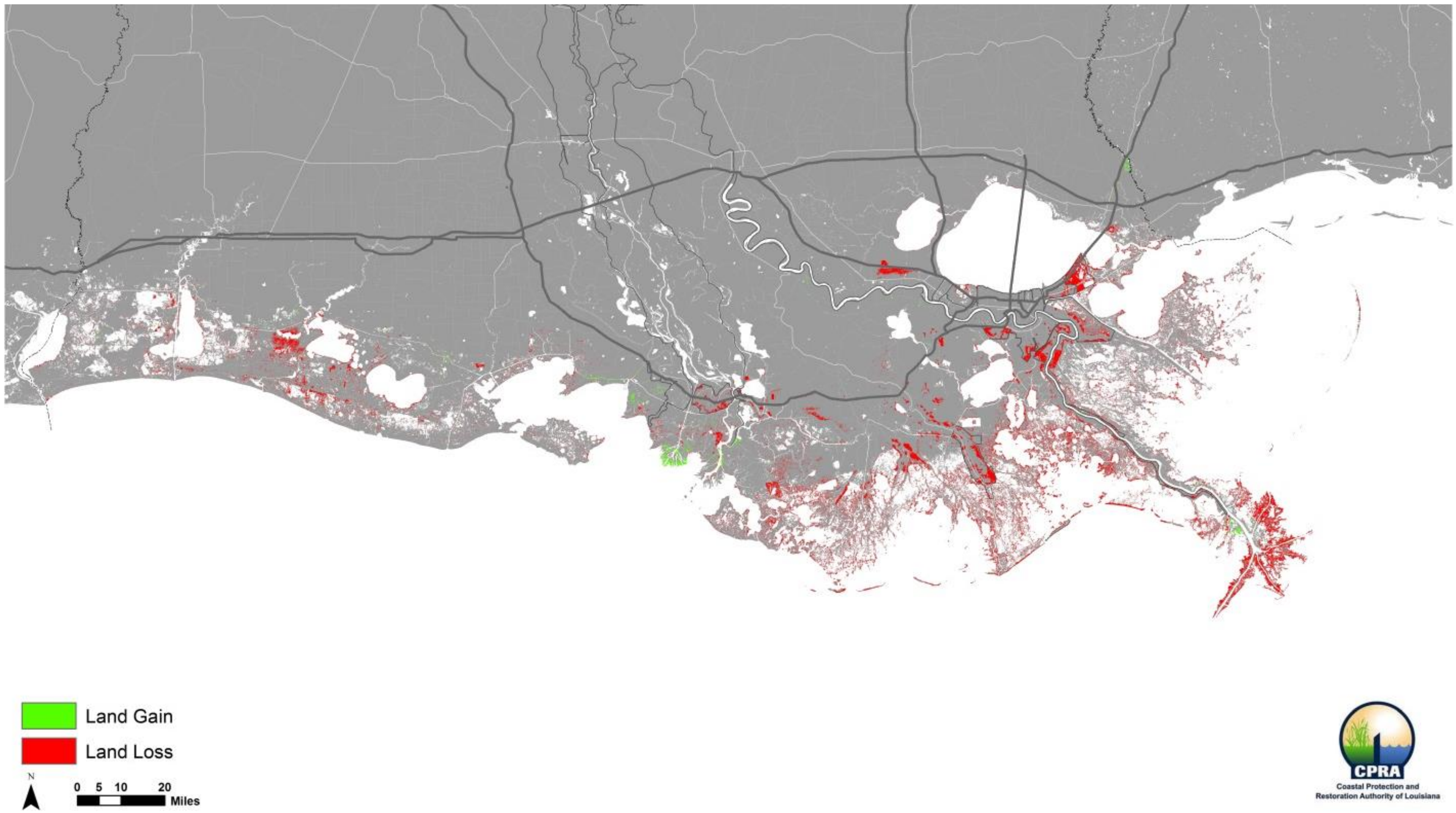


Figure 89: Land Change from Initial Conditions after 25 Years of Medium Scenario – FWOA. Net Land Change (Land Gain-Land Loss) at Year 25 is -1,590 km^2 for the Medium Scenario.

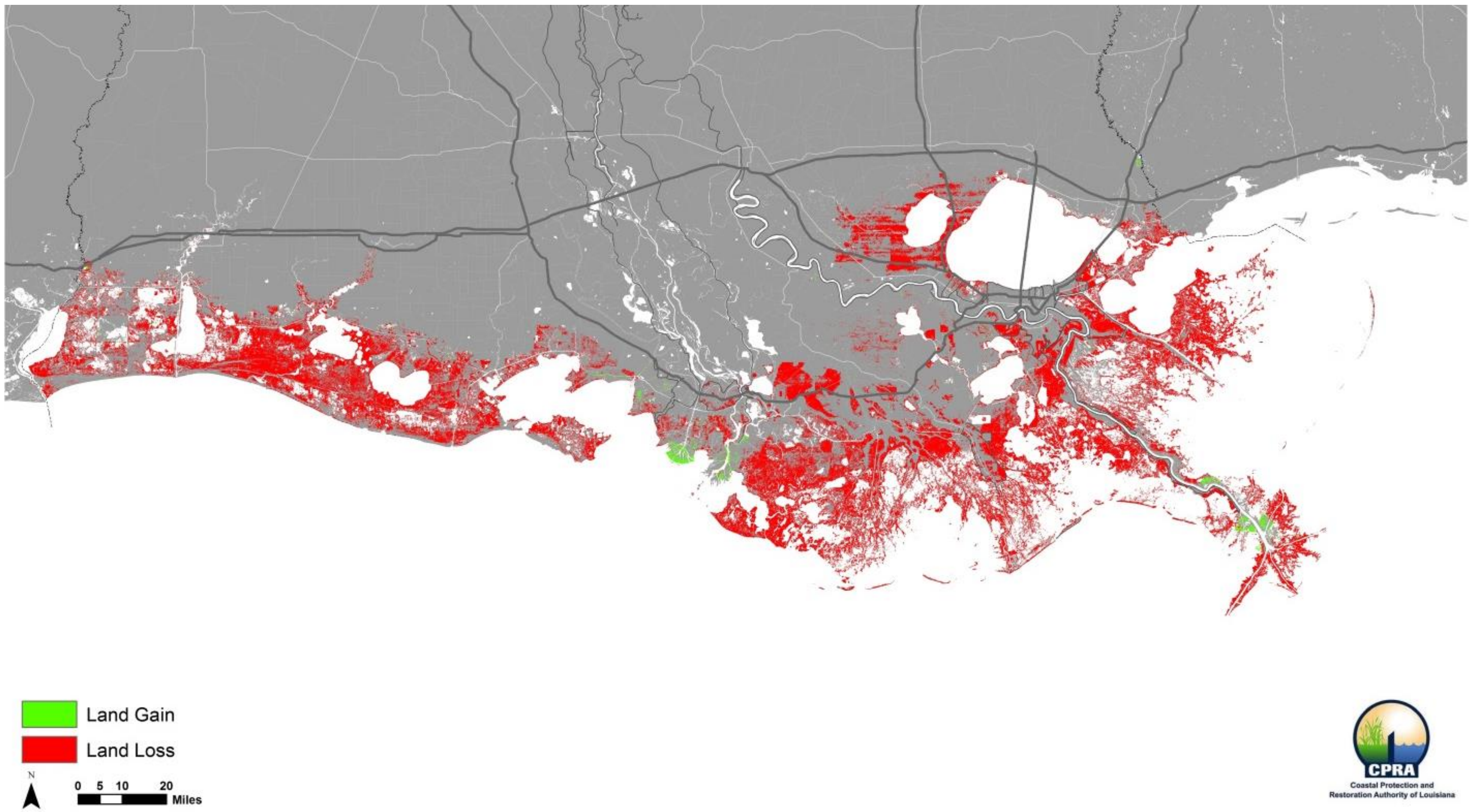


Figure 90: Land Change from Initial Conditions after 50 years of Medium scenario – FWOA. Net Land Change (Land Gain-Land Loss) at Year 50 is -7,320 km^2 for the Medium Scenario.

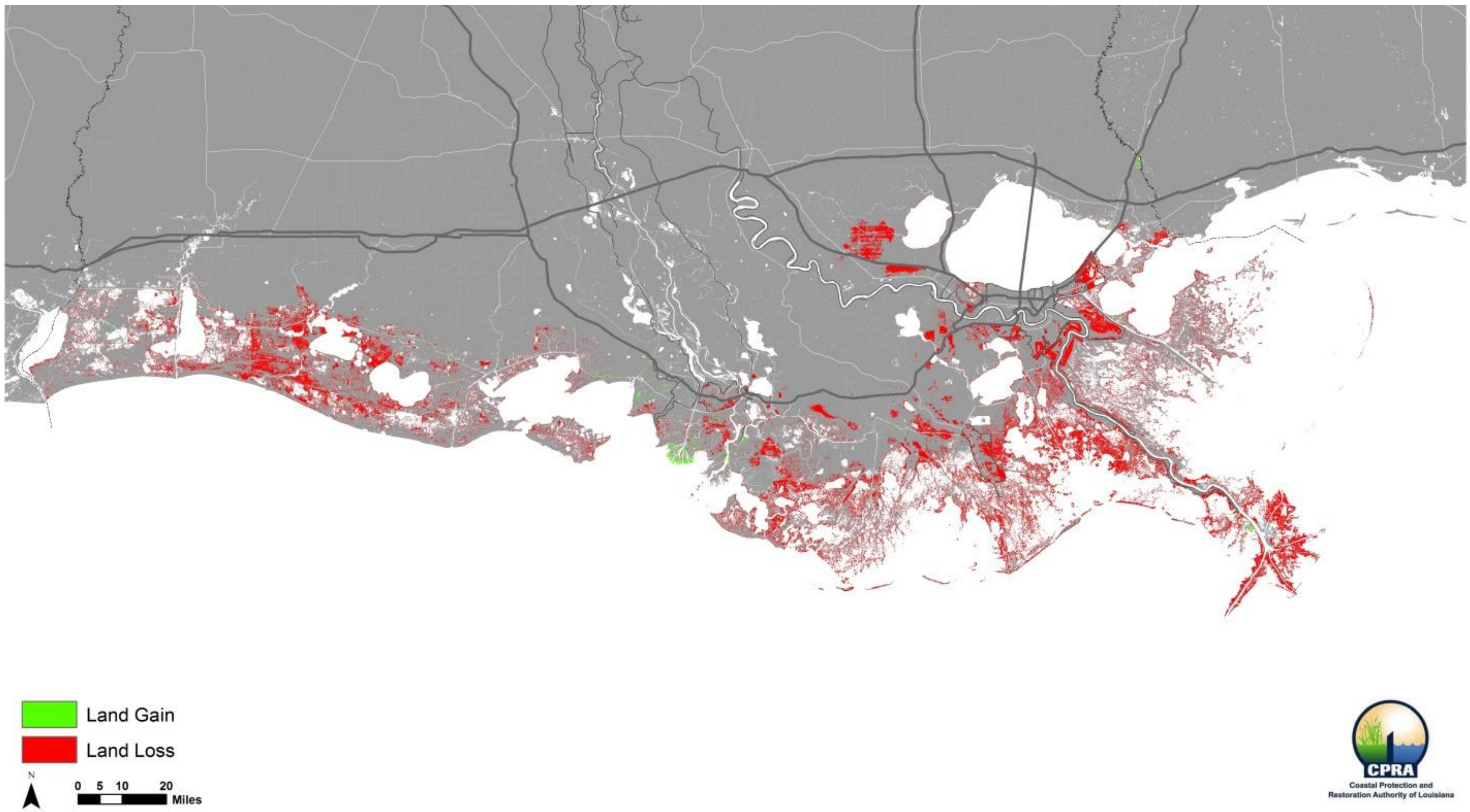


Figure 91: Land Change from Initial Conditions after 25 Years of High Scenario – FWOA. Net Land Change (Land Gain-Land Loss) at Year 25 is -3,340 km^2 for the High Scenario.

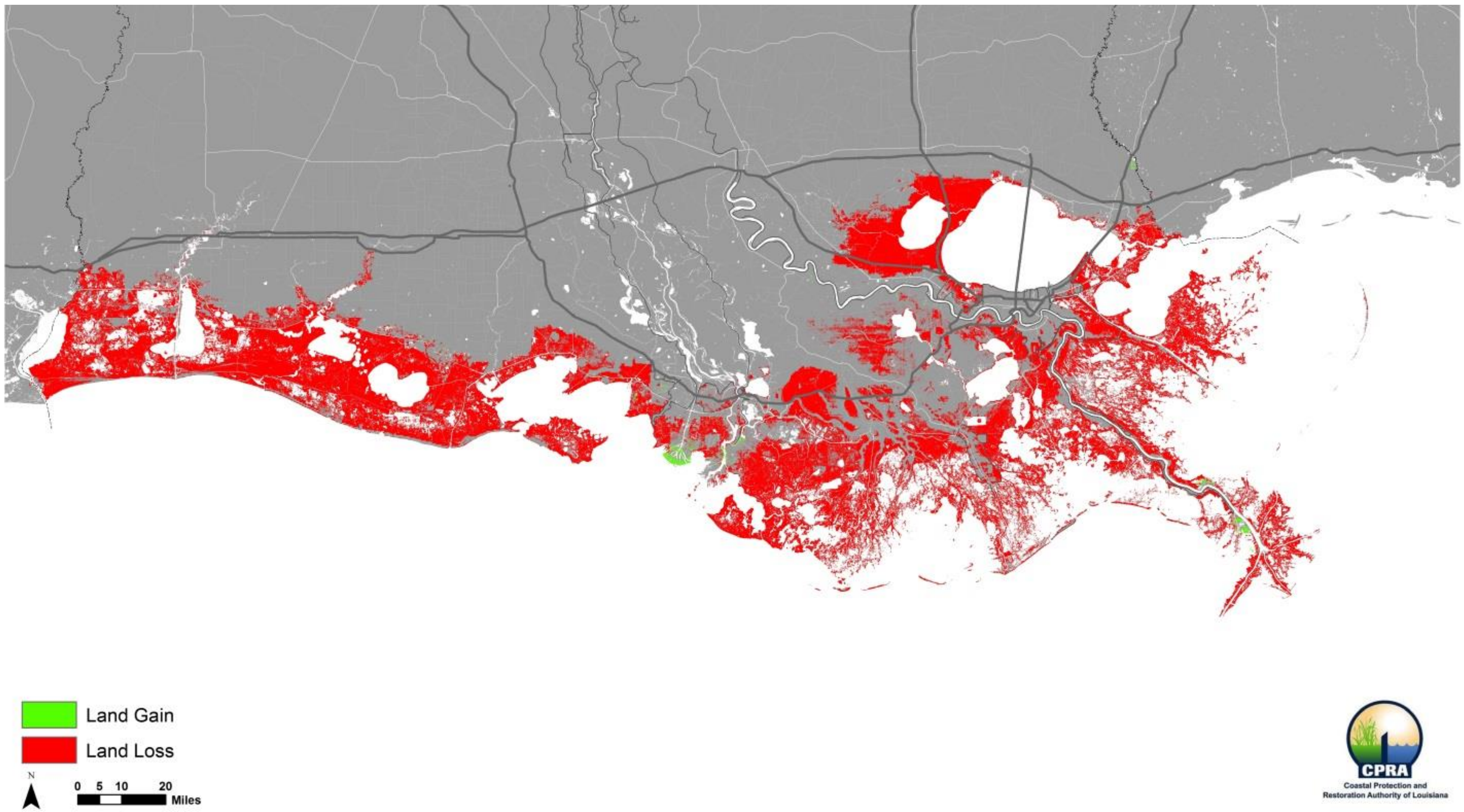


Figure 92: Land Change from Initial Conditions after 50 Years of High Scenario – FWOA. Net Land Change (Land Gain-Land Loss) at Year 50 is -10,990 km² for the High Scenario.

3.4 Vegetation

In this section, coast wide vegetation changes over 50 years under the three different future scenarios are discussed. For this analysis, individual species in the vegetation subroutine of the ICM (Louisiana Vegetation Model version 2 (LaVegMod v2)) were grouped into six habitats as summarized in Table 5. These habitats are not the same as those described by Chabreck (1972). Chabreck (1972) described habitats based on relative proportions of the different dominant species, while this approach used a simplified scheme of assigning each of the modeled species to only one habitat.

During the first 20 years, the forecasted changes under all three scenarios are very similar (Figure 93 - Figure 98). However, some general spatial patterns were noted. In the first two decades, fresh marsh expands primarily through the conversion of forested wetlands in the eastern coast. Saline marsh expands and replaces brackish marsh, which is most pronounced in the western coast, but this is a coast wide phenomenon.

Under the low scenario, trends observed in the first two decades continue for another two decades (Figure 93 and Figure 94). Under the medium scenario, trends change around year 25, with all habitat types declining coast wide and bare ground increasing (Figure 96). Change in the eastern coast is similar to that observed coast wide (Figure 96). In the central coast, declines are slower than coast wide under the medium scenario. This is most likely due to the input of freshwater and sediments to this region from the Atchafalaya River. Along the western coast, fresh, intermediate, and brackish marshes that are not converted to saline marshes are lost to open water (Figure 95 and Figure 96). Under the high scenario, the model forecasts a precipitous decline in all habitats starting around year 20 and continuing to year 50 (Figure 98) as land is converted to open water and saline habitats migrate inland (Figure 97). The model also shows an increase in bare ground at the same time. The gradual increase in bare ground under the medium and high scenarios is primarily driven by the eastern coast (Figure 97 and Figure 98). It reflects the very rapid salinity intrusion forecasted in these scenarios into Upper Barataria Basin. It seems that the brackish marsh species are able to rapidly migrate inland (Figure 95 and Figure 97), but the saline marsh species are not. This lack of movement of the saline marsh species is most likely due to their lower establishment along the fresher end of the salinity gradient (brackish species establish at a very low likelihood at 0.4 ppt average annual salinity, while saline species start establishment at 4 ppt). This allows brackish marsh species to be present at small percentages at low salinity and rapidly expand when salinity increases, whereas saline species can only expand when salinity consistently increases. In the western coast, both marsh types migrate inland, but bare ground forms along the Gulf shoreline (Figure 97 and Figure 98). Since all species have the same dispersal probability, this is not likely the limiting factor keeping species from colonizing these bare areas. More likely, the future conditions in these areas are outside of the current niche of the species in the model. In the real world, it is likely that these areas would be colonized by other species that are not in the model (e.g., *Batis maritima*). These species are not currently common dominants in Louisiana, but are common dominants in the more saline estuaries in Texas (Mitchell et al., 2014). Under the high scenario, the largest areas of remaining marsh at the end of the 50-year forecast are in the influence area of the Atchafalaya River and at the mouth of the Pearl River (Figure 98). This demonstrates the importance of freshwater input in maintaining existing marshes, especially in the face of significantly increased relative sea level.

Table 5: List of Vegetation Species Included in Each Habitat Type.

Habitat	Species
Forested Wetland	*Nyssa aquatica* L., *Quercus laurifolia* Michx., *Quercus lyrata* Walter, *Quercus nigra* L., *Quercus texana* Buckley, *Quercus virginiana* Mill., *Salix nigra* Marshall, *Taxodium distichum* (L.) Rich., *Ulmus americana* L.
Fresh Floating Marsh	*Eleocharis baldwinii* (Torr.) Chapm., *Hydrocotyle umbellata* L. *Panicum hemitomon* Schult.
Fresh Attached Marsh	*Cladium mariscus* (L.) Pohl, *Eleocharis baldwinii* (Torr.) Chapm. *Hydrocotyle umbellata* L., *Morella cerifera* (L.) Small, *Panicum hemitomon* Schult., *Sagittaria latifolia* Willd., *Schoenoplectus californicus* (C.A. Mey.) Palla, *Typha domingensis* Pers., *Zizaniopsis miliacea* (Michx.) Döll & Asch.
Intermediate Marsh	*Sagittaria lancifolia* L., *Phragmites australis* (Cav.) Trin. ex Steud., *Iva frutescens* L., *Baccharis halimifolia* L.
Brackish Marsh	*Paspalum vaginatum* Sw., *Spartina patens* (Aiton) Muhl.
Saline Marsh	*Avicennia germinans* (L.) L., *Distichlis spicata* (L.) Greene, *Juncus roemerianus* Scheele, *Spartina alterniflora* Loisel.

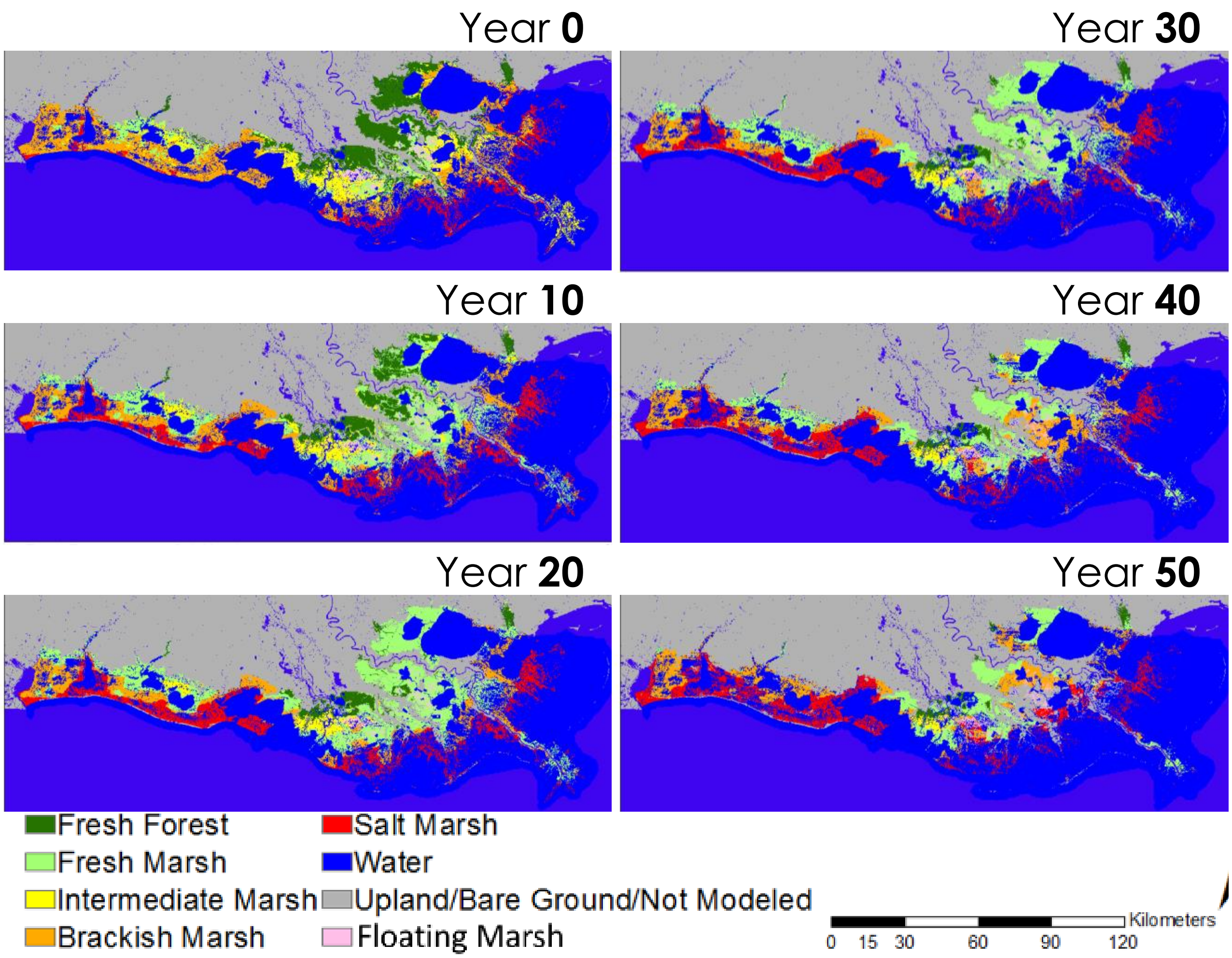


Figure 93: Coast Wide Change in Habitats Over the 50 Year Forecast Using the Low Scenario.

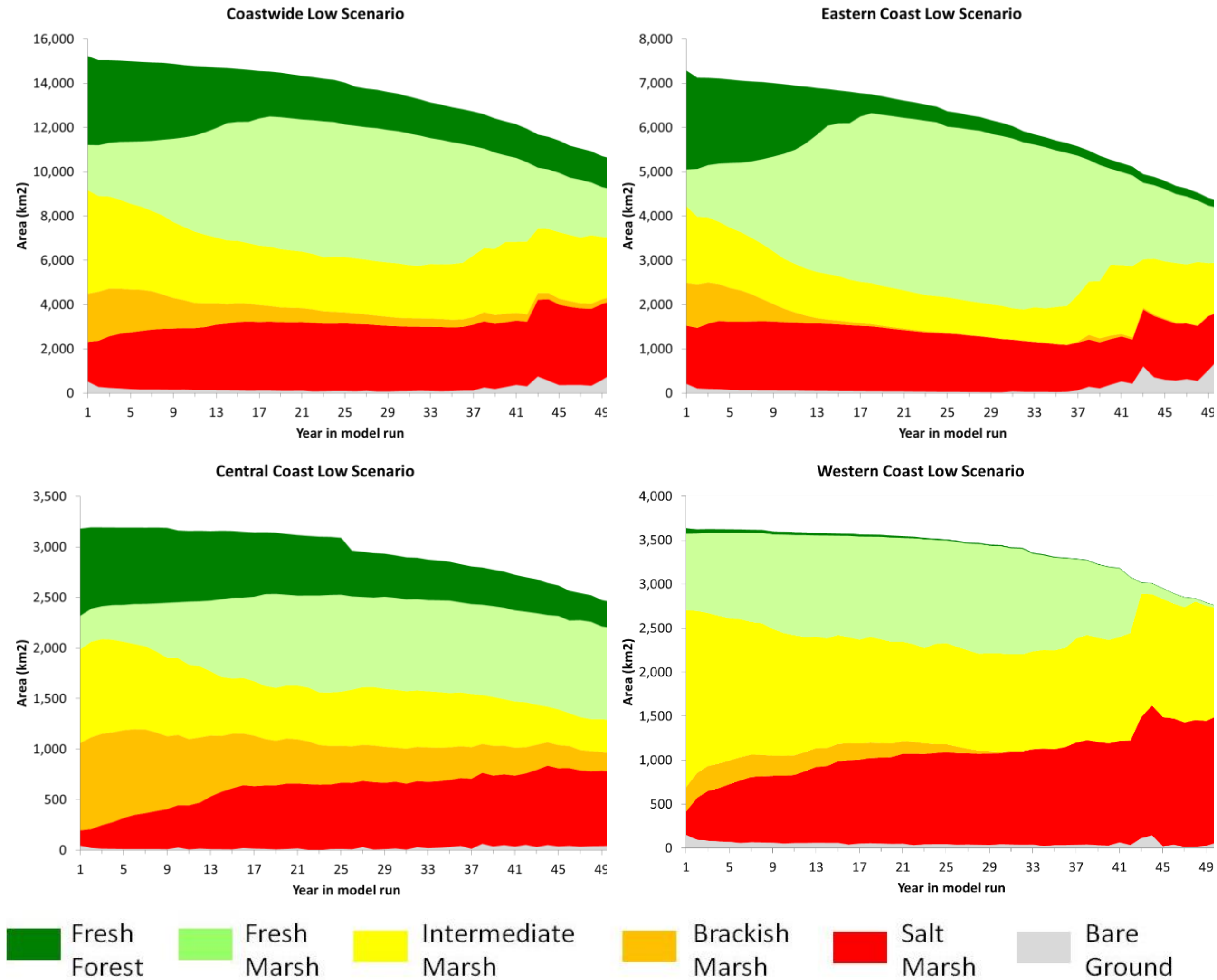


Figure 94: Change in Habitats Forecasted Using the Low Scenario: Coast Wide and Three Regions of the Coast.

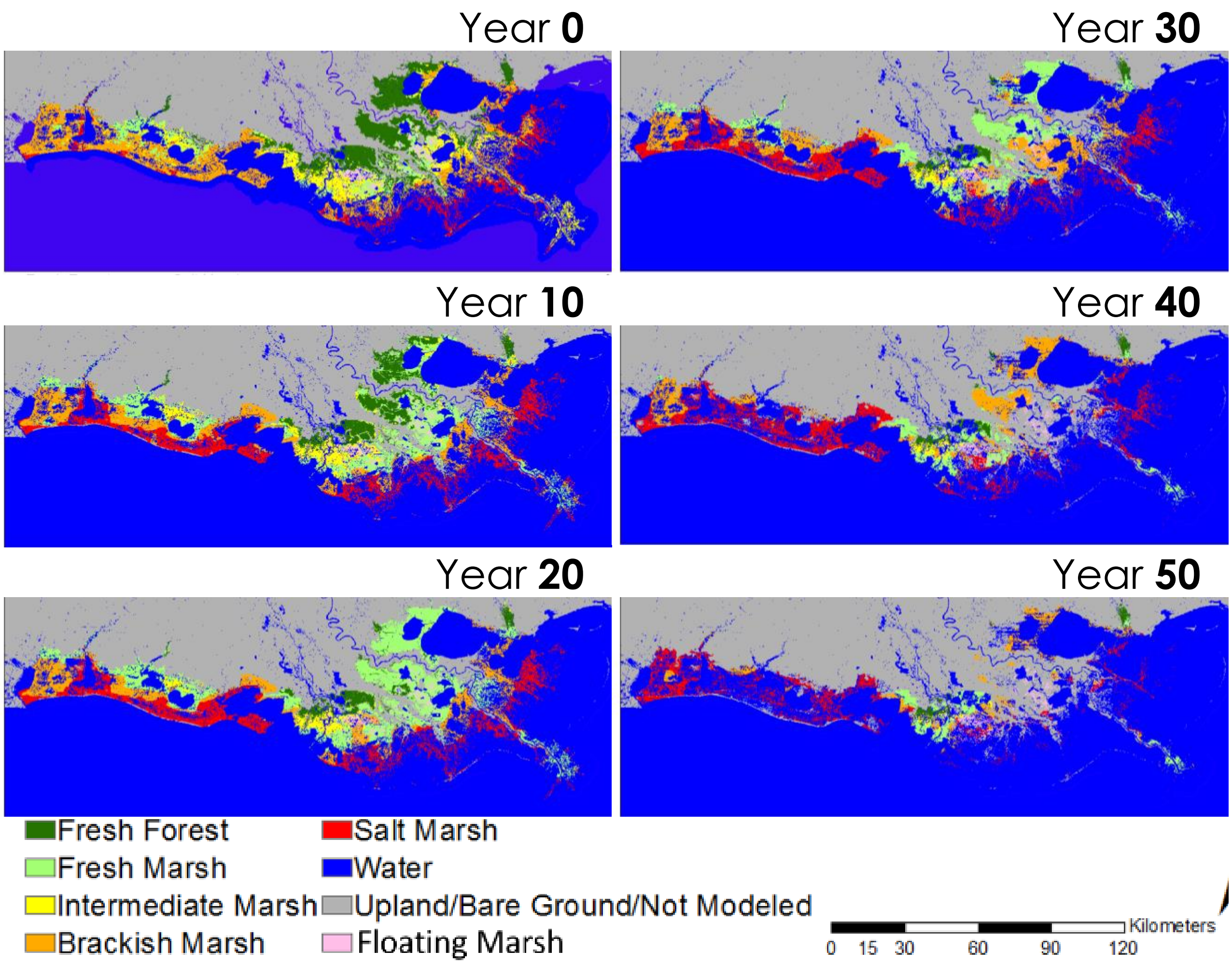


Figure 95: Coast Wide Change in Habitats Over the 50 Year Forecast Using the Medium Scenario.

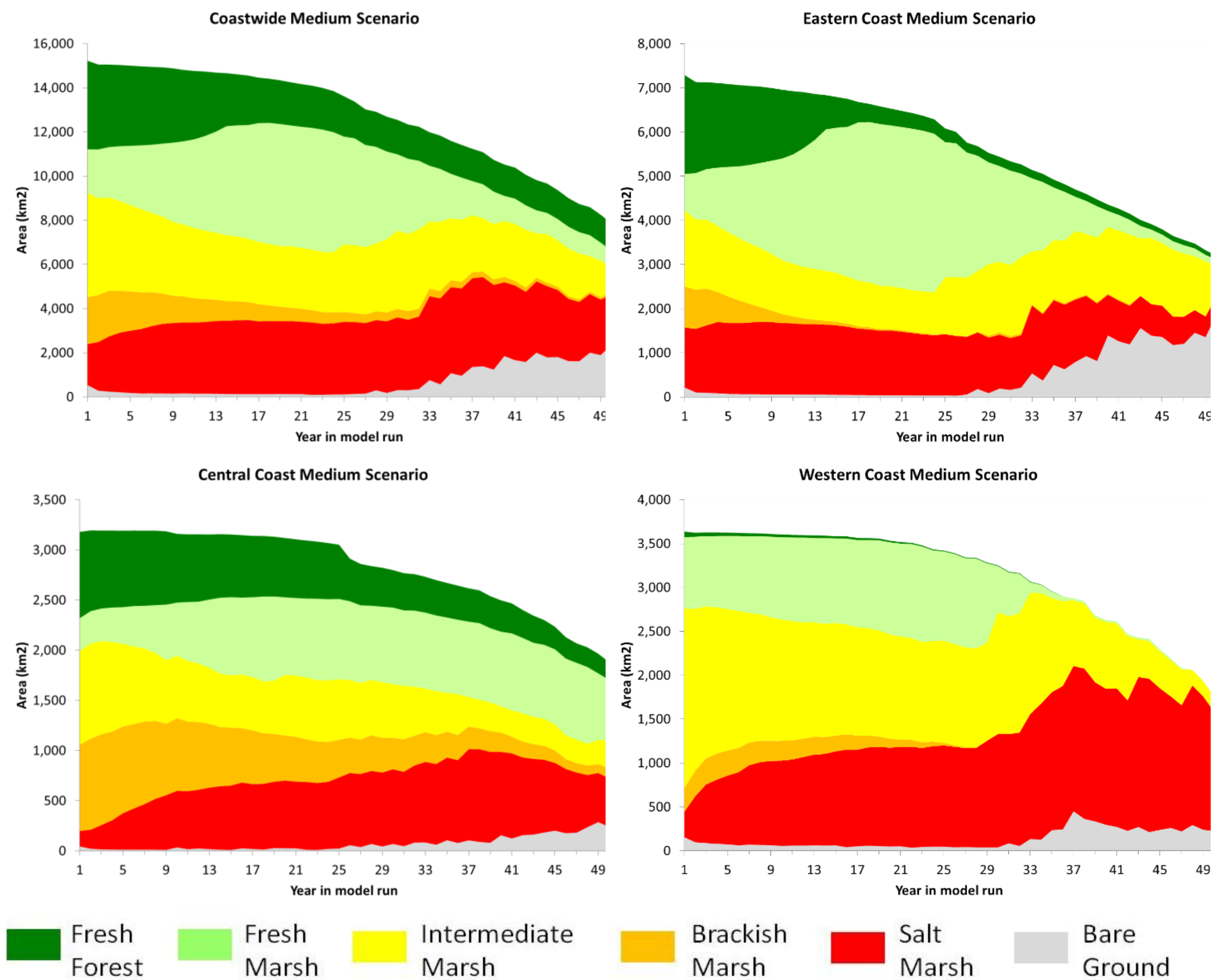


Figure 96: Change in Habitats Forecasted Using the Medium Scenario: Coast Wide and Three Regions of the Coast.

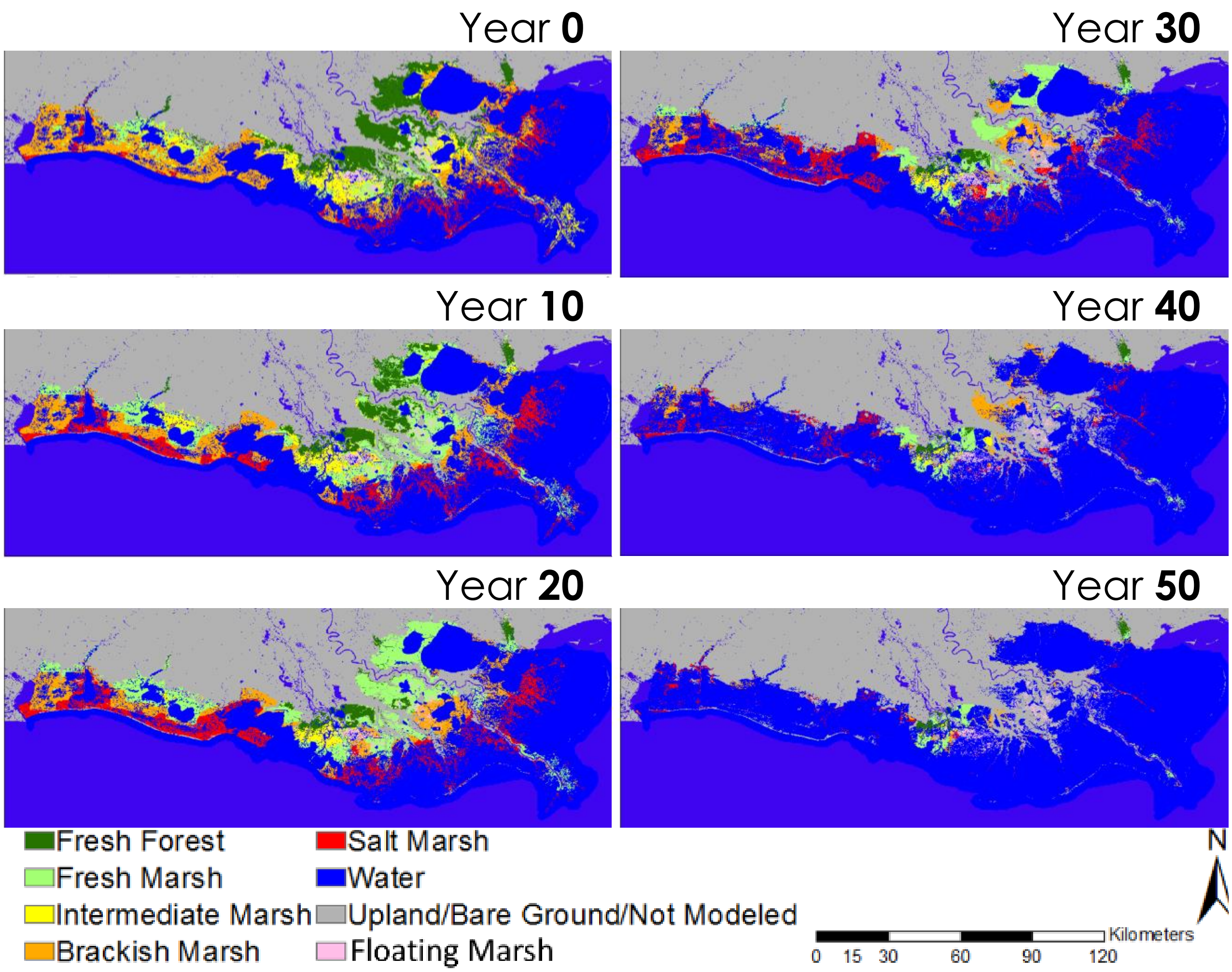


Figure 97: Coast Wide Change in Habitats Over the 50-Year Forecast Using the High Scenario.

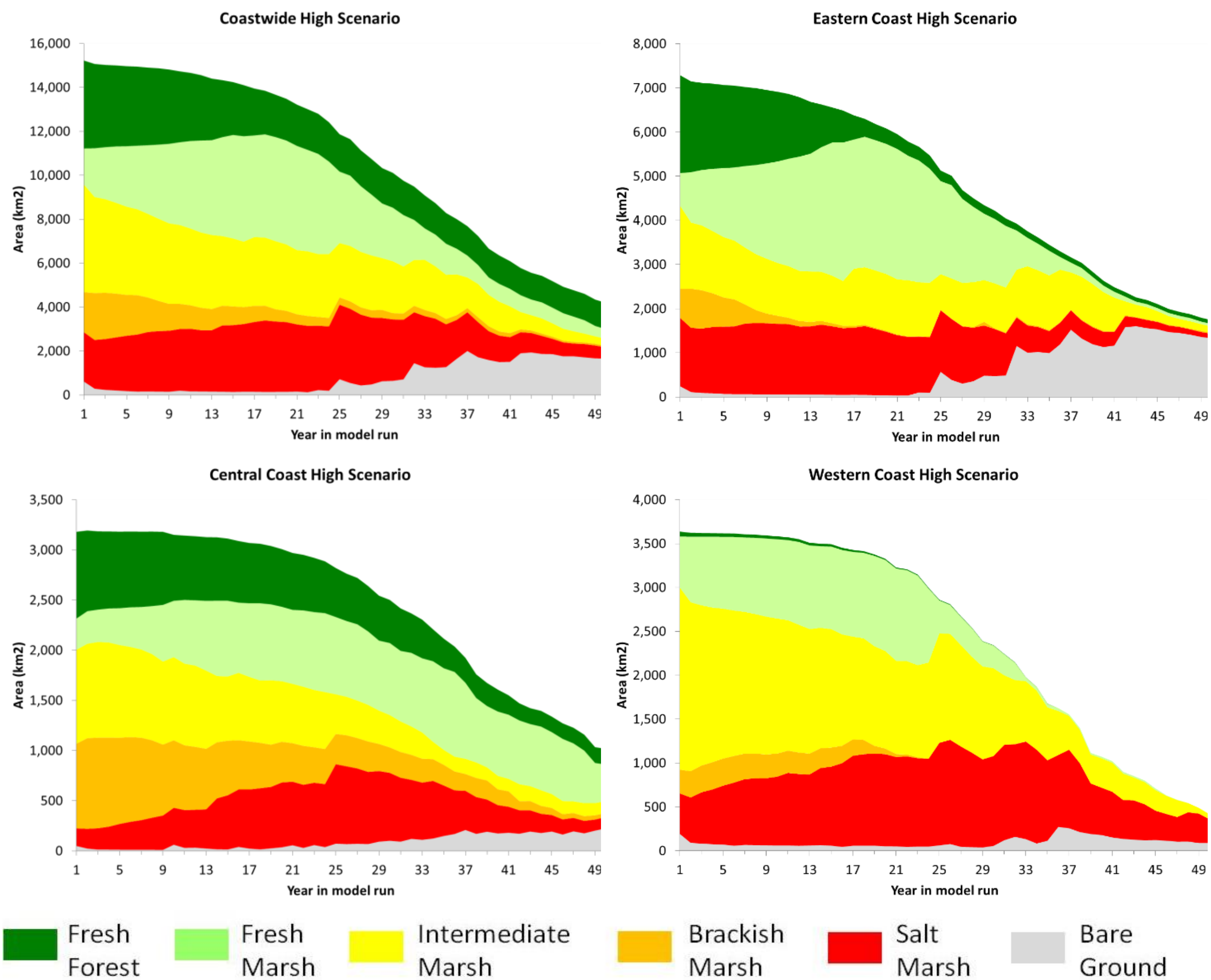


Figure 98: Change in Habitats Forecasted Using the High Scenario: Coast Wide and Three Regions of the Coast.

3.5 Barrier Islands

3.5.1 Annual Processes and Forcing Functions

The natural processes and forcing functions for long-shore sediment transport, silt loss, bayside erosion, and relative sea level rise were modeled on an annual basis (see Attachment C3-4: BIMODE). These processes and functions resulted in barrier shoreline changes and island elevation adjustments. The overall shoreline change trend was net erosion as the barrier shorelines eroded and migrated landward over time. Figure 99 depicts a plan view of shoreline change on decadal time steps through year 20 for East-Trinity Island in the Isles Dernieres. Incremental landward retreat of the Gulf-side shoreline and the bayside shoreline erosion is observed. These erosional shoreline changes result in the narrowing of island width and corresponding land area reduction over time. In the absence of significant storms, Gulf-side changes are attributed primarily to long-shore transport.

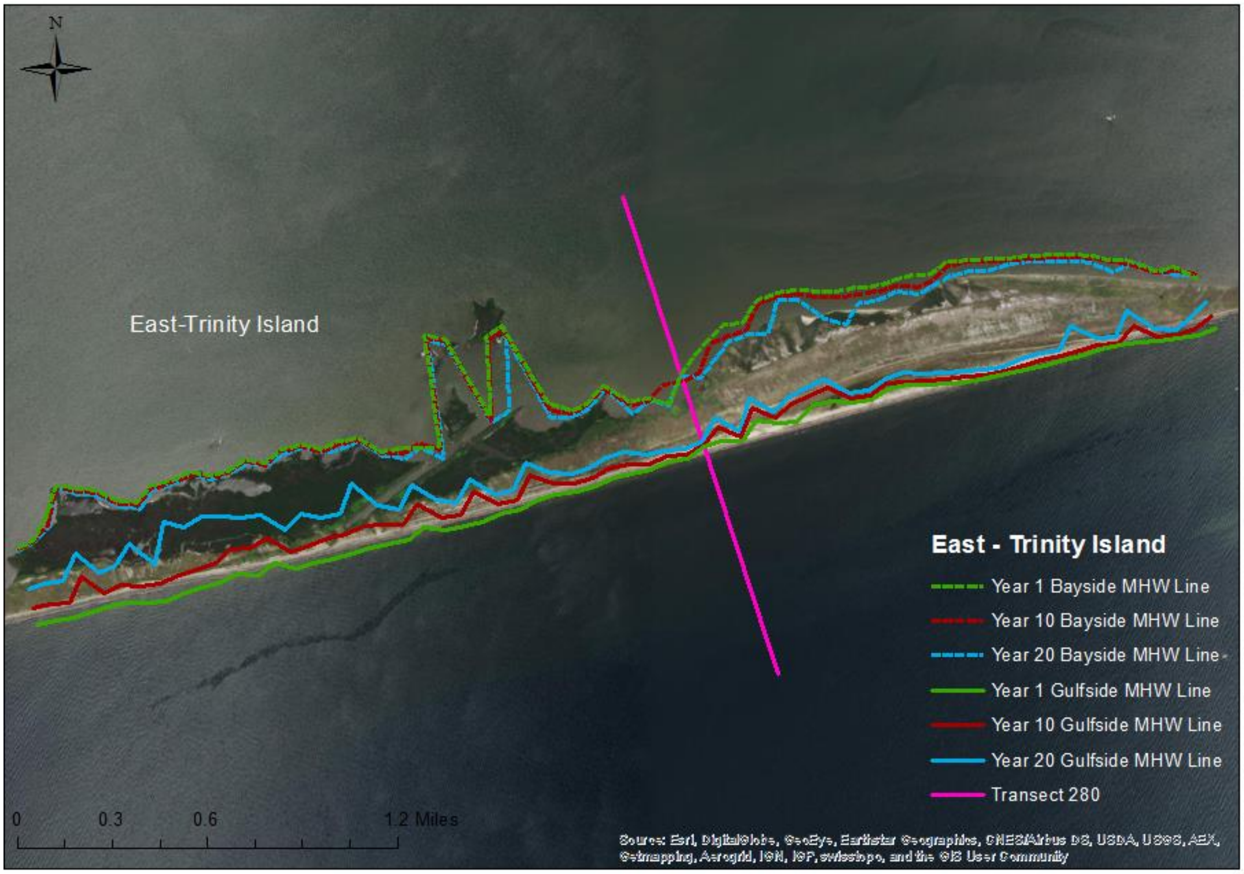


Figure 99: Plan View of East-Trinity Island Shoreline Changes through Year 20.

Figure 100 depicts a representative cross section for East-Trinity Island at the corresponding decadal time steps through year 20. The shoreface erosion and silt loss on the Gulf-side, erosion of the bayside shoreline, and vertical lowering of the profile to account for the effects of relative sea level rise are observed as the corresponding profile adjustments were instituted in the model. Storm #107 modeled in year 2 passed within 40 km of the island which caused significant erosion of the island (Attachment C3-3: Storms in the ICM Boundary Conditions).

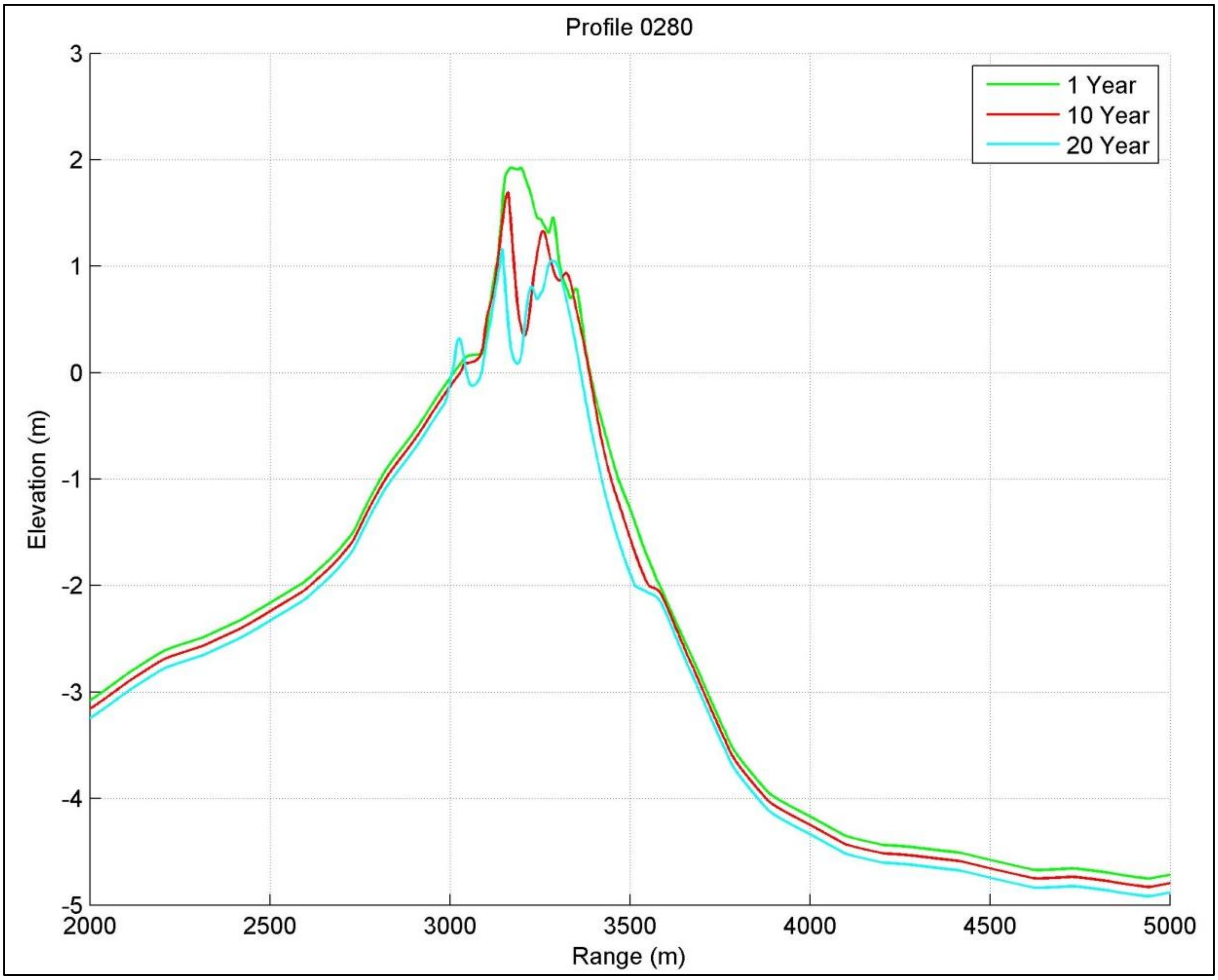


Figure 100: Representative Cross Sectional Comparison of East-Trinity Island through Year 20.

Other observations from viewing the Keyhole Markup Language (KMZ) shoreline files in Google Earth on decadal time steps included localized shoreline advance as the islands elongated and spit formation from sediment movement alongshore. This was observed on the west end of Grand Terre between years 10 and 30 as depicted in Figure 101.

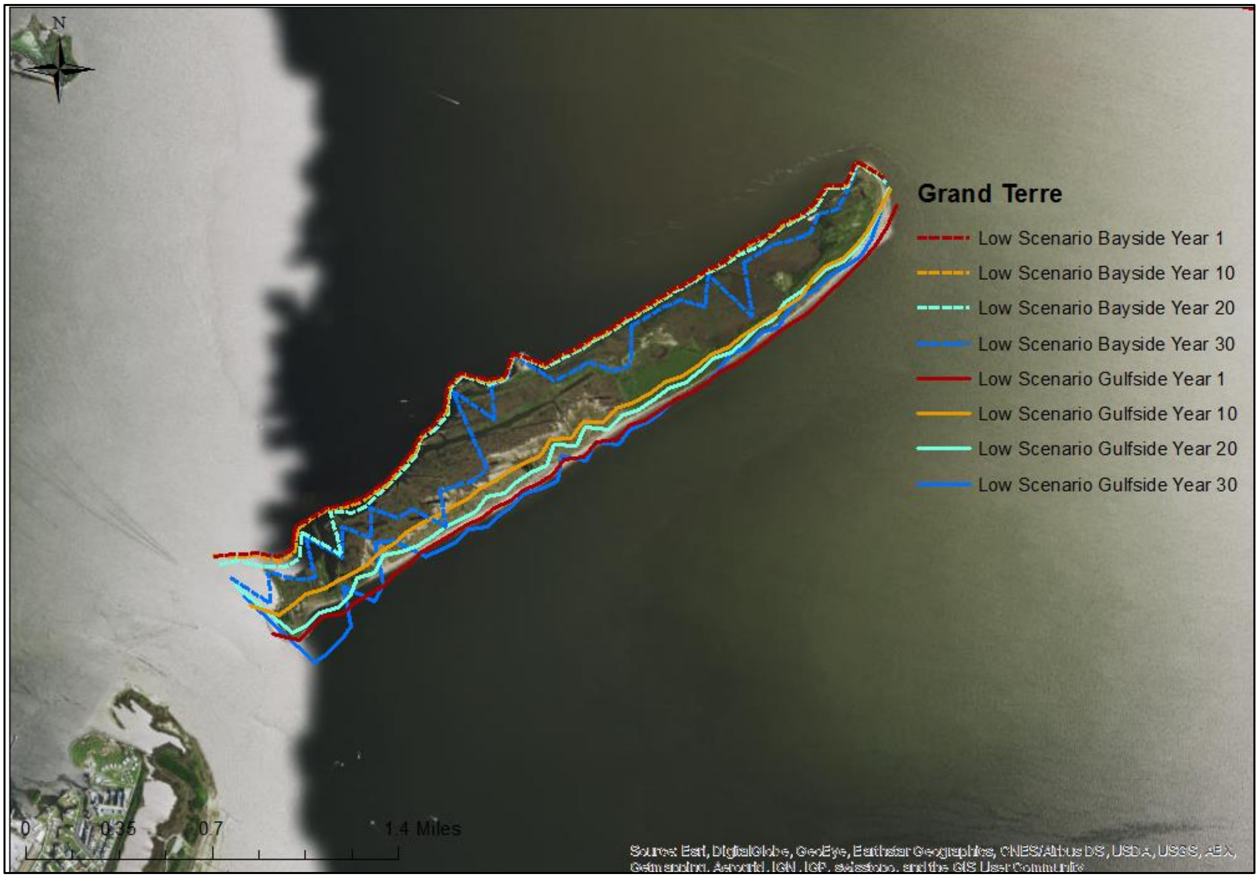


Figure 101: Plan View of Grand Terre Gulf-Side and Bayside Shorelines through Year 30.

3.5.2 Episodic Processes and Forcing Functions

The episodic processes and forcing functions for cross-shore sediment transport and breaching were modeled during years when storms impacted the barrier shorelines (Attachment C3-4: BIMODE). Erosive effects of the storms included erosion of the Gulf-side shoreface, beach berm, dune, and marsh platform resulting in land loss. Accretionary effects of the storms included overwash resulting in land area gains. Figure 102 depicts a representative comparison of pre-storm and post-storm profiles for East-Trinity Island in the Isles Dernieres region. Storm #569 was modeled in year 16 (Attachment C3-3: Storms in the ICM Boundary Conditions) and passed within approximately 10 km of East-Trinity Island. Shoreface erosion and corresponding overwash are observed on the beach berm. Significant land loss of the back-barrier platform and minor overwash onto the submerged profile in the back bay are also observed.

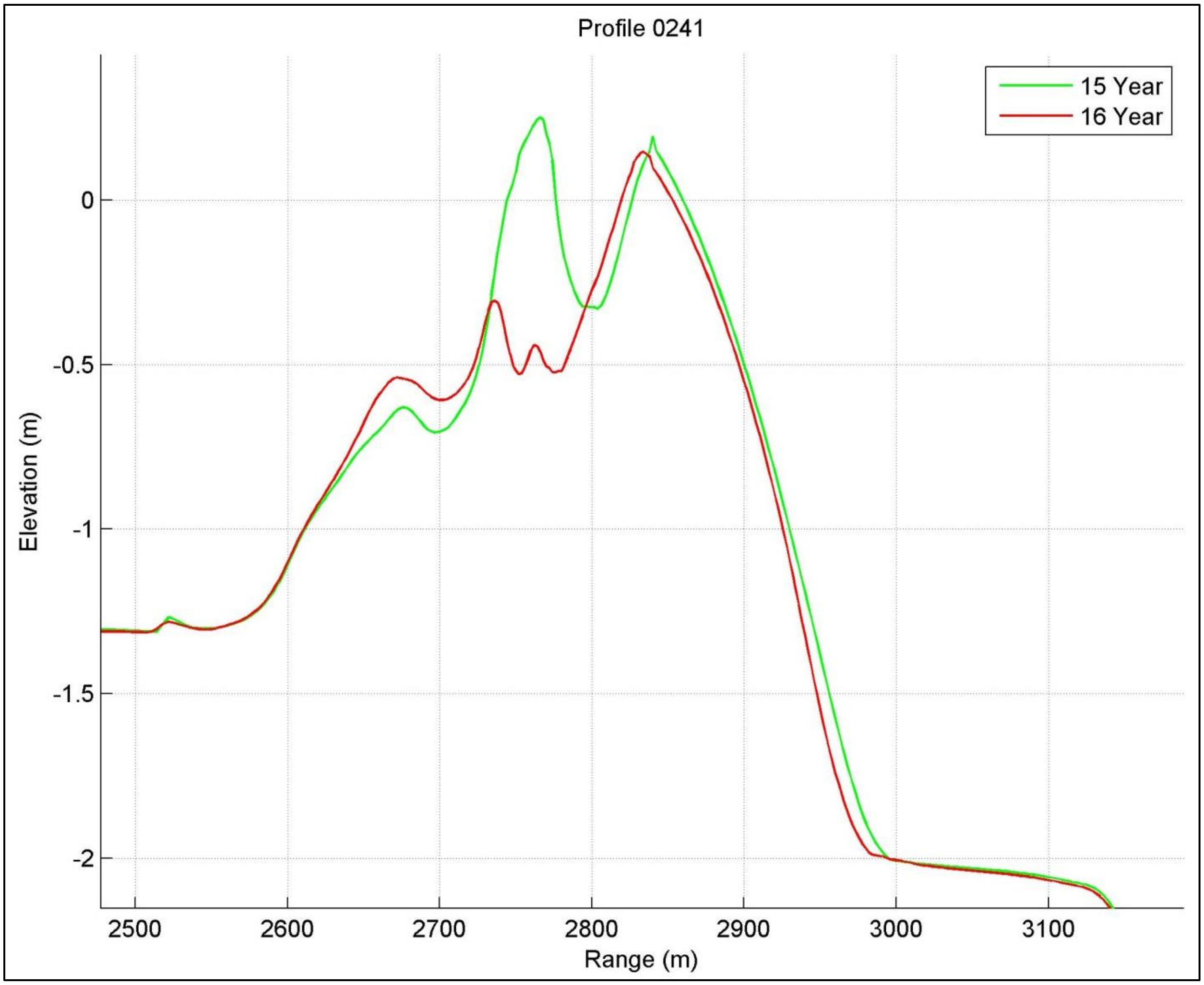


Figure 102: Representative Cross Sectional Comparison of East-Trinity Island through Year 20.

Figure 103 and Figure 104 depict a plan view of pre-storm and post-storm shorelines and pre-storm and post-storm profiles, respectively, for the Chaland Headland which is one of the Barataria Barrier shorelines. Storm #143 was modeled in year 35 (Attachment C3-3: Storms in the ICM Boundary Conditions) and passed within 80 km of Chaland Headland. Storm impacts resulted in island breaching as evidenced by comparing the pre- and post-storm conditions.

Figure 103: Plan View of Pre and Post-Storm Shorelines for Chaland Headland at Years 34-35.

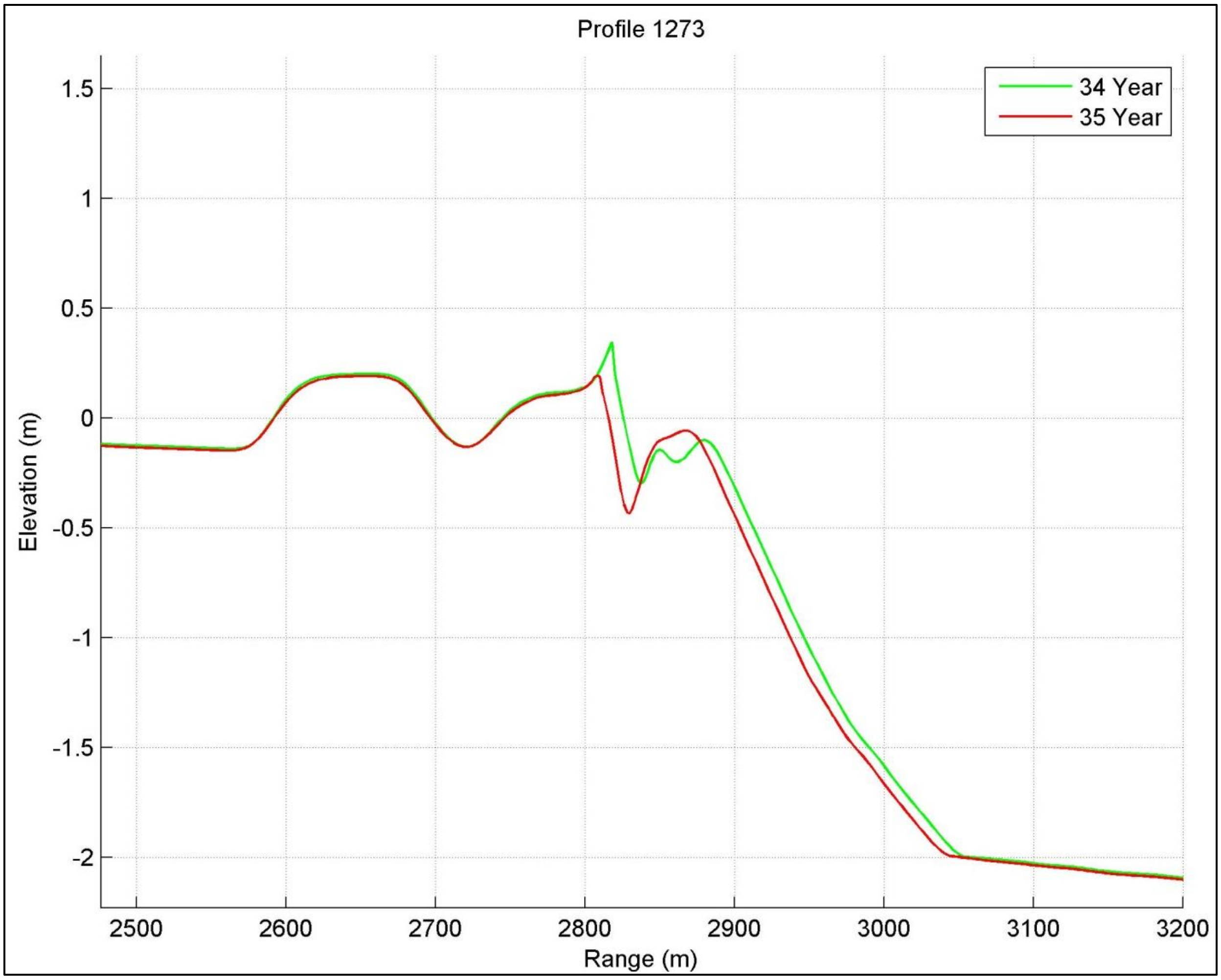


Figure 104: Pre and Post-Storm Cross Sectional Comparison for Chaland Headland at Years 34-35.

3.5.3 Regional Results

Presented in Attachment C3-4: BIMODE are plan views of Gulf-side and bayside shorelines at years 1, 10, 30, and 50 and representative cross sections at years 1, 25, and 50. Figure 105 depicts an example of the shoreline changes over 50 years for East-Trinity Island for the low scenario. Figure 106 depicts an example of the profile changes over 50 years for Caminada Headland for all three scenarios: low, medium, and high. The overall regional trends for the 50-year period include significant land loss over time, island migration due to overwash from storm induced cross-shore transport, island breaching in the wake of a major storm, and island disappearance. The primary difference among the scenarios is the increased vertical lowering of the profiles which translates to increased land loss to account for the increased subsidence and sea level change.

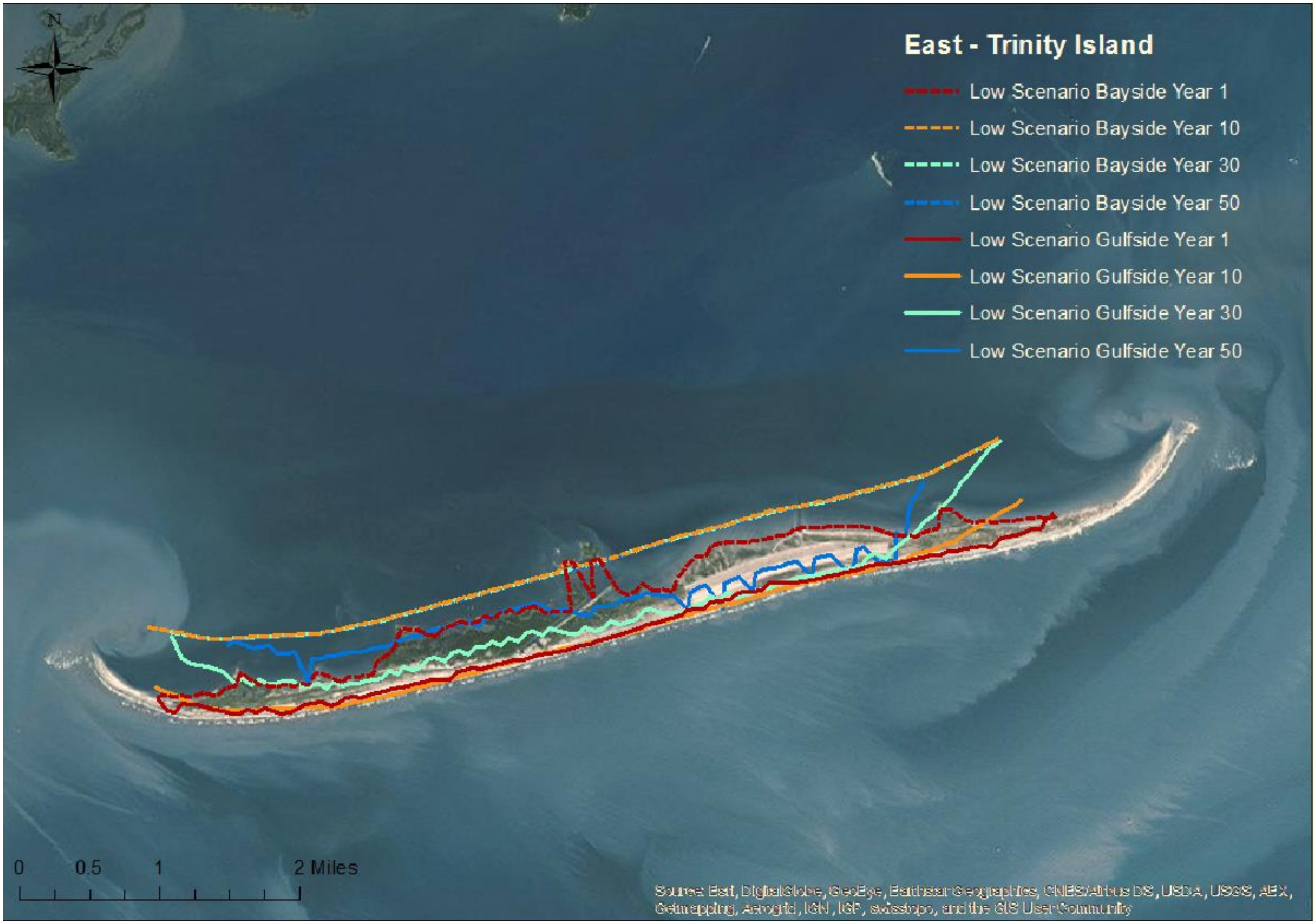


Figure 105: Plan View of East-Trinity Island Gulf-Side and Bayside Shorelines through Year 50 for Low Scenario.

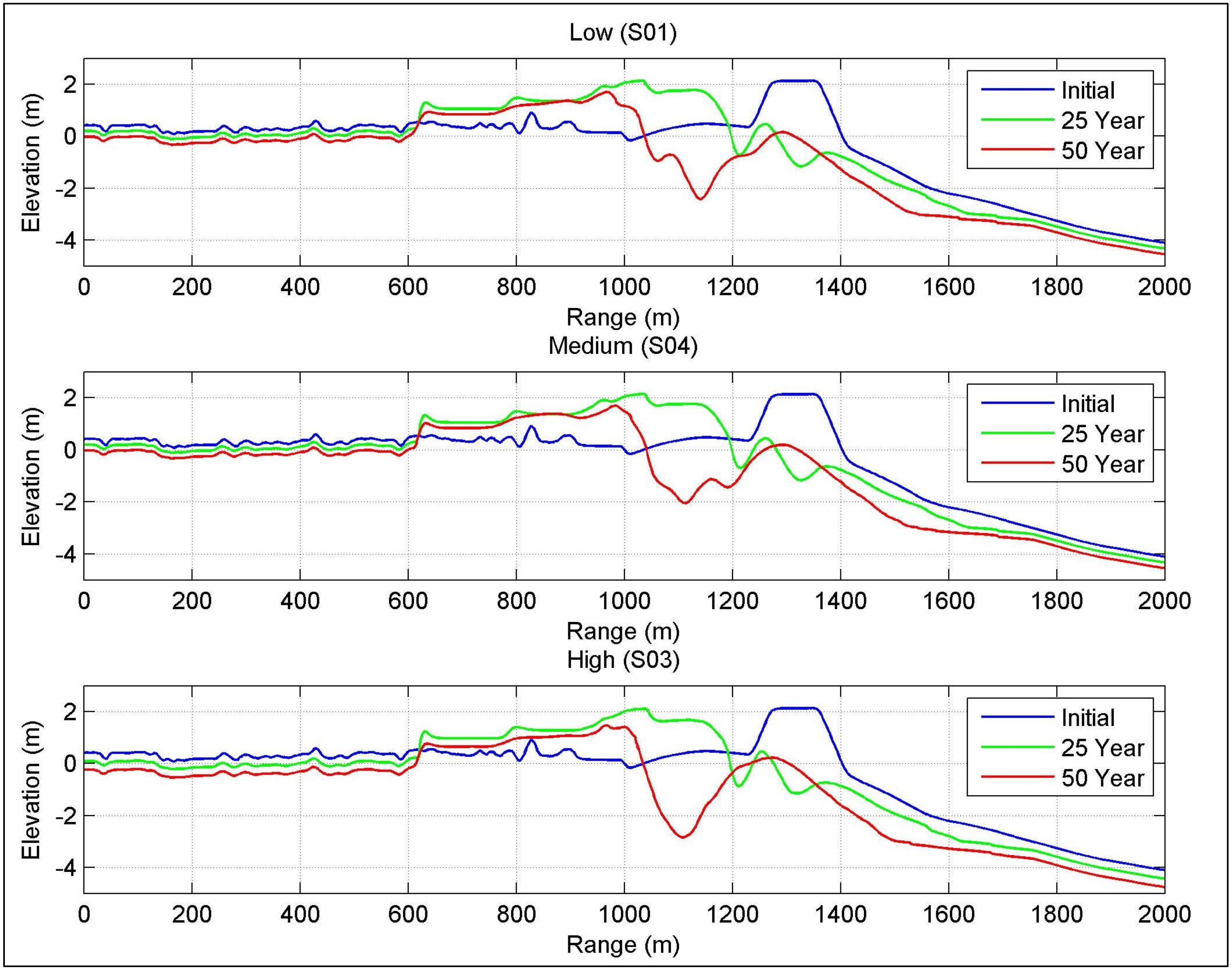


Figure 106: Cross Sections of Caminada Headland through Year 50 for Low, Medium, and High Scenarios.

3.5.4 Land Area Analysis

The changes in profiles were used to calculate the change in land area over time for 5-year periods for each scenario for the barrier shorelines using the same algorithm as is used in the morphology subroutine. Figure 107 through Figure 112 present the land area changes over time for different sections of the barrier shorelines. As predicted, higher land loss rates are observed for the medium and high scenarios attributable to accelerated sea level rise and more subsidence. Table 6 through Table 8 present the land area changes over time by region and by scenario, including initial and final land areas, percentage of land loss, and predicted year of disappearance if applicable.

Breton Island and the Chandeleur Islands are predicted to disappear within the 50-year period of analysis. The other four sections are predicted to have some land area remaining. The Caminada barrier shorelines experienced the highest percent land loss while the Barataria Barrier shorelines experienced the lowest percent land loss.

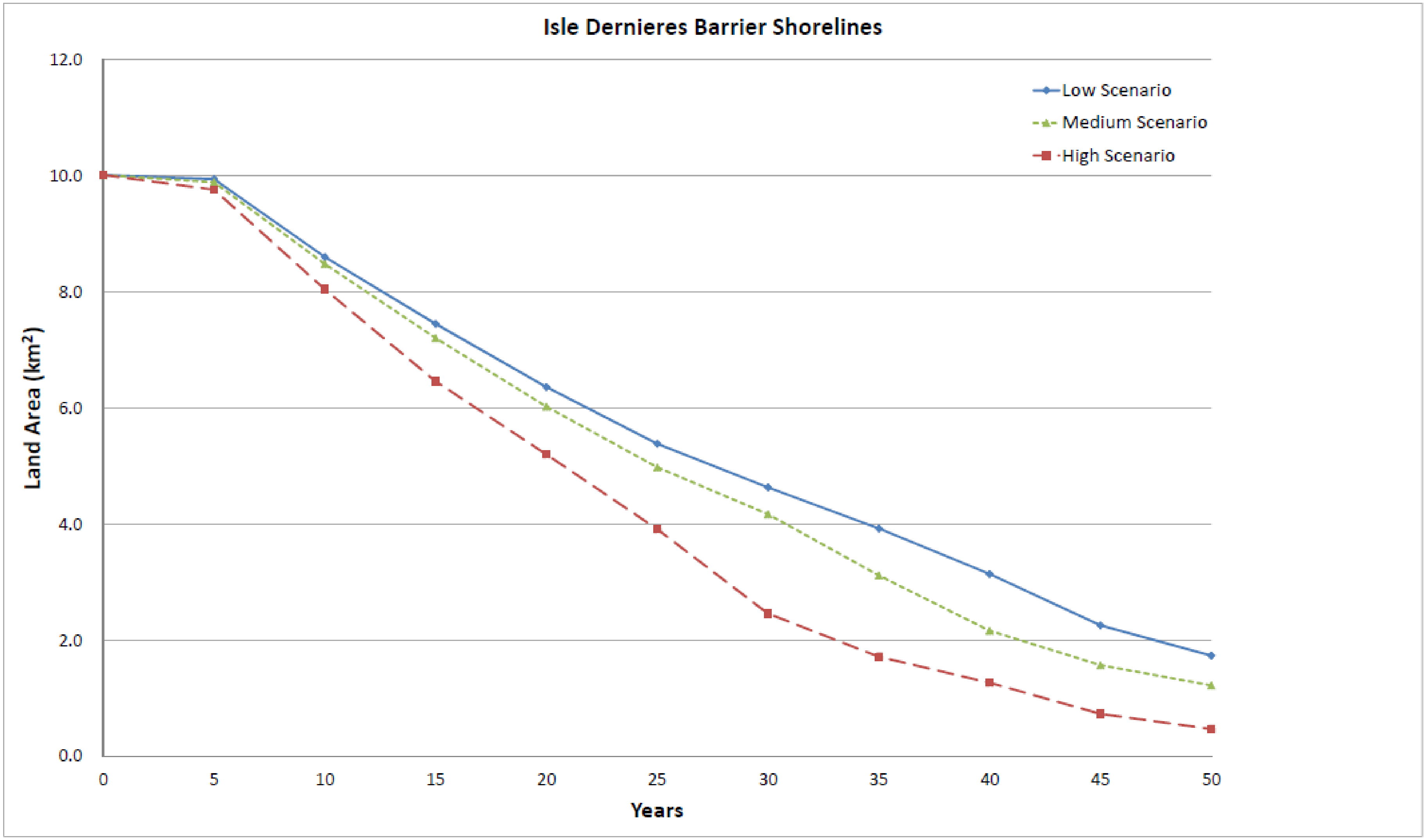


Figure 107: Land Area Changes Over Time for Isle Dernieres Barrier Shorelines.

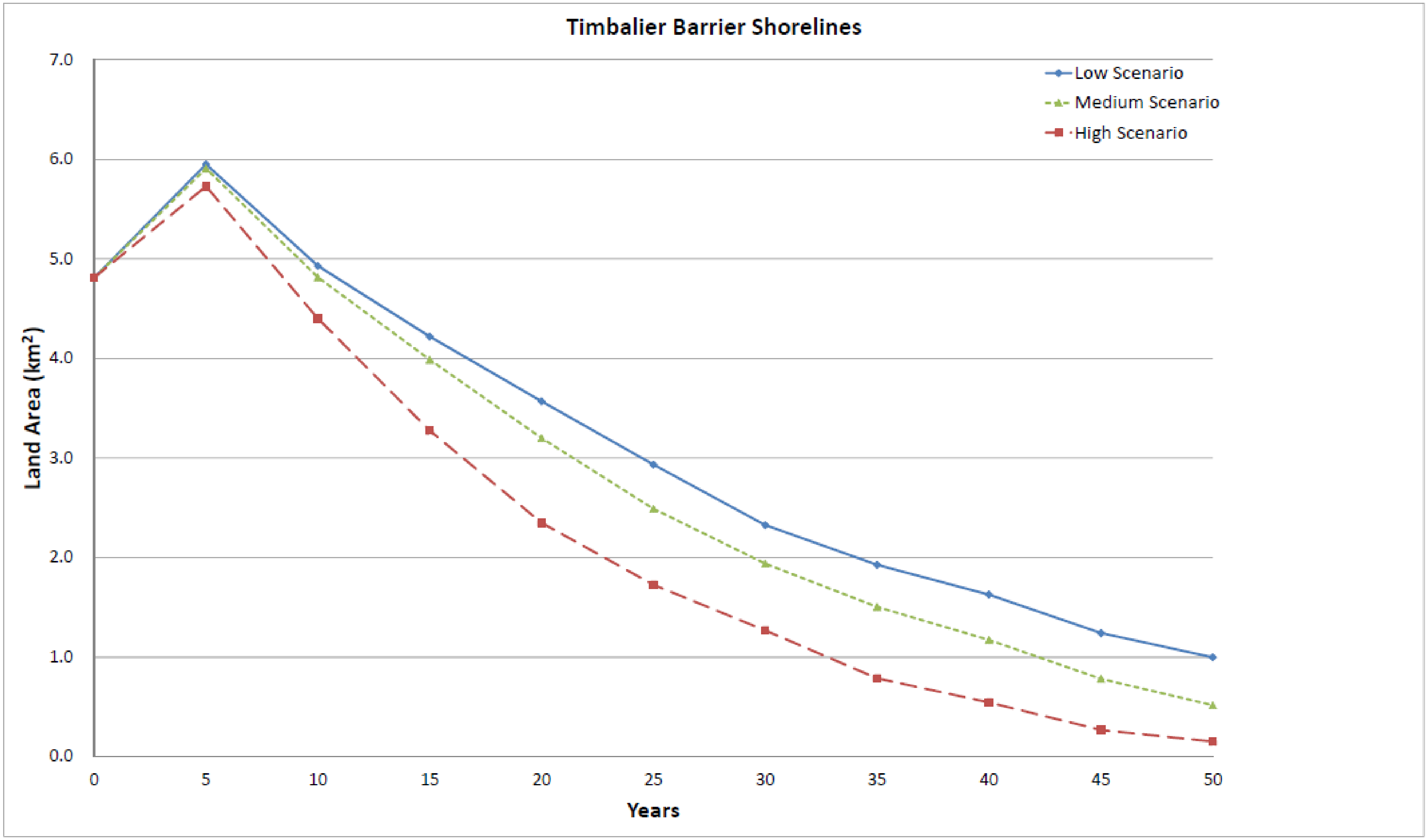


Figure 108: Land Area Changes Over Time for Timbalier Barrier Shorelines.

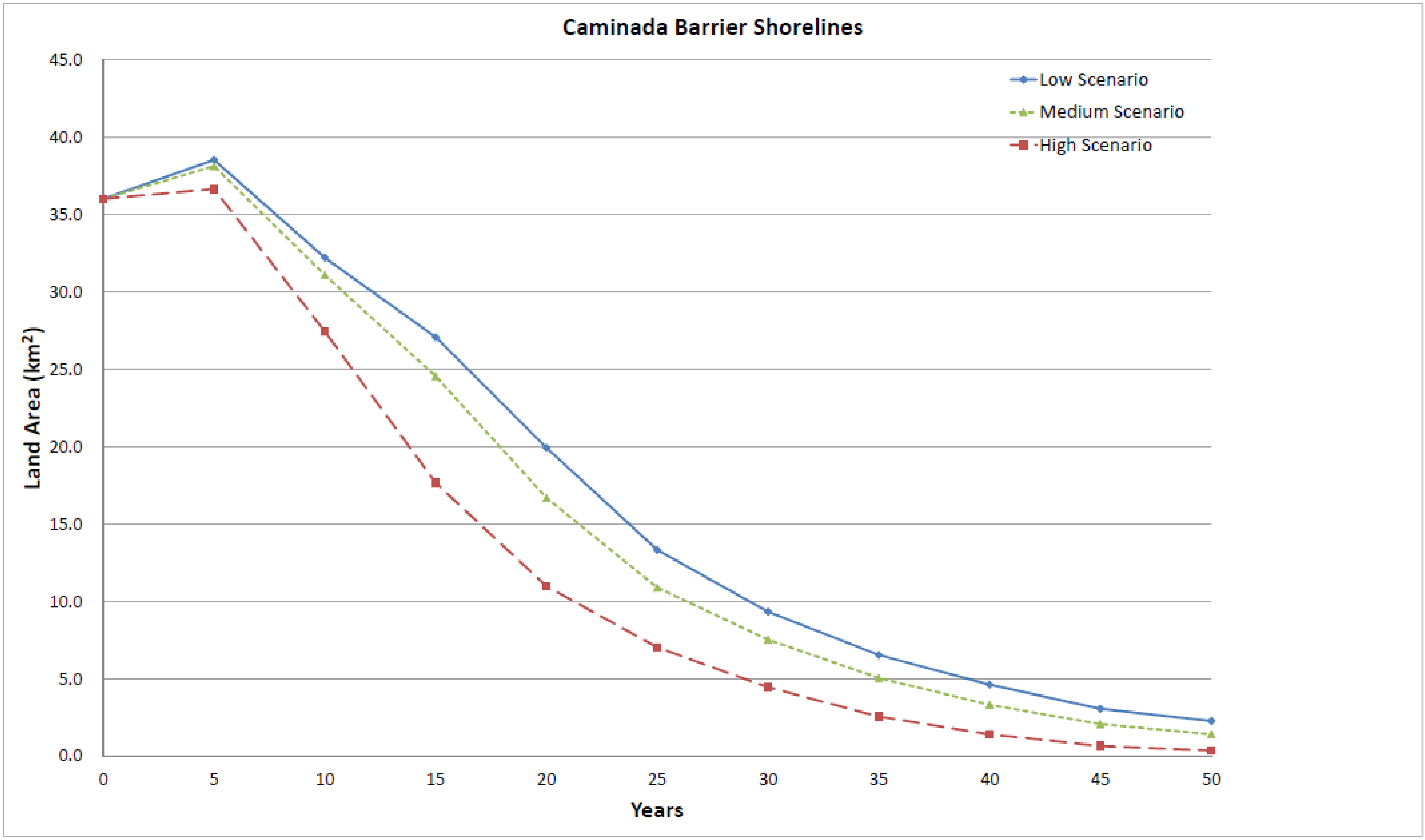


Figure 109: Land Area Changes Over Time for Caminada Barrier Shorelines.

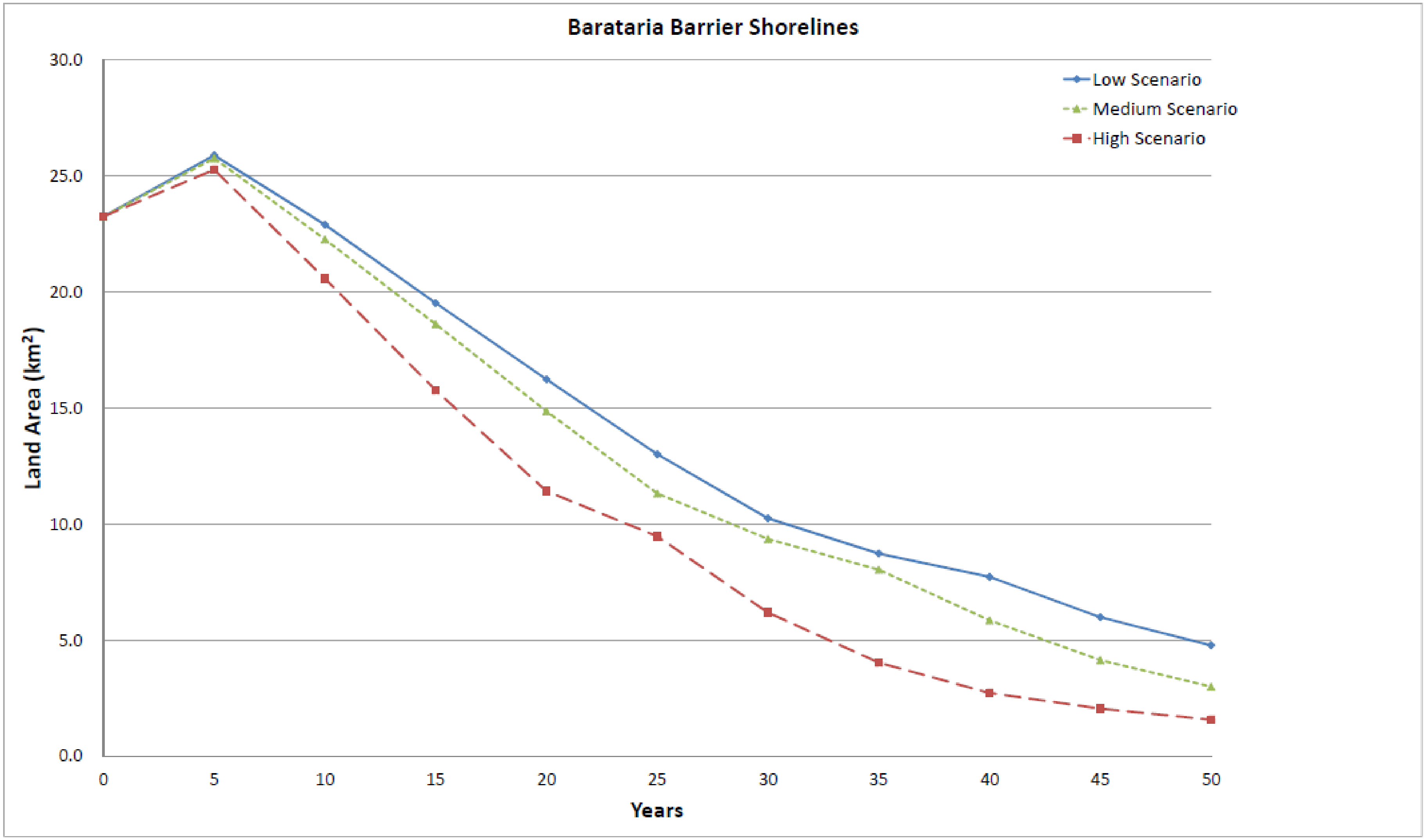


Figure 110: Land Area Changes Over Time for Barataria Barrier Shorelines.

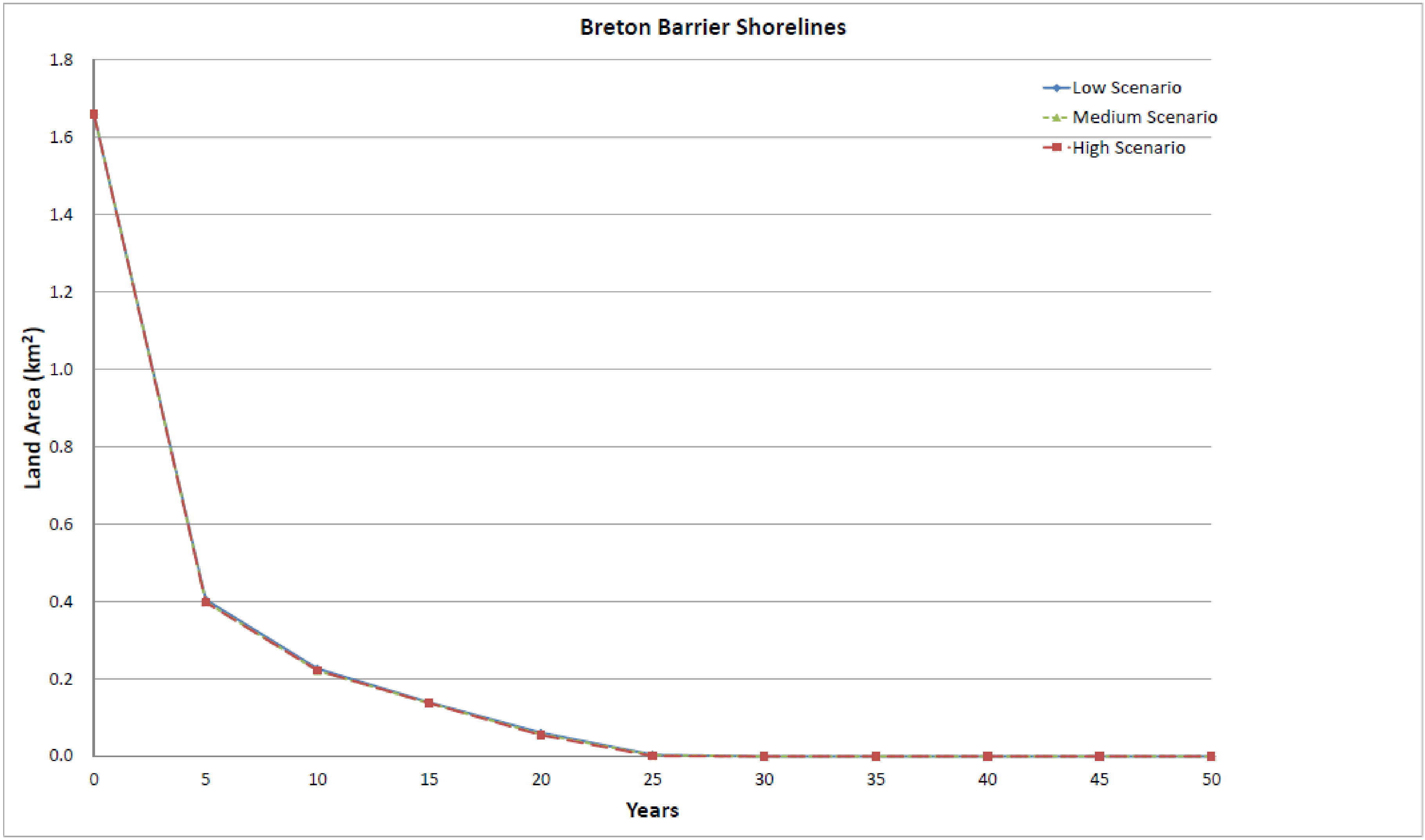


Figure 111: Land Area Changes Over Time for Breton Barrier Shorelines.

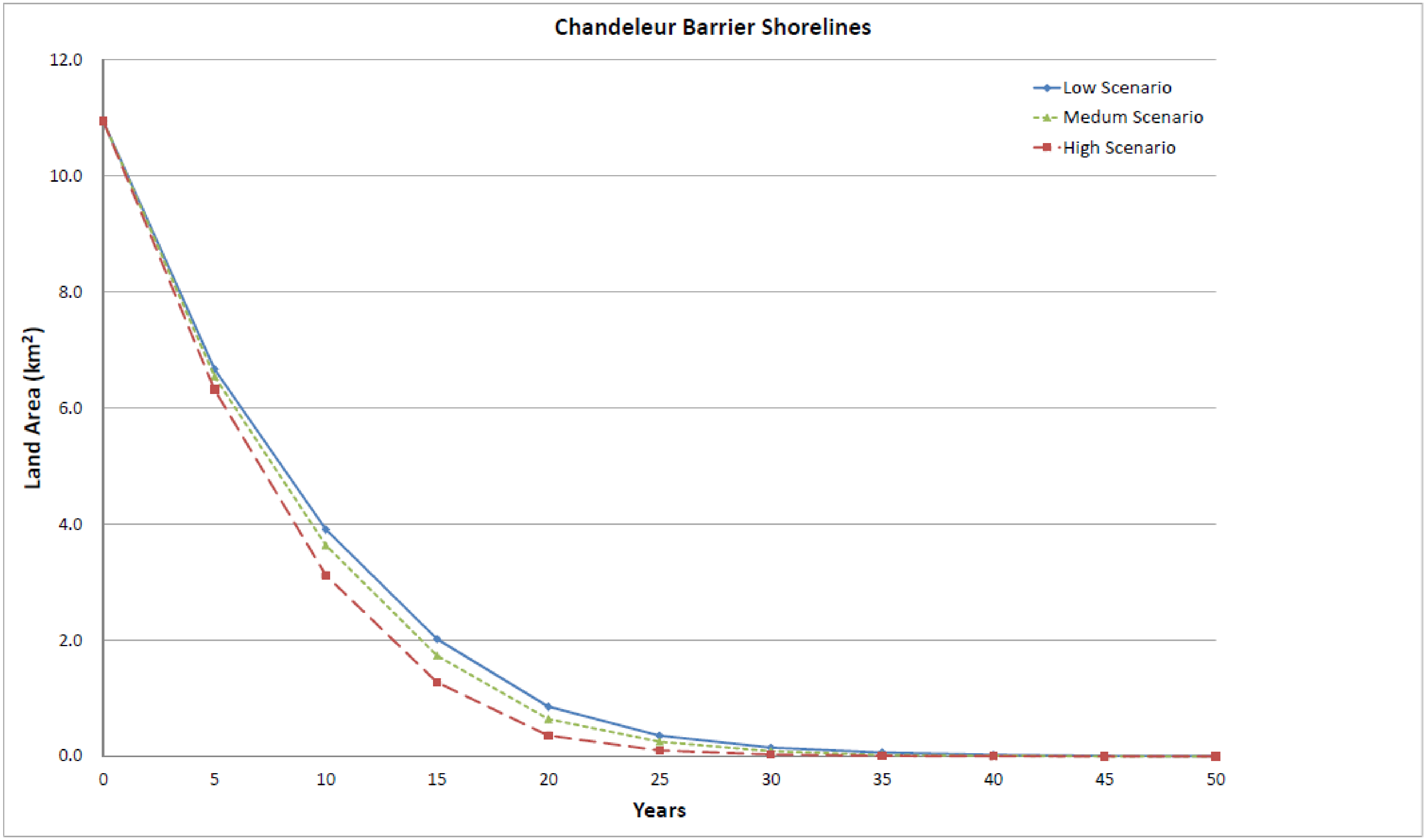


Figure 112: Land Area Changes Over Time for Chandeleur Barrier Shorelines.

Table 6: Land Area Changes for Low Scenario.

Region	Land area (initial) (km²)	Land area (final) (km²)	Percent land loss	Estimated year of disappearance
Isle Dernieres	10.0	1.7	83%	-
Timbalier	4.8	1.0	79%	-
Caminada	36.0	2.3	94%	-
Barataria	23.3	4.8	79%	-
Breton	1.7	0.0	100%	30
Chandeleur	10.9	0.0	100%	40

Table 7: Land Area Changes for Medium Scenario.

Region	Land area (initial) (km²)	Land area (final) (km²)	Percent land loss	Estimated year of disappearance
Isle Dernieres	10.0	1.2	88%	-
Timbalier	4.8	0.5	89%	-
Caminada	36.0	1.4	96%	-
Barataria	23.3	3.0	87%	-
Breton	1.7	0.0	100%	25
Chandeleur	10.9	0.0	100%	35

Table 8: Land Area Changes for High Scenario.

Region	Land area (initial) (km²)	Land area (final) (km²)	Percent land loss	Estimated year of disappearance
Isle Dernieres	10.0	0.5	95%	-
Timbalier	4.8	0.2	97%	-
Caminada	36.0	0.4	99%	-
Barataria	23.3	1.6	93%	-
Breton	1.7	0.0	100%	25
Chandeleur	10.9	0.0	100%	30

3.6 Habitat Suitability Indices (HSIs)

The 2017 Coastal Master Plan utilized HSIs to evaluate changes in habitat quality for 14 fish, shellfish, and wildlife species with several of the fish and shellfish species having separate HSI models for the juvenile and adult life stages. The results of the three FWOA scenarios (low, medium, and high) are discussed here for six species: eastern oyster, small juvenile brown shrimp, adult spotted seatrout, largemouth bass, green-winged teal, and American alligator. These species were selected because they are recreationally- or commercially-important, and because they represent a range of different estuarine communities and trophic levels.

3.6.1 Eastern Oyster

The variables in the oyster HSI model include several temporal measures of salinity and the percentage of water bottom in an ICM cell that is covered with hard substrate (i.e., "cultch", which did not change in FWOA simulations). According to the model, the most suitable oyster habitat consists of areas with a high percentage of cultch coverage and salinities between approximately 10 and 20 ppt (Attachment C3-12: Oyster HSI Model).

Although there was some inter-annual variability related to differences in riverine discharge (and thus salinity), the suitability of habitat for oysters generally increased over time in each of the FWOA scenarios, particularly over the last half of the simulation period (Figure 113 - Figure 115). This is consistent with the increasing rate of sea level rise in the scenarios, which forced higher-salinity waters farther up into the estuarine basins. Consequently, interior areas of known or assumed cultch became more suitable habitat for oysters. In contrast, some areas close to the Gulf became less suitable for oysters because salinities were too high during the latter years of the simulations. This was most notable in areas that are currently saline, such as Lower Terrebonne and Lower Barataria basins, and in the high FWOA scenario (Figure 115).

3.6.2 Small Juvenile Brown Shrimp

This HSI model represents young-of-the-year brown shrimp that have recently settled to their inshore nursery habitats. Accordingly, the model variables include average salinity and water temperature between April and June (when this life stage is most common in the estuaries), as well as the percentage of the ICM cell that is covered by emergent marsh vegetation (Attachment C3-13: Brown Shrimp HSI Model). The model indicates that the most suitable habitats are fragmented marshes with average salinities between approximately 10 and 20 ppt.

The low and medium FWOA scenarios showed that habitat suitability for small juvenile brown shrimp increased over time in most areas of the coast (Figure 116 and Figure 117). This increase was most apparent in interior areas during the last half of the simulation period, because the greater salinity intrusion during this time converted low-salinity interior marshes, swamps, and open waters into more suitable habitat for brown shrimp. However, there were some areas of the coast, such as Lower Terrebonne and Lower Barataria basins, where habitat suitability decreased during the latter part of the simulation. This was mostly due to high rates of wetland loss in these areas, though high salinities were also a factor. The net result in these basins was a shift in habitat distribution over time from the lower to the upper estuary.

The negative effects of wetland loss were greater and more widespread in the high FWOA scenario, so that by the end of simulation habitat suitability was decreasing in most areas and especially in the Deltaic Plain (Figure 118). Consequently, the amount of suitable habitat at year 50 was lower in the high FWOA scenario than in the low and medium FWOA scenarios.

3.6.3 Adult Spotted Seatrout

The adult spotted seatrout HSI model includes average salinity and water temperature over the entire year, as well as marsh coverage (Attachment C3-16: Spotted Seatrout HSI Model). The most suitable habitats are fragmented marshes with salinities >10 ppt and temperatures >20° C. The greater suitability of higher salinities and temperatures indicates that the model is more appropriate for evaluating the adult's summer spawning habitats rather than their overwintering habitats in the estuaries.

The results of FWOA simulations of adult spotted seatrout habitat suitability were similar to those of the small juvenile brown shrimp. Habitat suitability increased over time across the coast, particularly in interior areas (e.g., Upper Barataria Basin, Mermentau Basin, and around Lake Maurepas) as salinity intrusion made these areas more suitable for adult seatrout (Figure 119 - Figure 121). Unlike small juvenile brown shrimp, however, habitat suitability for adult seatrout was relatively unaffected by high rates of wetland loss toward the end of the simulations. This is because adult spotted seatrout are much less dependent on marsh coverage than the brown shrimp, and the model accordingly assigns relatively high habitat suitability to open water areas (Attachment C3-16). There was little difference in these patterns among the FWOA scenarios, except that the increase in habitat suitability due to salinity intrusion was greater with each successive scenario (Figure 119 - Figure 121).

3.6.4 Largemouth Bass

The largemouth bass HSI model includes average salinity and water temperature between March and November (the months of highest abundance in the estuaries), as well as marsh coverage (Attachment C3-18: Largemouth Bass HSI Model). The most suitable habitats for bass are fragmented marshes with salinities <2 ppt.

Habitat suitability for largemouth bass generally decreased over time in each of the FWOA scenarios with the greatest decreases, again, occurring during the last half of the simulation period (Figure 122 - Figure 124). Decreased suitability was due to salinity intrusion, which made interior low-salinity marsh habitats less suitable for bass. Wetland loss was also a major reason for decreased suitability because, in contrast with the other fish and shellfish species modeled, cells that were primarily open water were given almost no habitat value for bass (Attachment C3-18). Areas of increased suitability were observed near the Atchafalaya River and Lake Maurepas due to the fragmentation of formerly solid fresh marshes and the conversion of swamps into suitable marsh habitats. This was most apparent in the low and medium FWOA scenarios (Figure 122 and Figure 123). In the high FWOA scenario, very little suitable habitat remained by the end of the simulation, with most found around the Atchafalaya River (Figure 124).

3.6.5 Green-Winged Teal

The variables in the green-winged teal HSI model include habitat type, the percentage of the ICM cell that is open water, and the average water depth of the cell between September and March (when this species occurs in coastal Louisiana; Attachment C3-7: Green-winged Teal HSI Model). The model indicates that the most suitable habitats for teal are shallow waters within fragmented fresh, intermediate, and brackish marshes.

The results of the FWOA simulations showed that habitat suitability for green-winged teal generally tracked patterns of wetland loss across the coast. In the low and medium FWOA scenarios, habitat suitability increased over time across much of the coast primarily because wetland loss increased the amount of fragmented marsh/shallow water habitat (Figure 125 and Figure 126). The conversion of swamps into suitable marsh habitats also contributed to the increase in suitability. However, in areas with high rates of wetland loss, such as the Bird's Foot Delta and Lower Barataria Basin, habitat suitability declined sharply over the latter years of the simulations, as these areas converted to mostly open water and the open water became deeper and more saline with sea level rise. This trend of increased habitat suitability over the first half of the simulation followed by a sharp decline was prevalent in the high FWOA scenario (Figure 127). In this scenario, very little highly-suitable teal habitat remained by the end of the simulation period.

3.6.6 American Alligator

The variables in the alligator HSI model include: the percentage of the ICM cell that is open water, the amount of wetland edge in a cell, habitat type, average water depth relative to the marsh surface over the year, and average annual salinity (Attachment C3-10: Alligator HSI Model). According to the model, the most suitable habitats for alligators are fragmented fresh and intermediate marshes associated with moderate water depths.

Alligator habitat suitability generally decreased over time in each of the FWOA scenarios, with much of the decrease occurring during the last half of the simulations (Figure 128 -Figure 130). Decreased suitability was observed in most areas of the coast as a result of salinity intrusion and increased water levels associated with sea level rise. However, there were some areas, such as around Lake Maurepas, where habitat suitability increased due to the conversion of swamps into more suitable fresh marsh. This was most obvious in the low and medium scenarios (Figures Figure 128 and Figure 129). In the high scenario simulation, increased salinities and extensive wetland loss combined to greatly reduce alligator habitat suitability across most of the coast, except around the Atchafalaya River (Figure 130).

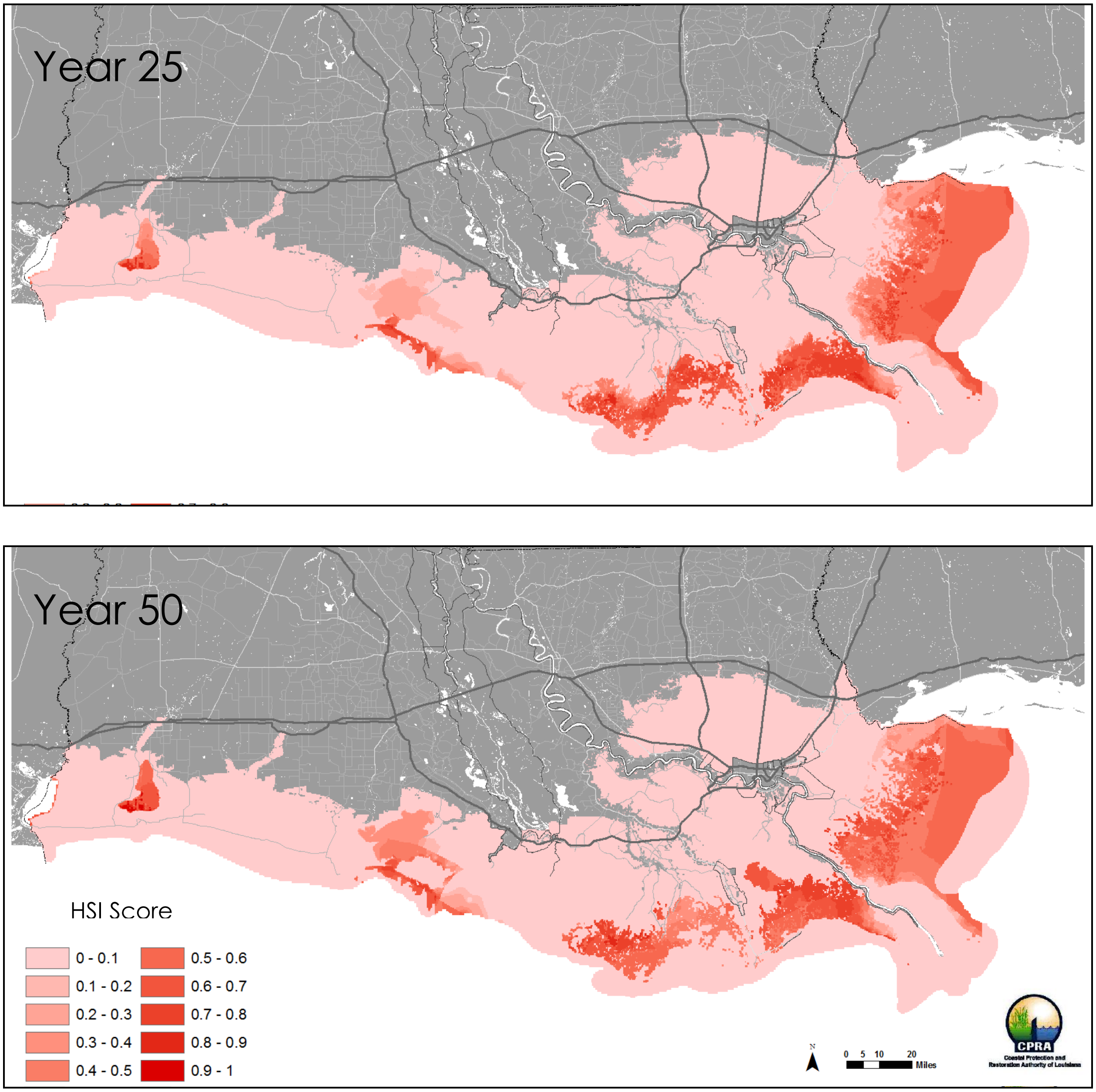


Figure 113: Coast Wide Habitat Suitability for Eastern Oyster at Years 25 and 50 of the Low FWOA Scenario. Dark red indicates areas of highest suitability**.**

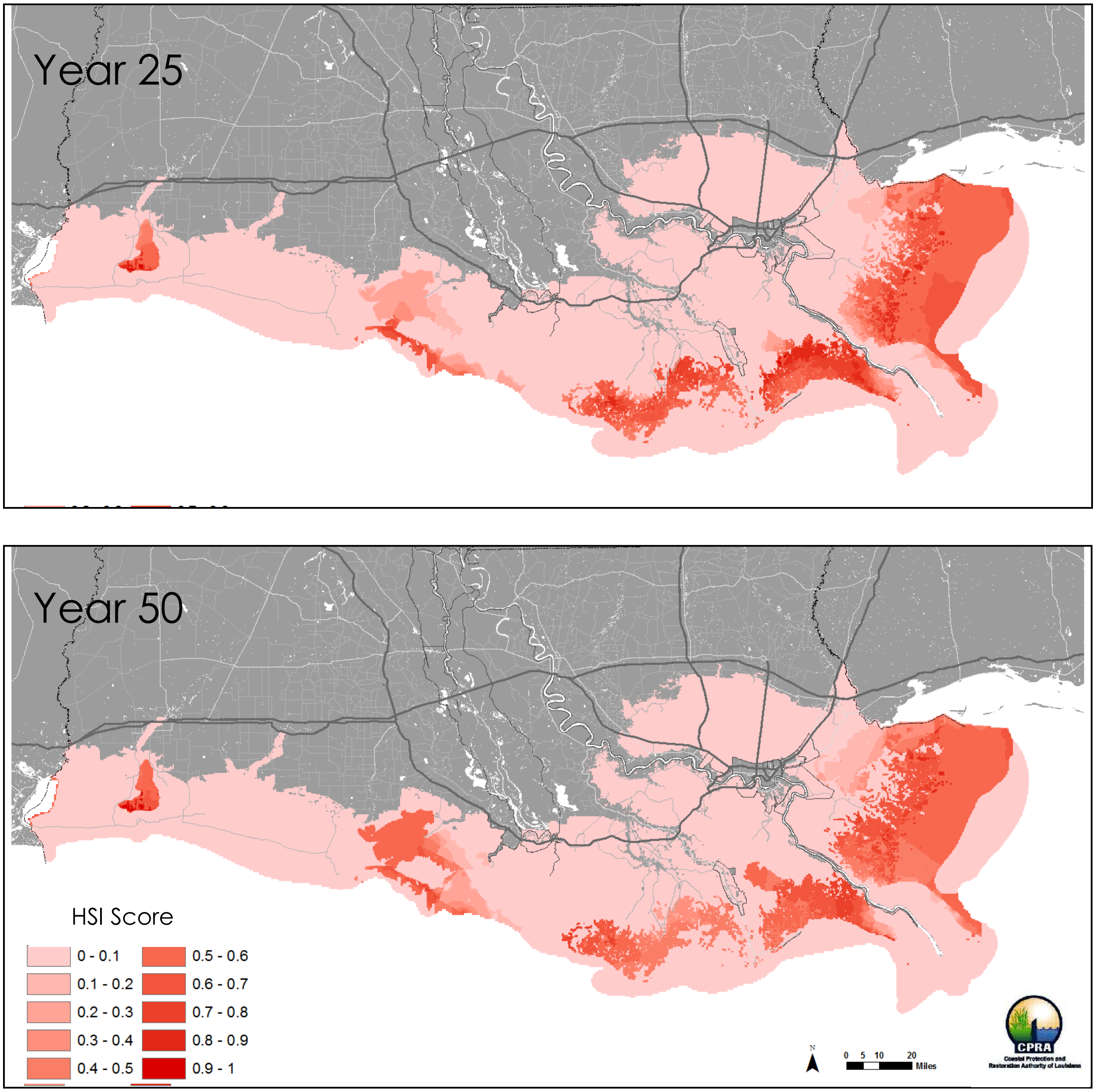


Figure 114: Coast Wide Habitat Suitability for Eastern Oyster at Years 25 and 50 of the Medium FWOA Scenario. Dark red indicates areas of highest suitability.

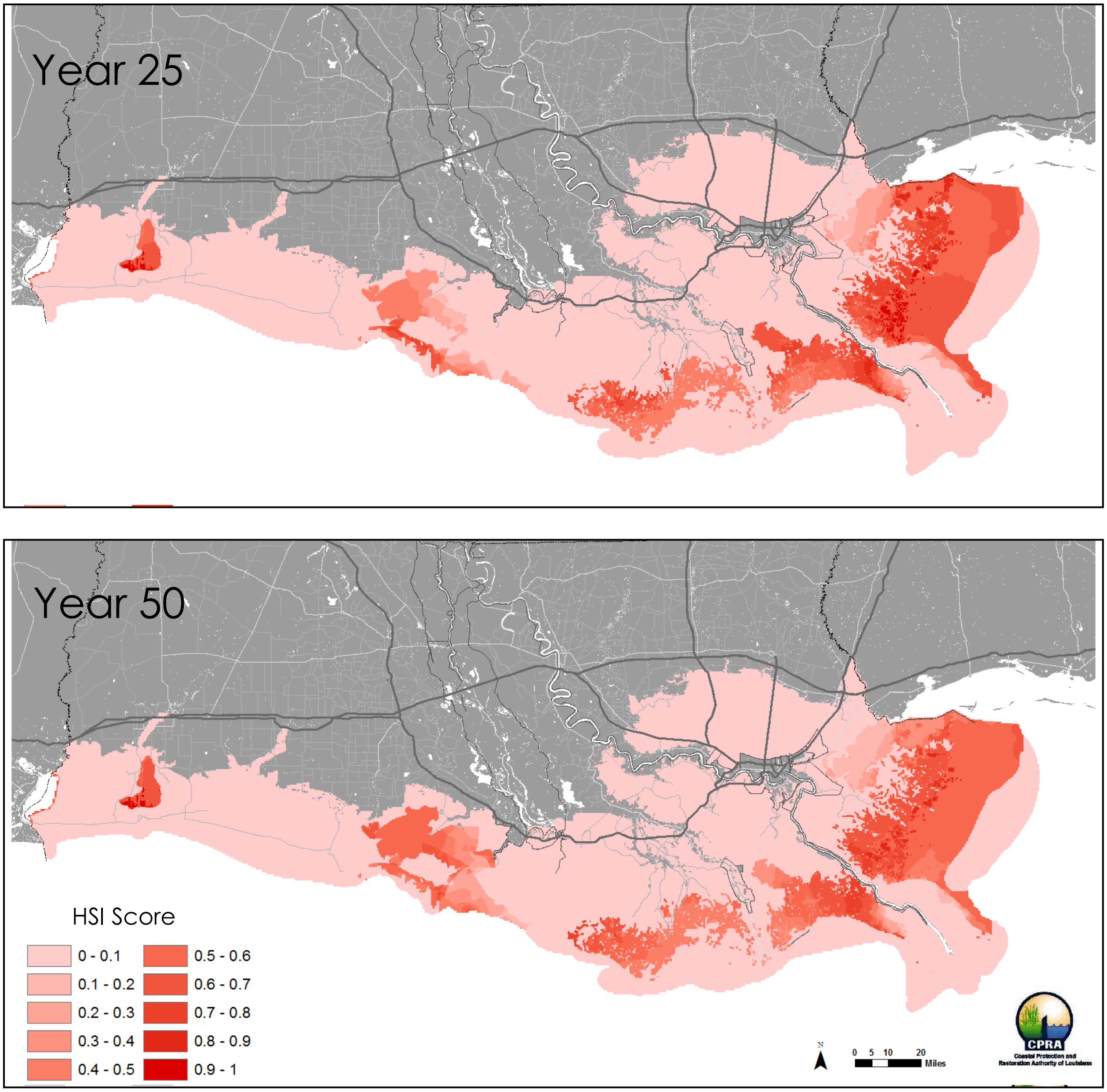


Figure 115: Coast Wide Habitat Suitability for Eastern Oyster at Years 25 and 50 of the High FWOA Scenario. Dark red indicates areas of highest suitability.

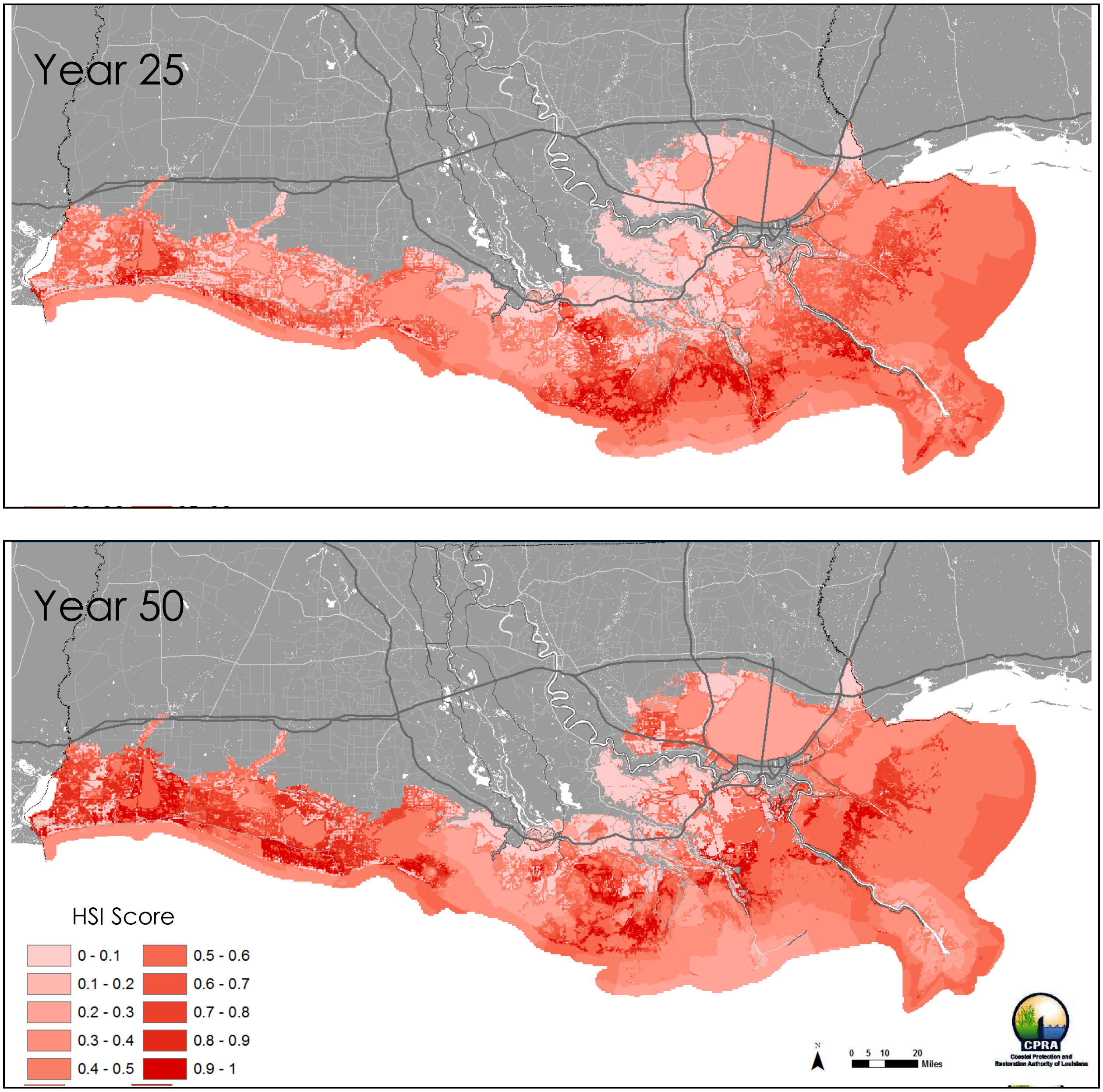
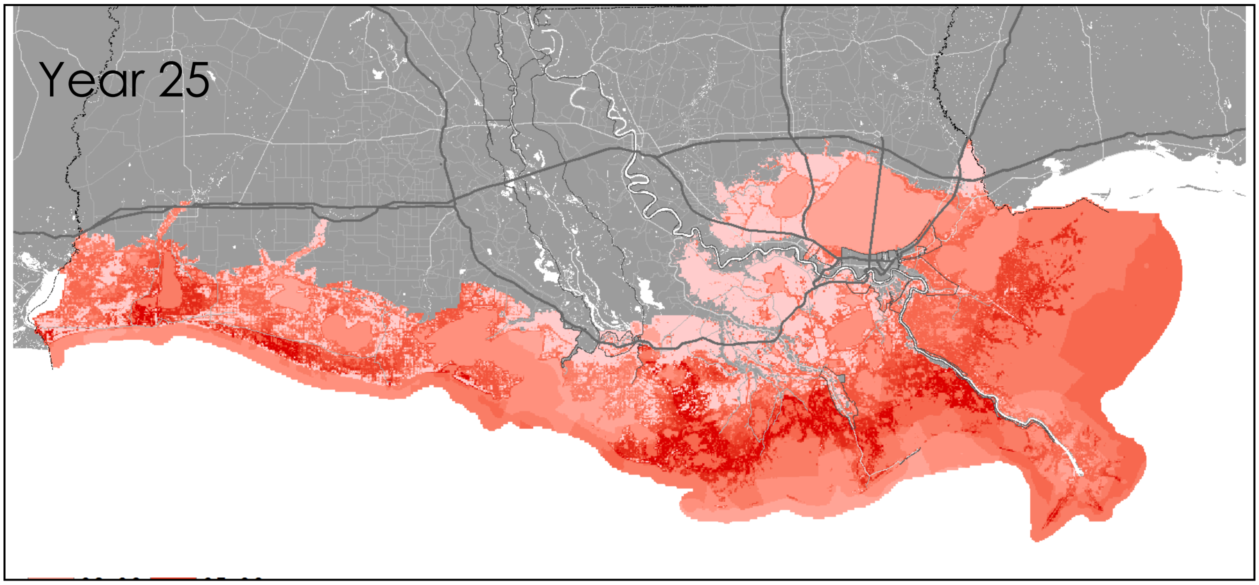


Figure 116: Coast Wide Habitat Suitability for Small Juvenile Brown Shrimp at Years 25 and 50 of the Low FWOA Scenario. Dark red indicates areas of highest suitability.



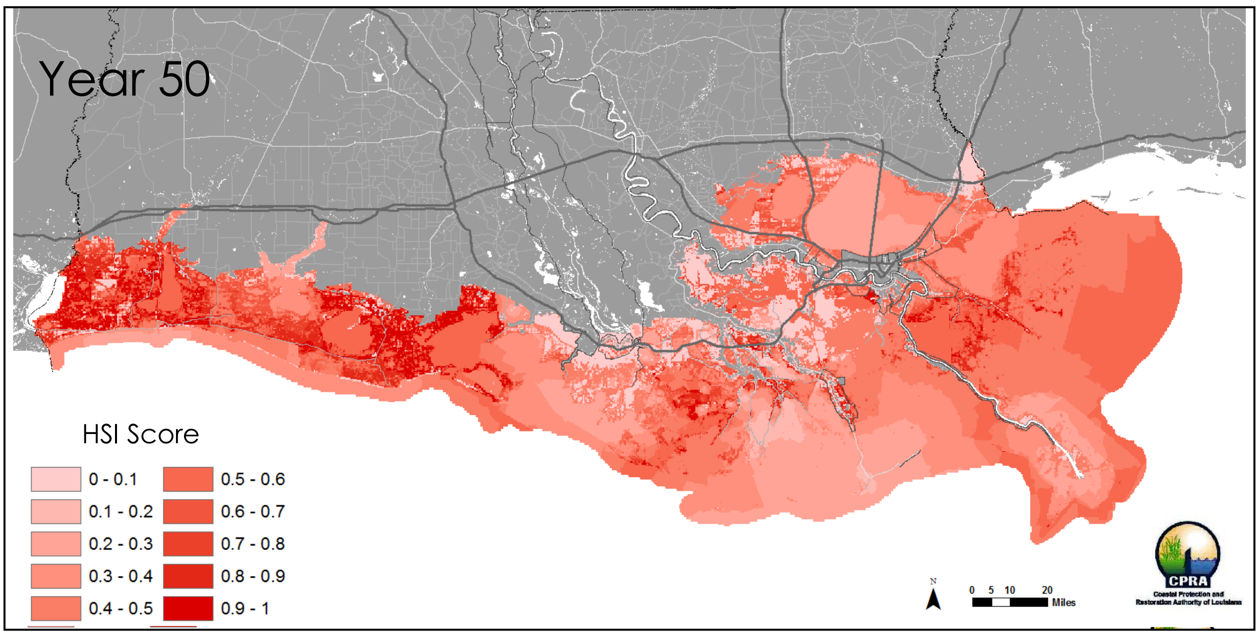


Figure 117: Coast Wide Habitat Suitability for Small Juvenile Brown Shrimp at Years 25 and 50 of the Medium FWOA Scenario. Dark red indicates areas of highest suitability.

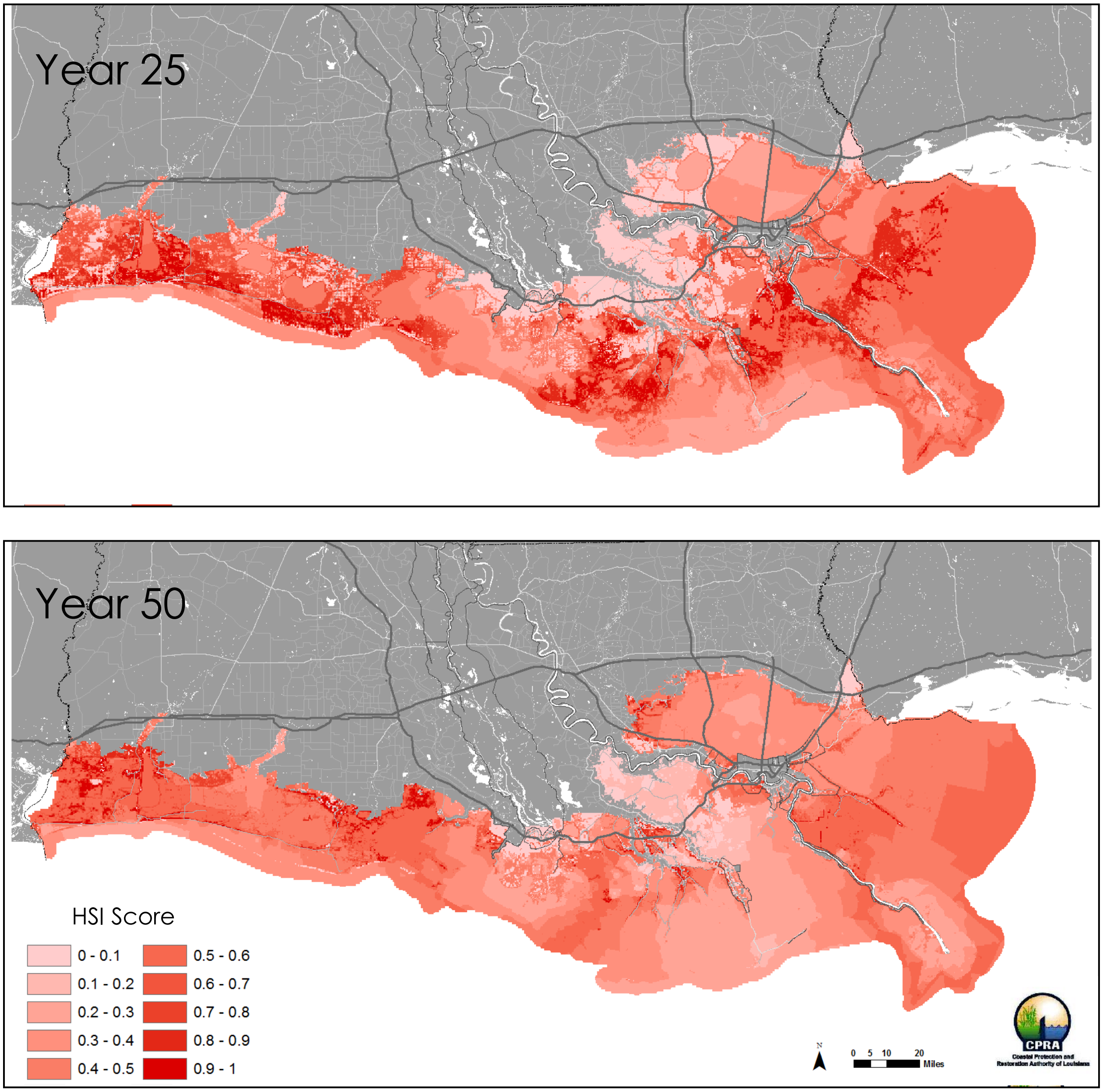


Figure 118: Coast Wide Habitat Suitability for Small Juvenile Brown Shrimp at Years 25 and 50 of the High FWOA Scenario. Dark red indicates areas of highest suitability.

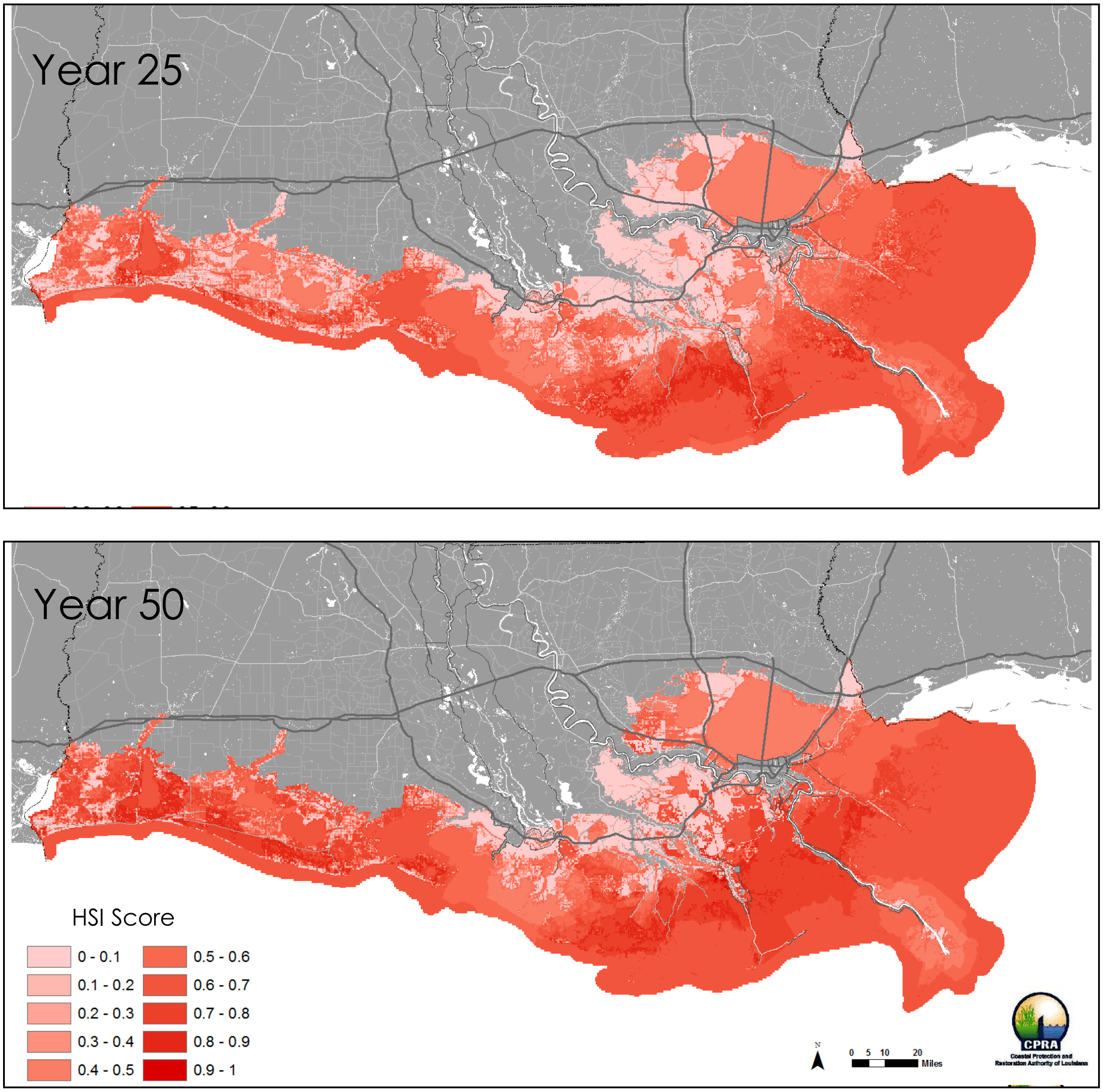


Figure 119: Coast Wide Habitat Suitability for Adult Spotted Seatrout at Years 25 and 50 of the Low FWOA Scenario. Dark red indicates areas of highest suitability.

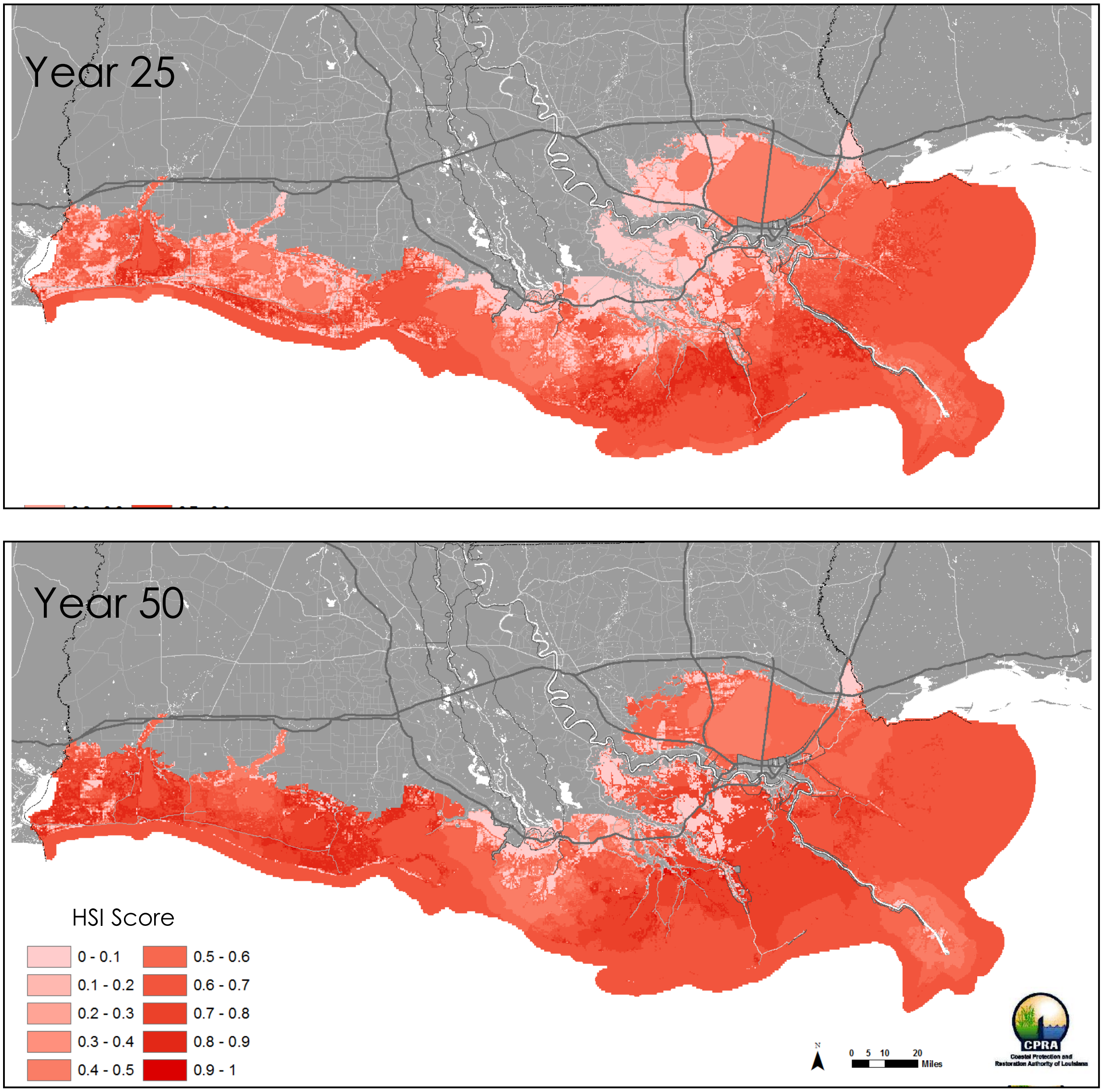


Figure 120: Coast Wide Habitat Suitability for Adult Spotted Seatrout at Years 25 and 50 of the Medium FWOA Scenario. Dark red indicates areas of highest suitability.

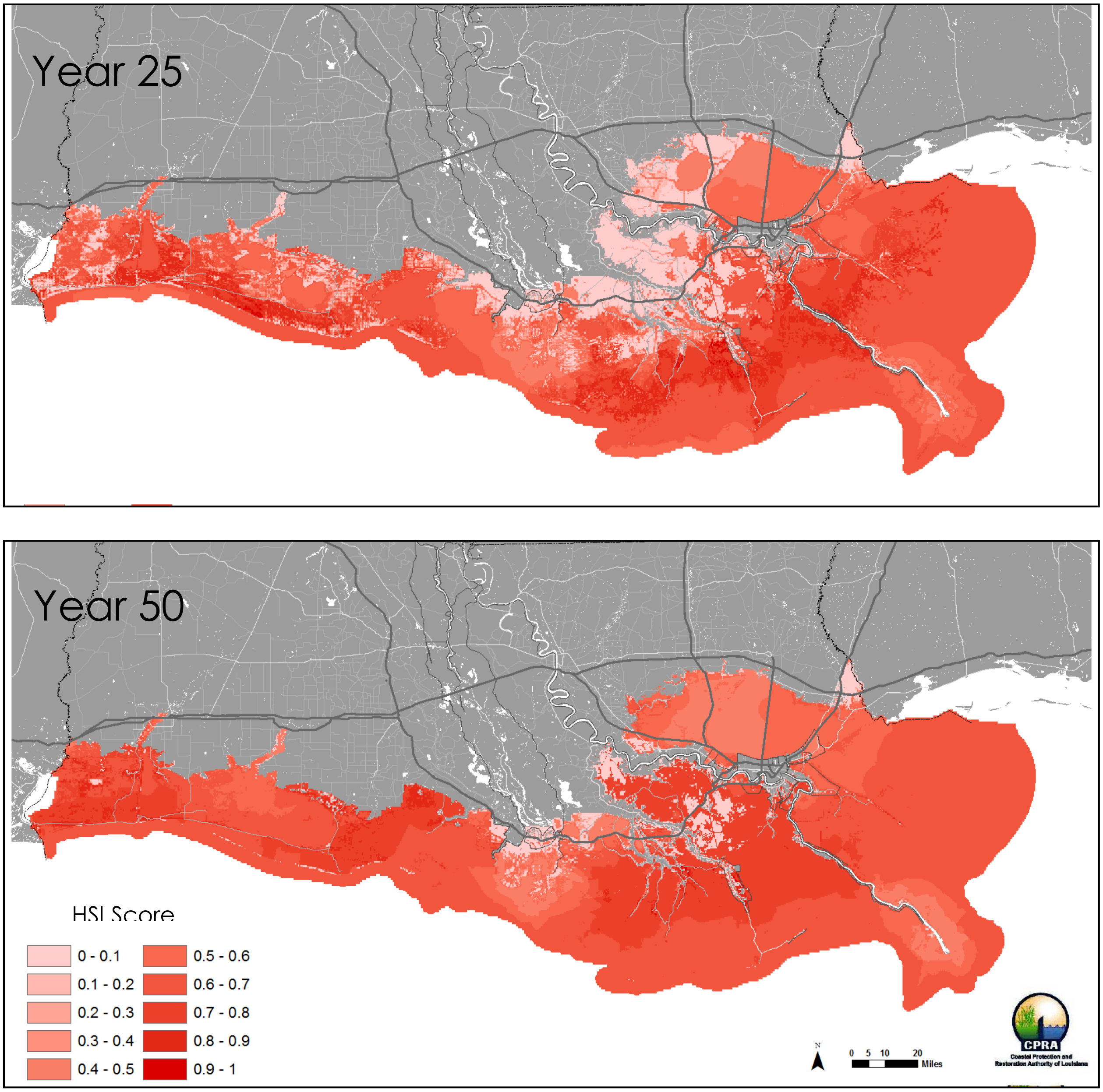


Figure 121: Coast Wide Habitat Suitability for Adult Spotted Seatrout at Years 25 and 50 of the High FWOA Scenario. Dark red indicates areas of highest suitability.

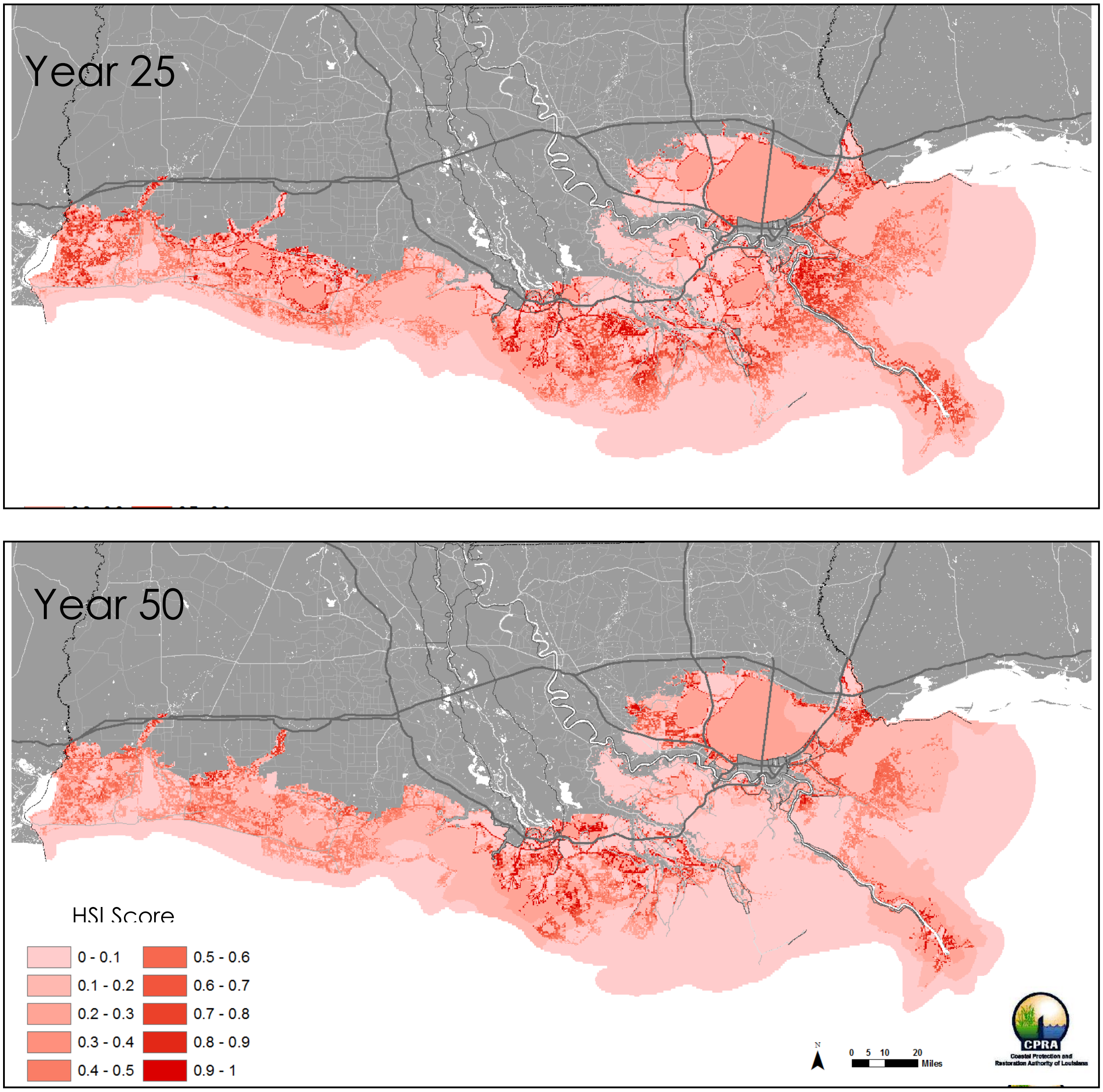


Figure 122: Coast Wide Habitat Suitability for Largemouth Bass at Years 25 and 50 of the Low FWOA Scenario. Dark red indicates areas of highest suitability.

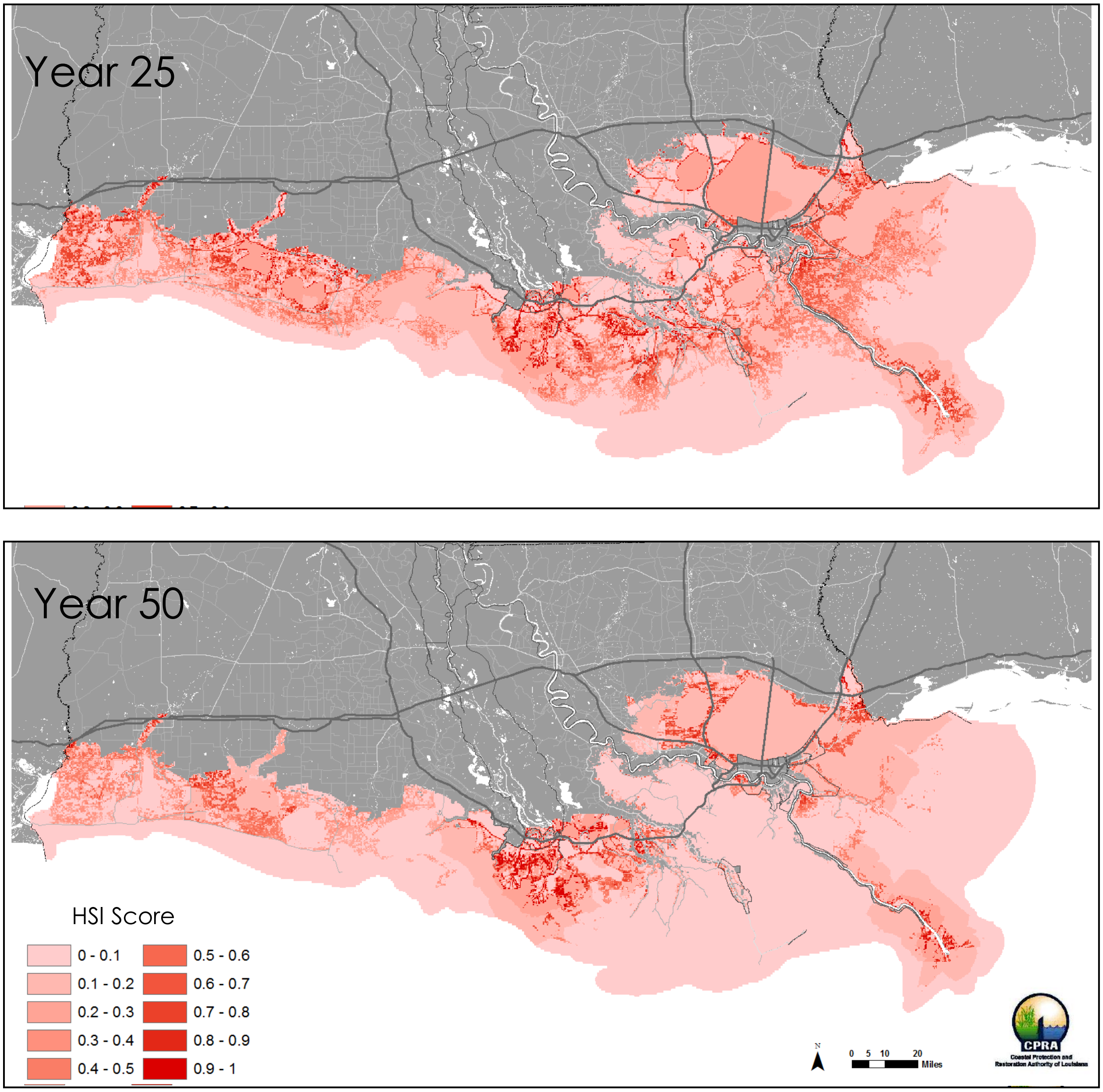


Figure 123: Coast Wide Habitat Suitability for Largemouth Bass at Years 25 and 50 of the Medium FWOA Scenario. Dark red indicates areas of highest suitability.

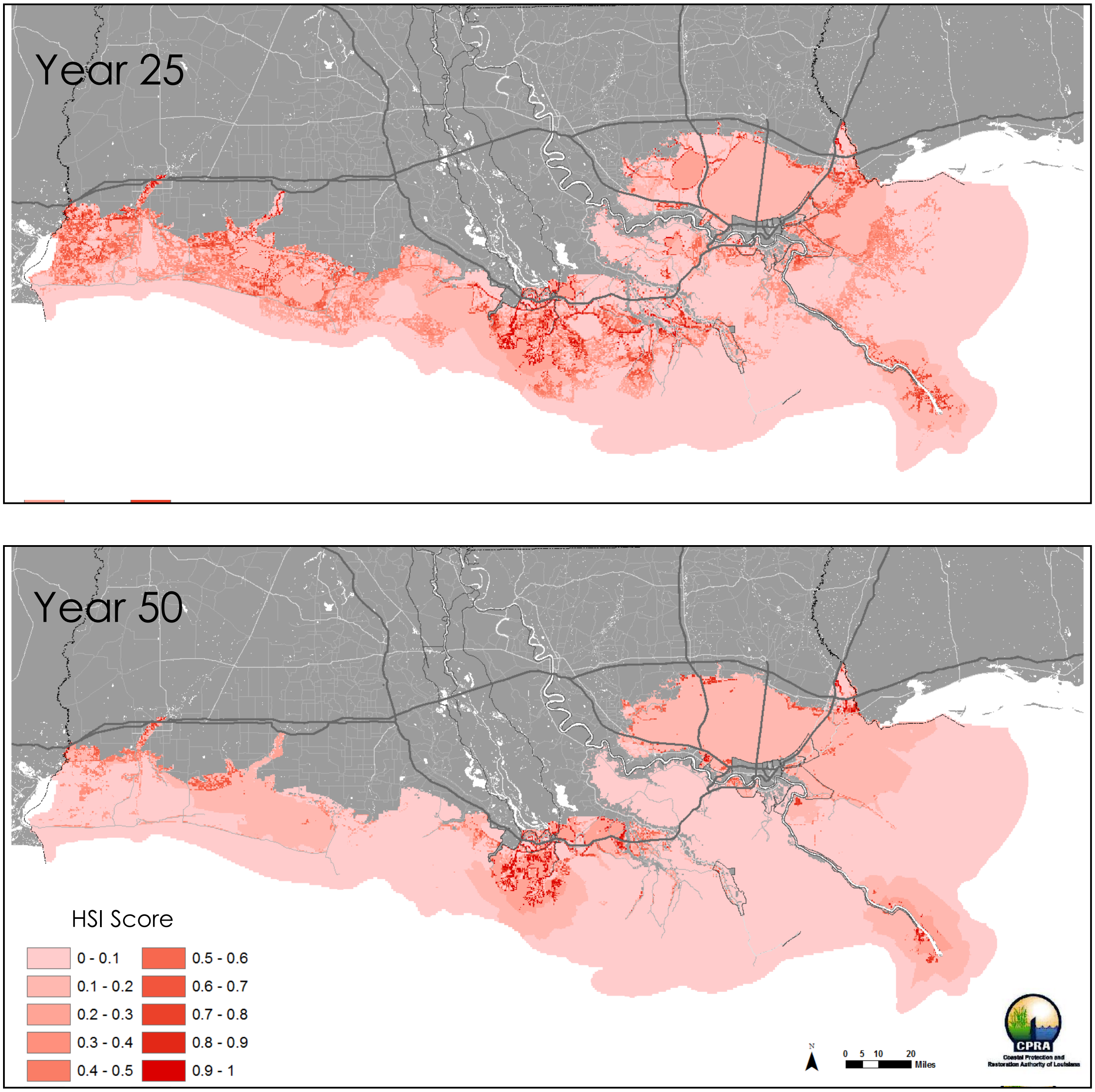


Figure 124: Coast Wide Habitat Suitability for Largemouth Bass at Years 25 and 50 of the High FWOA Scenario. Dark red indicates areas of highest suitability**.**

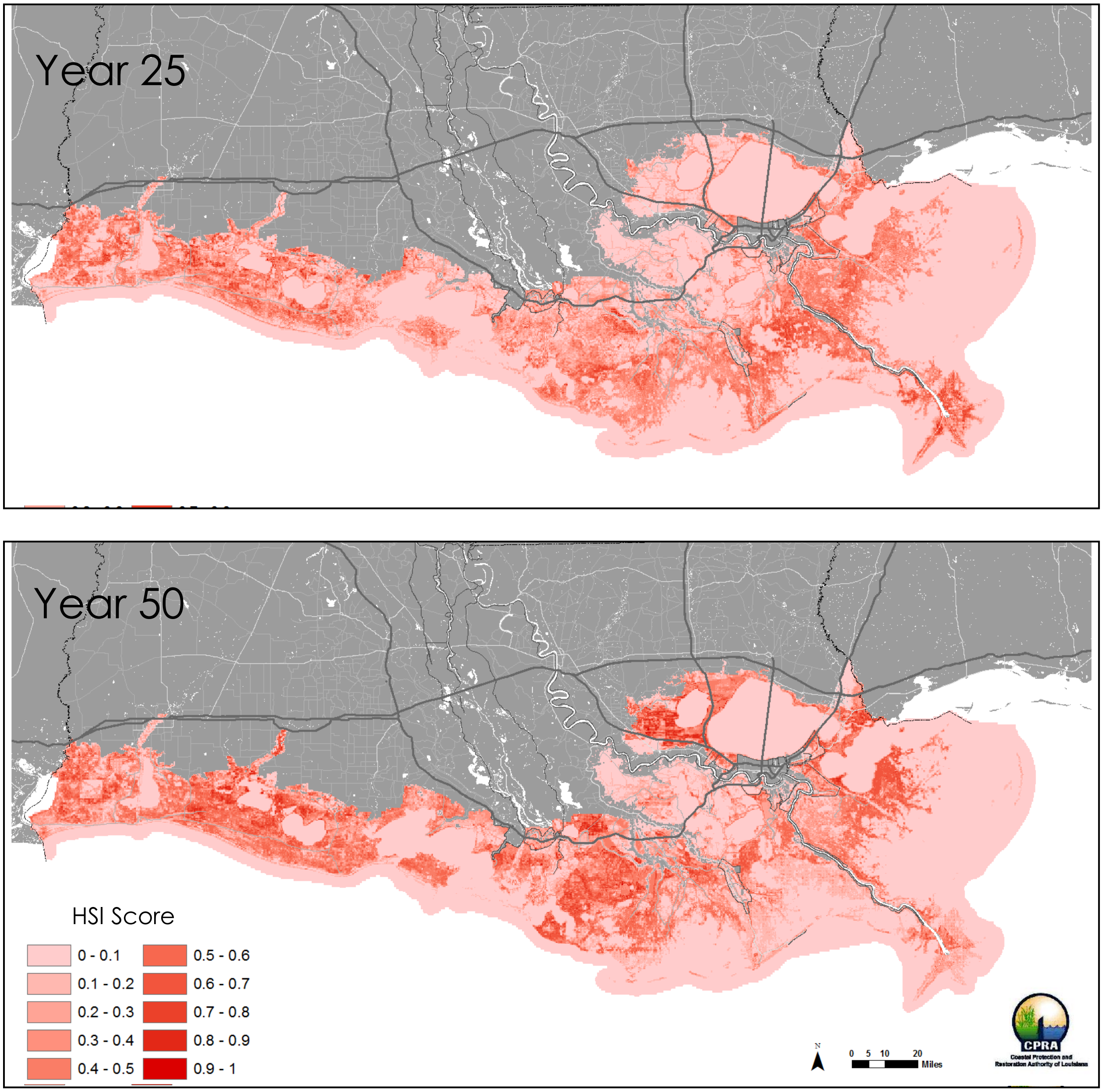


Figure 125: Coast Wide Habitat Suitability for Green-Winged Teal at Years 25 and 50 of the Low FWOA Scenario. Dark red indicates areas of highest suitability.

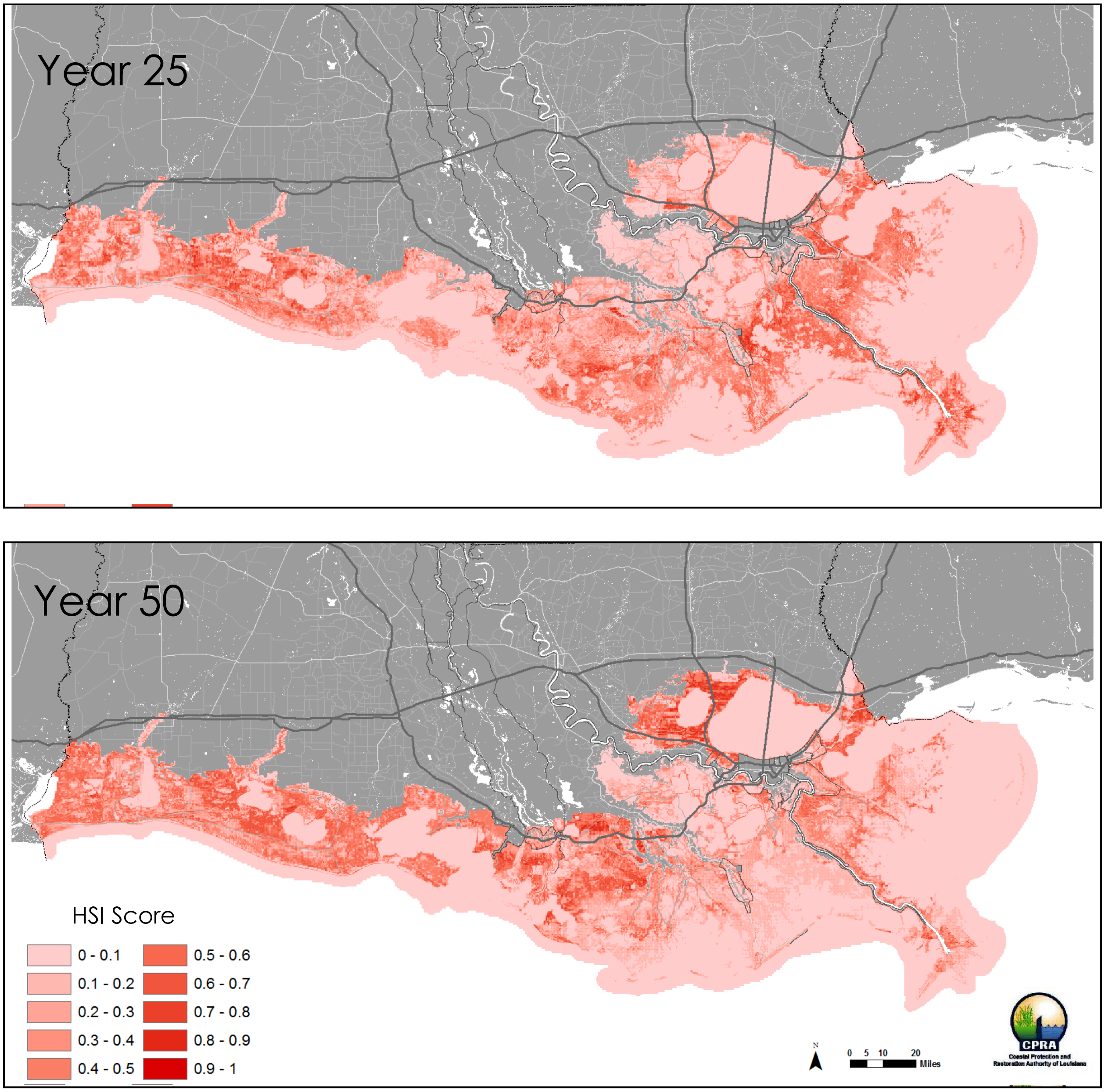


Figure 126: Coast Wide Habitat Suitability for Green-Winged Teal at Years 25 and 50 of the Medium FWOA Scenario. Dark red indicates areas of highest suitability.

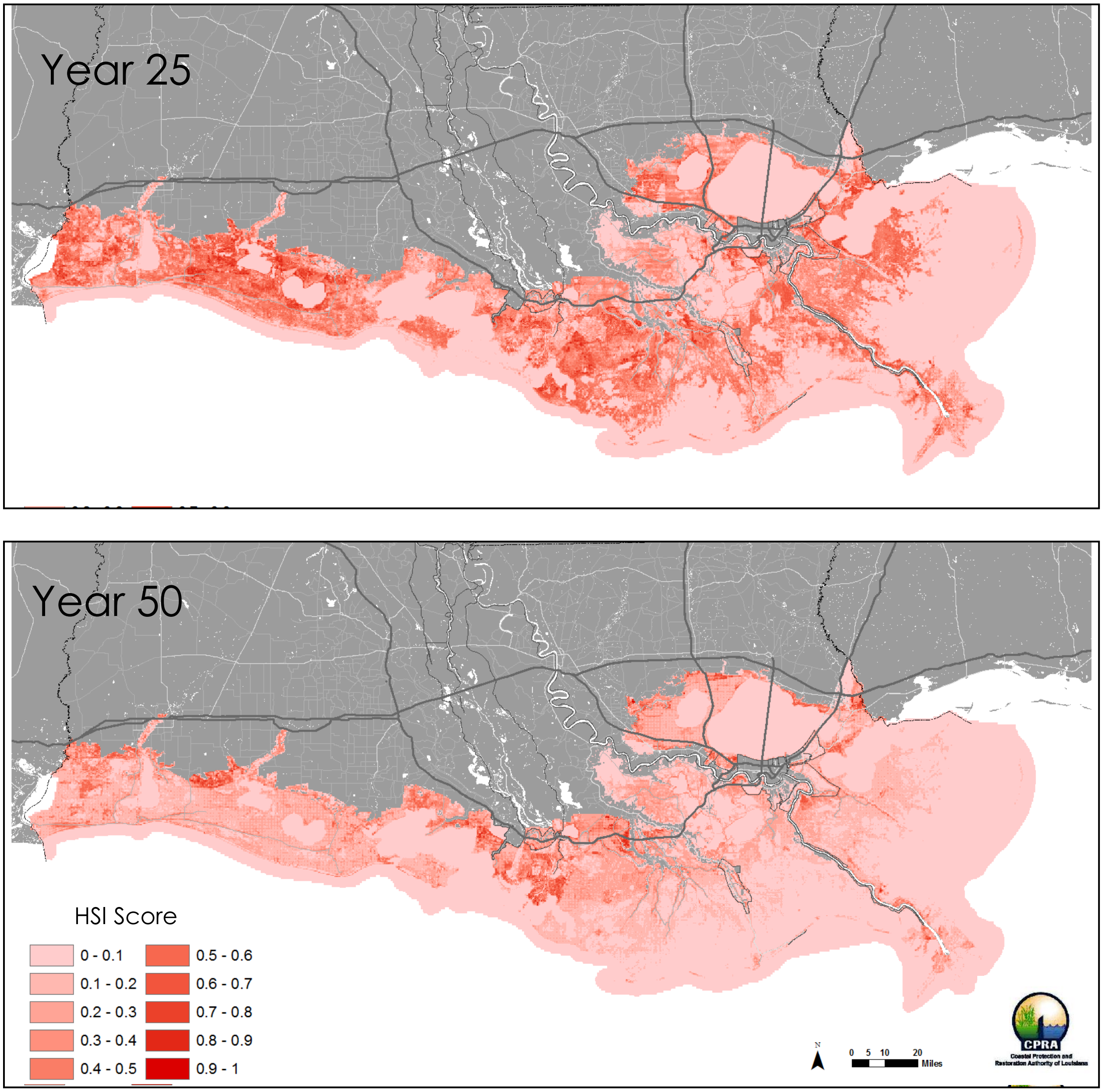


Figure 127: Coast Wide Habitat Suitability for Green-Winged Teal at Years 25 and 50 of the High FWOA Scenario. Dark red indicates areas of highest suitability.

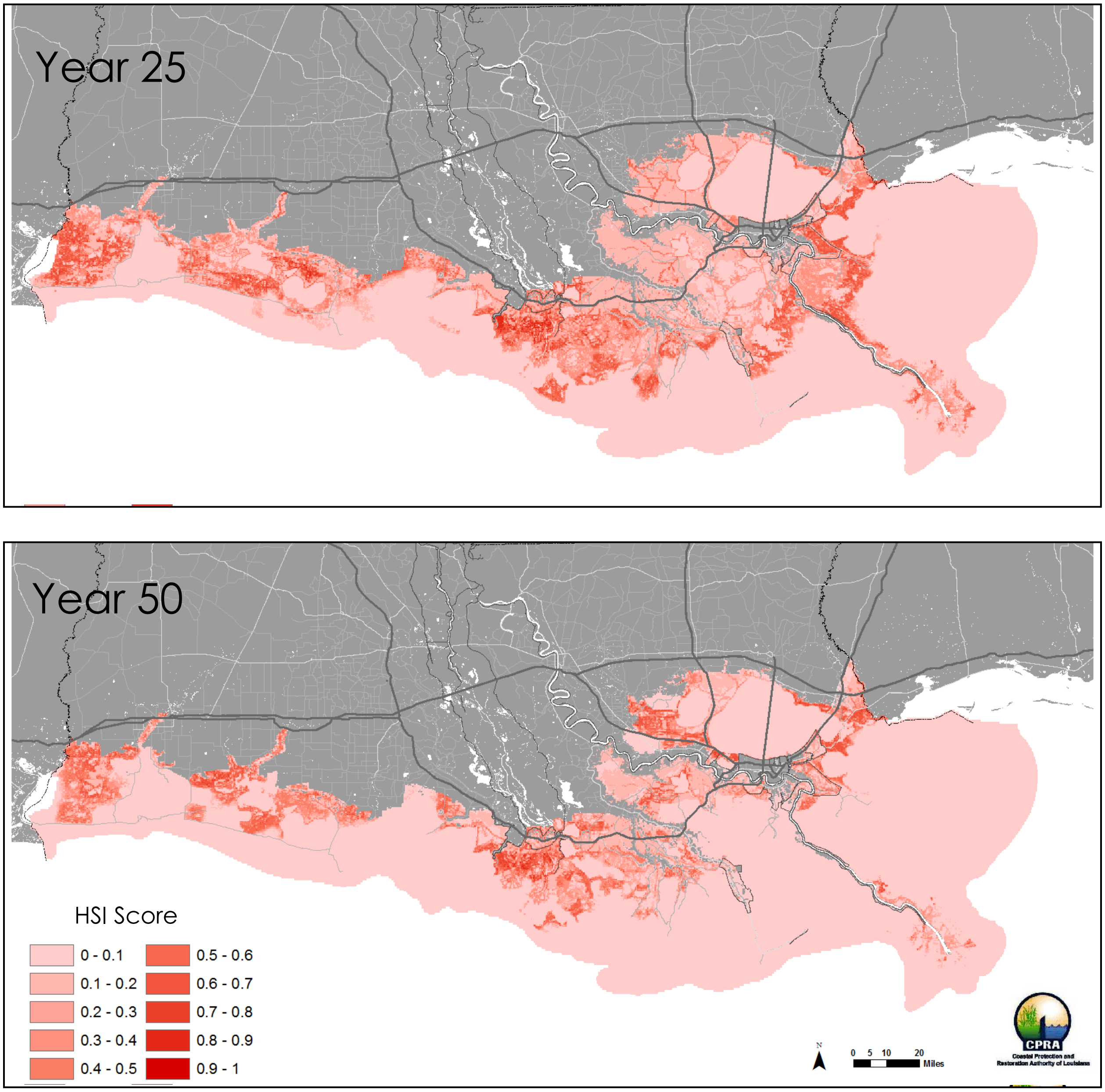
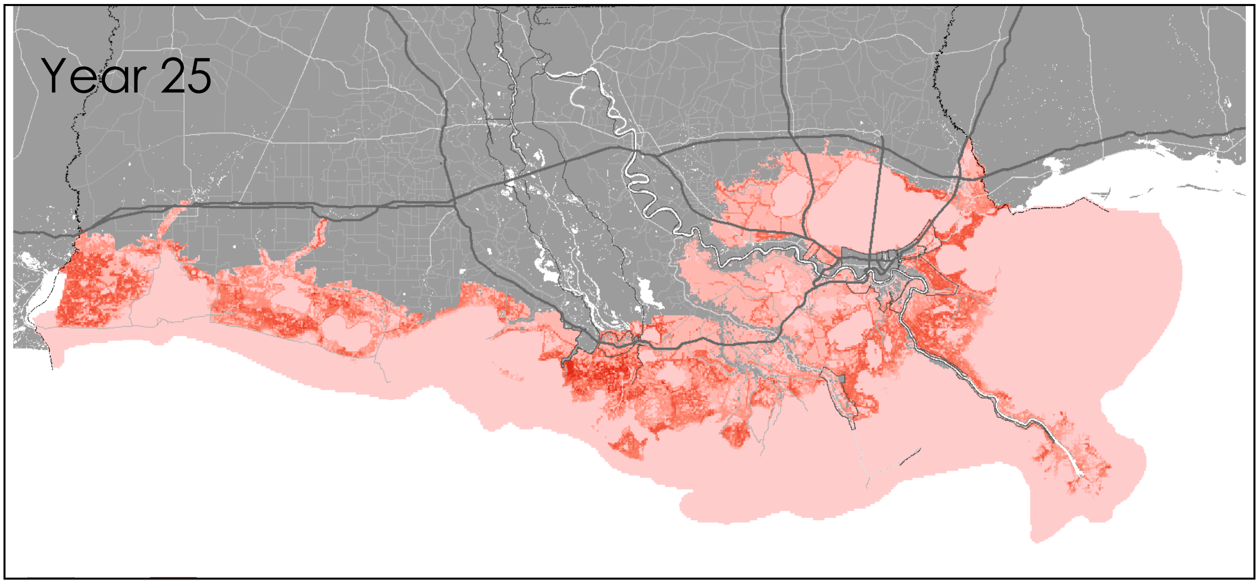


Figure 128: Coast Wide Habitat Suitability for American Alligator at Years 25 and 50 of the Low FWOA Scenario. Dark red indicates areas of highest suitability.



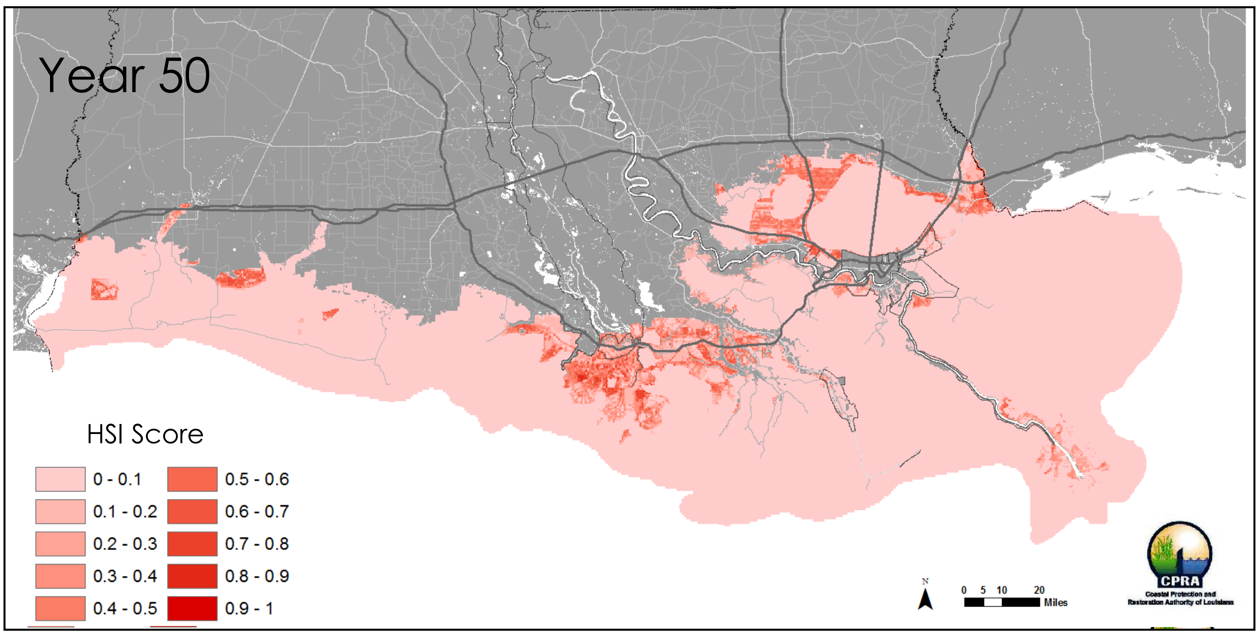


Figure 129: Coast Wide Habitat Suitability for American Alligator at Years 25 and 50 of the Medium FWOA Scenario. Dark red indicates areas of highest suitability.

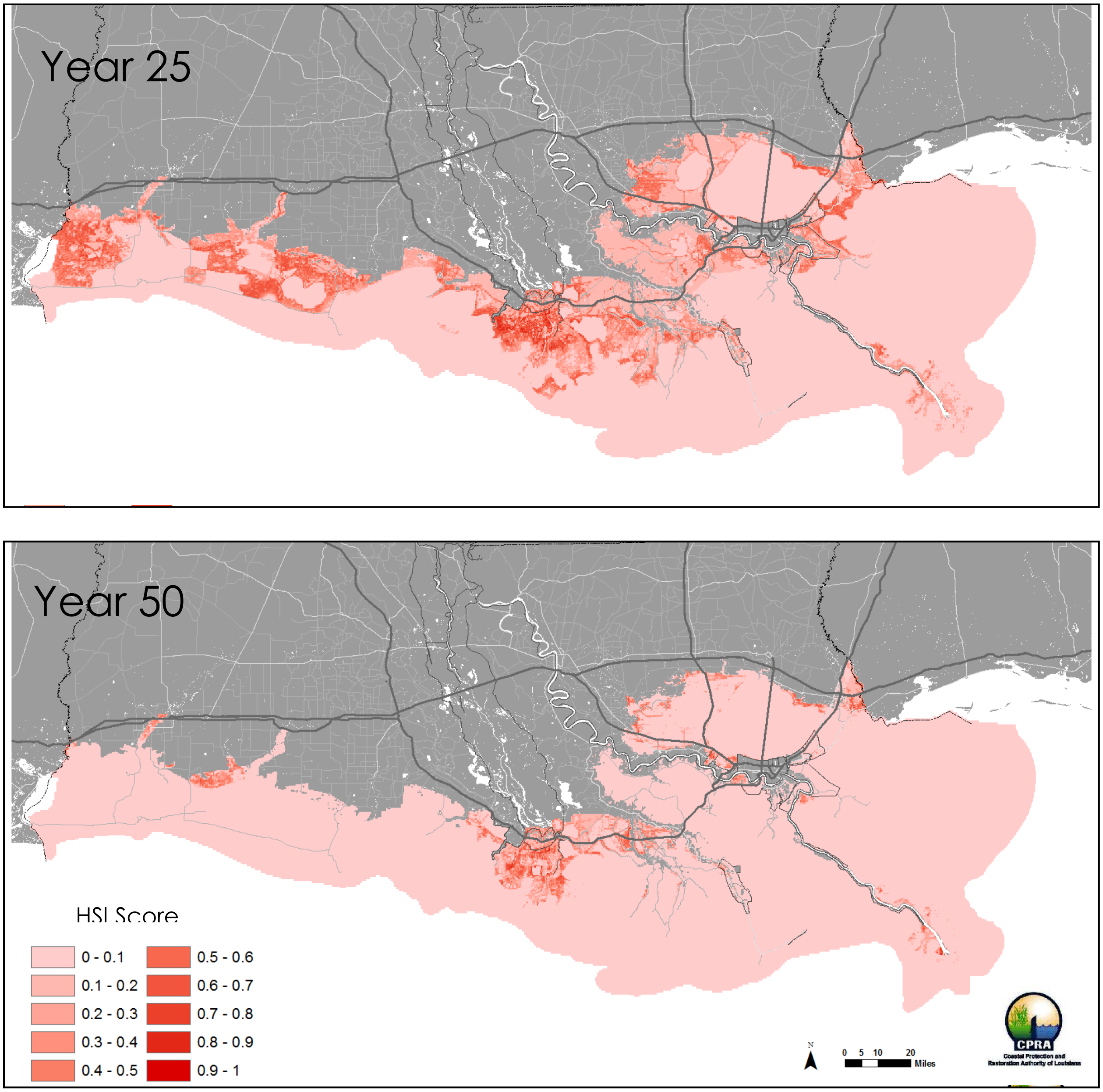


Figure 130: Coast Wide Habitat Suitability for American Alligator at Years 25 and 50 of the High FWOA Scenario. Dark red Indicates areas of highest suitability**.**

3.7 Ecopath with Ecosim Fish and Shellfish Model

The Fish and Shellfish model has been used to simulate biomass changes of 55 groups over 50 years of FWOA under the low, medium, and high scenarios. In addition to predator-prey interactions and fishing, species in the model respond to environmental factors, including salinity, Total Kjeldahl Nitrogen (TKN) as a measure of primary productivity potential, percent wetland cover, and percent cultch. The results of four species are shown here: the adults of spotted seatrout (*Cynoscion nebulosus*), and eastern oyster (*Crassostrea virginica*), and the juveniles of brown shrimp (*Farfantepenaeus aztecus*), and largemouth bass (*Micropterus salmoides*). The distribution of biomass for the month of April is shown for each species and scenario. It is important to note that the predictions of absolute biomass shown in these figures are uncertain; therefore, the output is best used to assess relative changes in biomass over time and space. A distribution trend that can be seen in all outputs is a concentration around the Mississippi River Delta. The reason for this is the high concentration of TKN in that area (Figure 131) as compared to other coastal areas. High concentrations of TKN result in a strong bottom-up effect in the food web model, increasing biomass of fish and shellfish. The absence of biomass of high salinity species right at the Bird's Foot Delta (where TKN is highest) is a result of the low salinity there (Figure 134).

Under the low scenario, spotted seatrout and brown shrimp (Figure 132 and Figure 133) are estimated to expand their range more inland over time. The salinity increase in those areas is the most important driver for this change (Figure 134). This salinity effect is a general trend where species with higher salinity tolerances increase their spatial distribution inland. An increase in oysters is seen as well in the low scenario, though its range expansion is limited by a lack of cultch in inland areas (Figure 135). Species that have low salinity tolerance show the opposite effect, as exemplified with largemouth bass (Figure 136). Biomass of largemouth bass decreases in year 50 as compared to year 25.

The medium scenario results in similar patterns as the low scenario, with an expansion of the distribution of higher salinity species into the upper estuaries in year 50. However, in the medium scenario, the effects of saltwater intrusion manifest earlier, resulting in some inland expansion of saltwater species in year 25, which can be seen in the distribution pattern of spotted seatrout (Figure 137). This is a result of salinities increasing sooner and reaching higher levels in the medium and high scenarios. In addition, in year 50 of the medium scenario, another effect becomes apparent; a small reduction in biomass where wetland loss occurs. This can be seen in the juvenile stages of estuarine-dependent species in areas that experience high wetland loss, such as brown shrimp in Barataria Bay (Figure 138). Estimates for eastern oyster and largemouth bass for the medium scenario are similar to the low scenario, with an increase in oyster biomass in year 50 as compared to year 25 (Figure 139), and a decrease in largemouth bass biomass (Figure 140).

Under the high scenario, the saltwater intrusion has taken place earlier in the simulation. As a result, the inland expansion of species with high salinity tolerance occurs earlier (by year 25), as can be seen for spotted seatrout (Figure 141). Spotted seatrout even undergoes a loss of biomass in year 50, which can be partially explained by salinity increases that exceed the tolerance range of spotted seatrout. An additional effect that drives the loss of biomass, mostly occurring in the Barataria Bay, is wetland loss. This wetland effect is clearly visible in year 50 for adult spotted seatrout and juvenile brown shrimp as compared to year 25 (Figure 141 and Figure 142). In the case of adult spotted seatrout, this is an indirect effect of wetland loss on spotted seatrout juveniles. The distribution of juvenile brown shrimp indicates there are still some increases in the upper estuaries as they turn more saline, but overall there is a loss of biomass as a result of wetland loss. The extent of potential wetland loss that is affecting estuarine-dependent species is shown in Figure 143, which is a comparison of year 25 in the low scenario (minimal wetland loss) and year 50 of the high scenario. The eastern oyster shows some minor inland expansion in year 50 of the high scenario in the PB and near the Atchafalaya River outfall (Figure 144). This is a result of salinity increases. Largemouth bass shows a decrease over time in the high scenario, as it did in the low and medium scenarios (Figure 145).

Comparing year 50 of all three scenarios (low, medium, and high), it becomes clear that the combined complex effects of the projected sea level rise, subsidence, precipitation, and evapotranspiration have an effect on the biomass estimates. For brown shrimp, all three scenarios show an inland expansion of the biomass distribution due to saltwater intrusion, but with higher rates of sea level rise and subsidence, the negative effect of wetland loss on brown shrimp biomass become more apparent (Figure 133, Figure 138, and Figure 142). Since this is after 50 years of simulation, this is not only affecting juveniles; the lower recruitment is reducing adult biomass as well, which can be seen for adult spotted seatrout (Figure 132, Figure 137, and Figure 141). This is most apparent in the Barataria Bay, which has a high rate of wetland loss, and is in addition to direct effects of increased salinity, exceeding the tolerance range of spotted seatrout. The high scenario does not have a negative effect on eastern oysters when compared to the low and medium scenarios (Figure 135, Figure 139, and Figure 144). However, this may be due to the fact that parasitism and disease (which both increase in higher salinities) are not included as direct effects, and that the increase in water depth itself is not included as an effect in the current simulations. An increase in water depth could place oysters below the photic zone, which decreases their food (phytoplankton) availability. Largemouth bass displays biomass concentrations in areas of low salinity, which are inland areas and areas with high freshwater discharge, such as at the outfall of the Caernarvon freshwater diversion and the Bird's Foot Delta (Figure 136, Figure 140, and Figure 145). These biomass concentrations become more restricted in the high scenario. It should be noted that none of the scenarios result in a crash of the fish and shellfish stocks.

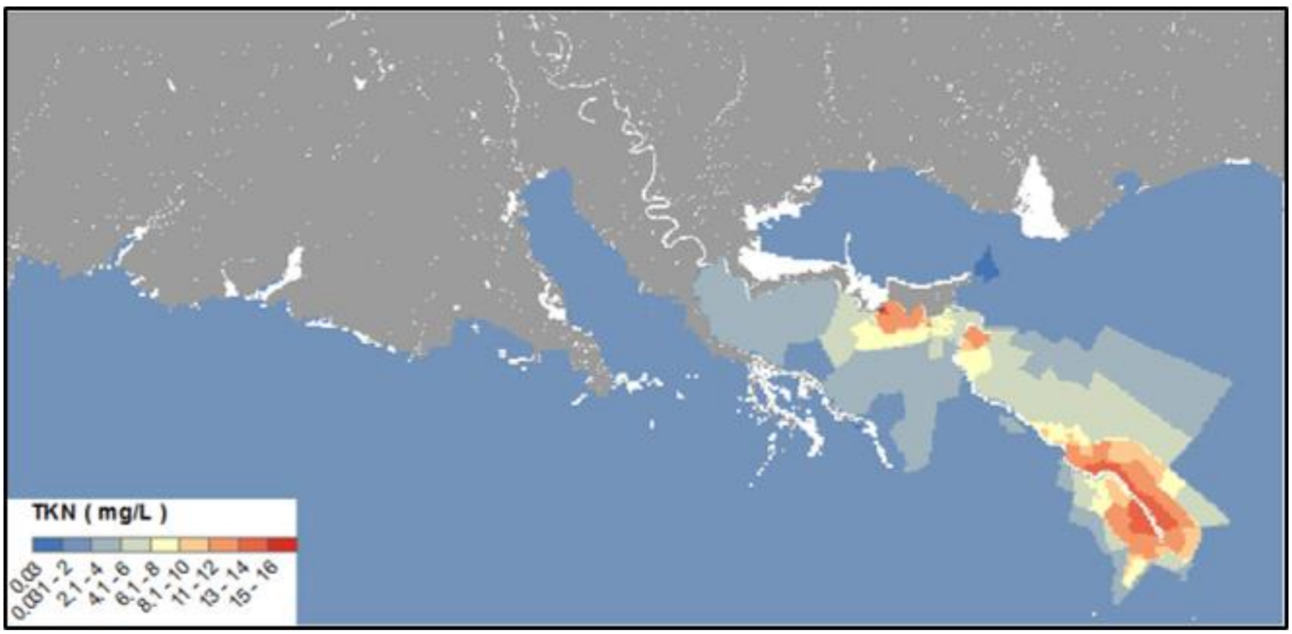


Figure 131: Distribution of TKN: Year 25 of the Low Scenario.

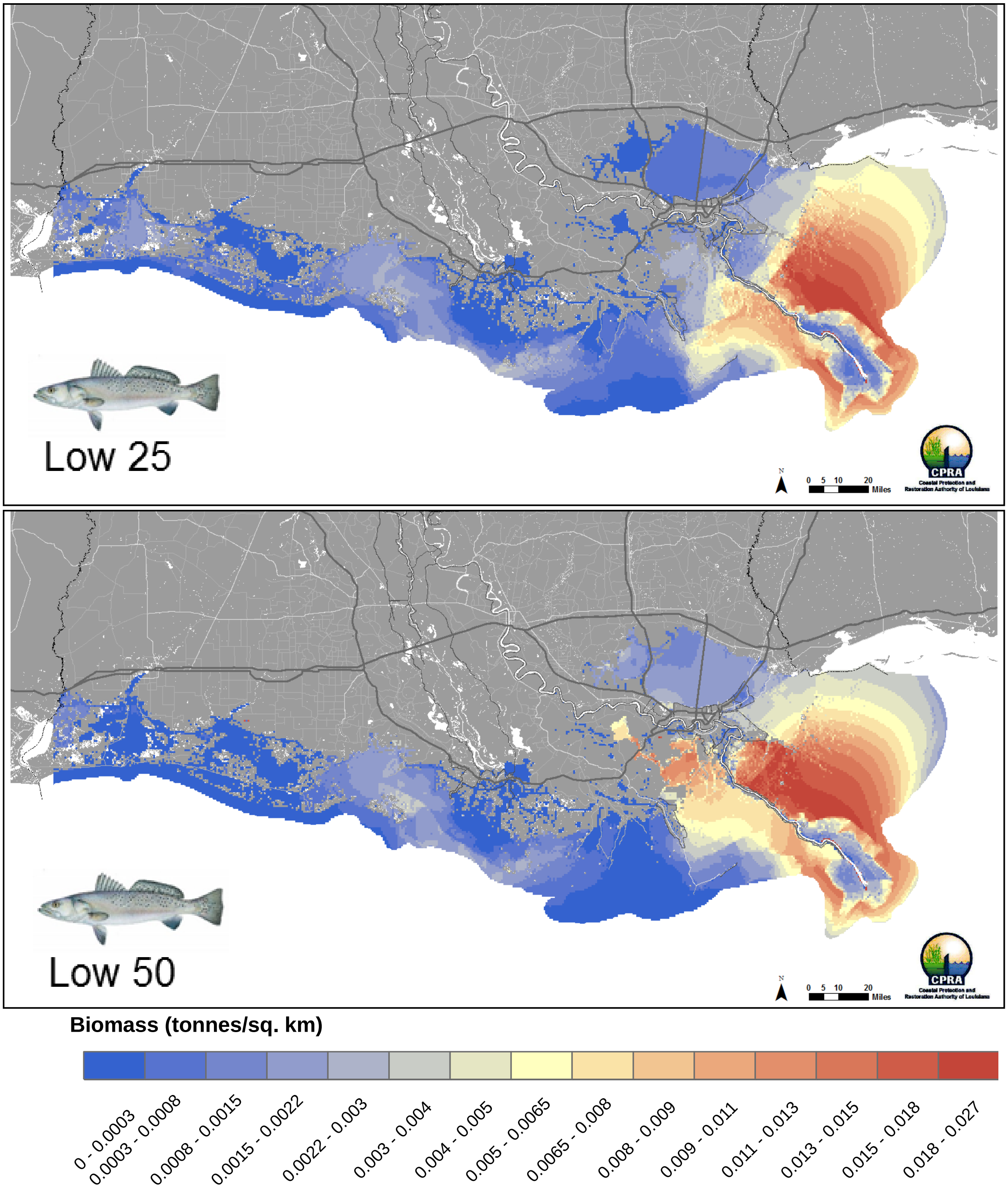


Figure 132: Biomass Distribution of Adult Spotted Seatrout in Year 25 (top) and Year 50 (bottom) of the Low Scenario.

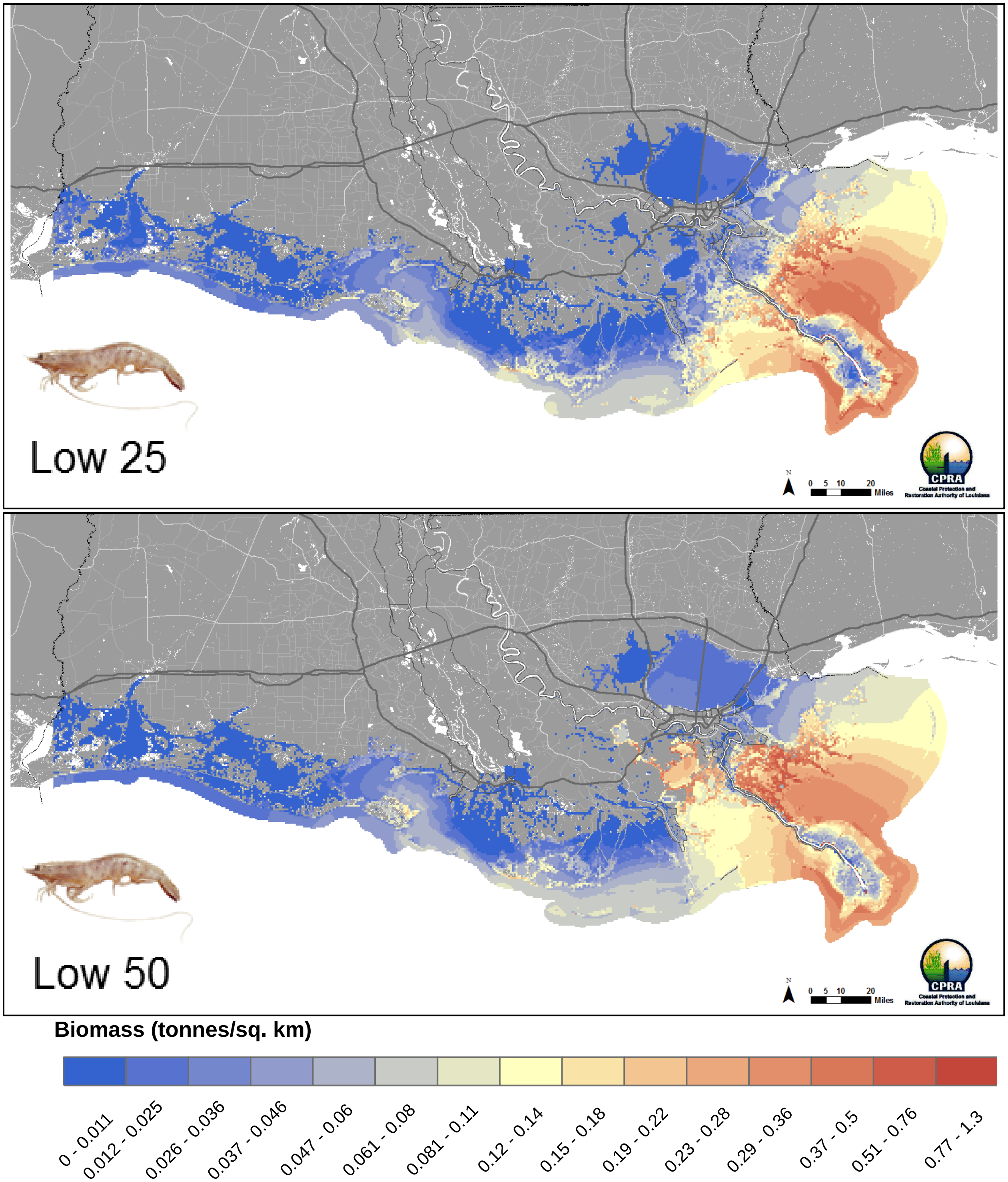


Figure 133: Biomass Distribution of Juvenile Brown Shrimp in Year 25 (top) and Year 50 (bottom) of the Low Scenario.

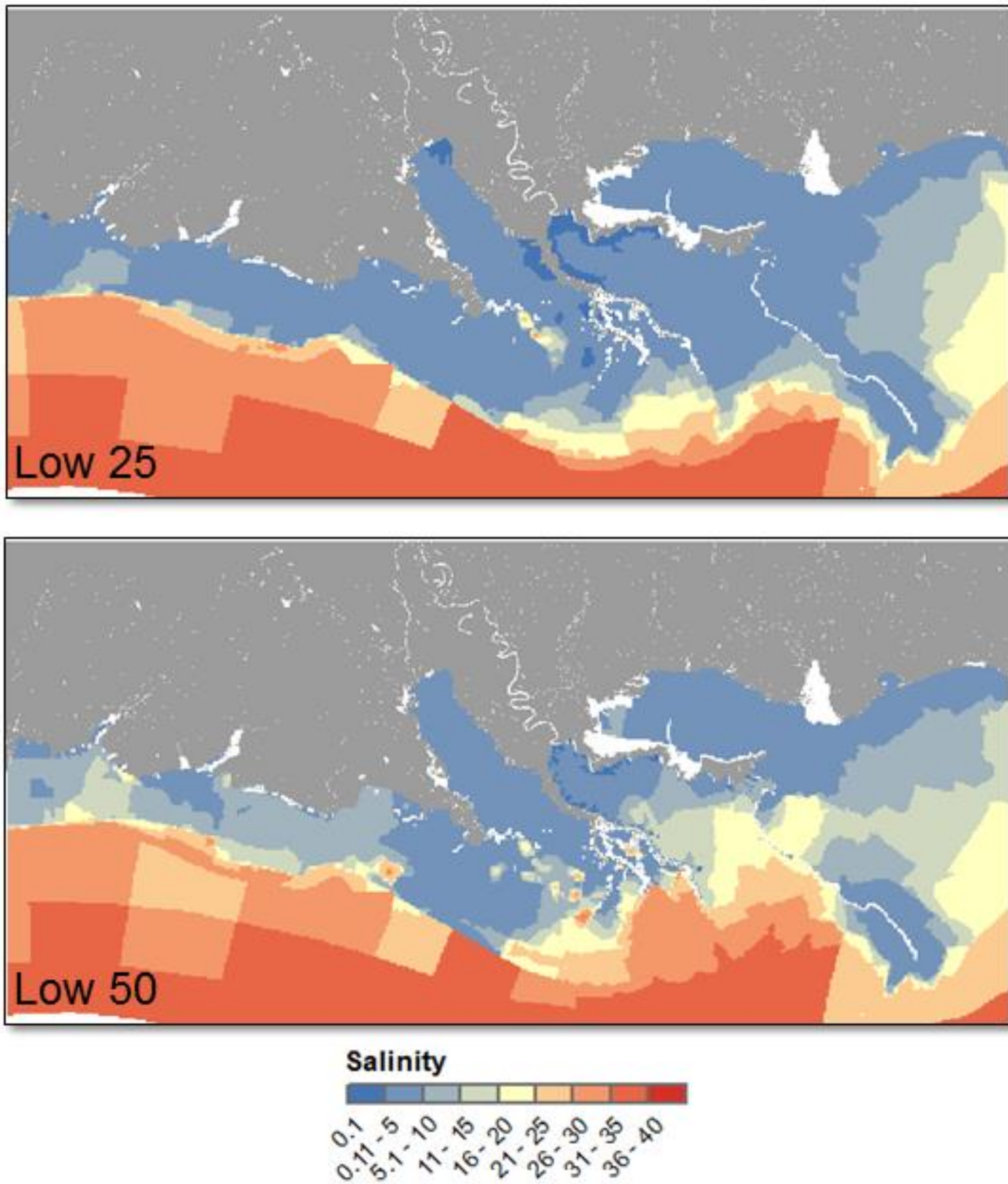


Figure 134: Mean Monthly Salinity in April of Year 25 and Year 50 in the Low Scenario Compared.

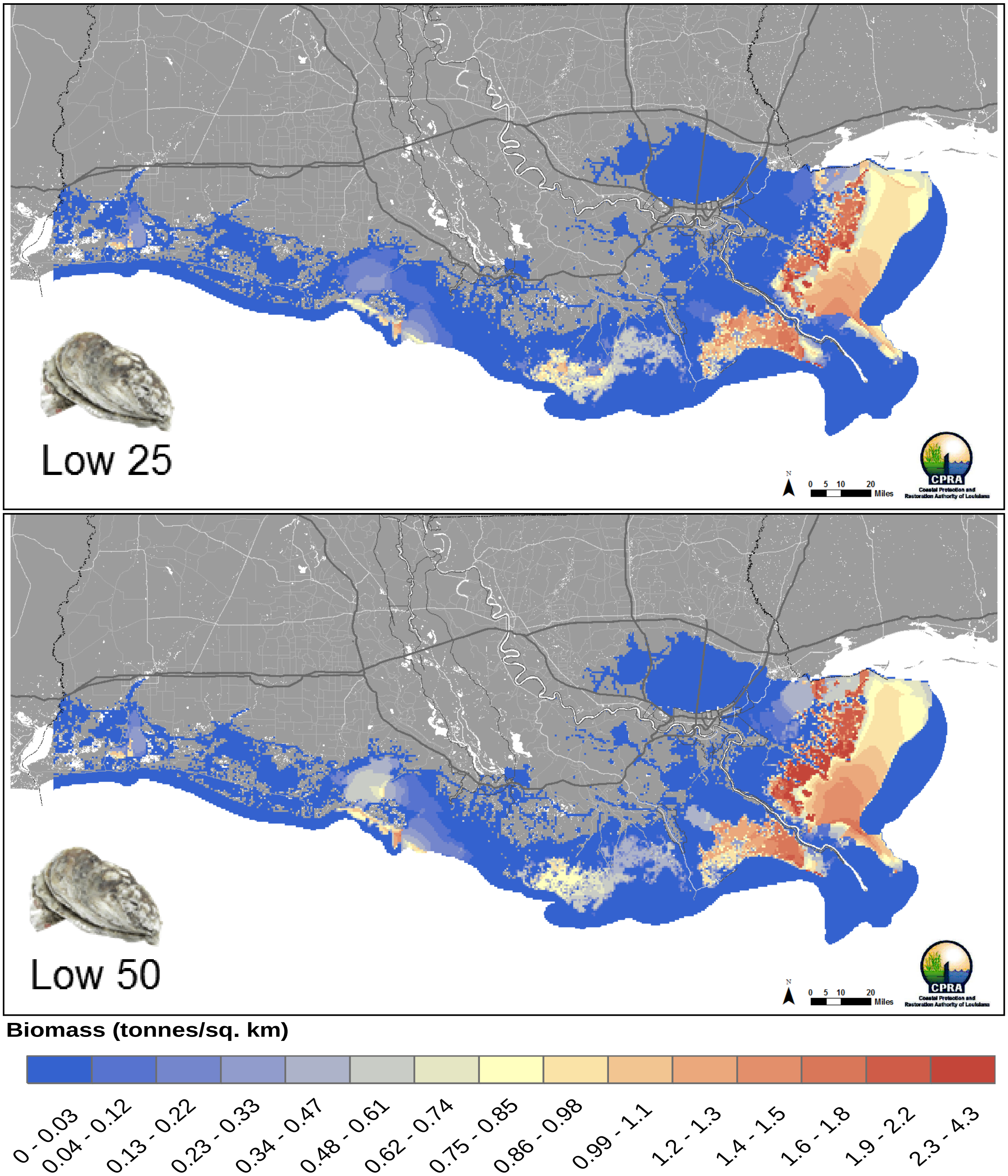


Figure 135: Biomass Distribution of Eastern Oyster (sack) in Year 25 (top) and Year 50 (bottom) of the Low Scenario.

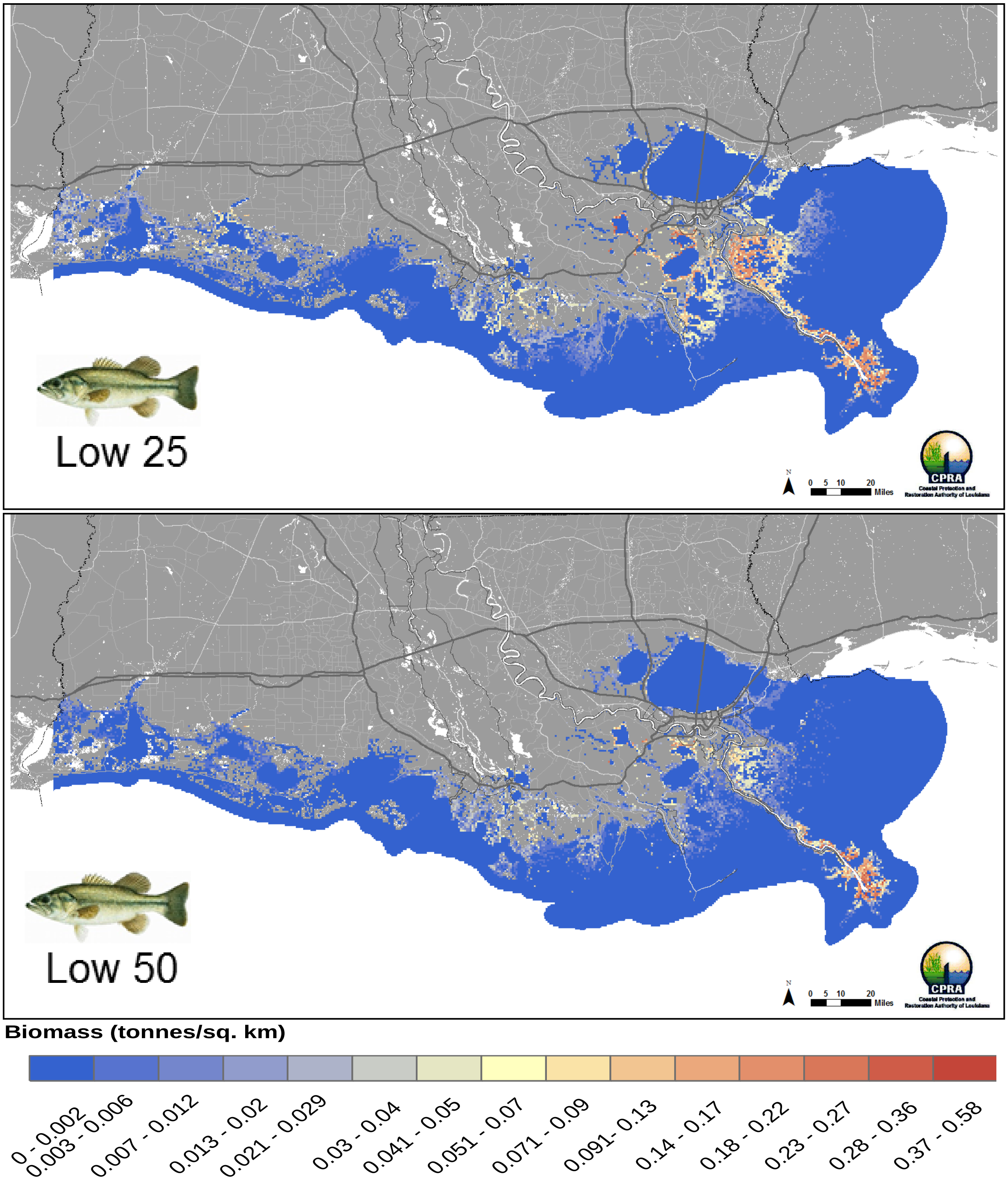


Figure 136: Biomass Distribution of Juvenile Largemouth Bass in Year 25 (top) and Year 50 (bottom) of the Low Scenario.

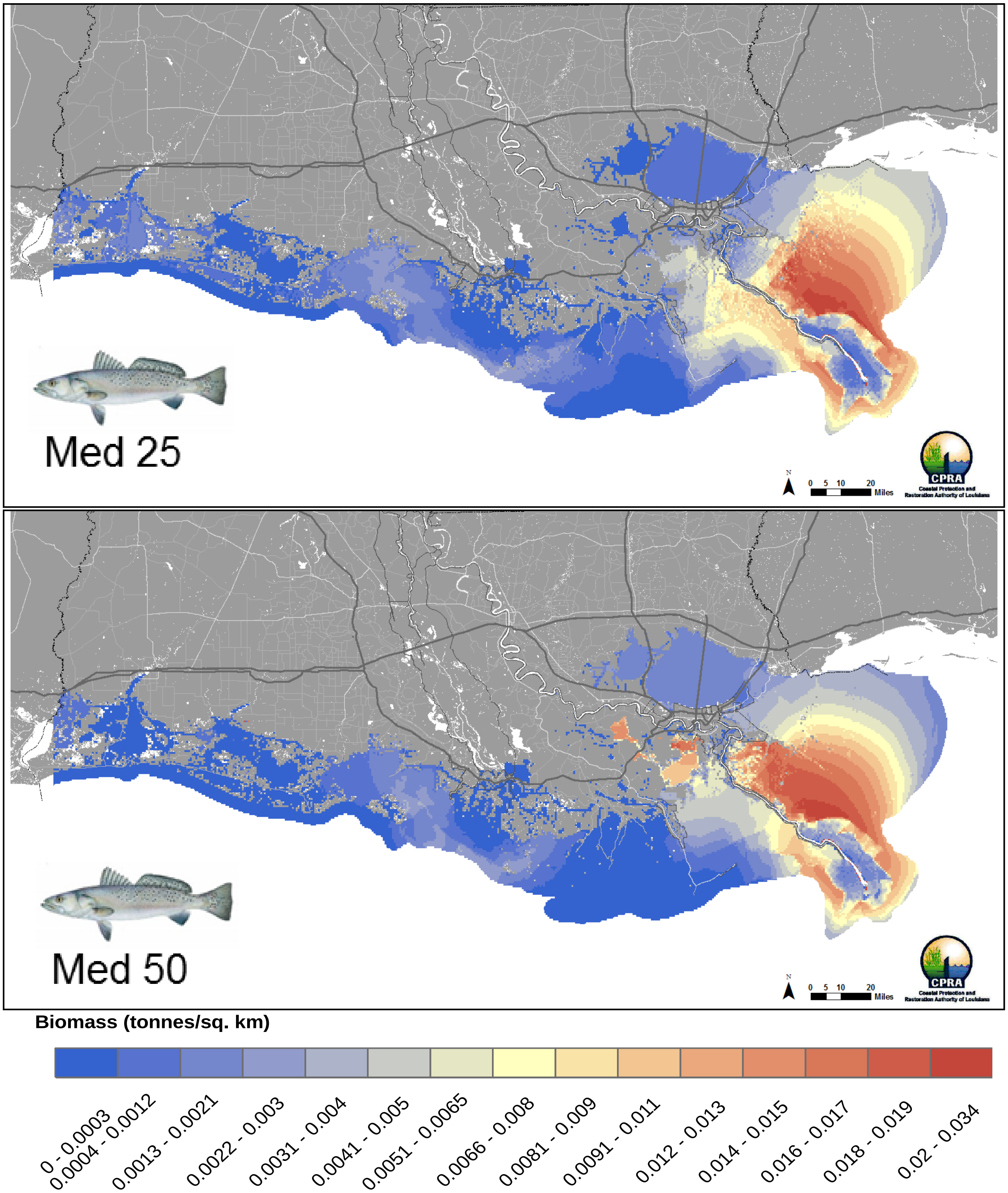


Figure 137: Biomass Distribution of Adult Spotted Seatrout in Year 25 (top) and Year 50 (bottom) of the Medium Scenario.

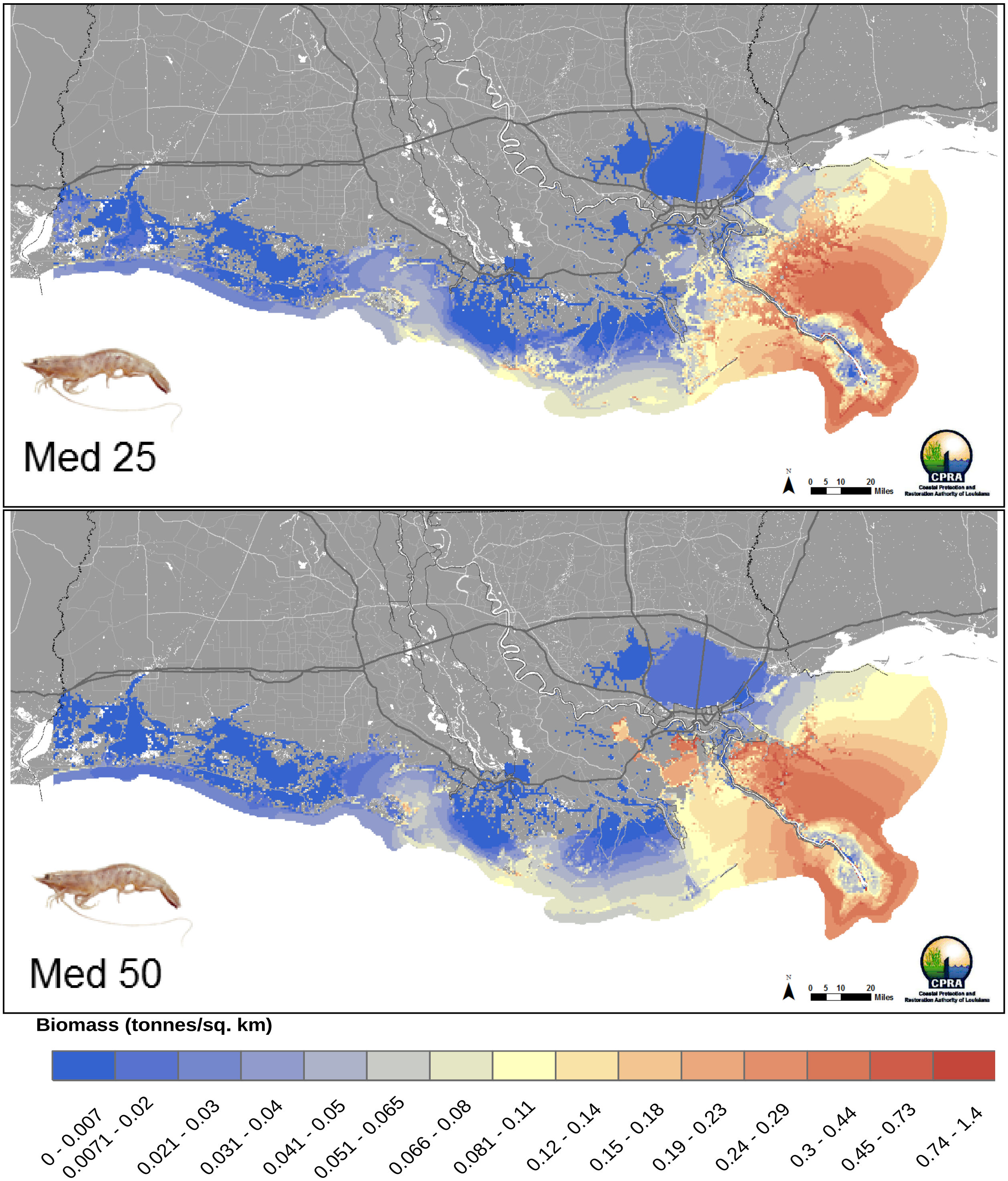


Figure 138: Biomass Distribution of Juvenile Brown Shrimp in Year 25 (top) and Year 50 (bottom) of the Medium Scenario.

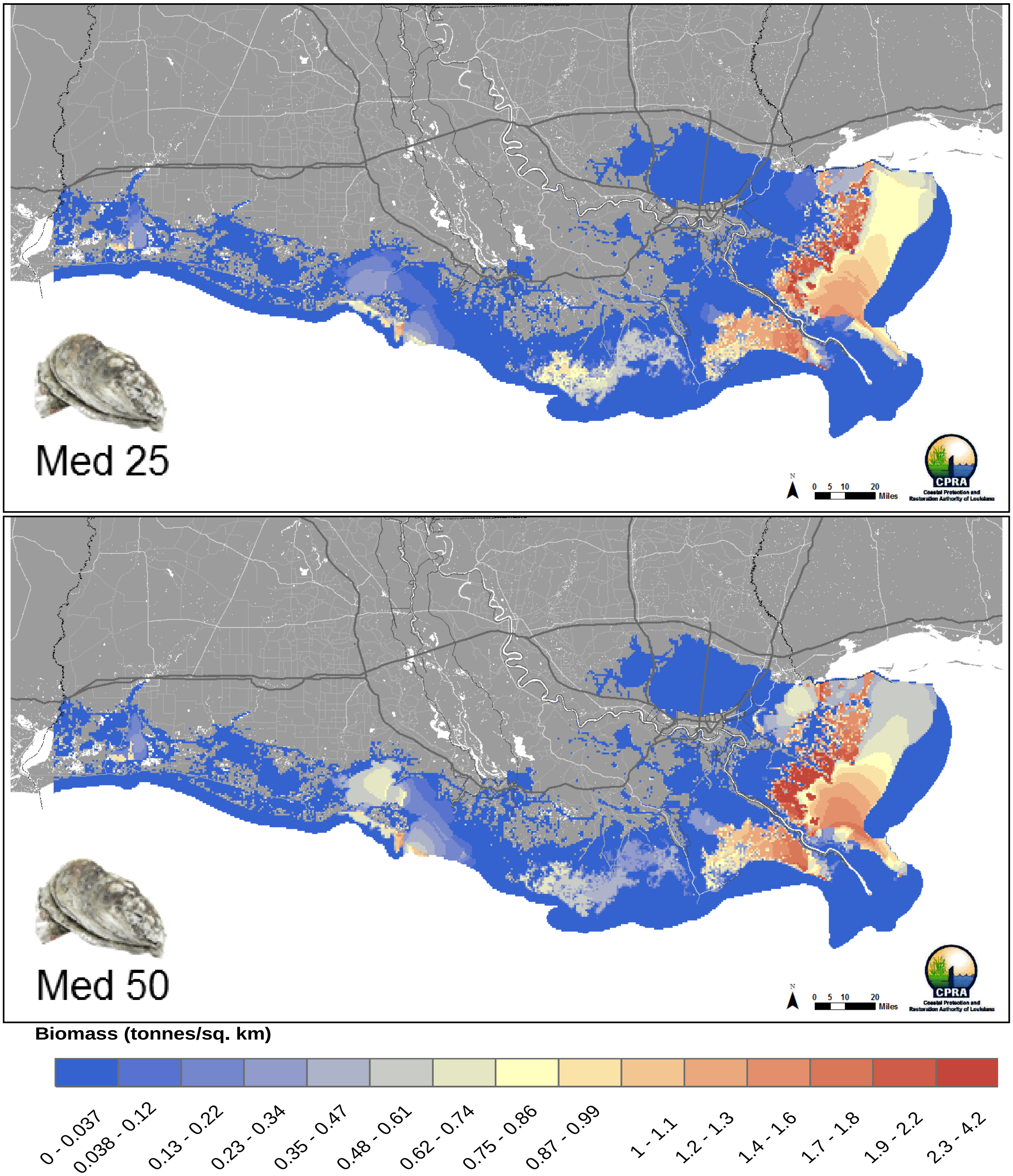


Figure 139: Biomass Distribution of Eastern Oyster (sack) in Year 25 (top) and Year 50 (bottom) of the Medium Scenario.

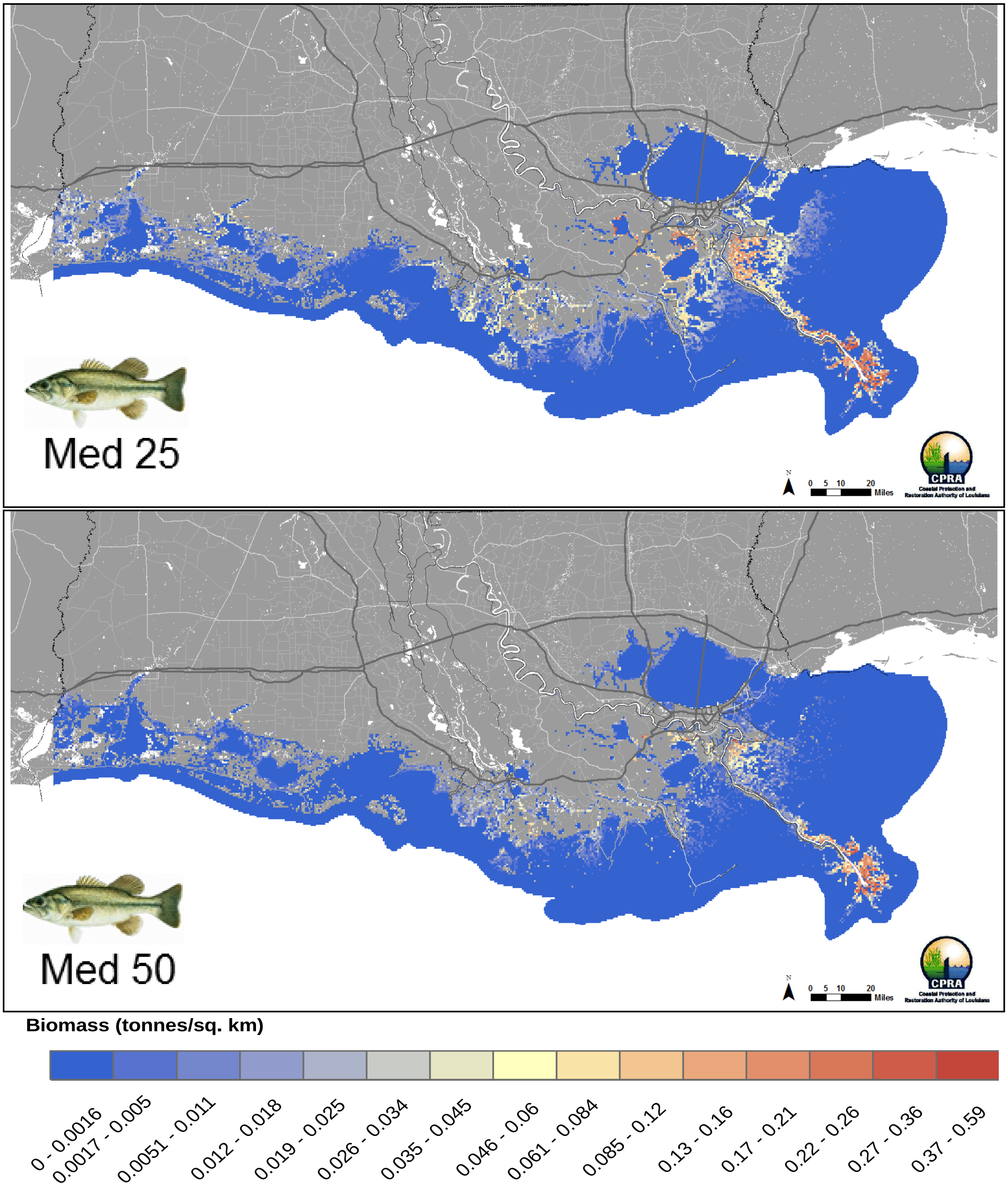


Figure 140: Biomass Distribution of Juvenile Largemouth Bass in Year 25 (top) and Year 50 (bottom) of the Medium Scenario.

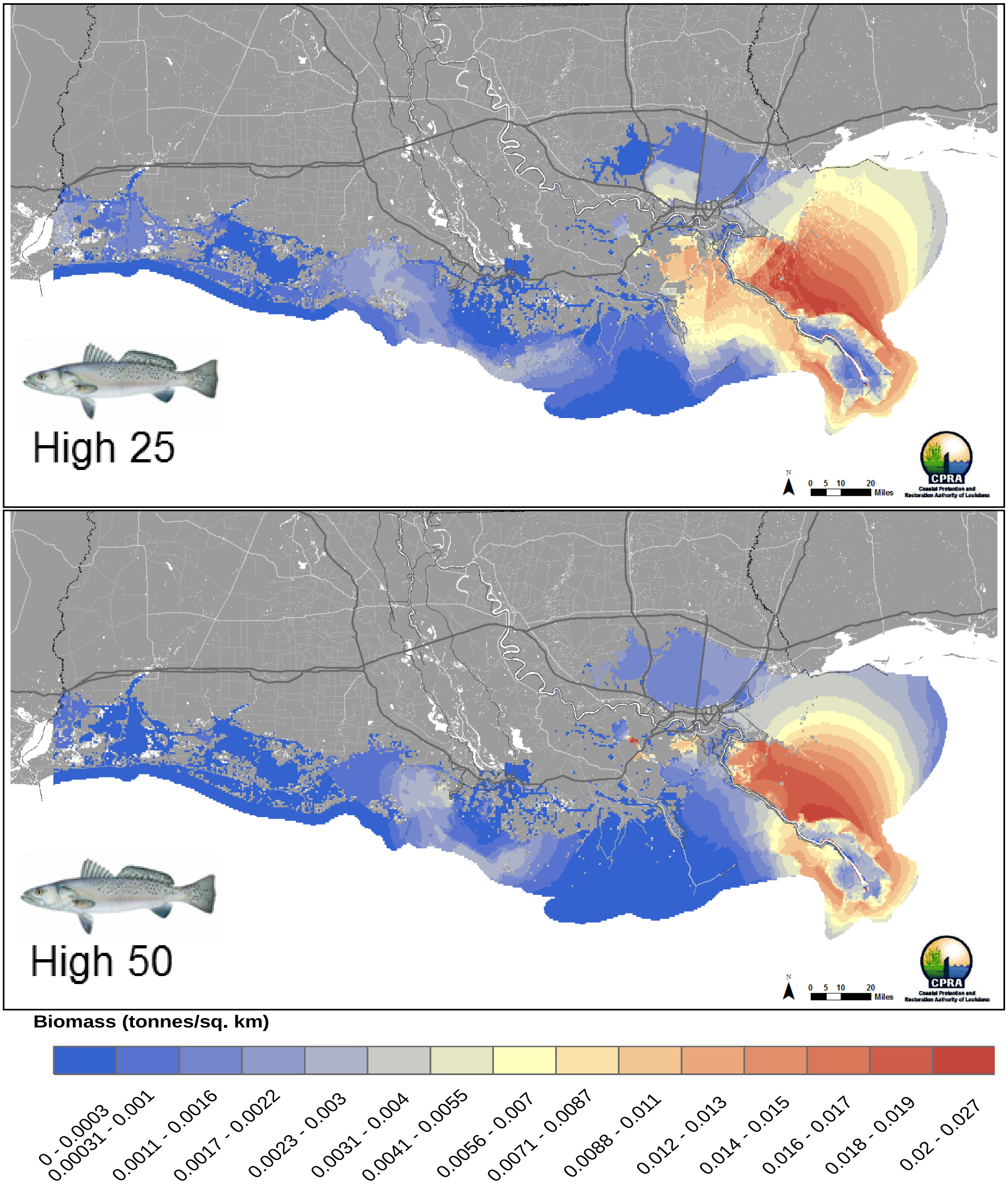


Figure 141: Biomass Distribution of Adult Spotted Seatrout in Year 25 (top) and Year 50 (bottom) of the High Scenario.

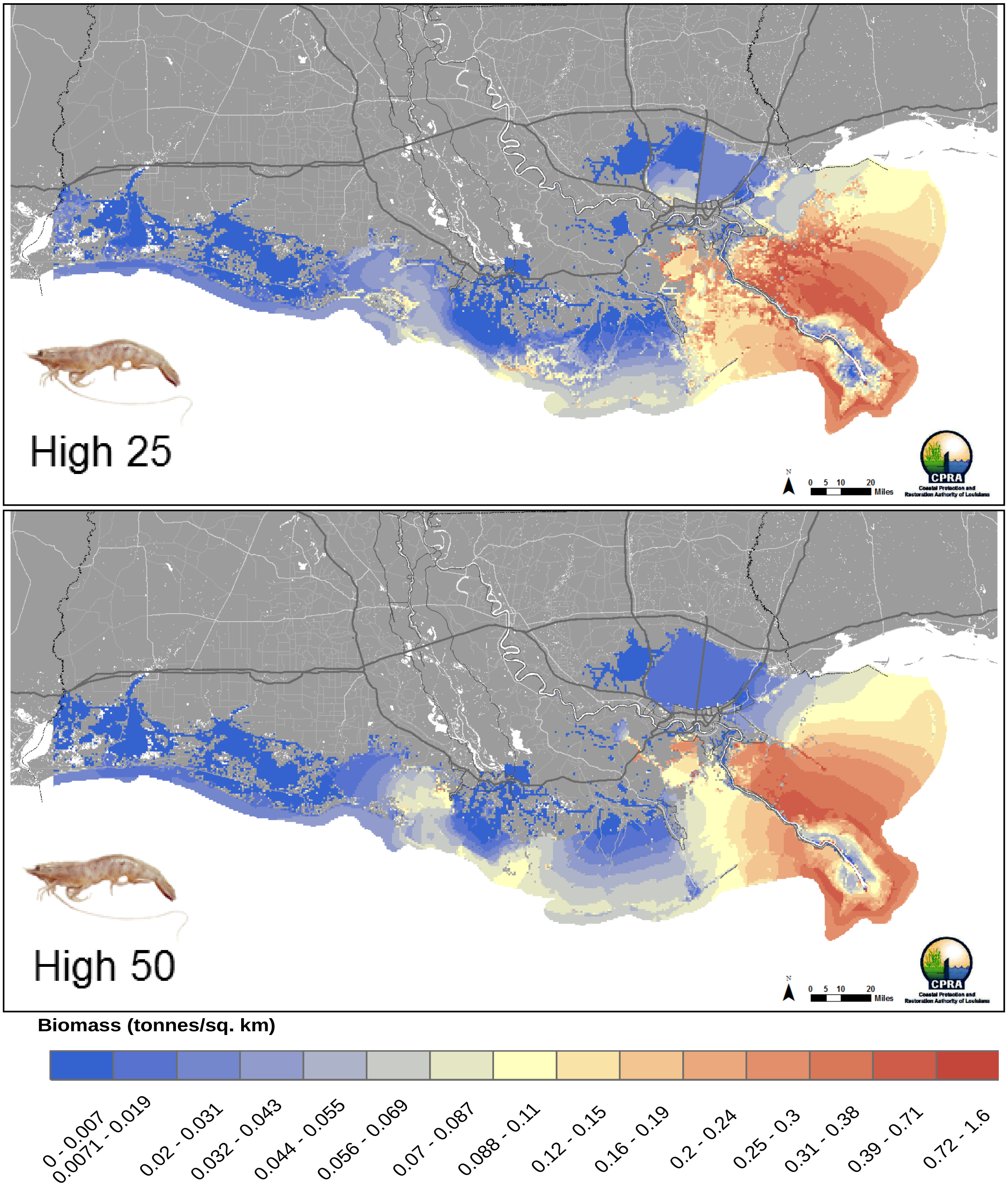


Figure 142: Biomass Distribution of Juvenile Brown Shrimp in Year 25 (top) and Year 50 (bottom) of the High Scenario.

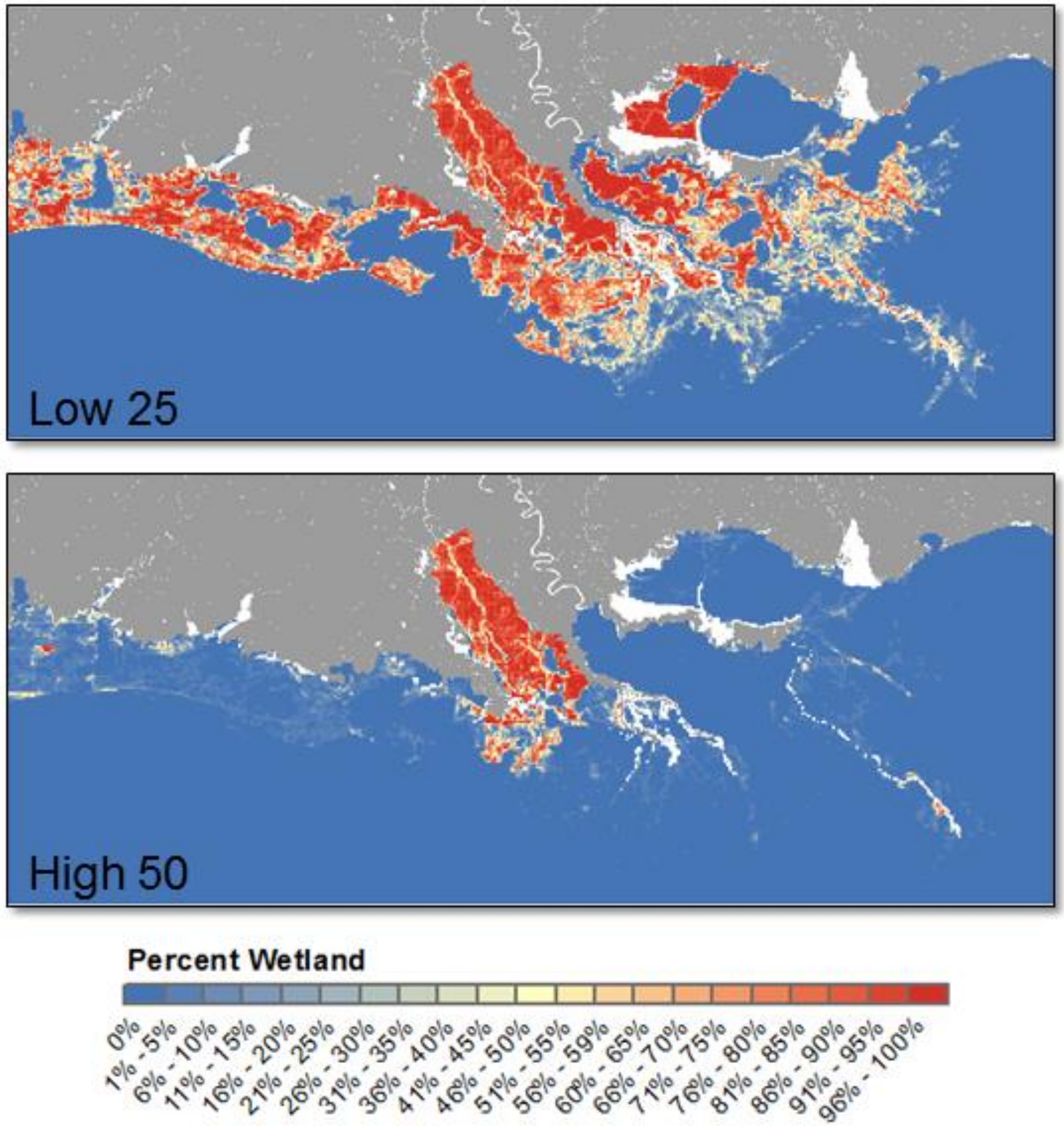


Figure 143: Percent Wetland in Year 25 of the Low Scenario (top) and Year 50 of the High Scenario (bottom), Showing the Differences in Projected Wetland Loss Depending on Time and Scenario.

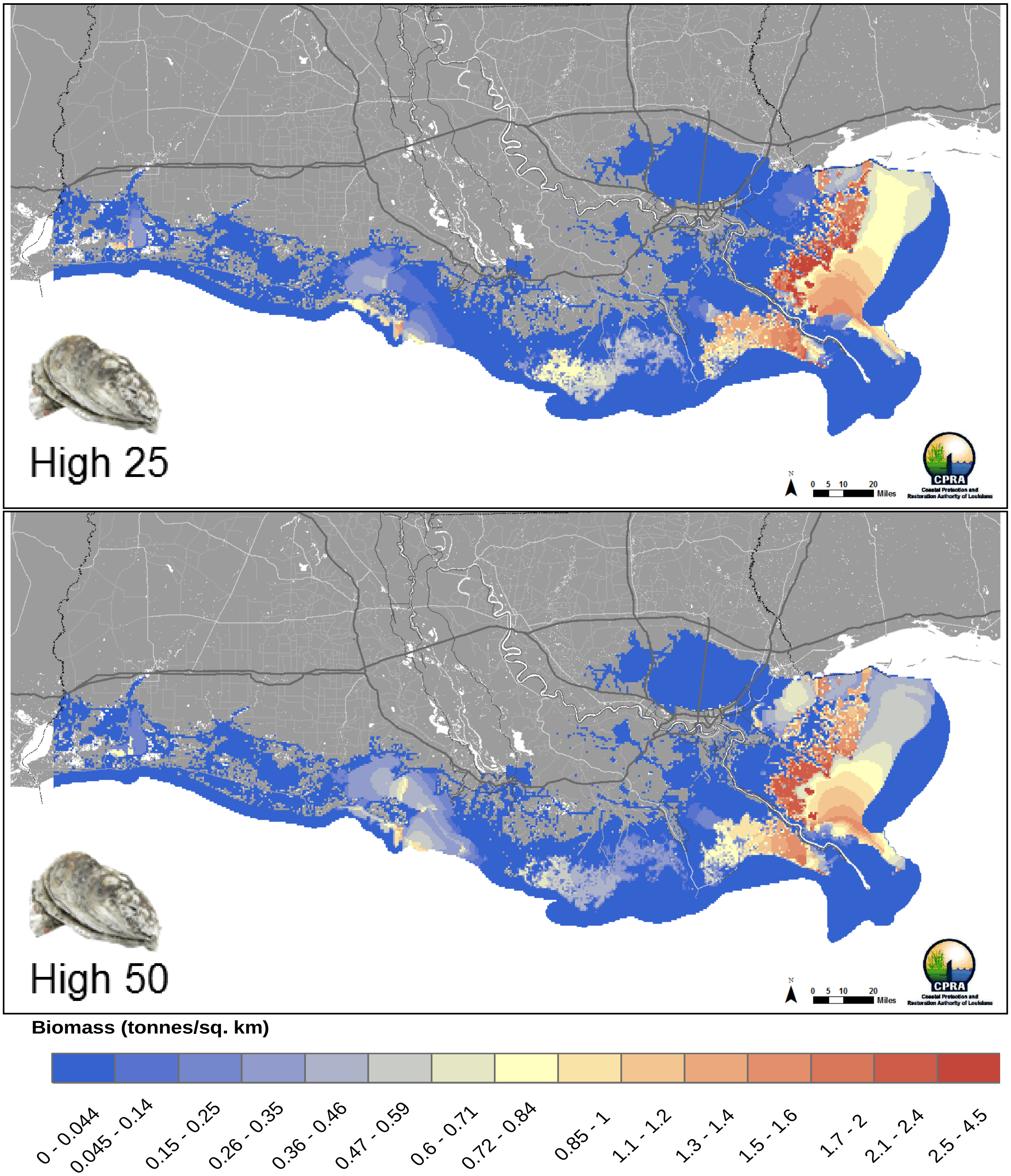


Figure 144: Biomass Distribution of Eastern Oyster (sack) in Year 25 (top) and Year 50 (bottom) of the High Scenario.

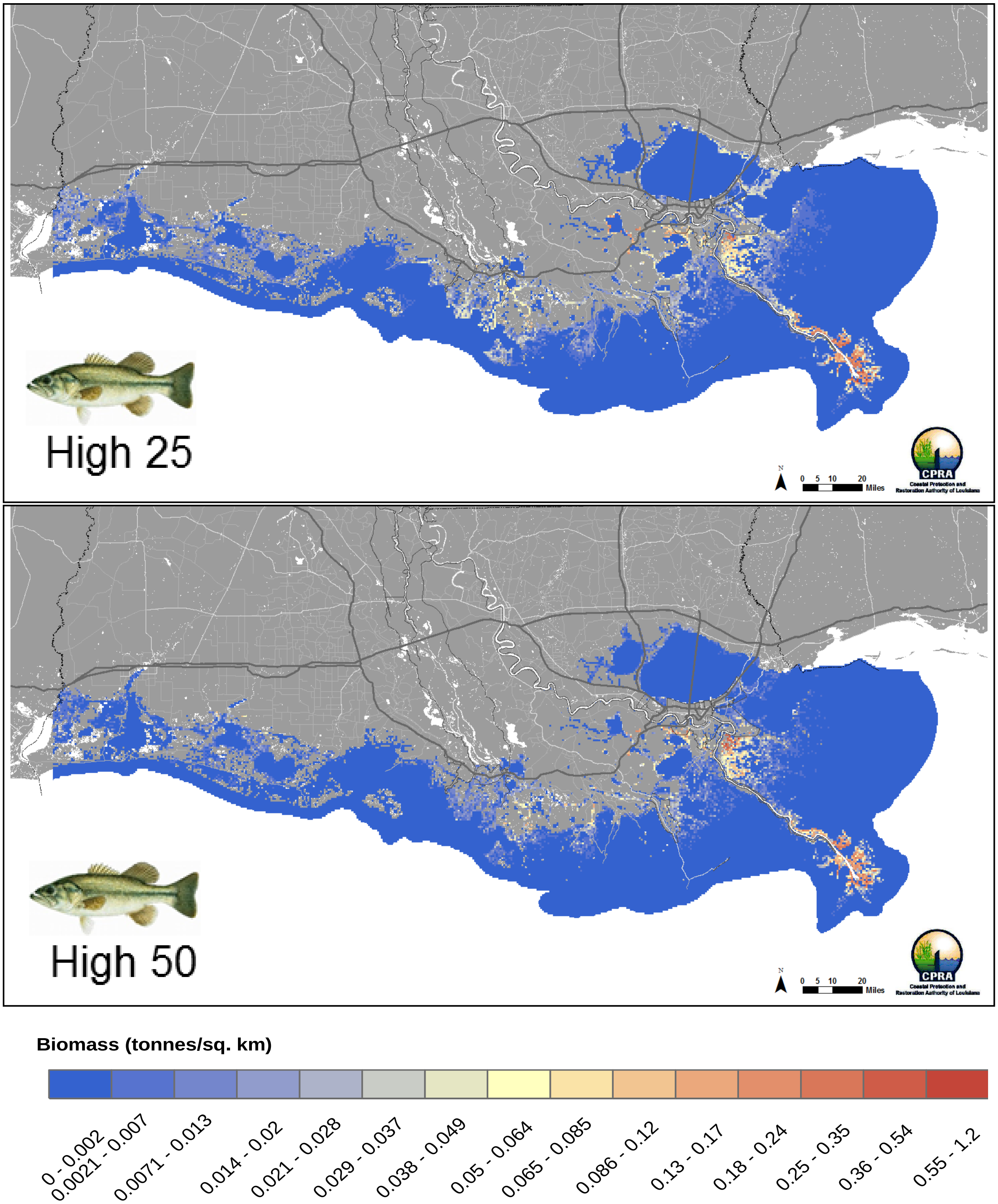


Figure 145: Biomass Distribution of Juvenile Largemouth Bass in Year 25 (top) and Year 50 (bottom) of the High Scenario.

3.8 Storm Surge and Waves

FWOA simulations using ADCIRC/SWAN were conducted by altering the initial conditions model configuration in the following ways:

- The initial water level was updated to account for sea level rise;
- Topographic and bathymetric values were updated to account for the change in elevations described by the ICM for a given year and scenario combination;
- Frictional characteristics were updated to account for the change in vegetation types described by the ICM for a given year and scenario combination; and
- Levees and raised features (e.g., roadways and coastal ridges) were updated to reflect design elevation upgrades and subsidence where applicable. See Appendix A: Project Definition for further information regarding development of the levee elevation dataset.

The following sections detail the consequence of these changes in surge and wave results as well as how the results vary over time. The two-dimensional difference plots shown are compared to the initial conditions model results in order to maintain a constant point of reference. Simulations were conducted to represent conditions at year 10, year 25 and year 50.

3.8.1 Low Scenario

Compared to other scenarios, the low scenario shows the least change in surge elevation during a storm simulation at each of the time levels. This is largely due to sea level rise generally playing a greater role in creating higher surge elevations than other model changes such as topographic elevations and changes to frictional characteristics to reflect future landscape conditions. Table 9 shows the sea level rise increment and associated initial water level (meters, NAVD88 2009.55) used during the low scenario for the surge and waves model.

Table 9: Initial Water Levels and Sea Level Rise Values for the Low Scenario.

Low scenario		
Year	**Sea level rise (meters)**	**Initial water level (meters, NAVD88 2009.55)**
10	0.06	0.37
25	0.18	0.49
50	0.43	0.74

Figure 146 through 151 illustrate differences in the maximum surge elevations and wave heights for Storm 014 for the three simulation years (10, 25, and 50). The contour palette used on Figures 146 through 151 was selected to categorize differences between FWOA and initial conditions simulations. White areas represent absolute changes of less than 0.25 meters.

Warm colors represent FWOA maximum surge elevations that are higher than those simulated for initial conditions by more than 0.25 meters. Similarly, cool colors represent FWOA maximum surge elevations that are lower than those simulated for initial conditions by more than 0.25 meters. Areas that appear as brown were flooded in FWOA and were not flooded during the initial conditions simulations. Areas that appear as gray are areas that were not flooded in FWOA and were flooded in the initial conditions simulation.

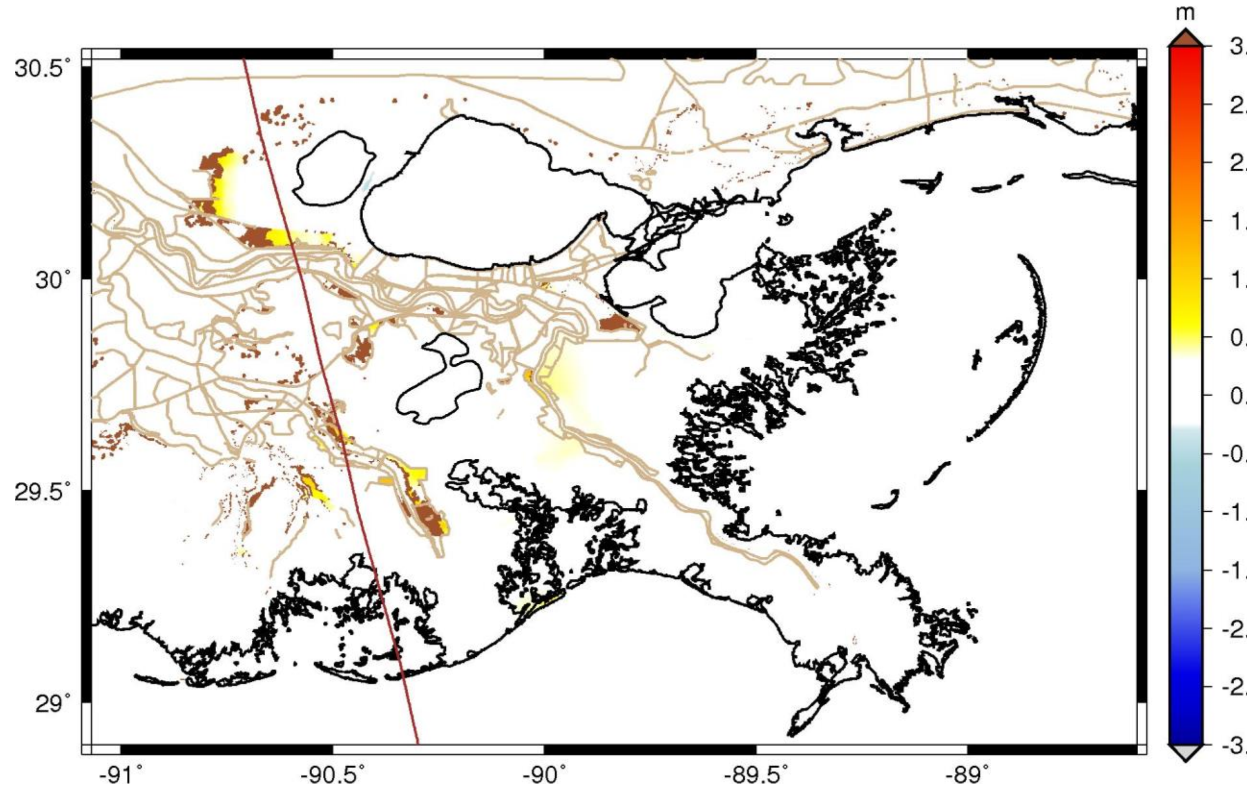


Figure 146: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 10 of the Low Scenario.

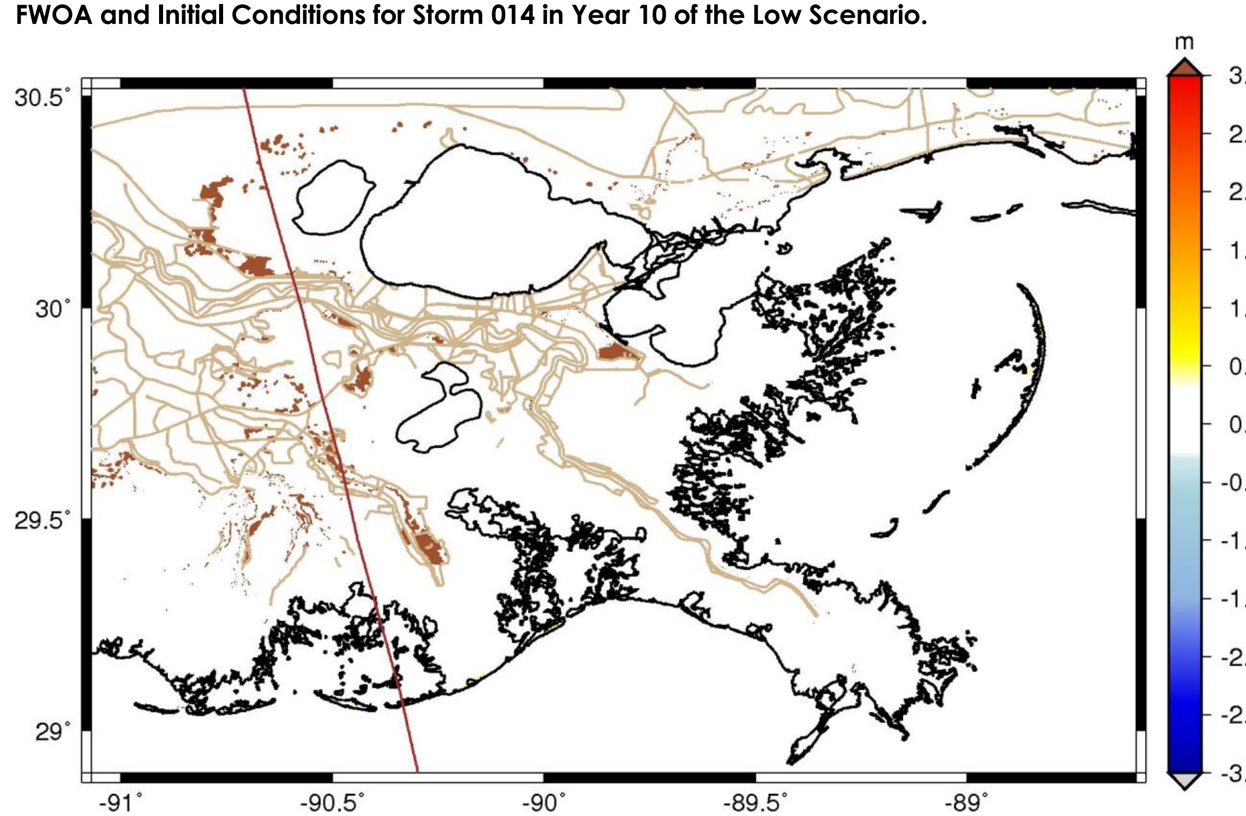


Figure 147: Differences Between Maximum Wave Height (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 10 of the Low Scenario.

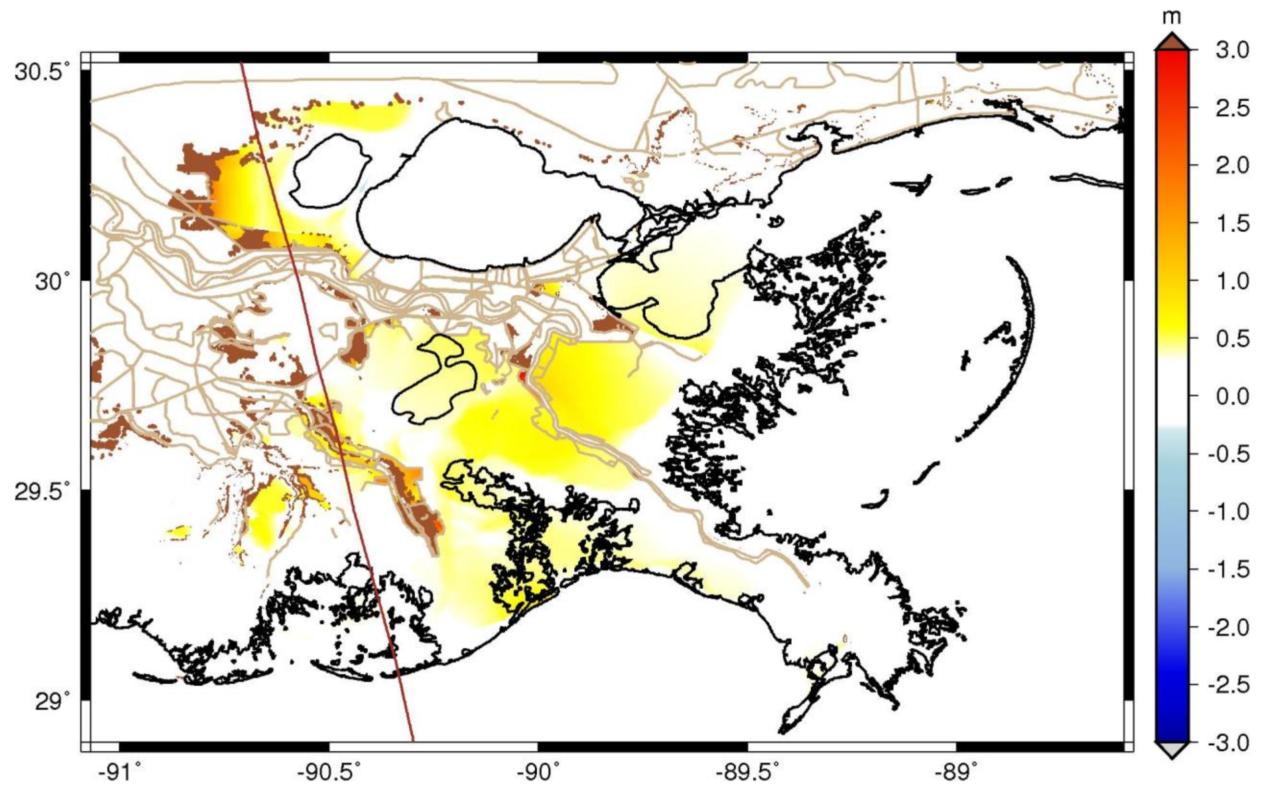


Figure 148: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 25 of the Low Scenario.

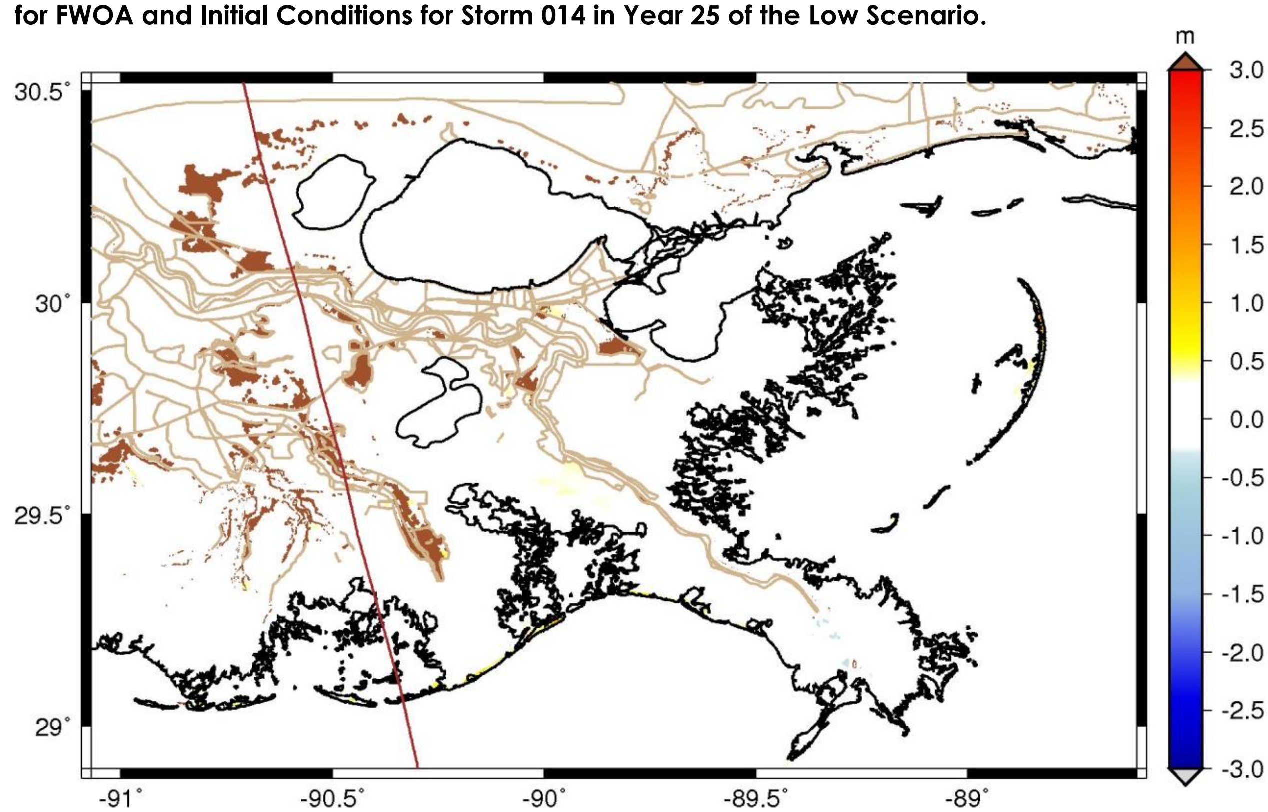


Figure 149: Differences Between Maximum Wave Height (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 25 of the Low Scenario.

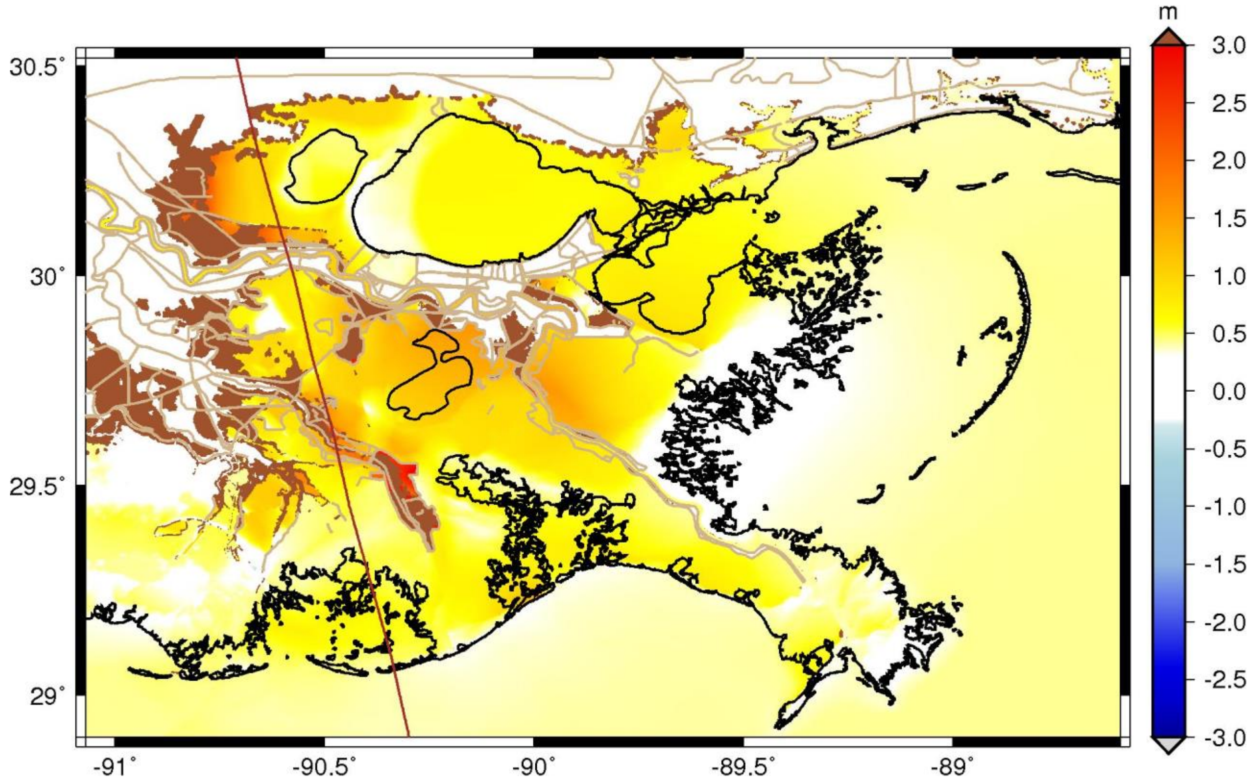


Figure 150: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 50 of the Low Scenario.

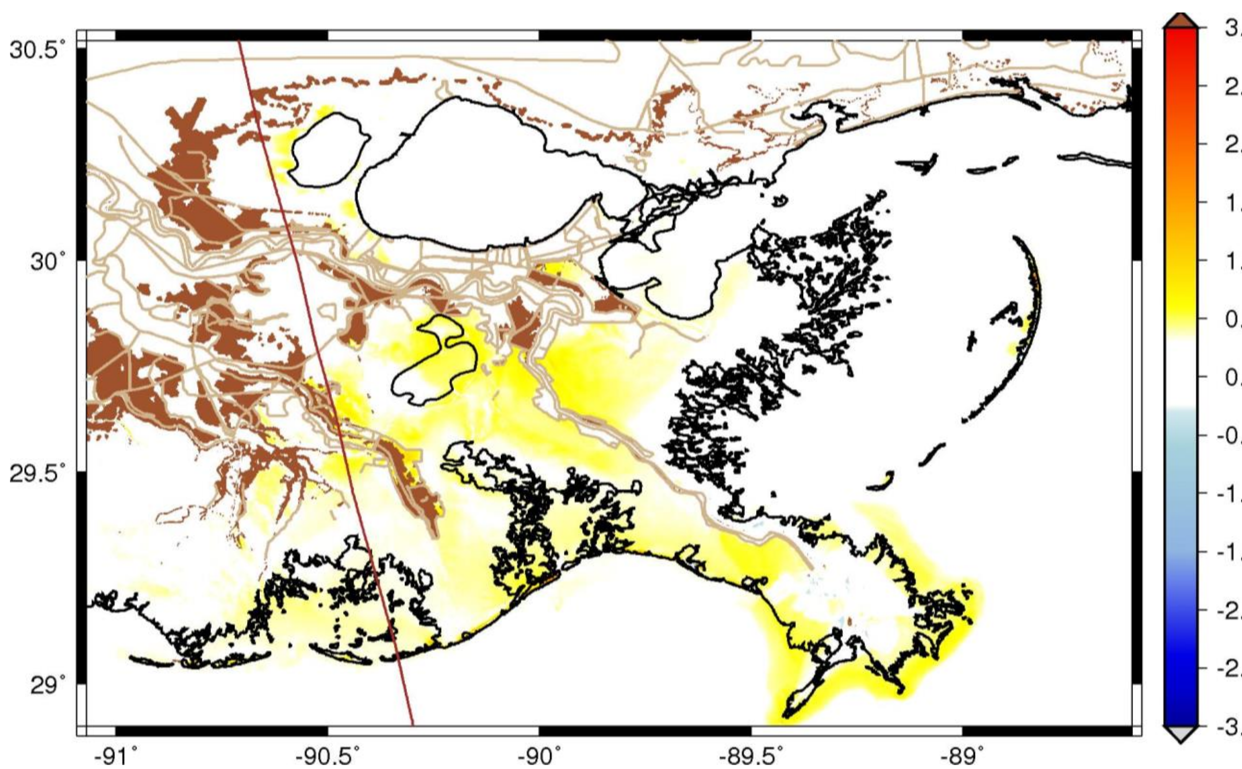


Figure 151: Differences Between Maximum Wave Height (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 50 of the Low Scenario.

In year 10, the offshore areas are generally white in color due to the relatively small increase in sea level. As this scenario progresses to later years, the offshore area generally remains a consistent contour for each storm yet increases relative to earlier years. The increase in elevation offshore largely reflects the sea level rise increment itself. Areas with an increase in maximum surge elevation equivalent to the imposed sea level rise increment demonstrate a linear sea level rise response.

In contrast to offshore areas, there are inland regions that do not show a change in maximum surge elevation that is consistent with the sea level rise increment. These areas are described as having a nonlinear response. Nonlinear responses are most easily seen inland and in later years. These changes occur due to changes in bottom friction, wind roughness length, and sea level rise, though sea level rise is generally the largest contributor to these changes. In addition to the nonlinear changes in surge elevation, it should also be noted that in later years, especially year 50, there are significant areas that are newly inundated, particularly across the Chenier Plain and west of Lake Pontchartrain. Inundation limits do not significantly change for Storm 014 during year 10. Year 25 sees more drastic changes across the Chenier Plain but only mild changes in Barataria Basin. Year 50 sees the most significant changes in inundation across the coast.

Figures 152 and 153 show surge elevation time series at two locations—Lake Borgne and Barataria Bay—for Storm 014. The Lake Borgne time series plot shows an increase in surge elevation slightly higher than the sea level rise increments, while the Barataria Bay time series plot shows a change in surge elevation slightly lower than the sea level rise increments.

Areas subject to depth-limited wave breaking generally resulted in greater wave heights in response to additional water depth. The areas that demonstrate changes in maximum wave height patterns are similar to those areas with notable changes in maximum surge elevation.

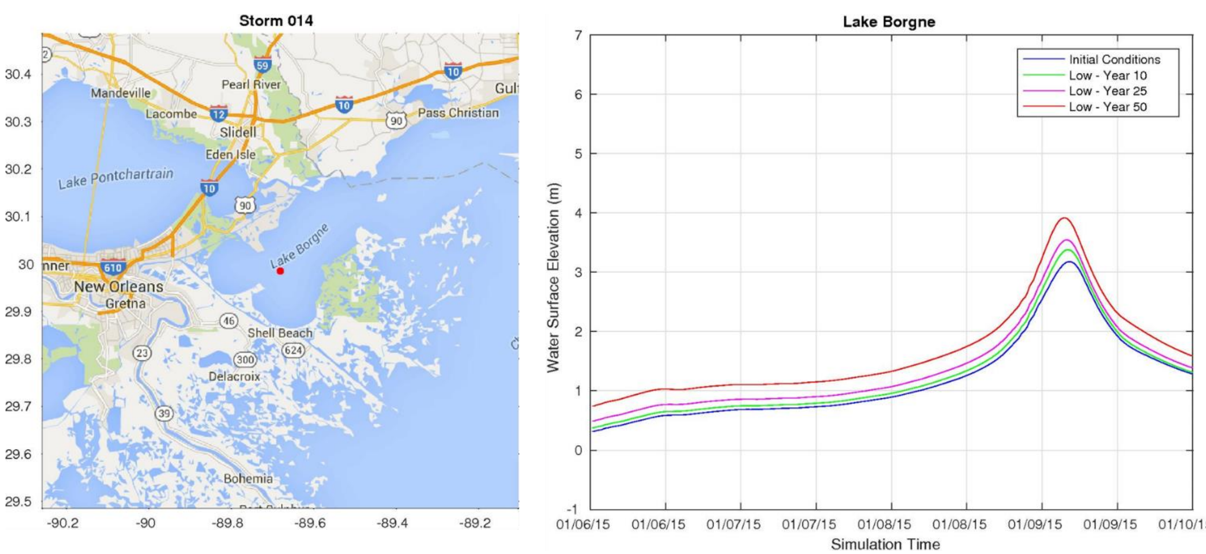


Figure 152: Surge Elevation (meters, NAVD88 2009.55) Time Series for Storm 014 in Lake Borgne for the Low Scenario.

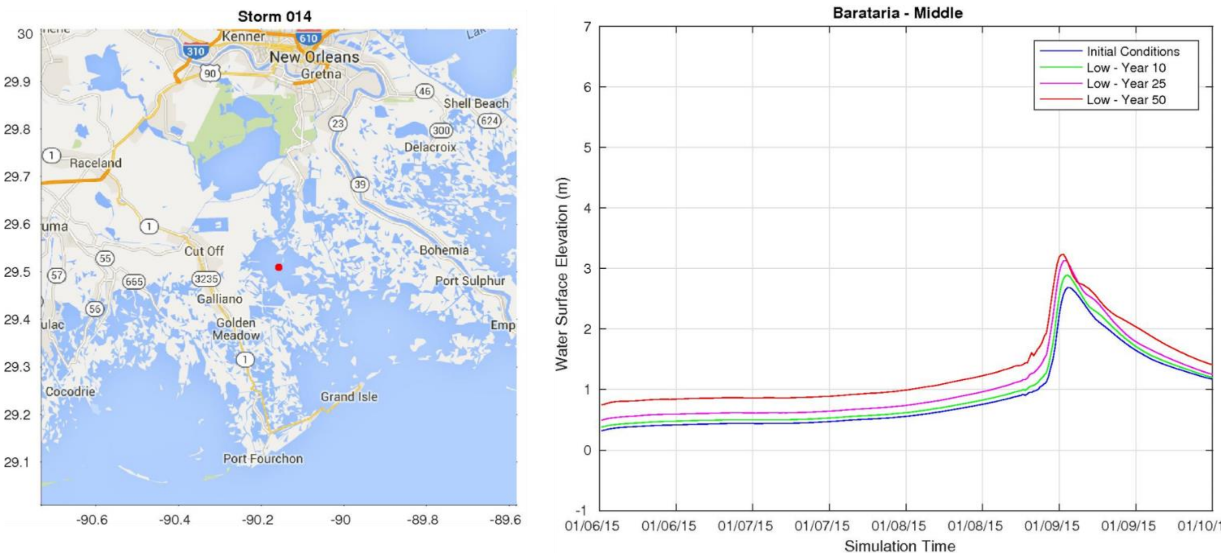


Figure 153: Surge Elevation (meters, NAVD88 2009.55) Time Series for Storm 014 in the Barataria Bay for the Low Scenario.

3.8.2 Medium Scenario

Like the low scenario, sea level rise, and changes in the landscape notably impact surge elevations throughout the model domain. Table 10 shows sea level rise values and model initial water levels used for each of the simulation years.

Table 10: Initial Water Levels and Sea Level Rise Values for the Medium Scenario.

Medium scenario		
Year	**Sea level rise (meters)**	**Initial water level (meters, NAVD88 2009.55)**
10	0.11	0.40
25	0.25	0.56
50	0.63	0.94

Figures 154 through 159 show the changes in maximum surge elevations and maximum wave heights with respect to the initial conditions simulations, and Figure 160 and Figure 161 show the time series of surge elevation. As expected, when compared to the low scenario and initial conditions model results, larger absolute changes occur offshore and inland due to the higher sea level rise rate and more significant landscape changes associated with this scenario. Due to higher sea level rise conditions, the areas subject to nonlinear increases in surge elevation are more expansive than the low scenario.

Inundation limits for the medium scenario are not significantly different than initial conditions in Year 10. However, year 25 conditions result in additional inundation, including behind lines of flood protection near Gonzales, Louisiana and across the Chenier Plain. Year 50 results in the most drastic change in inundation areas, as expected.

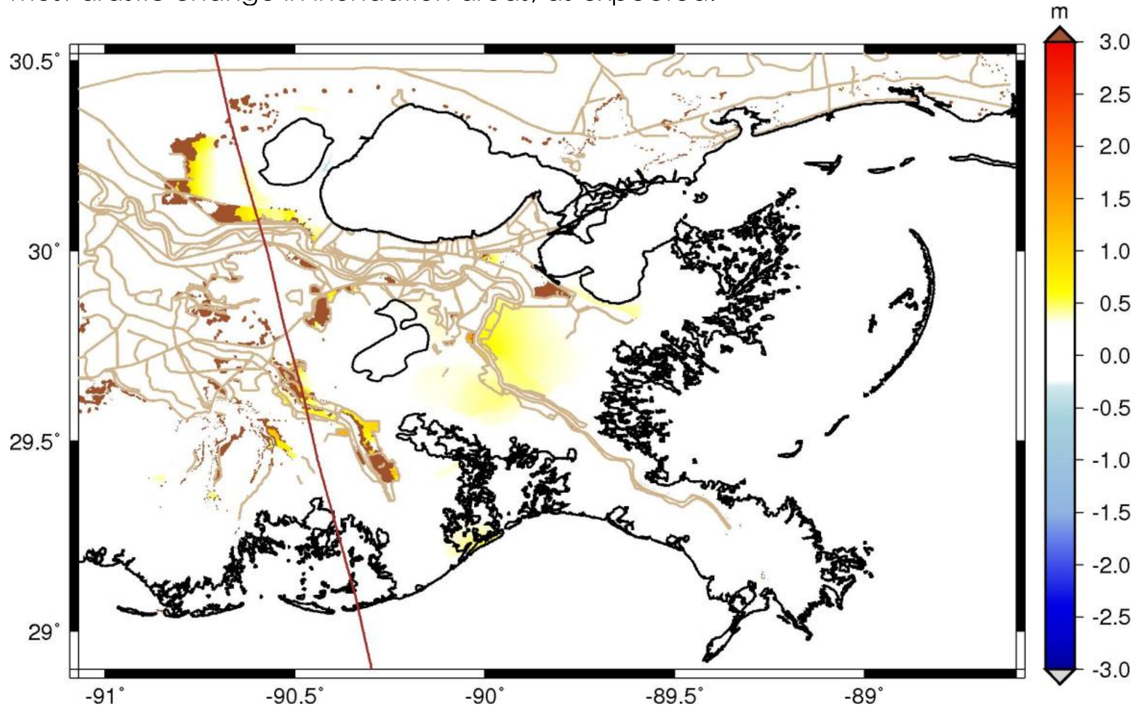


Figure 154: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 10 of the Medium Scenario.

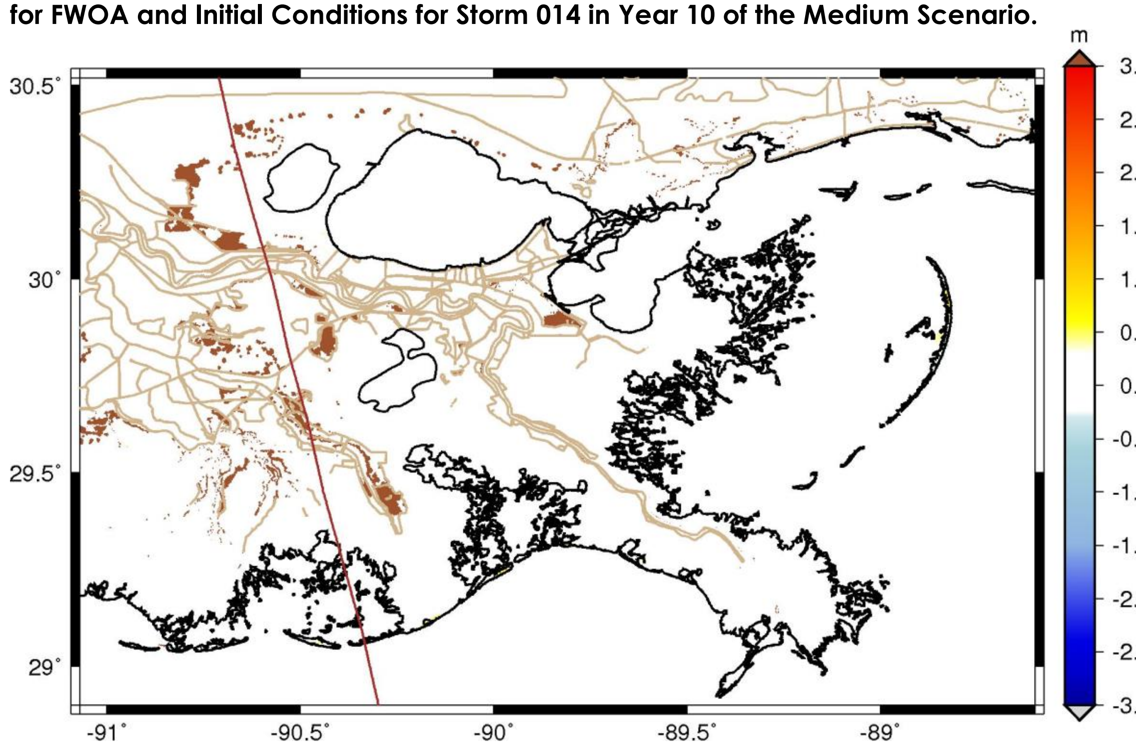


Figure 155: Differences Between Maximum Wave Height (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 10 of the Medium Scenario.

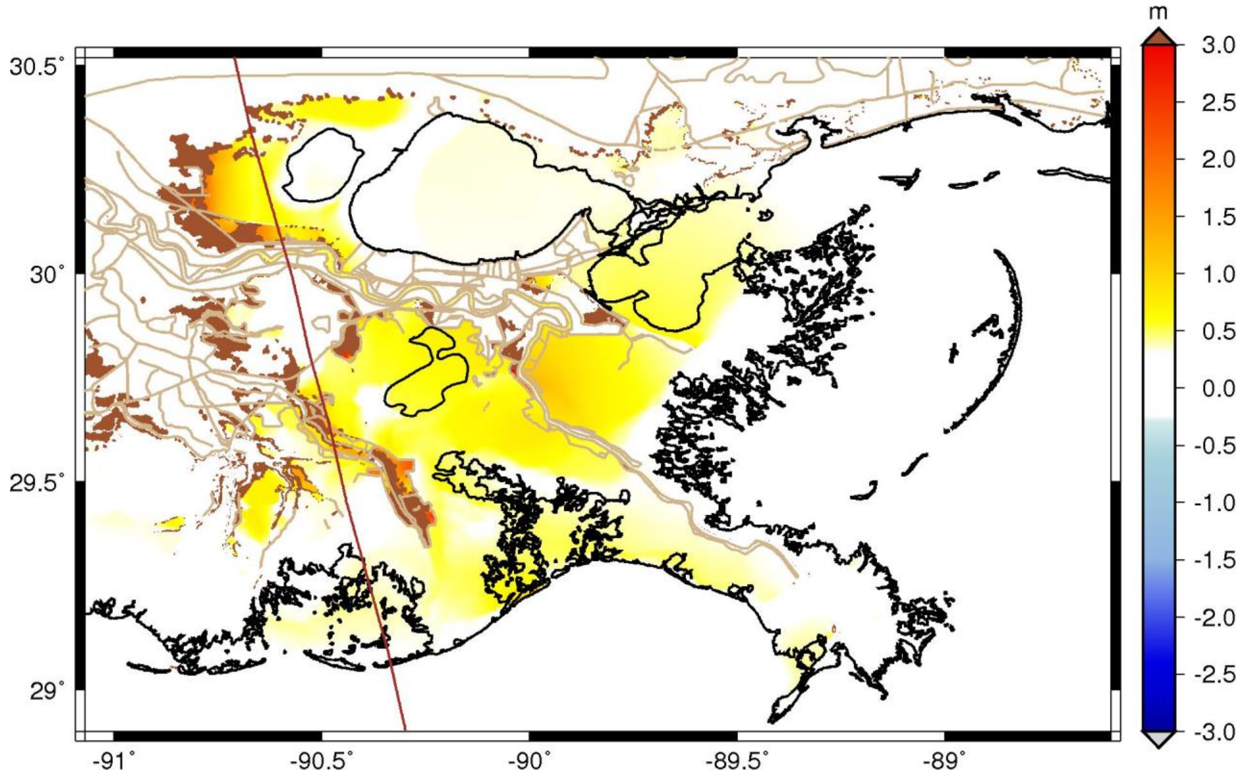


Figure 156: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 25 of the Medium Scenario.

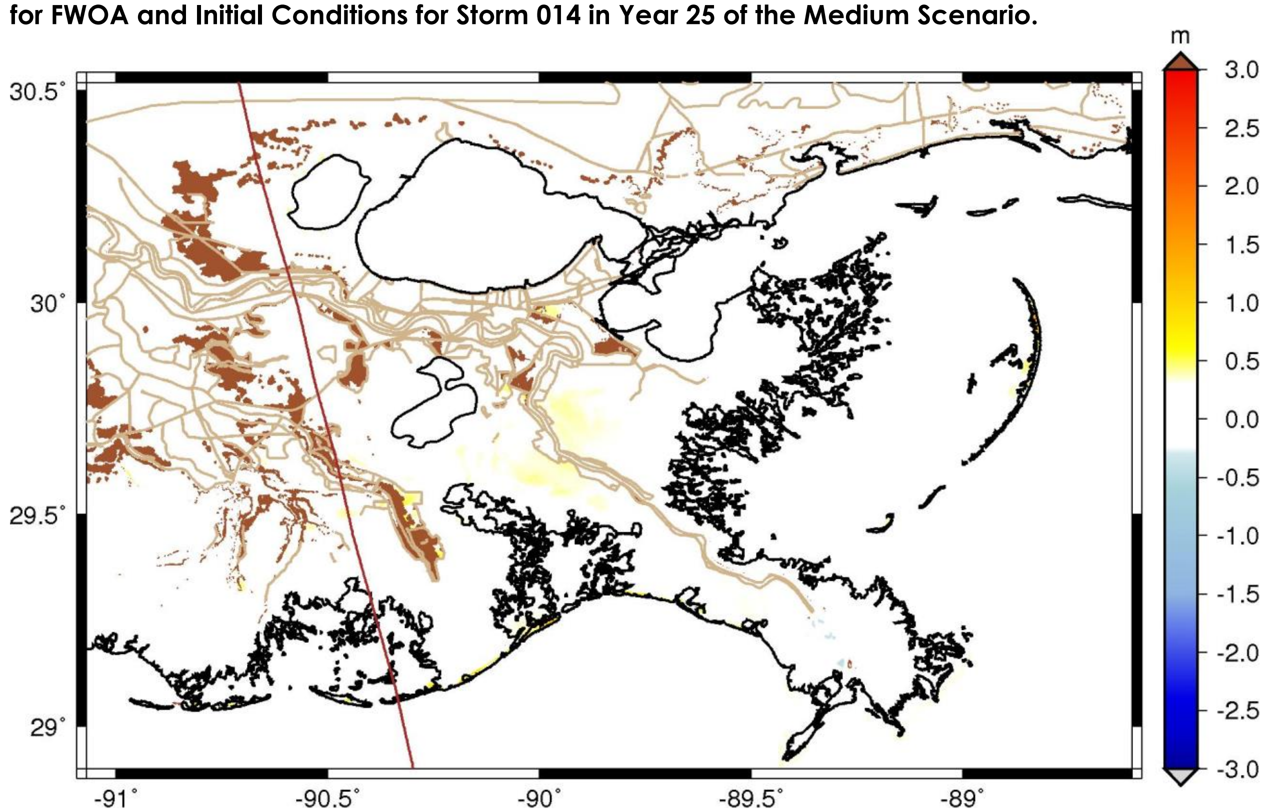


Figure 157: Differences Between Maximum Wave Height (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 25 of the Medium Scenario.

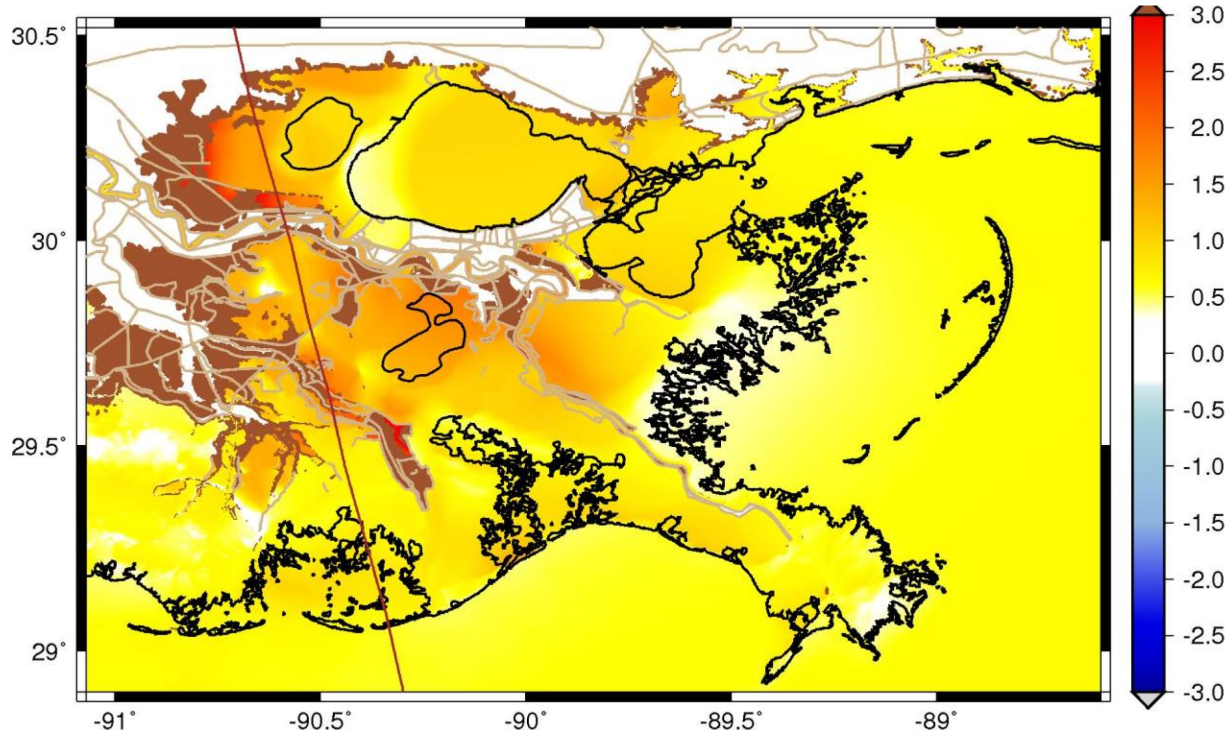


Figure 158: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 50 of the Medium Scenario.

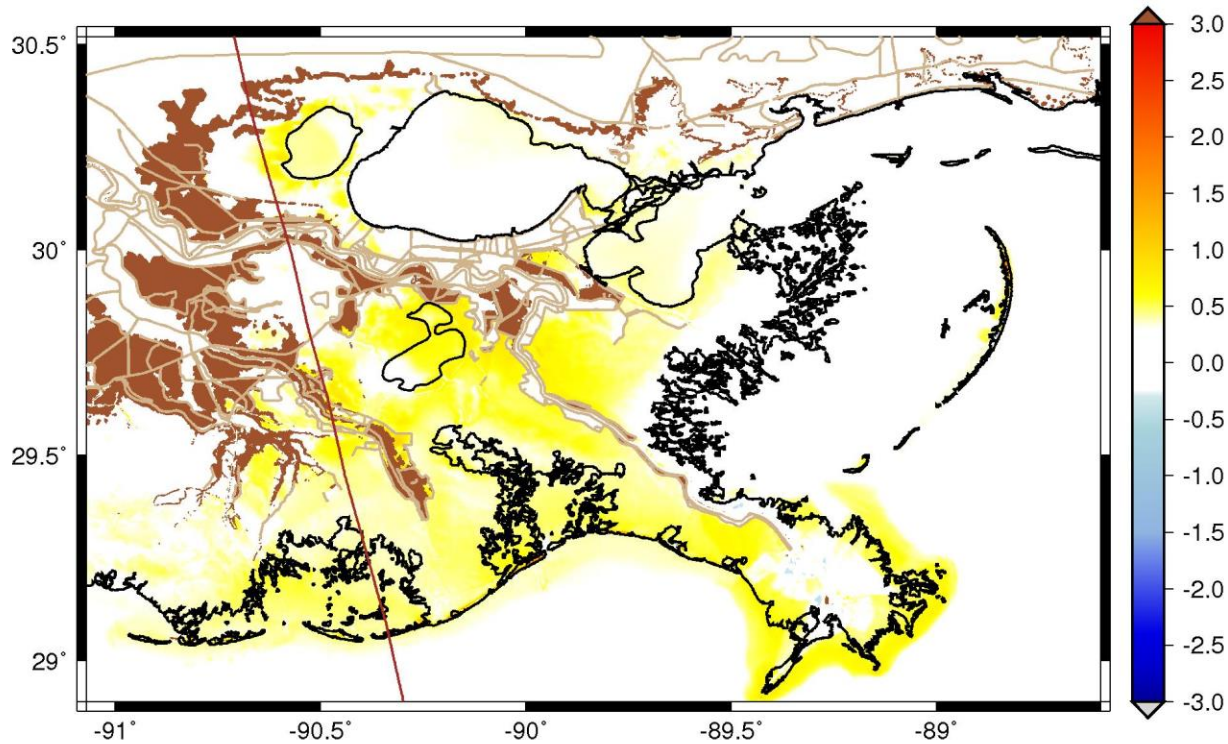


Figure 159: Differences Between Maximum Wave Height (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 50 of the Medium Scenario.

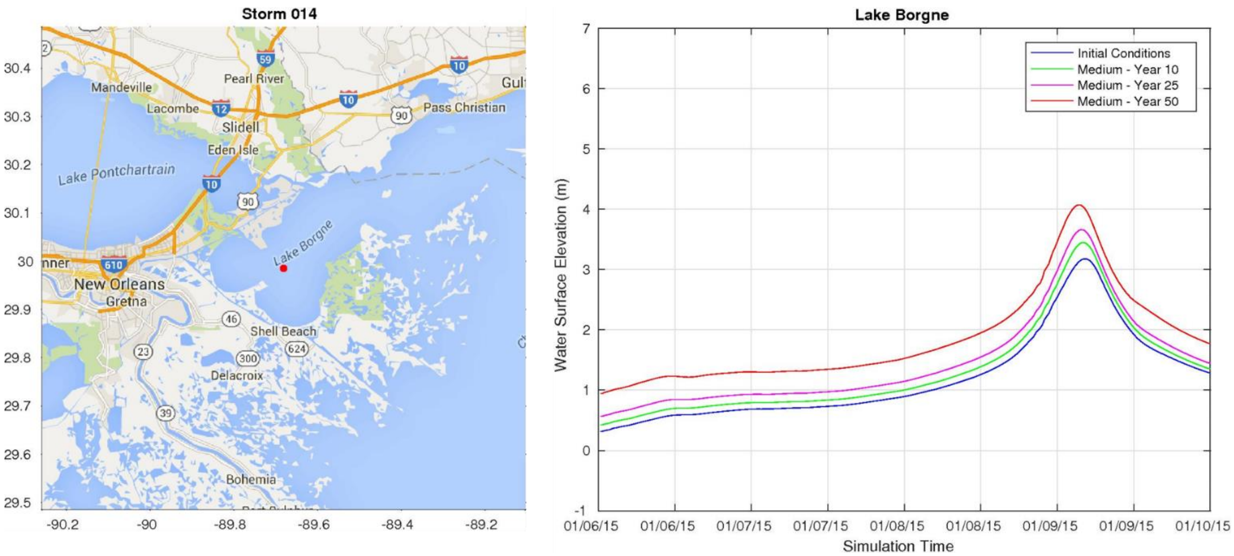


Figure 160: Surge Elevation (meters, NAVD88 2009.55) Time Series for Storm 014 in Lake Borgne for the Medium Scenario.

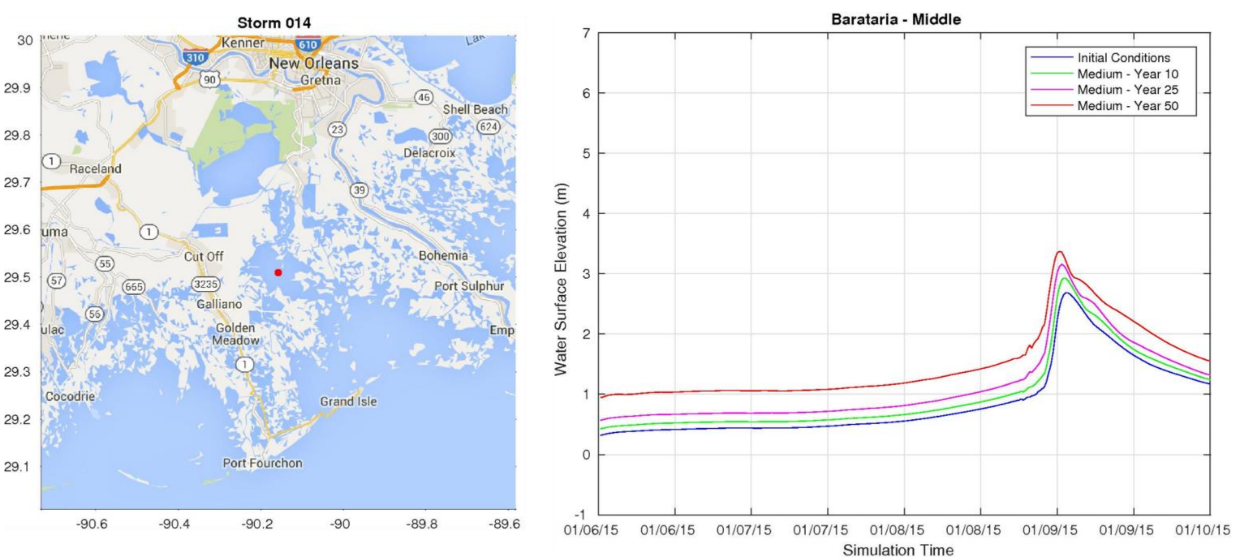


Figure 161: Surge Elevation (meters, NAVD88 2009.55) Time Series for Storm 014 in Barataria Bay for the Medium Scenario.

3.8.3 High Scenario

The high scenario shows the greatest increase in surge elevations due to the combination of the highest sea level rise rate, largest regional subsidence, and fewest remaining wetlands and other vegetated communities as defined by the ICM. Table 11 shows sea level rise values and model initial water levels used for each of the simulation years. Figures 162 through 167 show the changes in maximum surge elevations and wave heights with respect to the initial conditions simulations, and Figures 168 and 169 show the time series of surge elevations for Storm 014.

Table 11: Initial Water Levels and Sea Level Rise Values for the High Scenario.

High scenario		
Year	**Sea level rise (meters)**	**Initial water level (meters, NAVD88 2009.55)**
10	0.11	0.42
25	0.32	0.64
50	0.83	1.14

Inundation extents during year 10 are most significantly different from initial conditions in the Chenier Plain because of the low-lying, relatively flat topography. Areas of nonlinear surge elevation change are most prevalent in this scenario, and the extents of these nonlinear changes cover the greatest area.

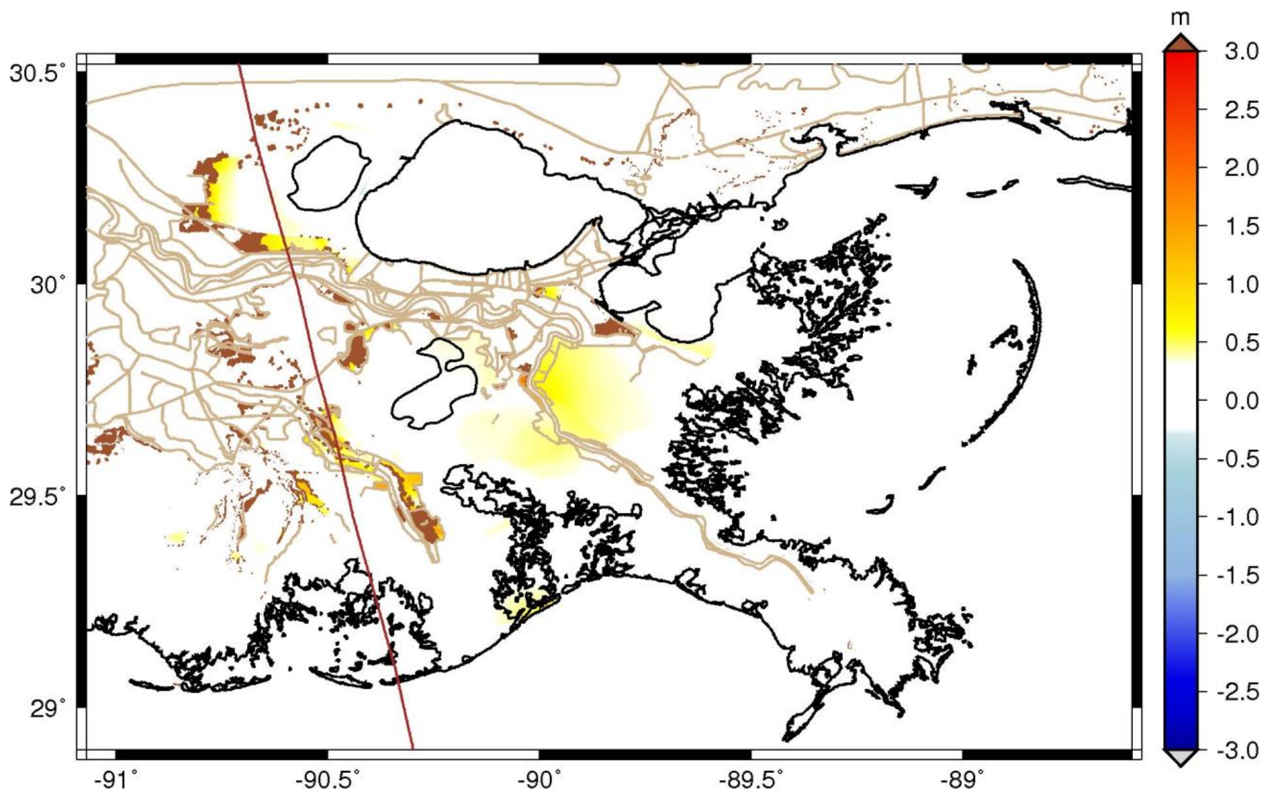


Figure 162: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 10 of the High Scenario.

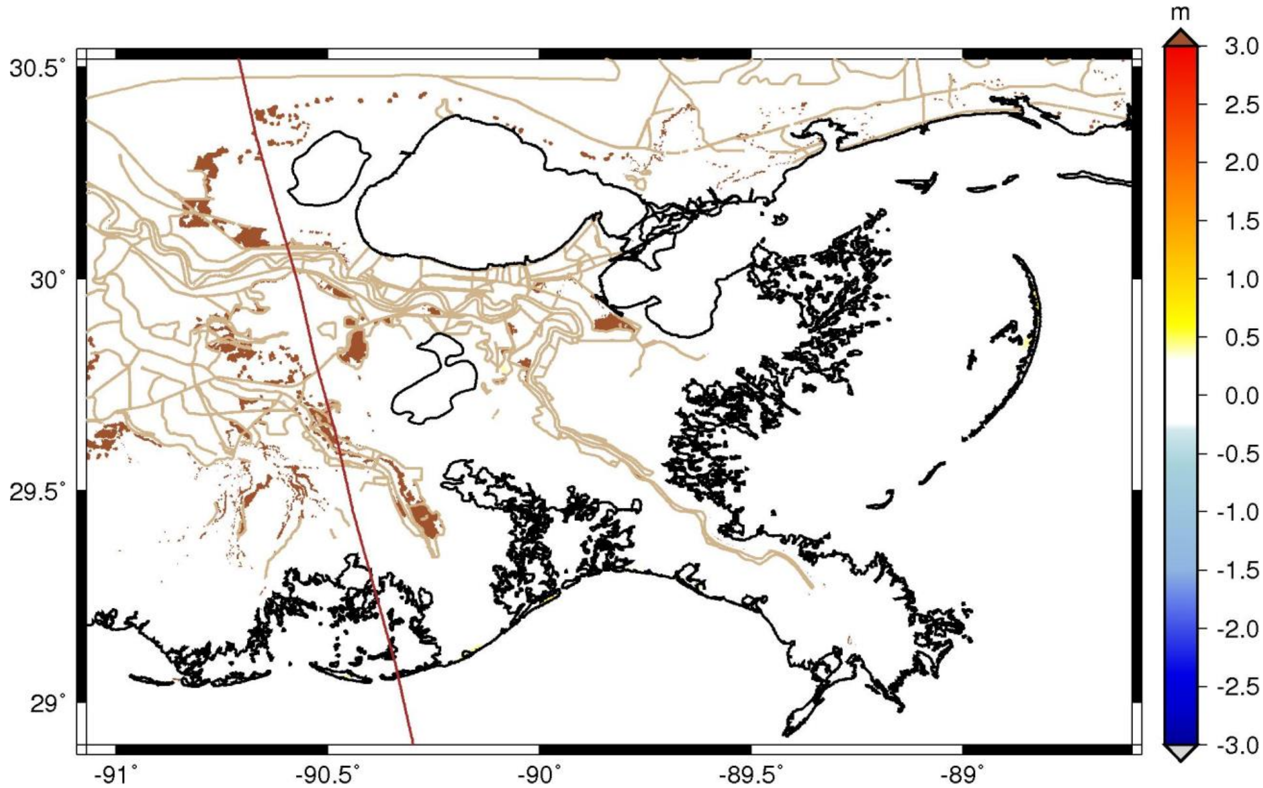


Figure 163: Differences Between Maximum Wave Height (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 10 of the High Scenario.

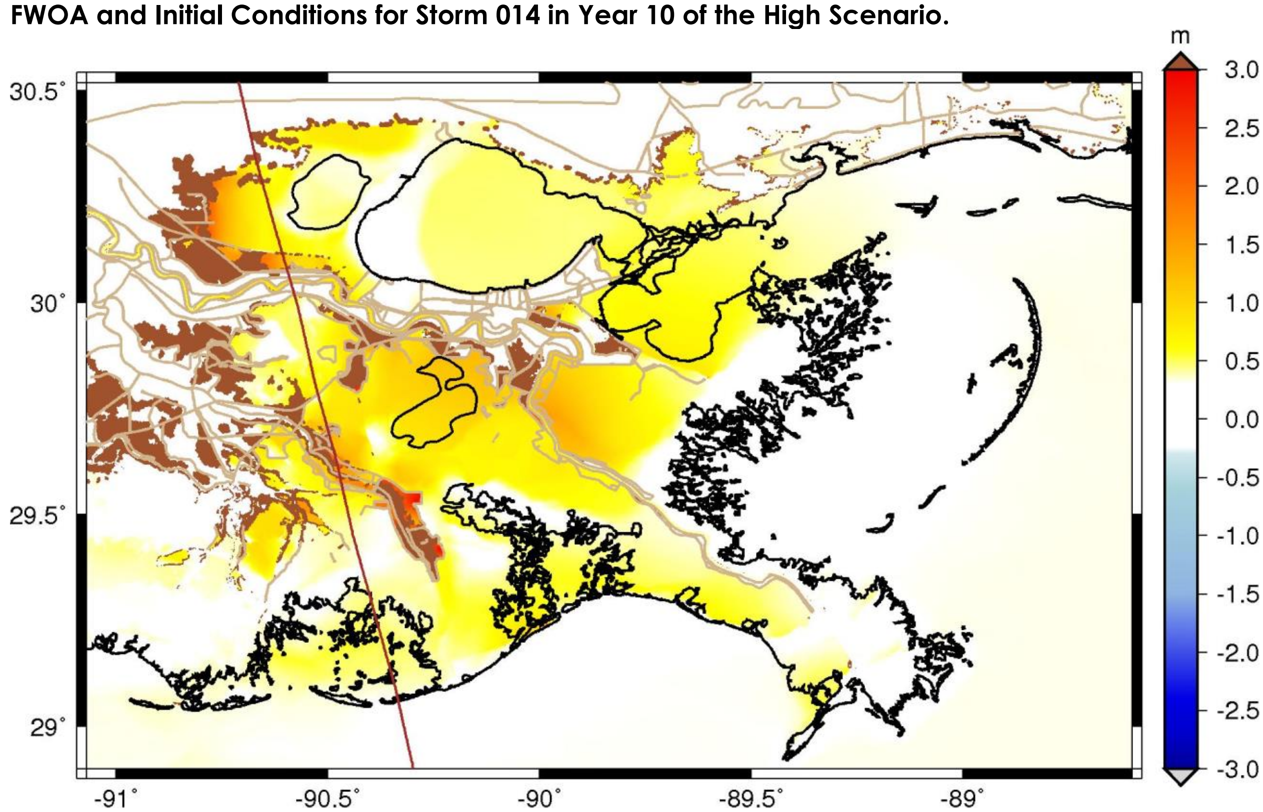


Figure 164: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 25 of the High Scenario.

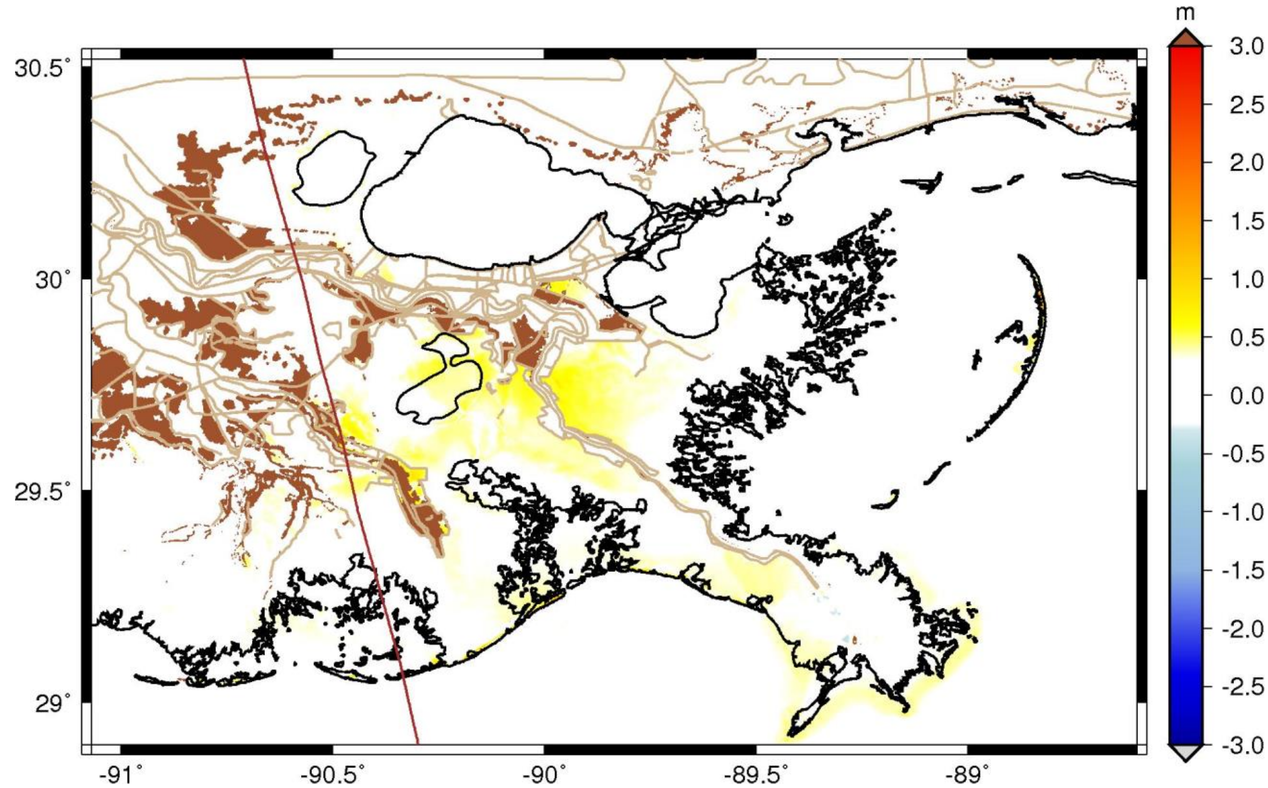


Figure 165: Differences Between Maximum Wave Height (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 25 of the High Scenario.

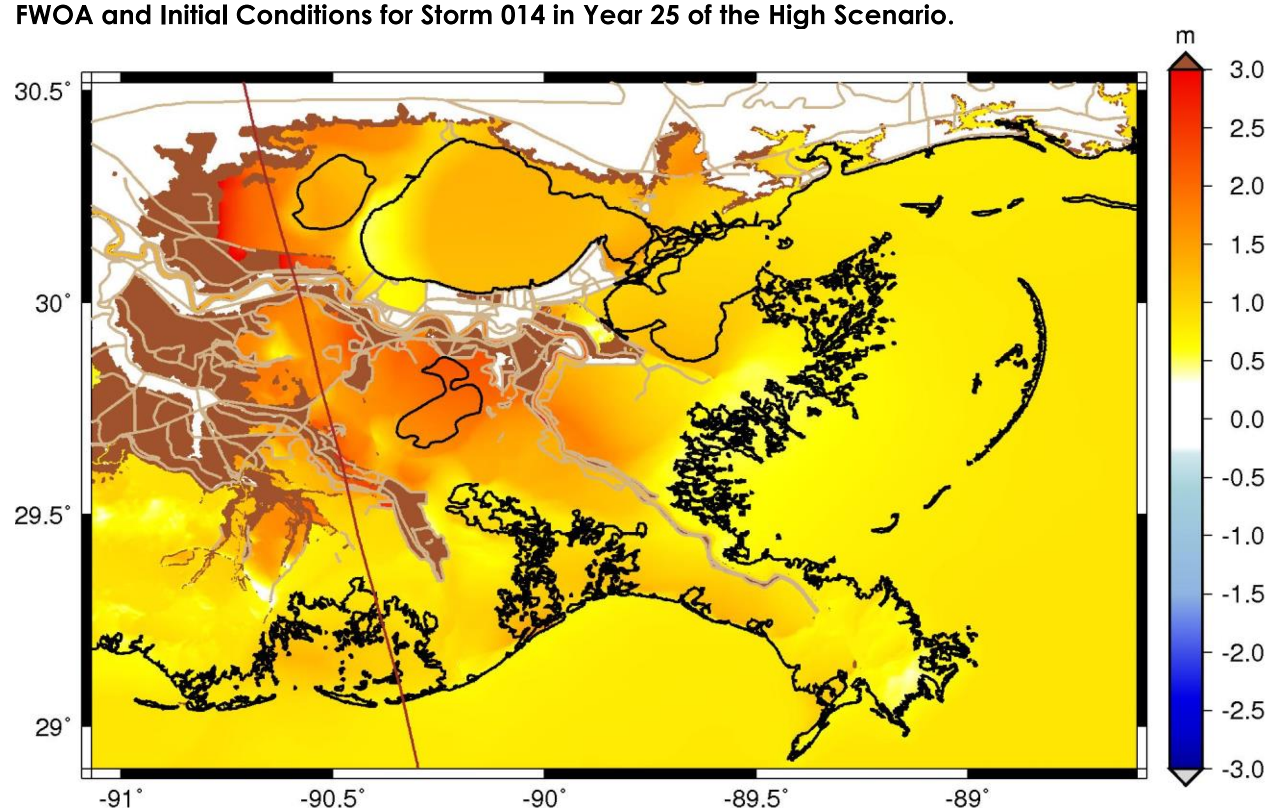


Figure 166: Differences Between Maximum Surge Elevations (meters) in Southeastern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 50 of the High Scenario.

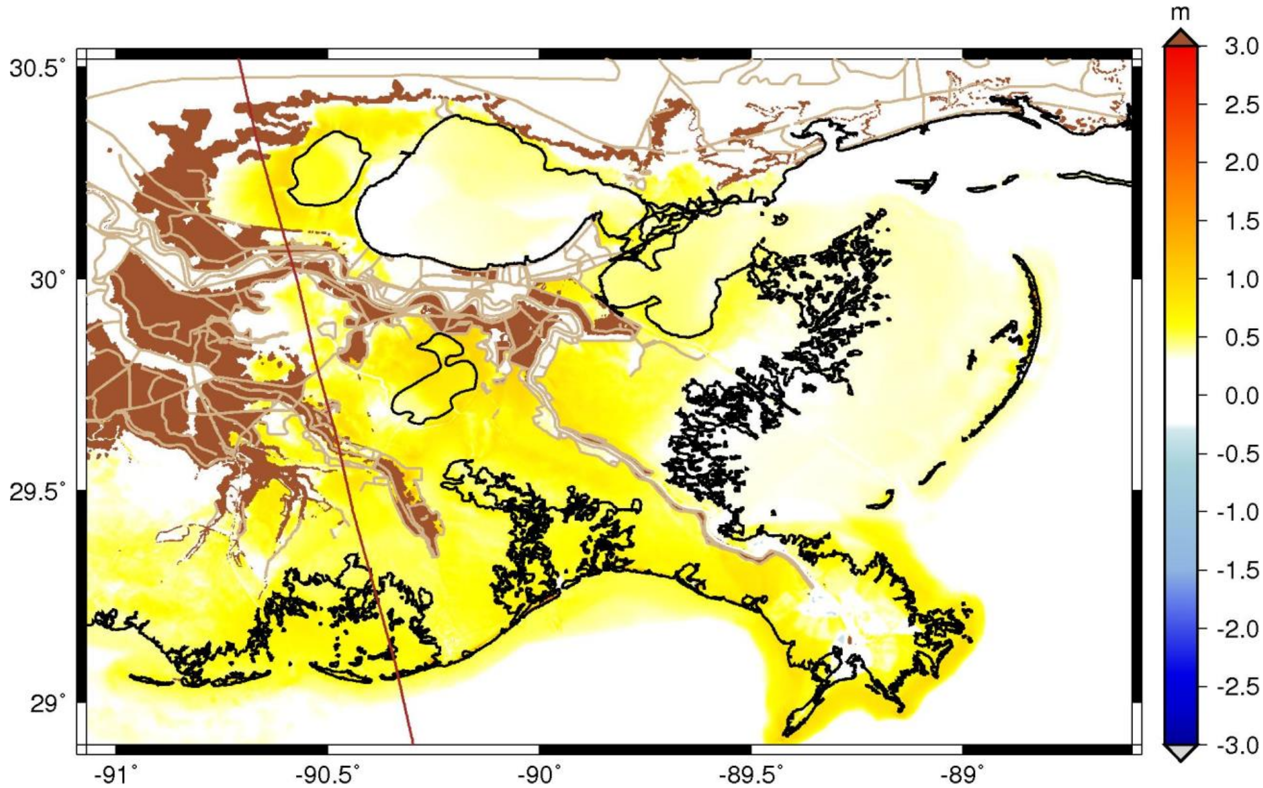


Figure 167: Differences Between Maximum Surge Elevations (meters) in Southwestern Louisiana for FWOA and Initial Conditions for Storm 014 in Year 50 of the High Scenario.

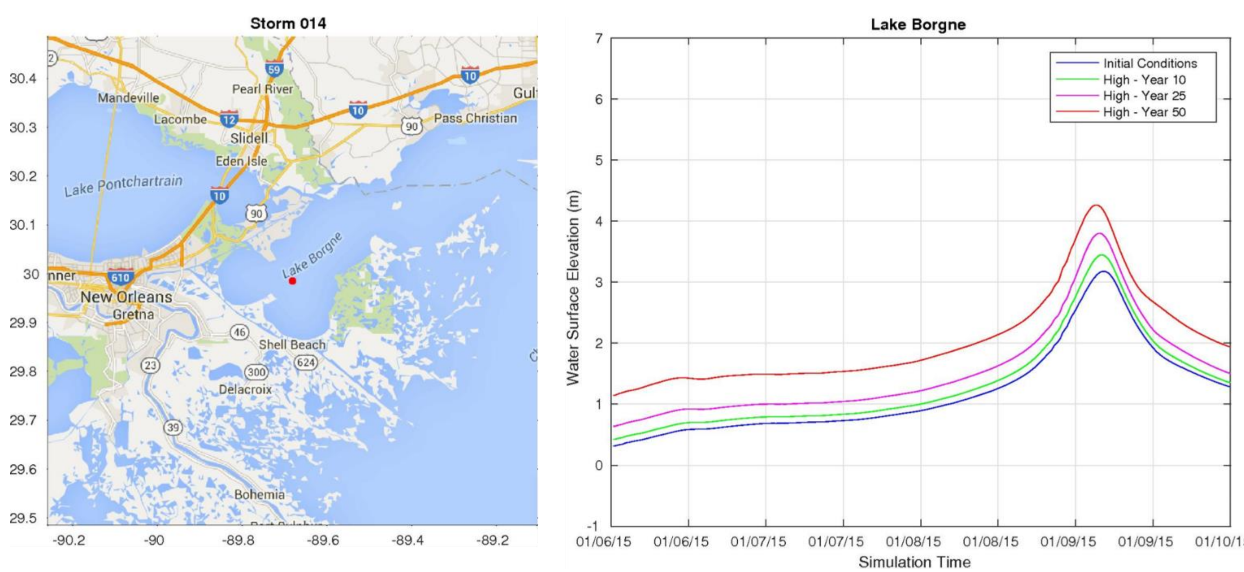


Figure 168: Surge Elevation (meters, NAVD88 2009.55) Time Series for Storm 014 in Lake Borgne for the High Scenario.

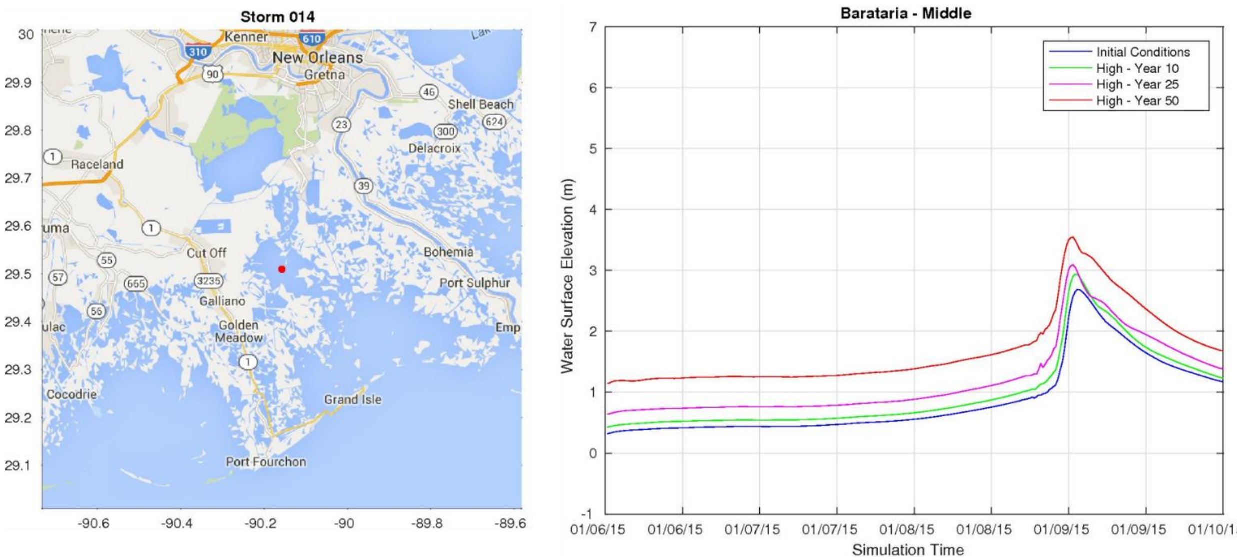


Figure 169: Surge Elevation (meters, NAVD88 2009.55) Time Series for Storm 014 in Barataria Bay for the High Scenario.

3.8.4 Cross-Scenario Comparisons

Figures 170 through 172 show how surge increases during each scenario within the Chenier Plain. Surge elevations are consistently greater than the sea level rise increment in areas inland from the coast for all scenarios and years. The increased surge elevations are due to the combination of sea level rise, subsidence of coastal features, and decreased friction across the Chenier Plain.

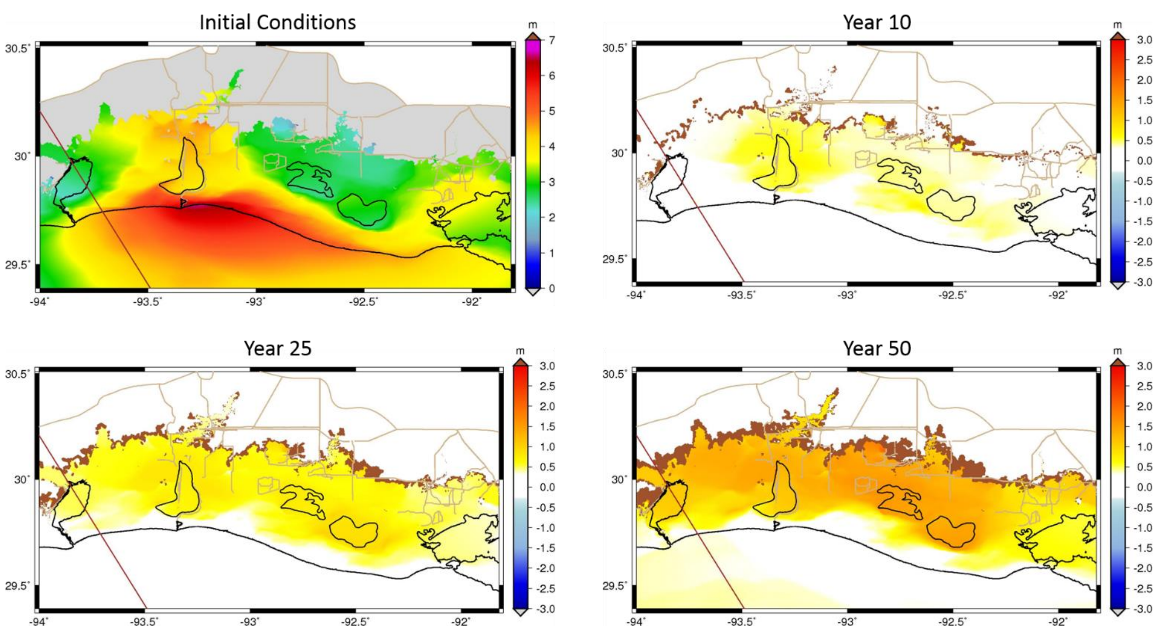


Figure 170: Differences Between Maximum Surge Elevations (meters) in Southwestern Louisiana for FWOA and Initial Conditions for Storm 218 of the Low Scenario.

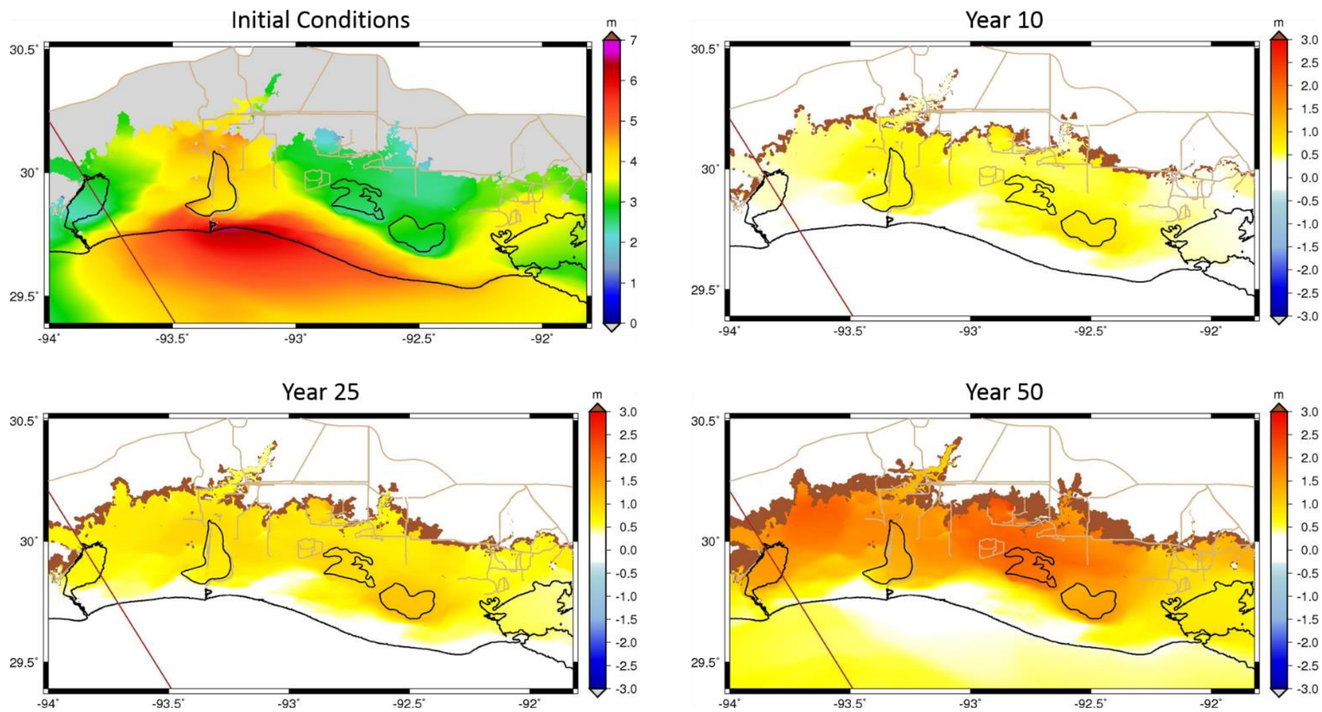


Figure 171: Differences Between Maximum Surge Elevations (meters) in Southwestern Louisiana for FWOA and Initial Conditions for Storm 218 of the Medium Scenario.

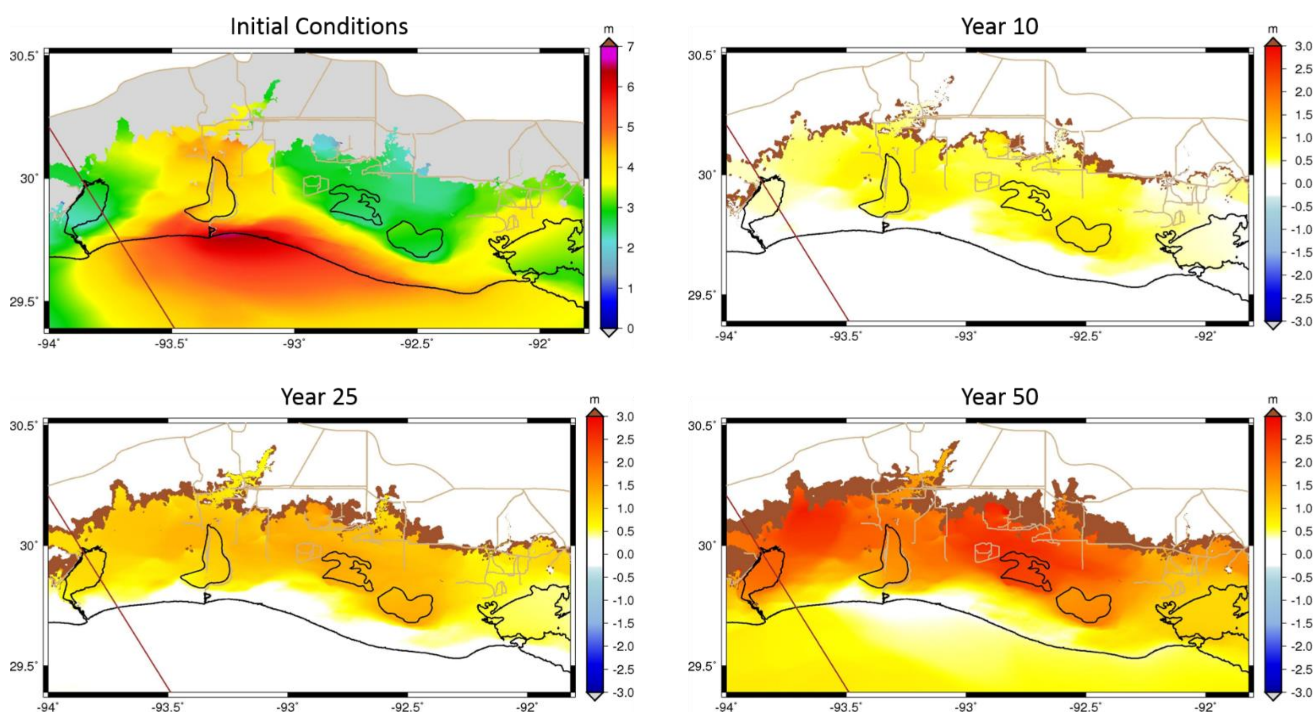


Figure 172: Differences Between Maximum Surge Elevations (meters) in Southwestern Louisiana for FWOA and Initial Conditions for Storm 218 of the High Scenario.

The outcomes of each scenario are most easily visualized at the year 50 interval given the largest relative sea level rise values and greatest landscape and vegetation change. Inspection of figures in the previous sections highlights notable changes to coastal flood hazards across coastal Louisiana. Some areas like the Chenier Plain, north of Barataria and Terrebonne Bays, and west of Lake Maurepas show consistently significant changes under future scenarios. The changes for each area for a given year and scenario vary due to the location along the coast, adjacent flood protection features or other raised features (e.g., highways), and changes in the landscape defined by the ICM.

To highlight the process for evaluating changes across scenarios, the region west of Lake Maurepas near Gonzales, Louisiana, has been selected. This area consistently demonstrates changes in inundation area and surge elevation through all scenarios. Figure 173 shows how the time series of surge elevation differs during year 50 for each scenario within Lake Maurepas, and Figure 174 shows the change in maximum surge elevation for the same simulations. Upon examination, there are two contributing factors. First, is the local topography and raised features. Interstate 55, between Lake Pontchartrain and Lake Maurepas, lies adjacent to Highway Old US 51 and a railroad. While Interstate 55 is elevated, Old US 51 and the railroad are not. This Old US 51 and the railroad are assumed to subside nearly 0.15 meters over the course of 50 years due to regional subsidence. This subsidence, combined with sea level rise, allows more storm surge to cross between Lake Pontchartrain and Lake Maurepas. This is illustrated in Figure 174 as lower magnitude differences on the western shore of Lake Pontchartrain leading to Lake Maurepas, as water can easily cross between the lakes where previously it built up against Old US 51.

Second, a significant frictional change is expected in future conditions as forested areas are degraded over time. Similar to the change due to Old US 51, Figure 174 shows lower magnitude differences on the western shore of Lake Maurepas, where previously frictional resistance caused surge to build up. Figures 175 and 176 show how the model frictional inputs change for future conditions compared to the initial conditions. First, Manning's roughness decreases, reducing bottom friction which had previously slowed the storm surge. Additionally, directional roughness lengths are also decreased, resulting in higher winds speeds interacting with the water column in future years. Figure 176 shows nearly a 40% reduction in directional roughness lengths in the direction of Gonzales, which equates to a 40% increase in the wind speed applied to the water column due to the decrease in shielding provided by the forested area. These landscape changes combine for a significant impact on surge elevations that is larger than the sea level rise increment, particularly when the hurricane winds blow from east to west.

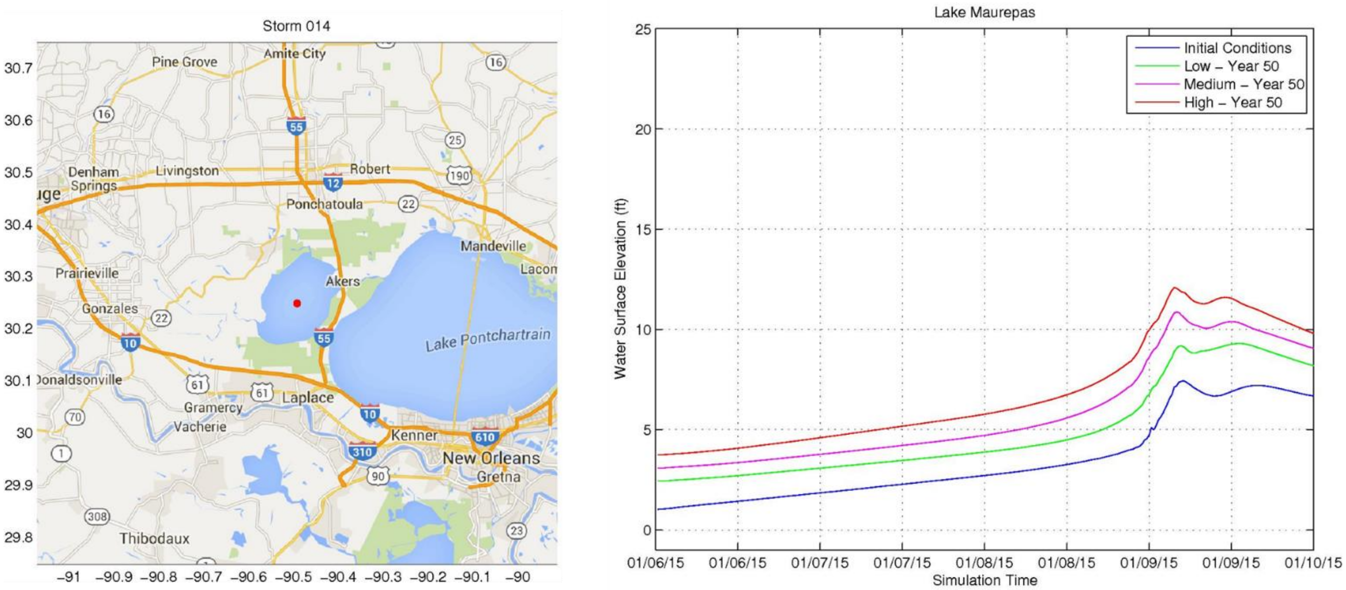


Figure 173: Surge Elevation (meters, NAVD88 2009.55) Time Series for Storm 014 near Lake Maurepas during Year 50 for All Scenarios.

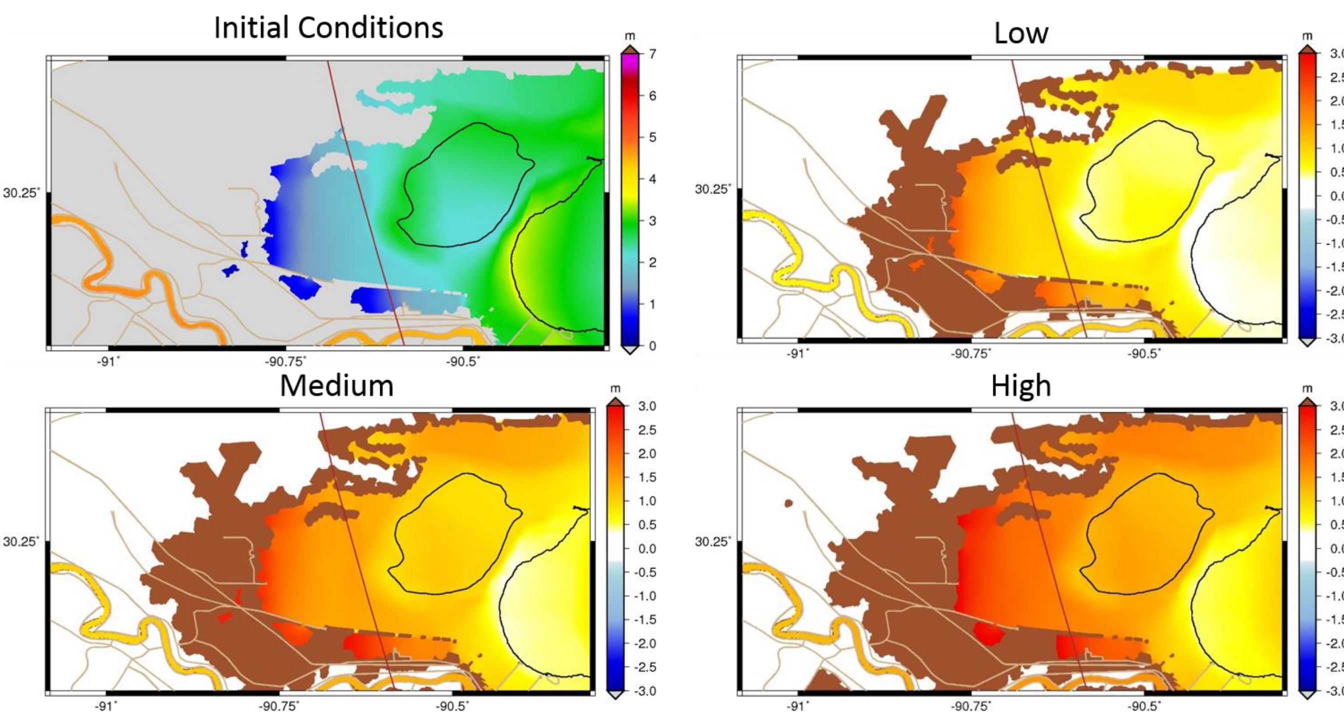


Figure 174: Differences Between Maximum Surge Elevations (meters) near Lake Maurepas for FWOA and Initial Conditions for Storm 014 during Year 50 for All Scenarios.

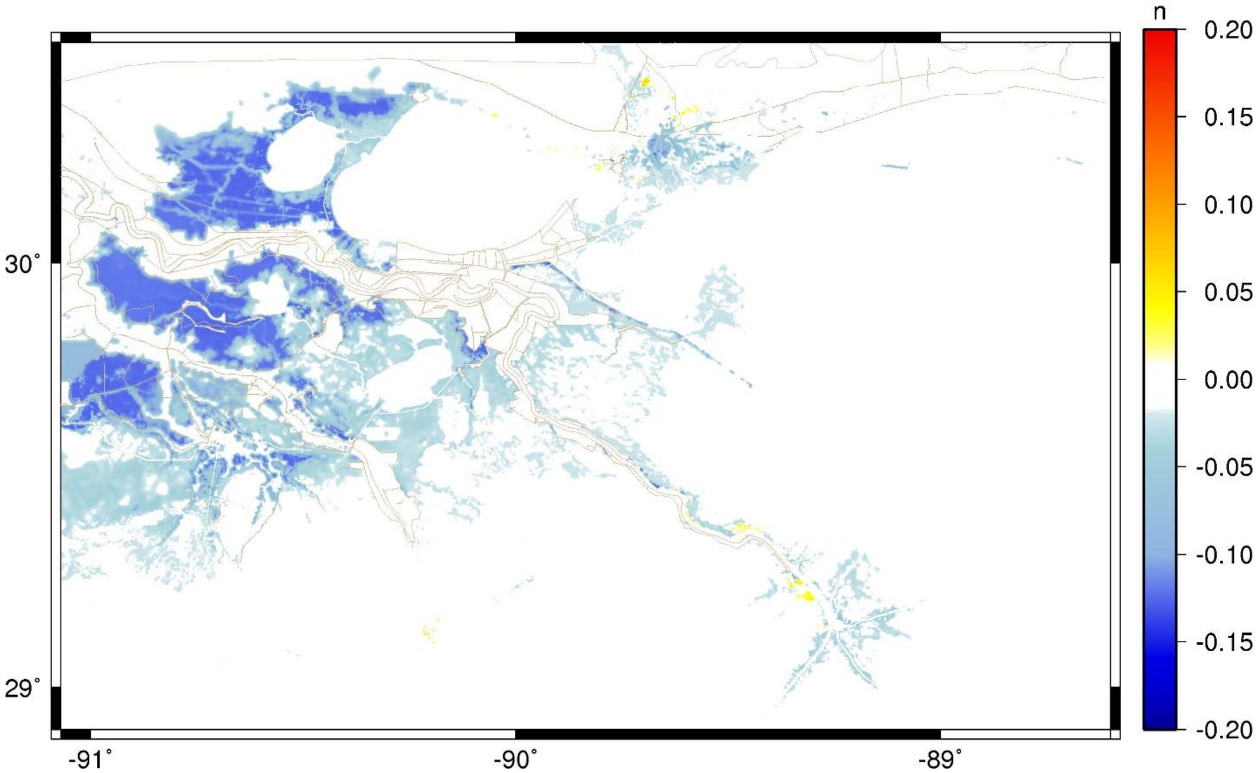


Figure 175: Change in Manning's n Roughness between the Initial Conditions and the High Scenario in Year 50. Cool colors indicate a decrease in Manning's *n* in the high scenario year 50, while warm colors indicate an increase in Manning's *n*.

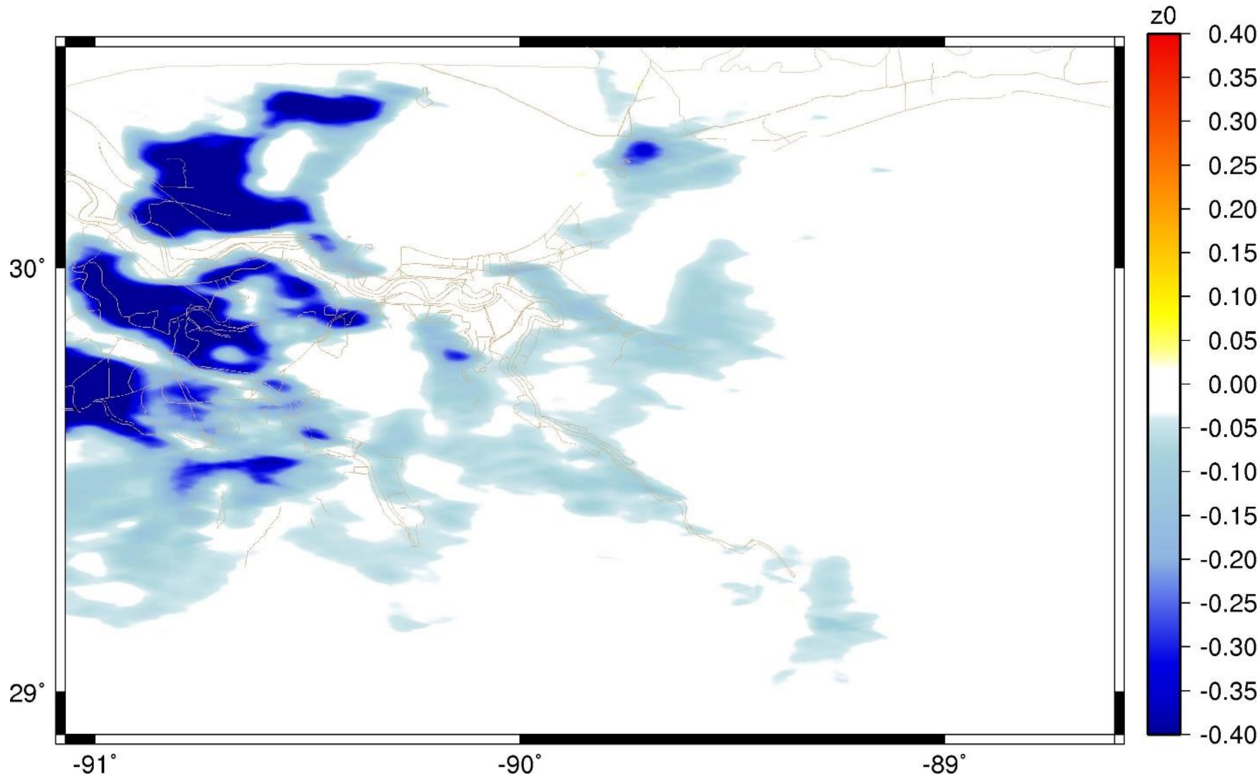


Figure 176: Change in Directional Roughness Length for an East to West Wind between the Initial Conditions and the High Scenario Year 50. Cool colors indicate a decrease in directional roughness length in the high scenario year 50, while warm colors indicate an increase in directional roughness length.

3.9 Flood Depths and Damage

The CLARA model was applied to estimate flood depths and damage under FWOA. Statistical estimates for FWOA presented here are based on a 60-storm sample consistent with the set of storms used to evaluate individual hurricane protection projects (Attachment C3-25, Sec. 6.5). FWOA flood depth and damage results were separately estimated for the same three fragility scenarios described in Section 2.2. In addition, simulations were conducted for the low, medium, and high environmental scenarios used commonly in all systems models in the 2017 Coastal Master Plan analysis (Appendix C – Chapter 2). Key inputs to the CLARA model that vary by environmental scenario include sea level rise, localized subsidence, overall storm frequency, and average storm intensity.

The CLARA model analysis also considers different assumptions about population and asset growth across the Louisiana coast over the 50-year study period, summarized in three population growth scenarios. Scenarios were developed by first separating CLARA model grid points in the coastal region into low, medium, and high growth areas (or "bins") based on an index of population density, 100-year flood depths faced in FWOA, and future land loss rate. The approach assumes that lower population density or higher flood and land loss risk would correlate to lower growth rates. These bins are reassigned dynamically and updated throughout the simulation, so that areas facing greater risks from land loss or flooding tend to shift to lower growth bins in future years.

Using this approach, three scenarios were developed building from current population counts and varying two parameters: 1) an assumed coast wide growth rate, and 2) a parameter specifying the plausible difference in the growth rates between low, medium, and high growth bins as compared to medium growth areas. Parameter values were selected and tuned based on historical U.S. Census data. The FWOA population growth scenarios evaluated include:

1. **No growth**: 0.00% per year growth rate, 1.0 % separation between bins;
2. **Concentrated growth**: 0.67% per year growth rate, 1.5% separation between bins; and
3. **Historic growth**: 0.67% per year growth rate, 1.0% separation between bins.

For further information on population growth scenario development, please see Attachment C3-25, Sec. 9.

FWOA scenario results were developed for the combination of three environmental, three fragility, and three population growth scenarios described above, for a total of 27 separate scenarios. These were also evaluated in three future time periods – year 10, year 25, and year 50 – yielding a total of 81 scenario/year combinations (cases). Selected results from this experimental design are described in the remainder of this section.

Flood depth results at the 100-year AEP interval at years 10, 25, and 50 are shown in Figure 177 and Figure 178 for the low and high environmental scenarios, respectively (IPET fragility scenario). In addition, Figure 179 shows the change in flood depths from initial conditions to the future year for all three environmental scenarios. In general, flood depths and 100-year flood extent in the low scenario increase steadily through the simulation period, with smaller increases noted in years 10 and 25, typically less than 1 m, and an expanded flood extent and notably higher flood depths (1-2 m in many locations) by year 50. The high scenario begins with similar results in year 10, by contrast, but shows more dramatic increases over time. In year 50, 100-year flood depth increases are estimated at two or more meters higher than initial conditions for nearly all areas of the coast, including portions of the northern boundary not currently inundated at the 100-year interval.

Enclosed protected system fragility scenario assumptions most notably affect the Greater New Orleans Hurricane and Storm Damage Risk Reduction System (HSDRRS) on the east and west banks of the Mississippi River. The 2017 Coastal Master Plan analysis assumes that the HSDRRS system will be maintained and upgraded regularly over time, counteracting the effects of subsidence on the effective heights of protection structures and largely maintaining the system's 100-year target for flood risk reduction. Nevertheless, 500-year flood depths in HSDRRS are shown to increase from the No Fragility to the IPET and MTTG fragility scenarios, especially in the high environmental scenario (Figure 180). When comparing 500-year flooding results for year 10, 25, and 50 across the three fragility scenarios, substantial flood depths and flood extents are noted within HSDRRS in year 25 and 50 when including plausible assumptions about levee fragility.

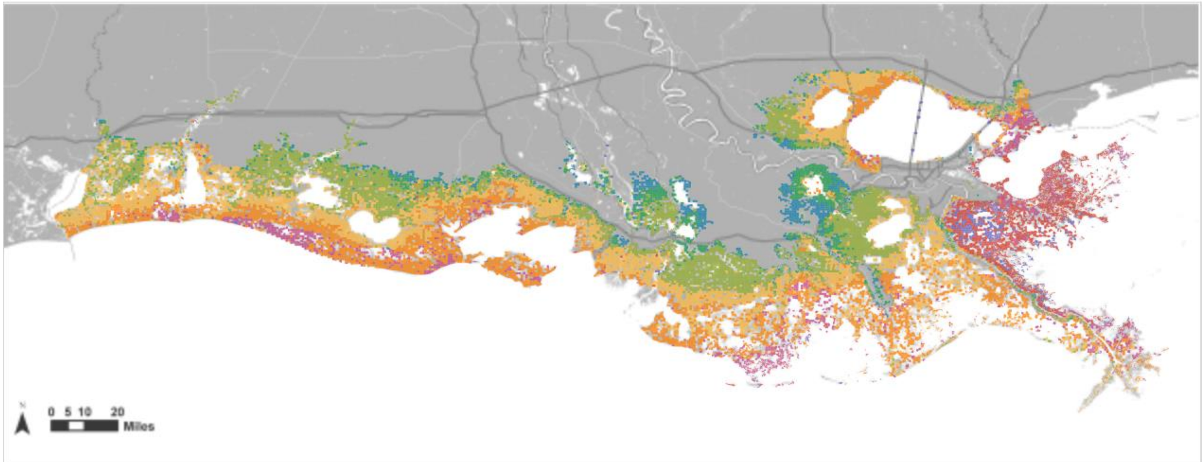
Coast wide FWOA damage (EAD) is shown in Figure 181 and Figure 182. Figure 181 shows coast wide EAD over time for each of the environmental and population growth scenarios, using the IPET fragility scenario. Figure 182, by contrast, holds the population growth scenario constant at "Historic Growth" and shows results for all environmental and fragility scenarios in years 10, 25, and 50. The error bars included in Figure 182 show the estimated 95% confidence interval for the damage estimates (see Attachment C3-25, Sec. 6.6).

Coast wide EAD results are similar across all scenarios in year 10, ranging from approximately $3-4 billion per year. In year 25, little variation is noted across the population growth scenarios (Figure 181), but the environmental scenario results begin to diverge. All FWOA scenarios show damage increasing, but greater damage increases are noted in the medium ($5.1-$5.6 billion) and high ($6.9-$7.9 billion) environmental scenarios in year 25 when compared with the low scenario, for instance (Figure 182).

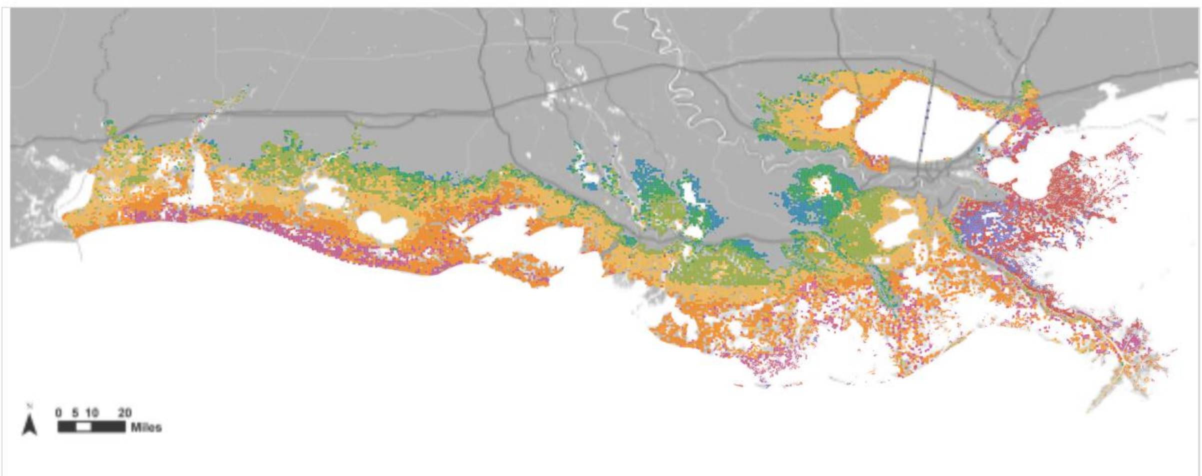
EAD results diverge substantially across scenarios by year 50 of the simulation, ranging from less than $5 billion (low environmental scenario, no fragility, no growth; not shown) to $22 billion (high environmental scenario, MTTG fragility, historic growth). Damage totals also vary notably across the population growth scenarios, especially in the medium and high environmental scenarios.

Spatial patterns of EAD across environmental scenario and year are shown in Figure 183. In the low scenario (top row), EAD increases occur largely in developed areas previously noted as high damage in the initial conditions estimate, also including east bank portions of Greater New Orleans. In the high scenario (bottom row), damage increase is more widespread, and a substantial fraction of risk regions show EAD totals greater than $100 million by year 50. In addition, in this scenario and year the Houma, Raceland, Hahnville/Luling, Laplace, Greater New Orleans-East Bank, and Slidell/St. Tammany Parish regions all show EAD totals in excess of $1 billion per year.

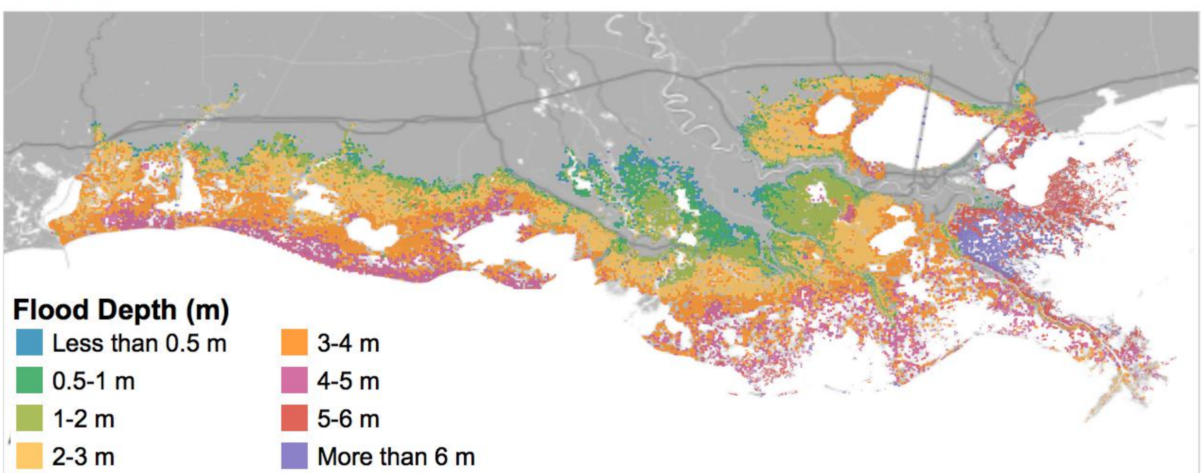
Year 10



Year 25



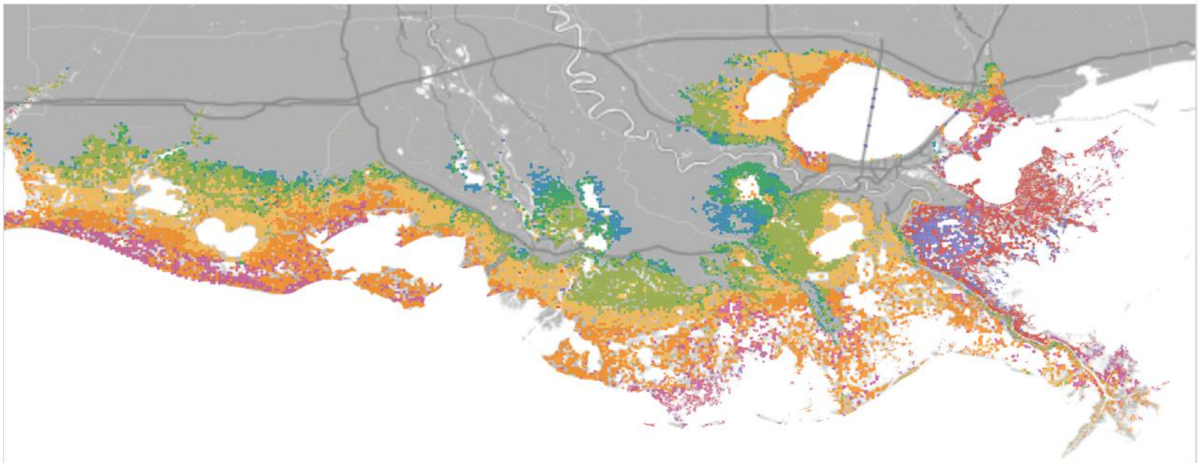
Year 50



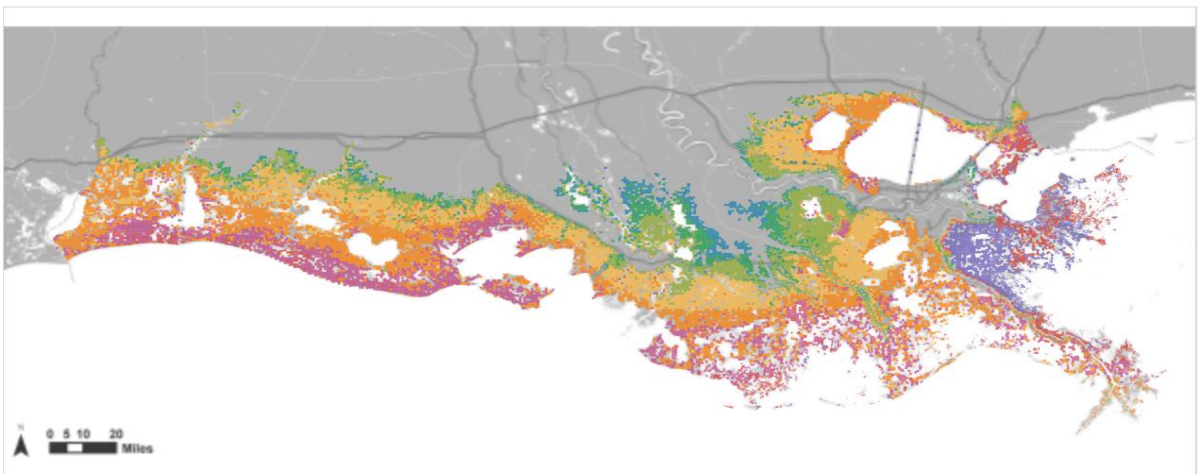
Note: 50th percentile 100-year flood depths of at least 0.2 m shown.

Figure 177: FWOA Low Scenario 100-Year Coast Wide Flood Depths – IPET Fragility Scenario.

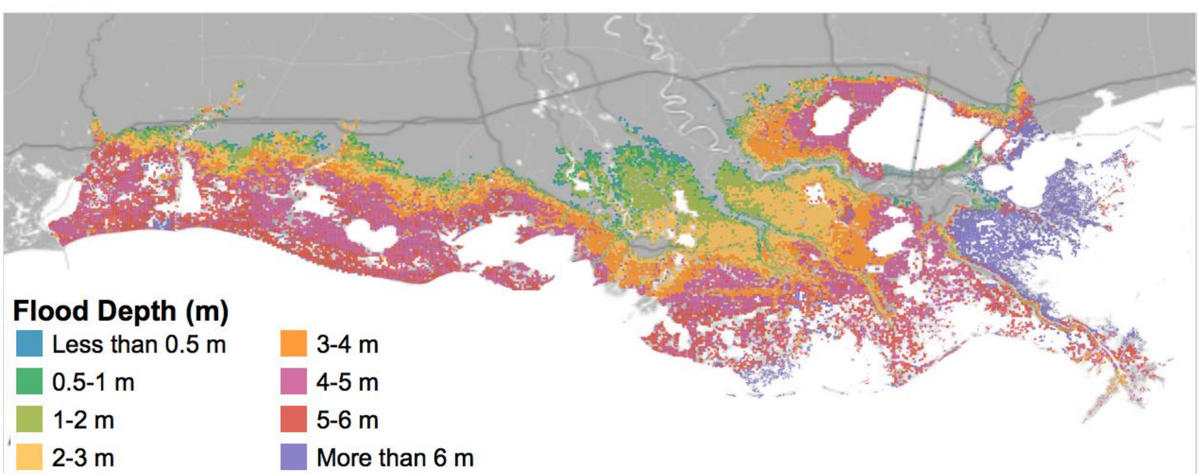
Year 10



Year 25

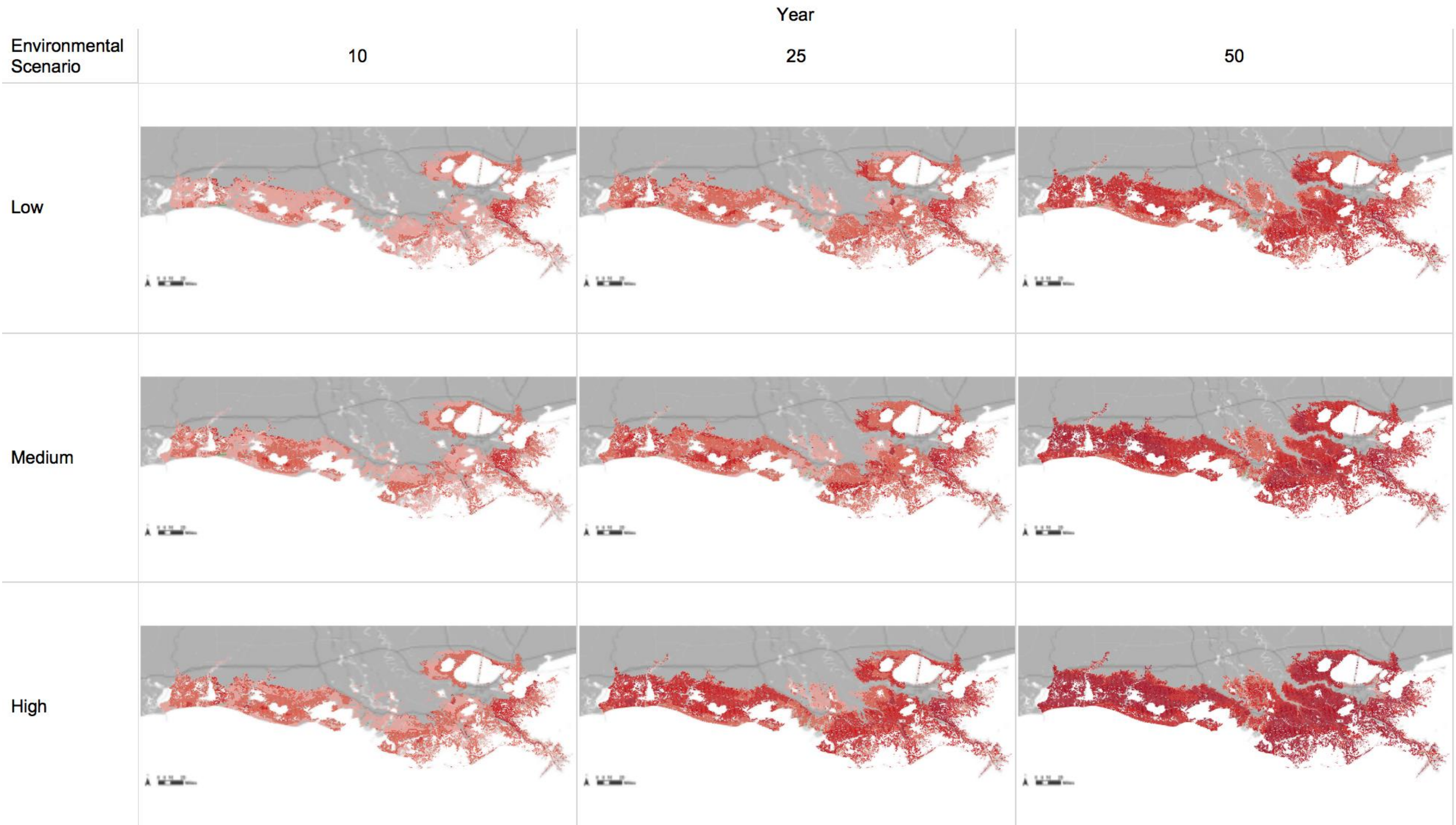


Year 50



Note: 50th percentile 100-year flood depths of at least 0.2 m shown.

Figure 178: FWOA High Scenario 100-Year Coast Wide Flood Depths – IPET Fragility Scenario.



Note: Change in 50th percentile 100-year flood depths from Initial Conditions to future year. Only grid points with an increase of at least 0.2 m are shown.

Change in Flood Depth (m)

More than -2 m | -1 to -2 m | -0.5 to -1 m | -0.2 to -0.5 m | 0.2 to 0.5 m | 0.5 to 1 m | 1 to 2 m | More than 2 m

Figure 179: Change in 100-Year Coast Wide Flood Depths by Environmental Scenario and Year – IPET Fragility Scenario.

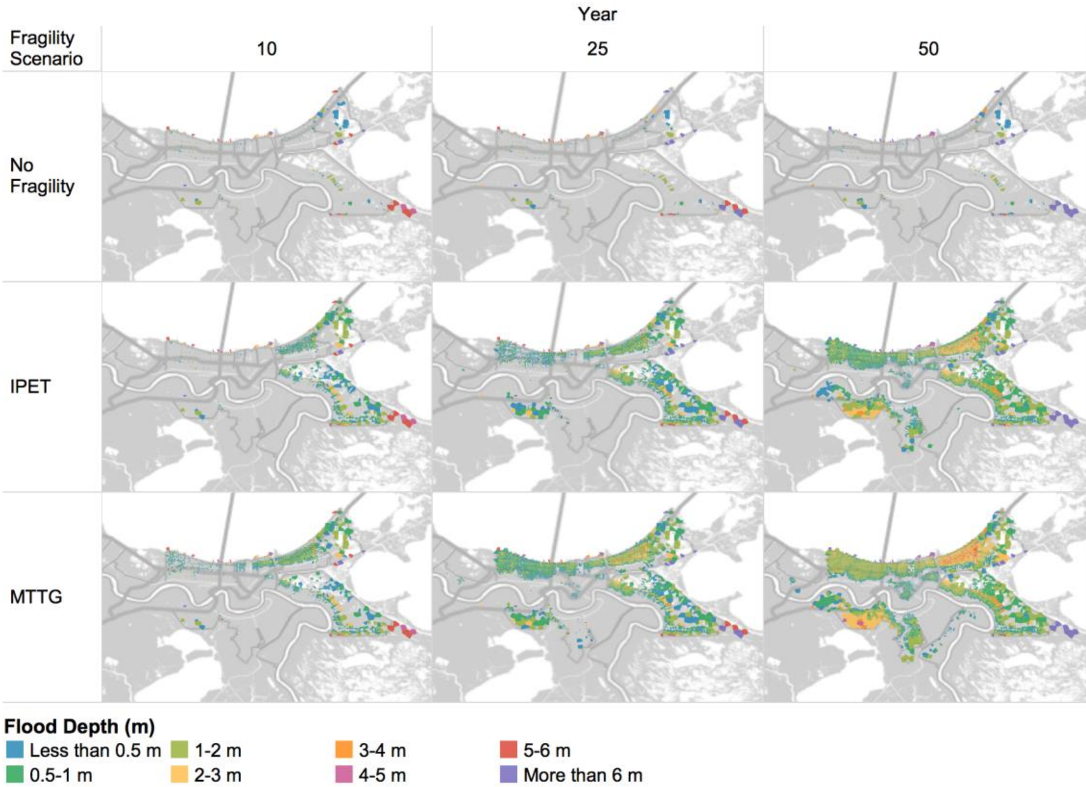


Figure 180: FWOA 500-Year Flood Depths, High Scenario - Greater New Orleans.

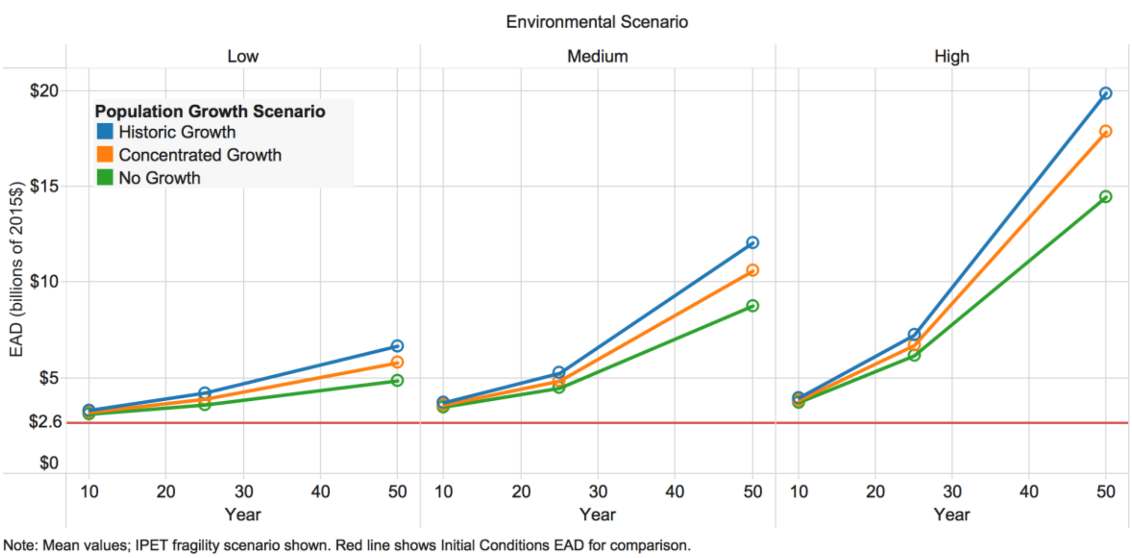
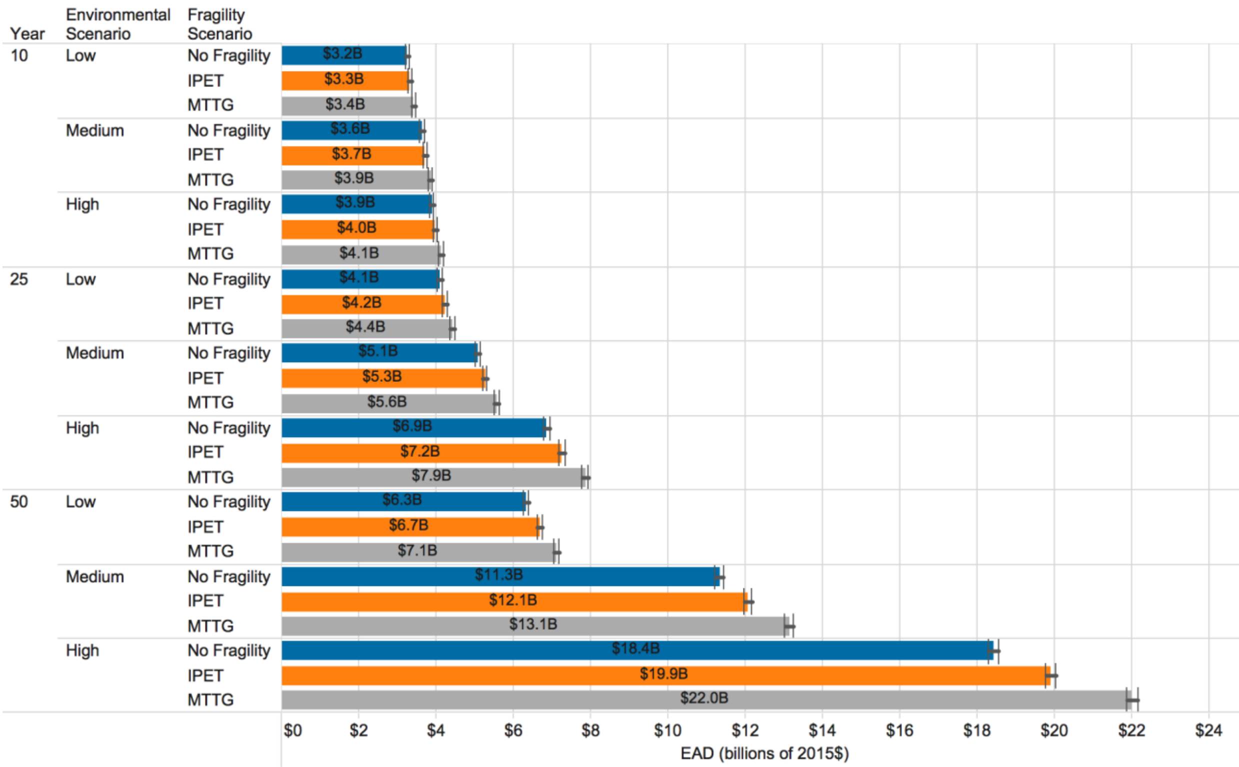
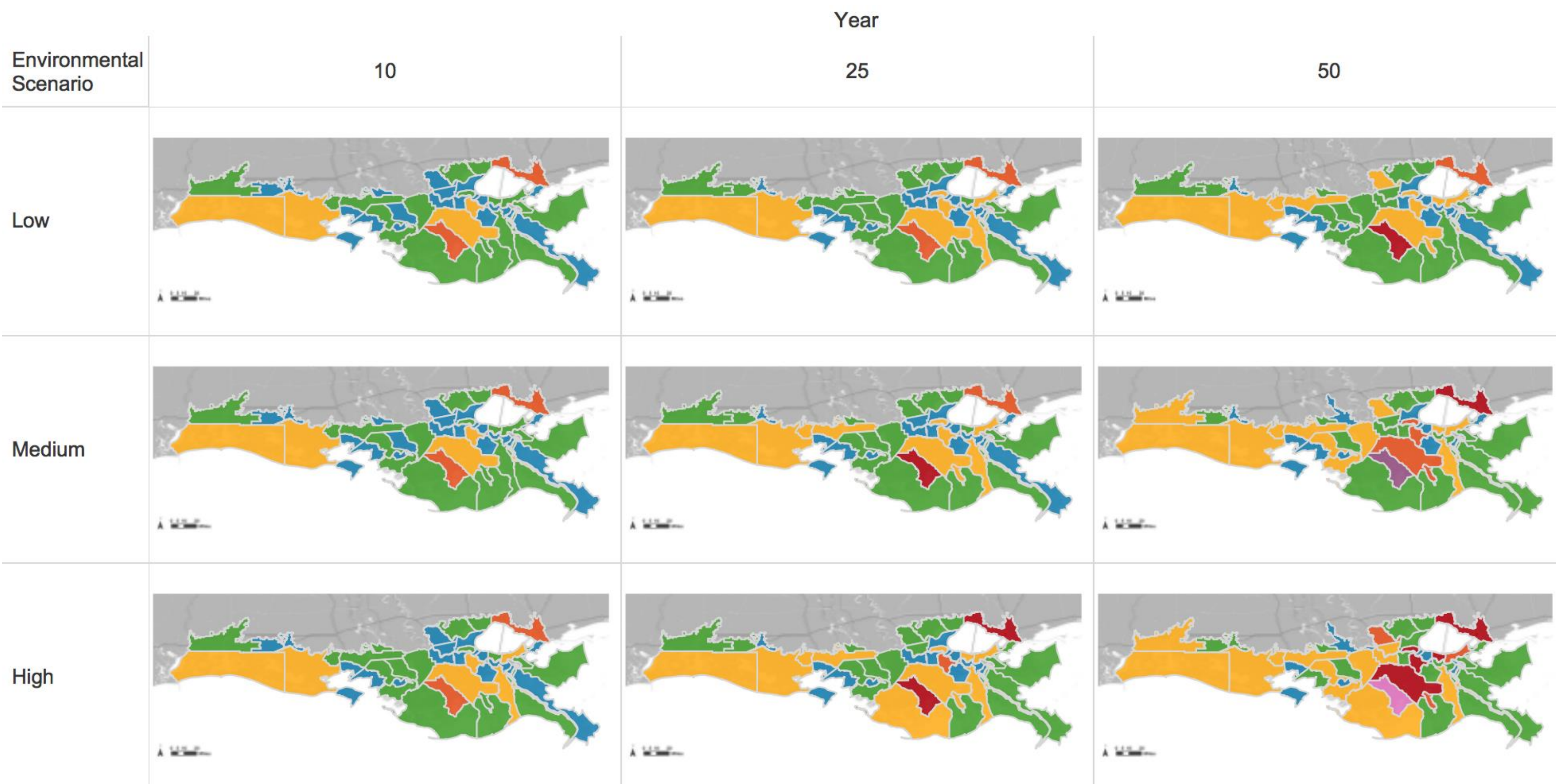


Figure 181: FWOA Coast Wide EAD Over Time by Environmental and Population Growth Scenario.



Note: Barplot shows mean values under the Historic Growth population growth scenario. The lines show 95 percent confidence intervals around the mean.

Figure 182: FWOA Coast Wide EAD Bar plot Summary by Year, Environmental, and Fragility Scenario.



Note: Results shown for the IPET fragility scenario and "Historical Growth" population scenario.

EAD (2015$)

< $10M | $10M - $100M | $100M - $500M | $500M - $1B | $1B - $2B | $2B - $4B | > $4B

Figure 183: FWOA Coast Wide EAD Map by Year and Environmental Scenario.

4.0 Project Outputs and Interpretations

The project-level analysis was completed to assess the restoration-specific effects of restoration projects and the protection-specific effects of risk reduction projects. The projects highlighted here have been selected to represent examples of the different types of restoration, structural and nonstructural risk reduction projects considered in the 2017 Coastal Master Plan. Project effects, even for the same type of project, will vary from one part of the coast to another and are dependent on local conditions. Thus, these descriptions should be considered illustrative of the nature of the effects that these types of projects could have over time. Each example project is considered individually and compared to FWOA conditions in the project area. Other effects (e.g., effects of restoration projects on risk reduction) are discussed in general terms in the Project Interactions section.

A set of metrics was also developed to reflect expected project outcomes not specifically addressed by outputs from existing models. The metrics utilize outputs from the ICM and CLARA models at varying temporal frequencies and spatial scales to assess the following: Sustainability of Land, Support for Navigation, Traditional Fishing Communities, Support for Oil and Gas Activities and Communities, Support for Agricultural Communities, Use of Natural Processes, Flood Protection of Strategic Assets, Flood Protection of Historic Properties, and a Social Vulnerability Index. Example project-level and alternative-level analyses and outputs are provided in Attachment C4-11.

4.1 Mid-Breton Sound Diversion (001.DI.23)[2]

The goal of the Mid-Breton Sound Diversion (001.DI.23) project is to restore wetlands by seasonally diverting a maximum of approximately 1,200 cms from the Mississippi River in the vicinity of Woodlawn, Louisiana into the adjacent wetlands of Breton Sound.[3] The diverted sediments, nutrients, and freshwater are expected to build new wetlands and sustain and enhance the productivity of wetland vegetation. The diversion is implemented in year 7 of the ICM simulation.

4.1.1 Landscape

In the high scenario, the impact of the project is slightly negative by year 10 with small increases in land loss primarily within the Breton Sound ecoregion (loss in eastern coast = -13.3 km^2; loss in Breton Sound Basin = -9.7 km^2; Figure 184). Land loss in the Breton Sound ecoregion consists of small areas lost throughout the basin with the highest concentration of loss near the diversion structure (Figure 185). This initial loss seen with the project compared to FWOA is primarily due to increases in mean annual water level, which is >10 cm throughout most marshes in the Breton Sound ecoregion (Figure 186). At year 10, there is also a significant freshening of this ecoregion relative to the FWOA ranging from 0 to 5 ppt reduction in mean annual salinity (Figure 187). Even

[2] Decadal animations of the 50-year simulation outputs can be found in Attachment C4-2: Mid-Breton Sound Diversion (001.DI.23), including stage, salinity, land, vegetation, HSIs, and EwE.

[3] It is modeled at 991 cms when Mississippi River flow equals 28,317 cms. There is no operation when river flow is below 5,663 cfs. There is a variable flow rate calculated using a linear function for river flow between 5,663 cfs and 28,317 cms and for river flow above 28,317 cms.

with these changes, the vegetation generally stays the same with only minor changes from saline and intermediate marsh converting to brackish and fresh marsh, respectively (Figure 188).

With the project in place, land loss occurs between years 11-15 and land gain occurs between years 16-20, but overall there is a small gain (+45.6 km^2) in the Breton Sound ecoregion by year 20 (Figure 184). It is interesting to note that overall land gain is smaller when considering the entire eastern coast. This is primarily due to accelerated land loss in the Bird's Foot Delta, due to less water (and thus sediment) being discharged into the Delta as it is removed from the system by the Mid-Breton Sound Diversion.

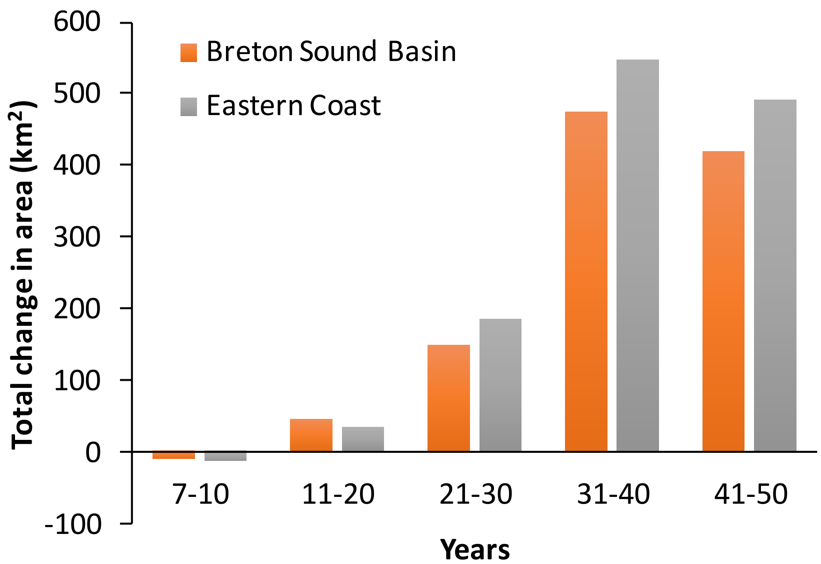


Figure 184: Change in Land Area within the Breton Sound Ecoregion and in the Eastern Coast in Response to the Mid-Breton Sound Diversion (relative to FWOA, high scenario).

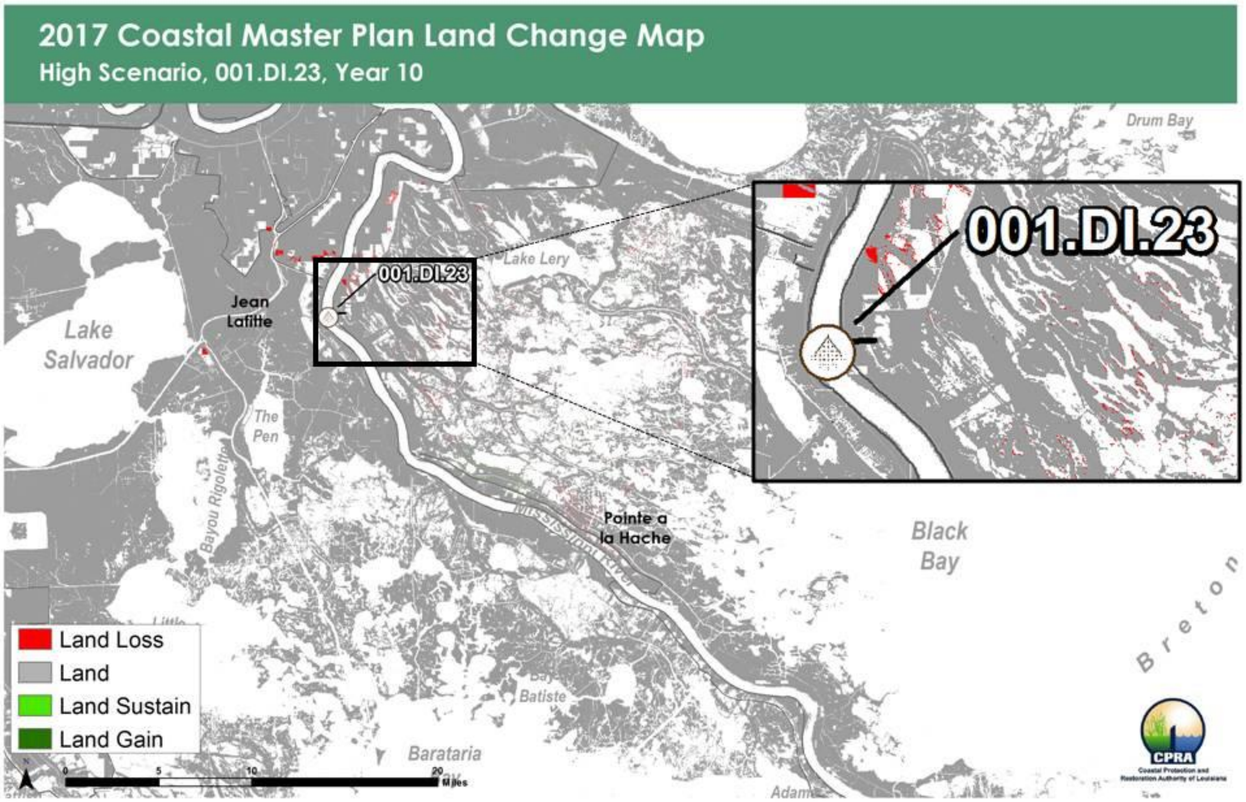


Figure 185: Land Change from the Mid-Breton Sound Diversion Relative to FWOA (year 10; high scenario).

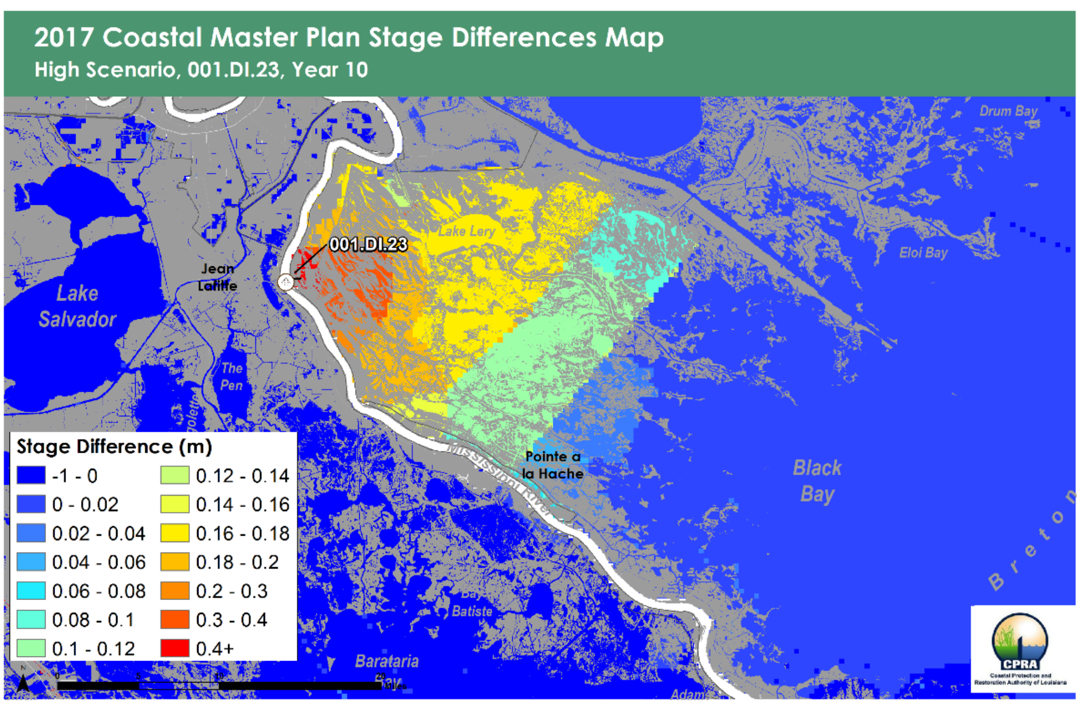


Figure 186: Change in Mean Annual Water Level Resulting from the Mid-Breton Sound Diversion Relative to FWOA (year 10; high scenario).

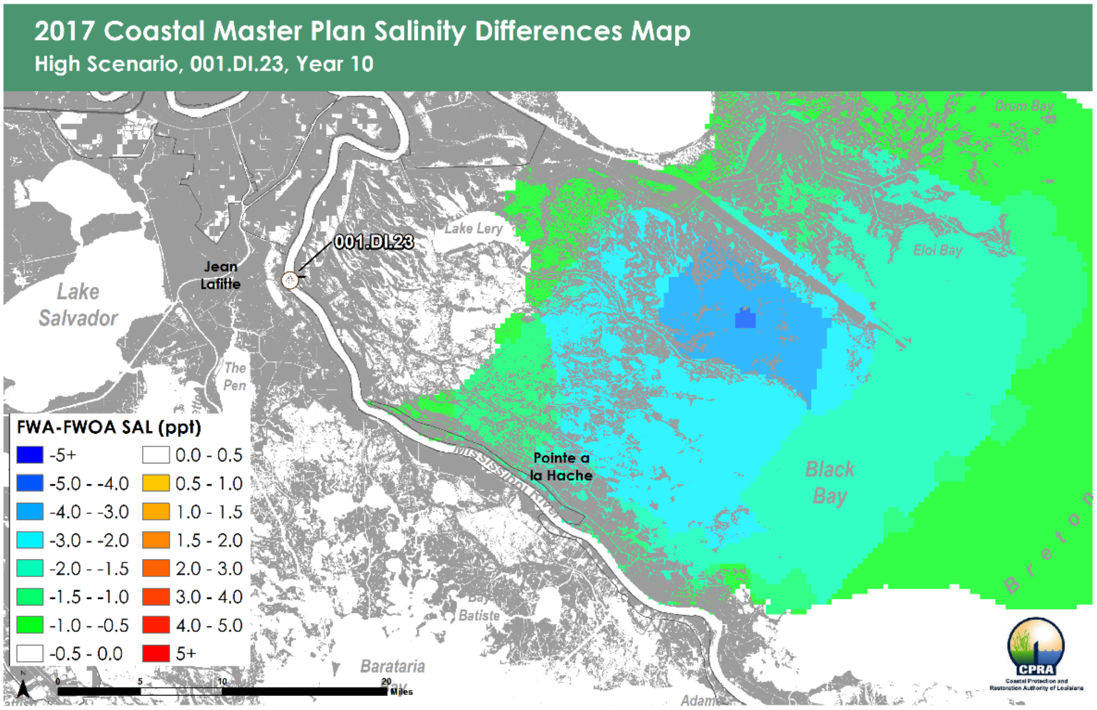


Figure 187: Change in Mean Annual Salinity Resulting from the Mid-Breton Sound Diversion Relative to FWOA (year 10; high scenario).

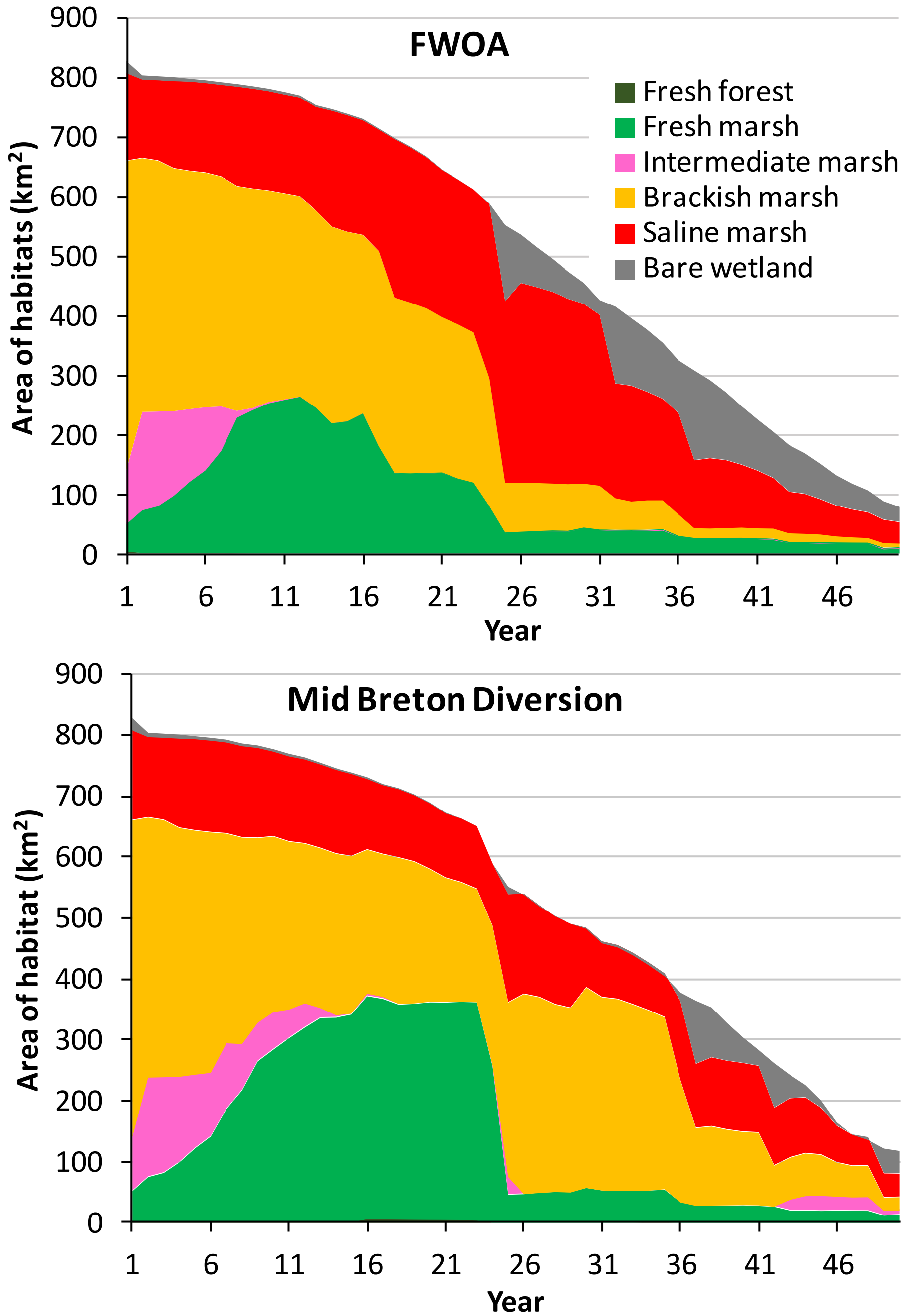


Figure 188: Change in Wetland Habitat Over Time within the Breton Sound Ecoregion under FWOA and with Mid-Breton Sound Diversion (high scenario).

With the diversion in place, there is overall land gain (Breton Sound ecoregion = +14.9 km^2; entire eastern coast = +18.5 km^2) compared to FWOA at year 30 (Figure 184). This appears primarily as land that is sustained, as there are only small areas of land gain in the immediate outfall area of the diversion; however, the diversion leads to local land loss in the ecoregion (Figure 189). Land loss occurs in areas where mean annual water levels are raised more than 12 cm (

Figure **170**), while land is sustained in areas where water levels are raised less than 12 cm and where average annual salinity is reduced by 5 ppt (Figure 191).

The wetland areas at year 30 are somewhat fresher with the diversion than without the diversion (+ 93 km^2 yr^{-1} fresh marsh; + 121 km^2 yr^{-1} intermediate marsh; - 164 km^2 yr^{-1} brackish marsh; and - 40 km^2 yr^{-1} bare ground; Figure 188). However, both in FWOA and with the diversion, a major change occurs in this ecoregion in year 24 (Figure 188). This change is due to a combination of land loss and increased sea level that allows for more overland flow (and thus saline water to move further inland). In FWOA, this changes most of the Breton Sound ecoregion from brackish to saline marsh, while with the diversion, a change from fresh marsh to brackish marsh is more prevalent (Figure 188). Bare ground is primarily a result of conditions becoming so extreme that they fall outside of the current range of species in the model. It is likely that other species accustomed to higher saline conditions would establish in these places, but these are currently not included in the ICM or are too distant for the model's dispersal mechanism to allow colonization.

As relative sea level rises, land loss accelerates rapidly in the Breton Sound ecoregion in FWOA, but the presence of the diversion is able to prevent some of this loss (Figure 184). In year 40, similar to the previous decade, land loss is accelerated in the central basin due to increased water levels, and only small land gains occur in the immediate outfall area. During this period the land gain is primarily in intermediate marsh (+ 182 km^2 yr^{-1}), while habitat loss is primarily in saline marsh (- 66 km^2 yr^{-1}; Figure 188).

By year 50, fewer areas are sustained and a drop in the overall land gain from the diversion occurs (Figure 184). At the end of 50 years, the diversion sustains existing land and creates new land with sediment input near the diversion, but land loss in this ecoregion continues even with the diversion in place (Figure 192). However, overall there is a substantial effect of more land (+ 48 km^2) at end of 50 years with the project than without it (Figure 184).

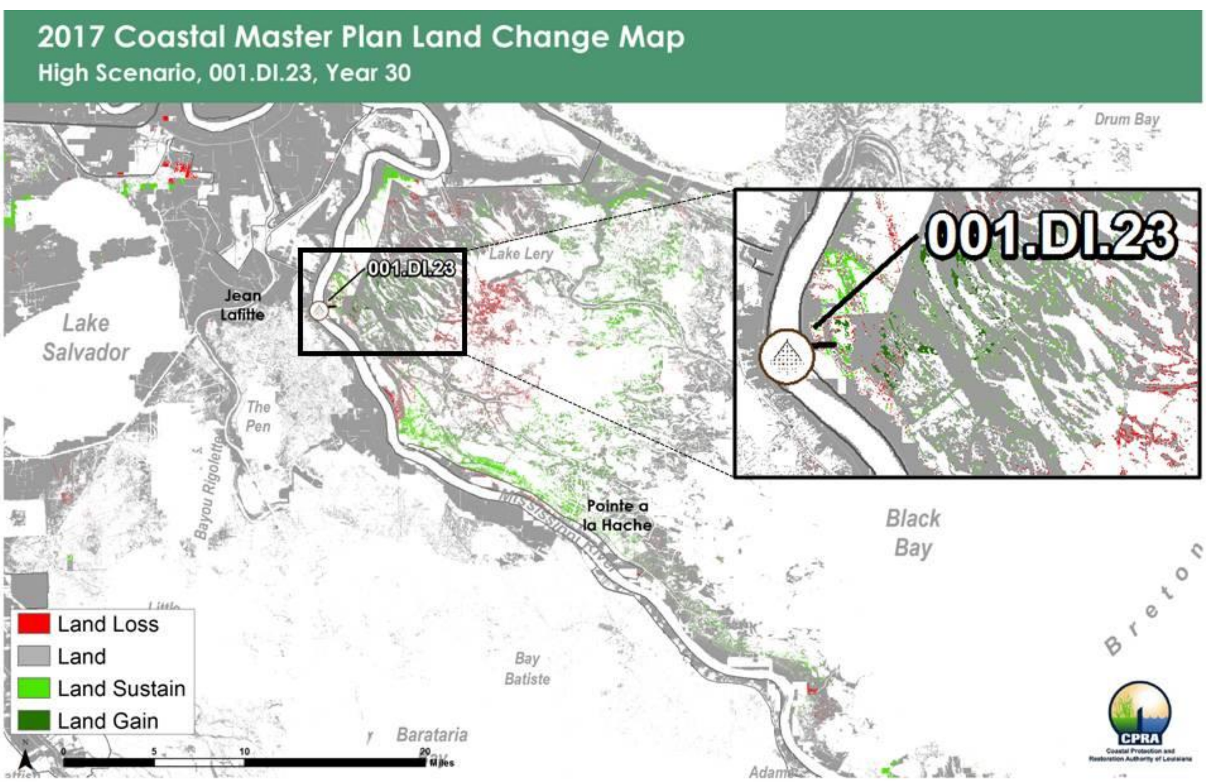


Figure 189: Land Change from the Mid-Breton Sound Diversion Relative to FWOA (year 30; high scenario). Inset focusses on immediate outfall area of the diversion.

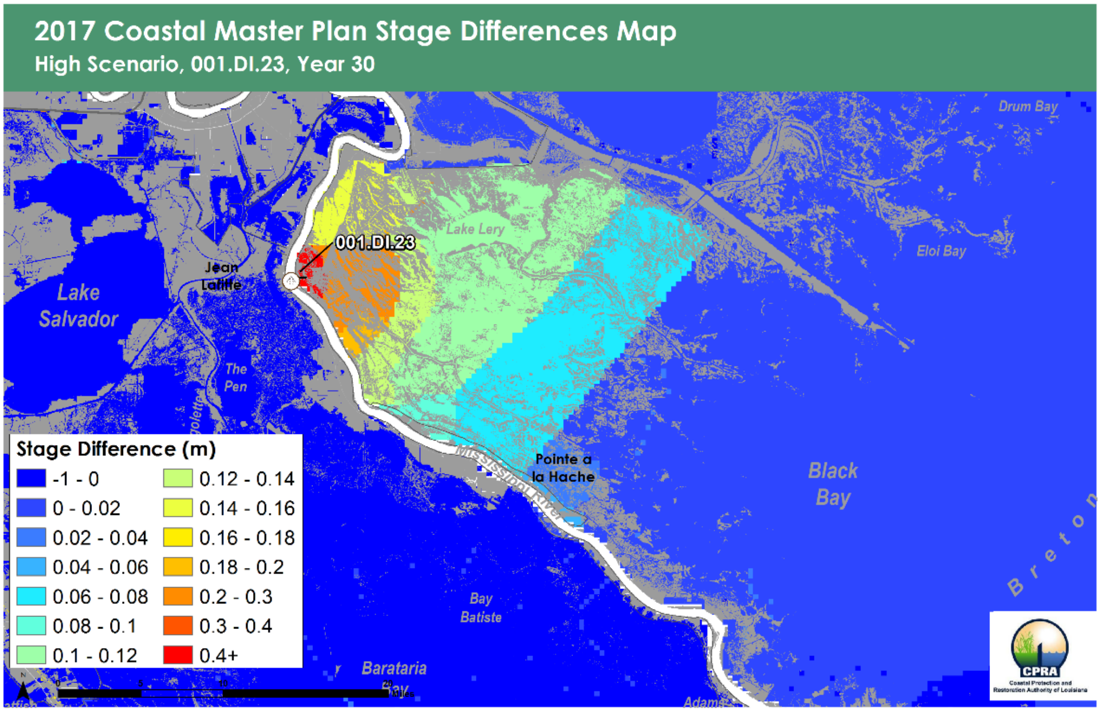


Figure 190: Change in Mean Annual Water Level from the Mid-Breton Sound Diversion Relative to FWOA (year 30; high scenario).

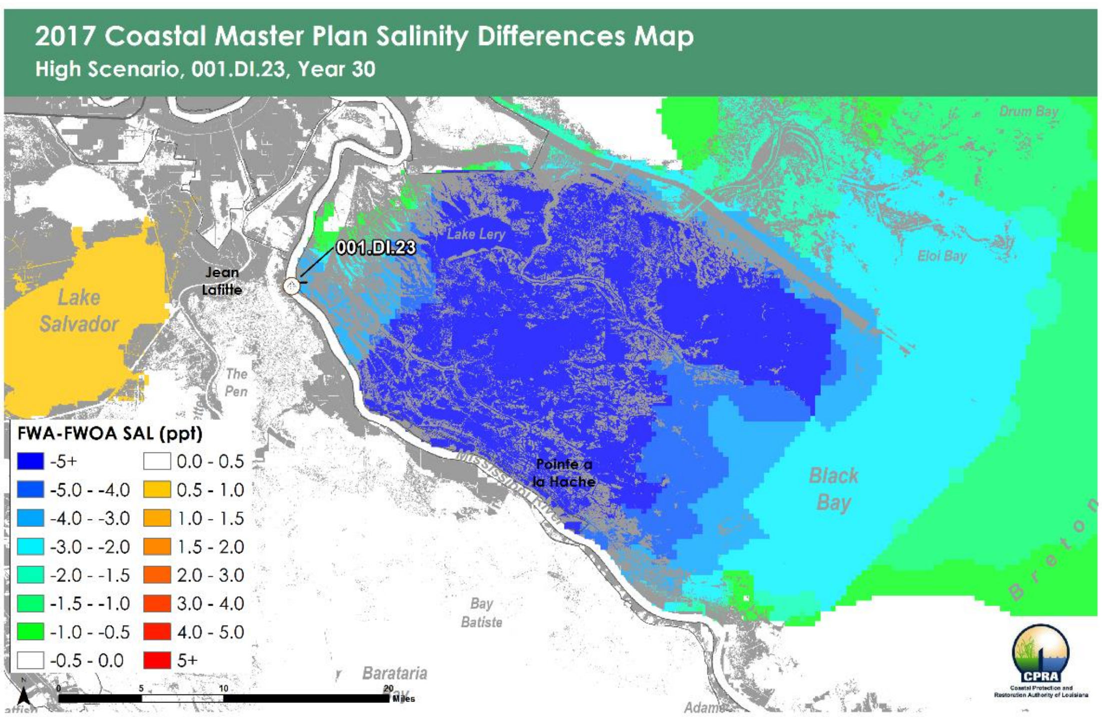


Figure 191: Change in Mean Annual Salinity from the Mid-Breton Sound Diversion Relative to FWOA (year 30; high scenario).

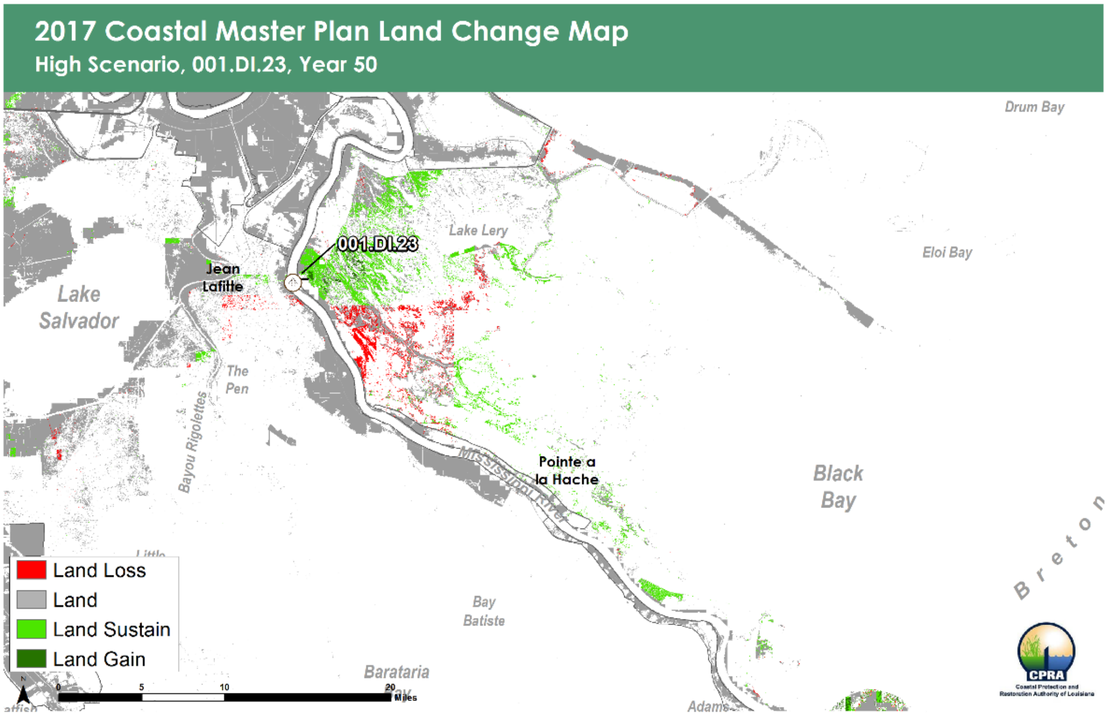


Figure 192: Land Change from the Mid-Breton Sound Diversion Relative to FWOA (year 50; high scenario).

Under the medium scenario, the diversion changes the habitat to fresher wetlands (Figure 193), and land loss is much slower when compared to the high scenario (Figure 184 and Figure 194). Under this scenario, land loss is greater than land sustained plus land gained in the first 20 years. By year 30, land loss due to the diversion is offset by land gained and land sustained. Only by years 40 through 50 of the simulation does the presence of the diversion provide a positive impact (Figure 194). However, at the end of 50 years, there is substantially more land with the project (+79 km^2) than without it.

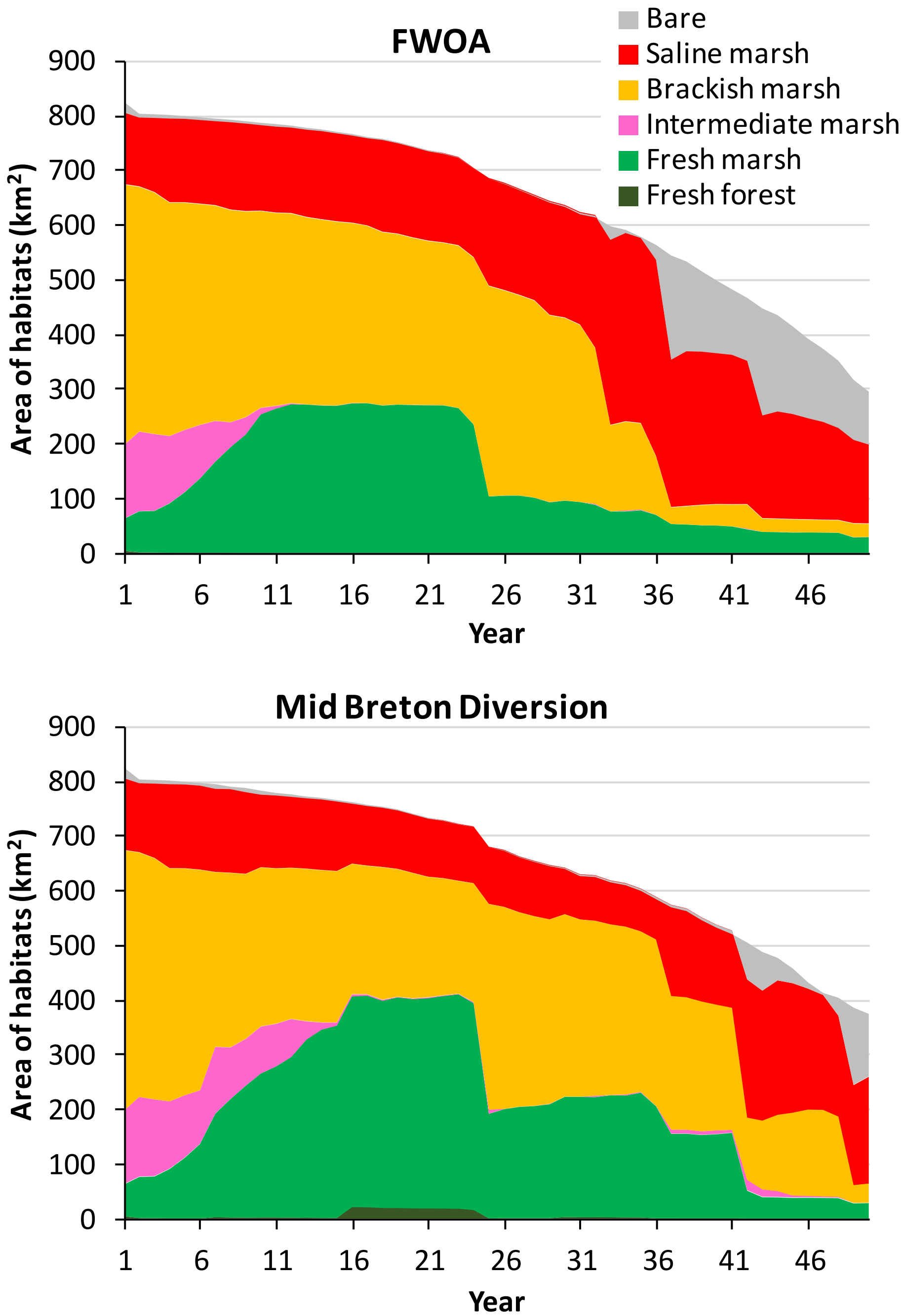


Figure 193: Change in Wetland Habitat over Time within the Breton Sound Basin under FWOA and with the Mid-Breton Sound Diversion (medium scenario).

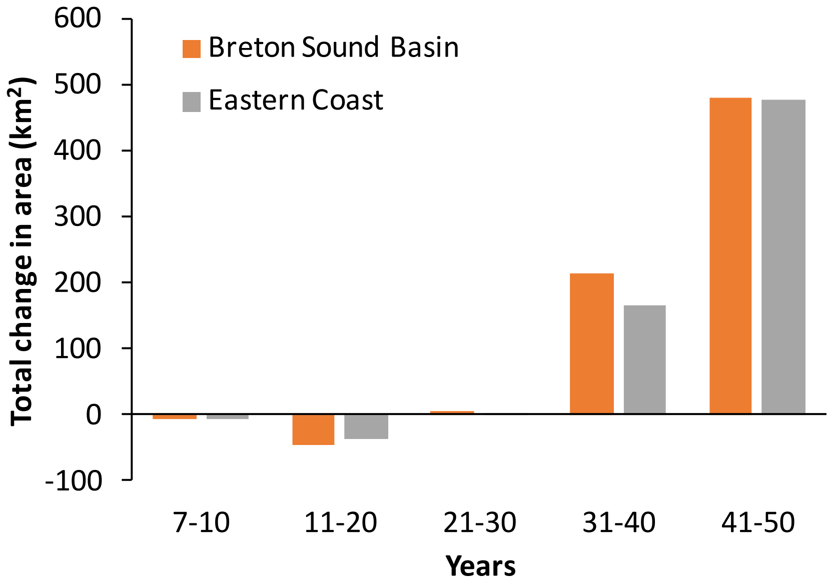


Figure 194: Change in Land Area within the Breton Sound Ecoregion and in the Eastern Coast in Response to the Mid-Breton Sound Diversion (relative to FWOA; medium scenario).

4.2 Fish, Shellfish, and Wildlife

Salinity reduction resulting from the diversion discharge decreases habitat suitability for small juvenile brown shrimp, adult spotted seatrout, and oysters. The decrease in suitability for brown shrimp and spotted seatrout typically ranged from -0.1 to -0.4 HSI relative to FWOA (Figure 195). Larger decreases in suitability are observed for oysters (often >0.5 decrease in HSI during the latter part of the simulation) due to this species' greater salinity limitations (Attachment C3-13).

Brown shrimp, spotted seatrout, and oysters all show the same general spatial-temporal pattern of change in habitat suitability relative to FWOA. During the early part of the simulation, the decrease in suitability is moderate and limited to the lower basin where the diversion discharge had the most effect on salinities (Figure 187 and Figure 195). During the latter part of the simulation, however, the difference in salinities between the project simulation and the increasingly saline FWOA is such that larger decreases in habitat suitability are observed throughout the basin for these species (e.g., brown shrimp, year 50; Figure 195). Interannual variability in river flows, and thus diversion discharge, contribute to the observed patterns. The years with high river flow rates, such as year 30 of the simulation, result in larger decreases in suitability; whereas, years with lower river flow rates result in less change in suitability. The increased habitat suitability for brown shrimp observed near the diversion outfall (Figure 195) is related to areas of bare ground in the FWOA (which receives a HSI score of 0.0) that are maintained as suitable vegetated wetland habitat in the diversion simulation.

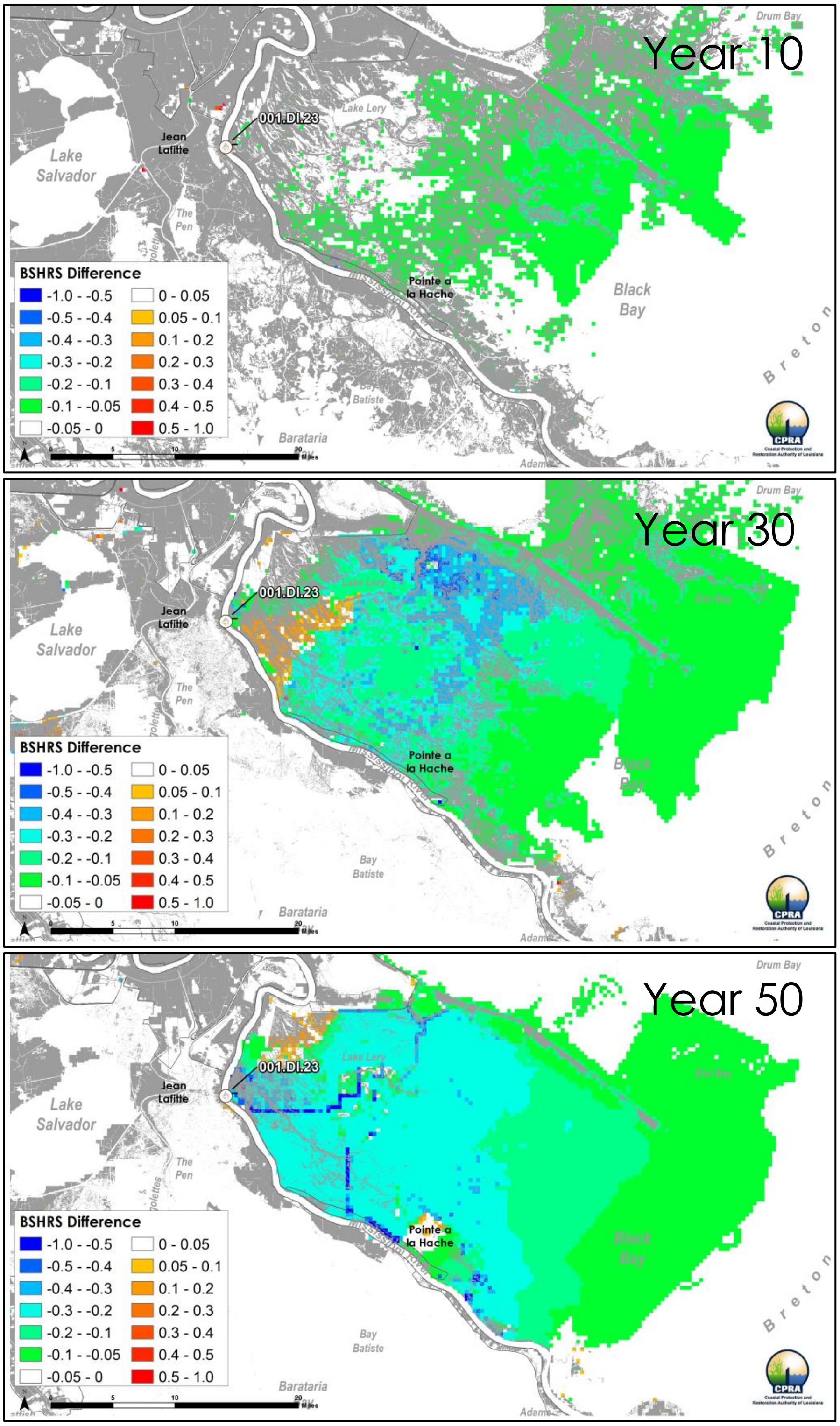


Figure 195: Difference in Small Juvenile Brown Shrimp Habitat Suitability for the Mid-Breton Diversion Relative to FWOA (years 10, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the diversion.

The Mid-Breton Sound Diversion generally increases habitat suitability for largemouth bass, green-winged teal, and American alligator. Increased suitability is due to salinity reduction and the maintenance and expansion of more favorable marsh types for the species (i.e., fresh and intermediate marshes). There are, however, some areas of decreased suitability relative to FWOA observed for alligator and teal during the early part of the simulation (e.g., alligator at year 10;
Figure 196). This is due to the elevated water levels from the diversion discharge (Figure 186), which increases water depths in low-elevation marshes and makes them less suitable for the shallow-water oriented alligator and teal (Attachments C3-7 and C3-10). Increased water levels are less evident in the latter part of the simulation, and thus have less of an effect on the HSIs.

The EwE food web model simulations of the Mid-Breton Sound Diversion show similar results to the HSI models. Biomass of largemouth bass generally increases relative to FWOA, whereas, the biomass of juvenile brown shrimp, adult spotted seatrout, and sack oyster generally decreases, particularly during the latter part of the simulation (
Figure 197 and Figure 198). For the most part, these differences are due to the salinity reduction from the diversion discharge, which increases or decreases prey consumption depending on the species. However, other environmental factors play a role in the biomass patterns. For example, primary productivity is limited near the diversion outfall and this subsequently results in reduced food availability, which in turn causes the decrease in largemouth bass biomass observed in the area (
Figure **197**).

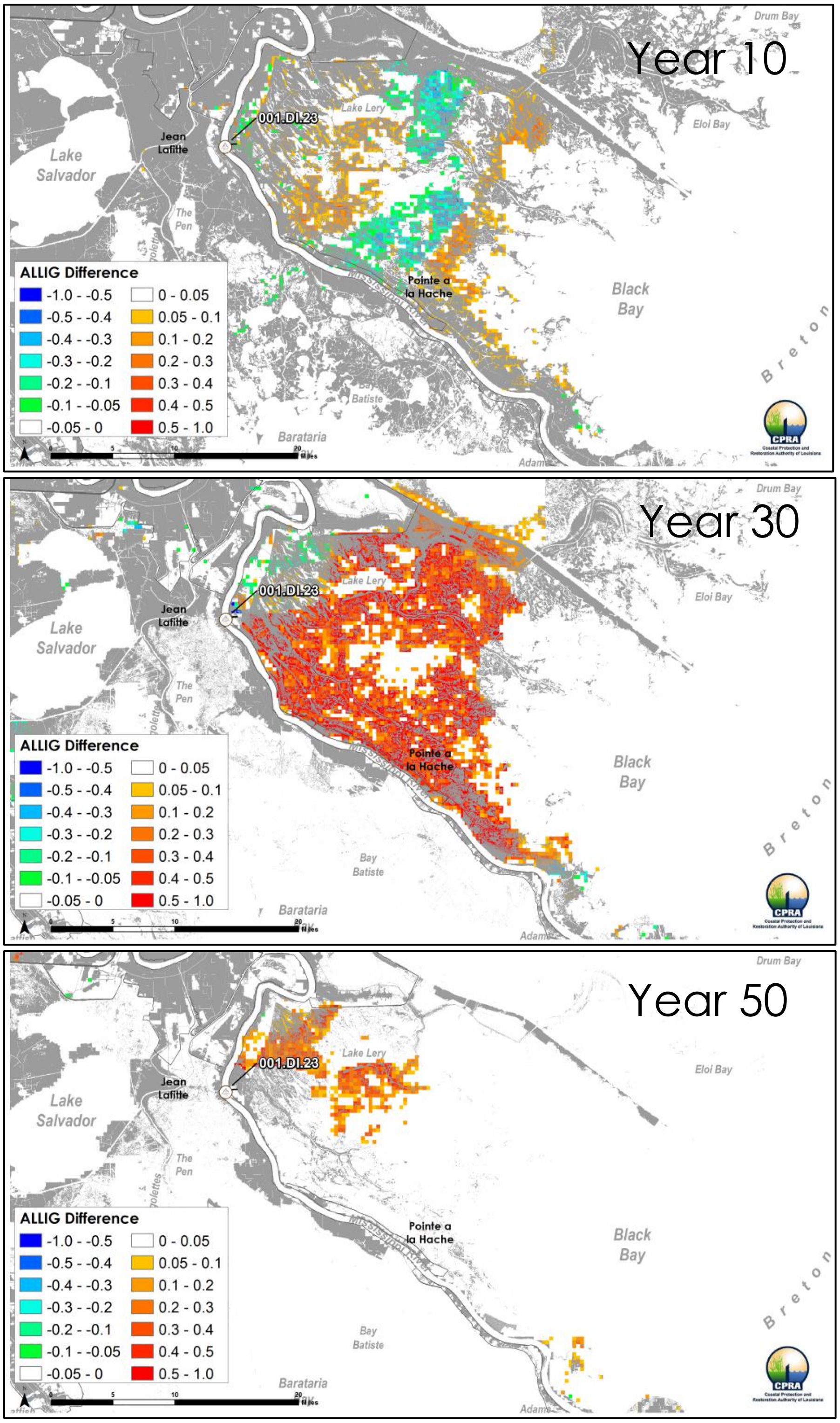


Figure 196: Difference in American Alligator Habitat Suitability for the Mid-Breton Diversion Relative to FWOA (years 10, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the diversion.

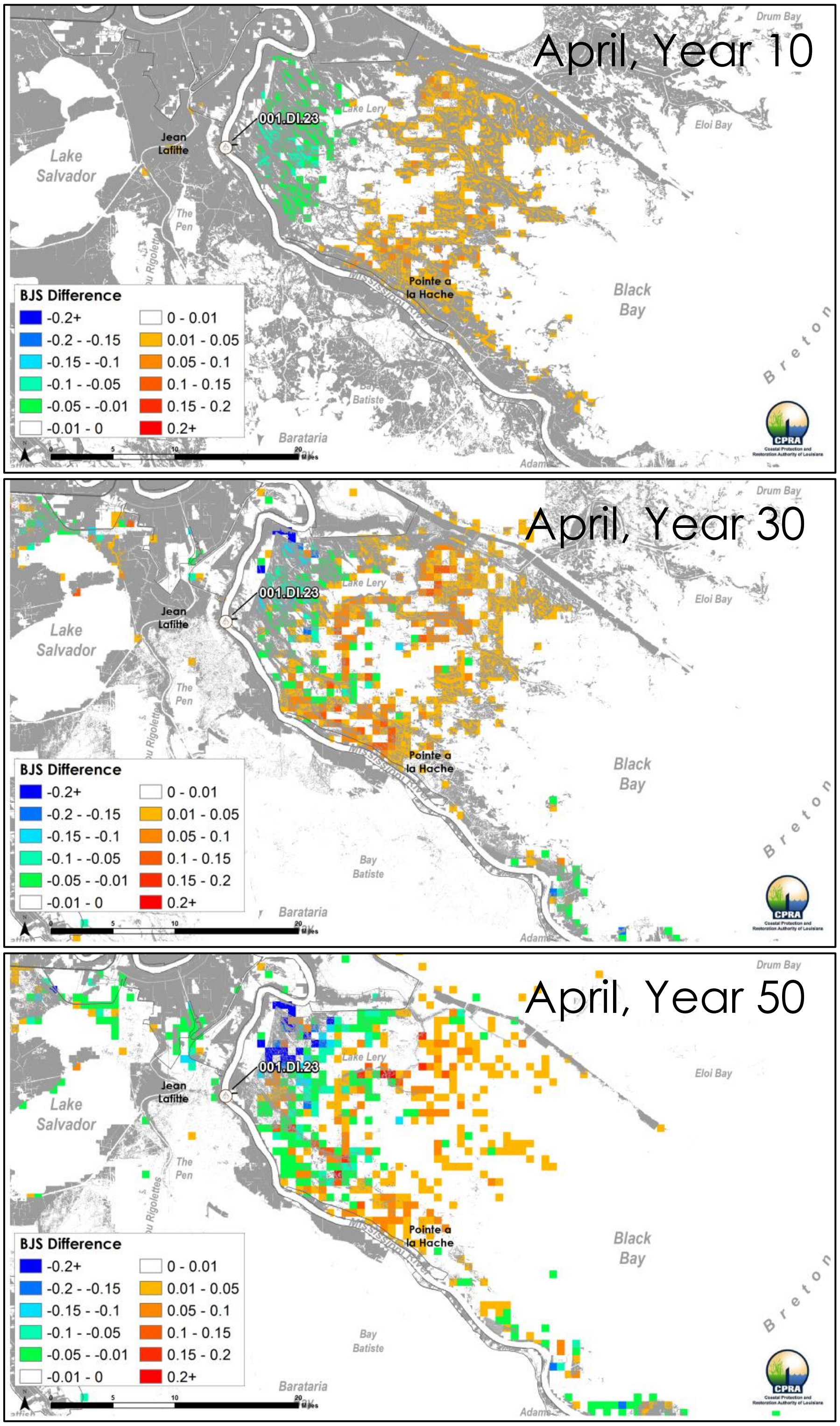


Figure 197: Difference in Juvenile Largemouth Bass Biomass for the Mid-Breton Diversion Relative to FWOA (years 10, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the diversion.

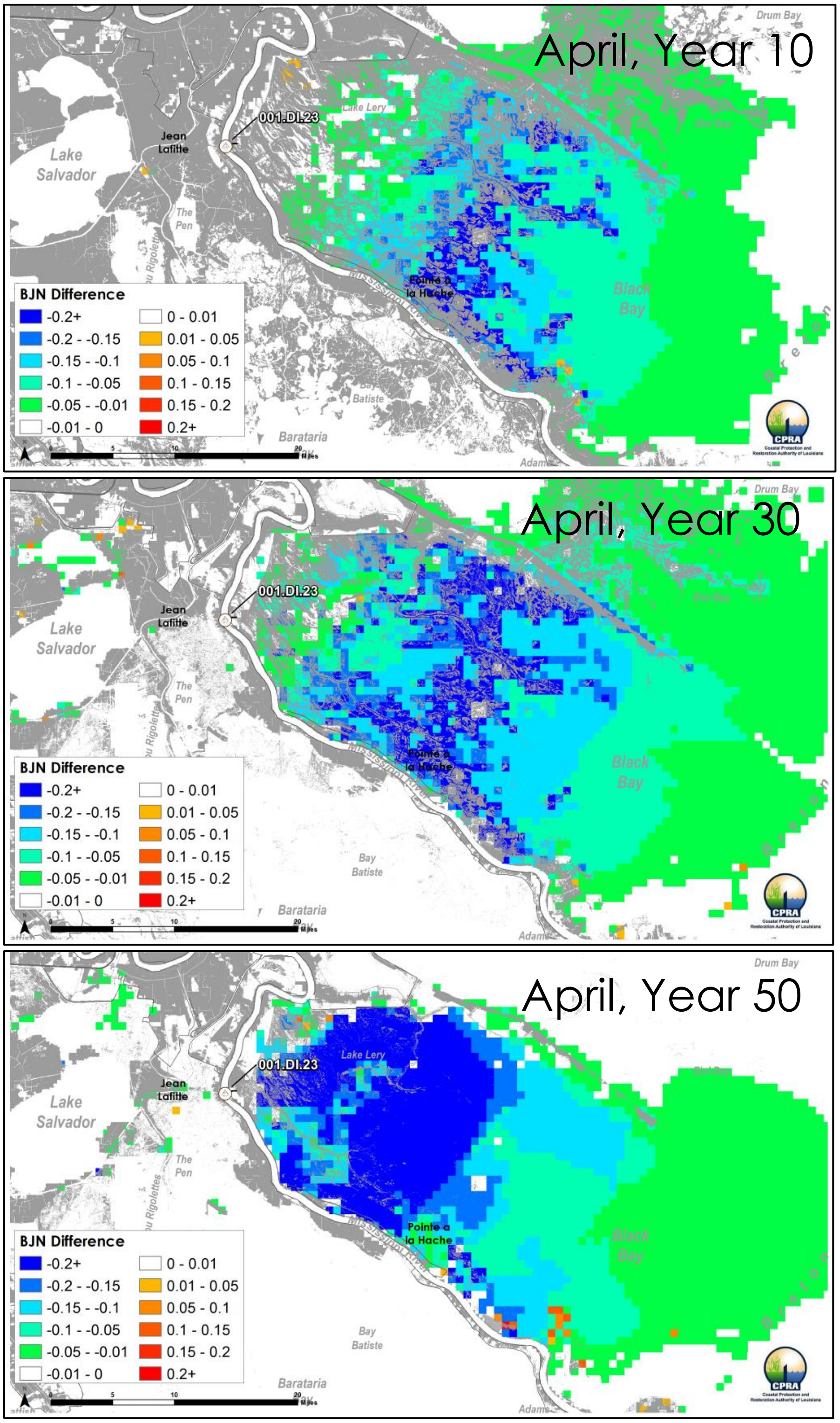


Figure 198: Difference in Juvenile Brown Shrimp Biomass for the Mid-Breton Diversion Relative to FWOA (years 10, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the diversion.

4.3 South Terrebonne Marsh Creation project (03a.MC.100)[4]

The South Terrebonne Marsh Creation (03a.MC.100) project is located in central Terrebonne Parish southwest of Dulac, Louisiana. The goal of this project is to re-create marsh and create new wetland habitat by depositing dredged sediment in a 92 km^2 area between Bayou du Large and the Houma Navigation Canal. For modeling purposes, the entire marsh creation project was implemented in year 19 of the ICM simulation. It was initially built to an elevation of 0.61 m (NAVD88).

4.3.1 Landscape

In the high scenario, the effects in year 20 (one year after project implementation) are evident, with land gain (areas that are water in the initial condition and are filled by dredged sediment) throughout the southern portion of the project area (Figure 199). Some areas are also sustained meaning that they were marsh in the initial condition and were lost by the time the project was implemented at which time they were filled with dredged material. Northern portions of the project area show open water even after project implementation indicating the depth criterion for marsh creation (0.76 m) was exceeded.

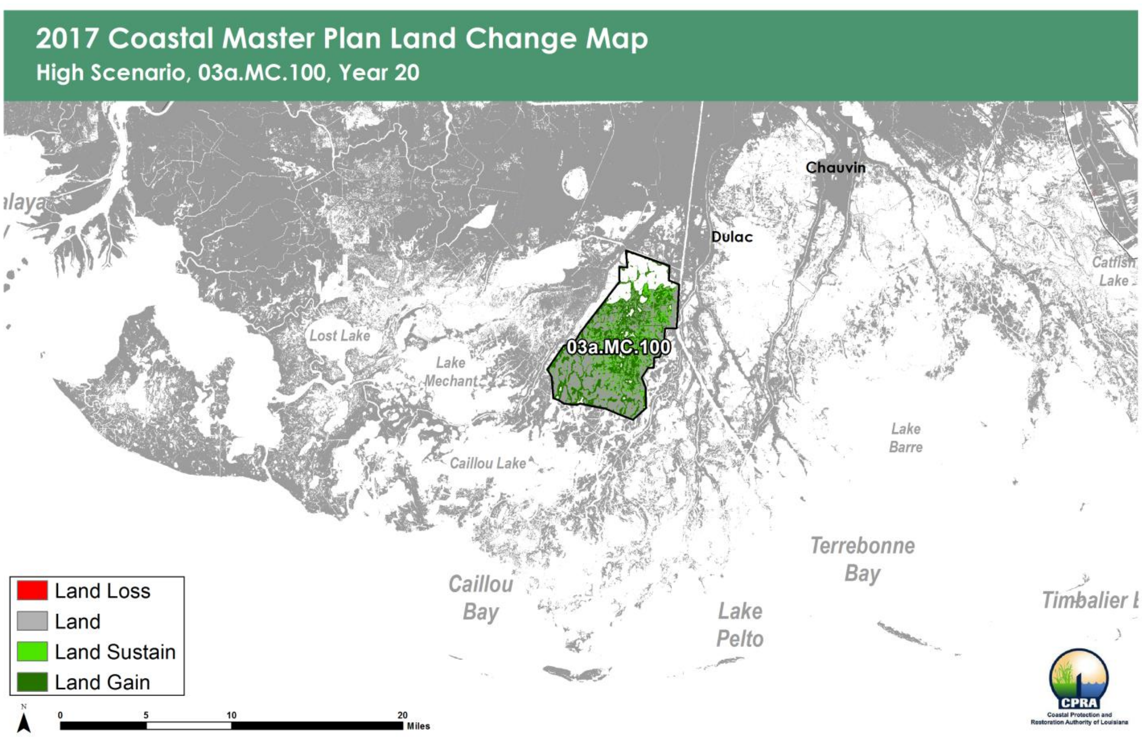


Figure 199: Land Change from the South Terrebonne Marsh Creation Relative to FWOA (year 20; high scenario).

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[4] Decadal animations of the 50-year simulation outputs can be found in Attachment C4-3: South Terrebonne Marsh Creation (03a.MC.100), including land and HSIs.

By year 30, the land sustaining effects of the project become more prevalent (Figure 200). This effect is likely due to the increased elevation resulting from project implementation, causing marshes to persist that otherwise would be lost to open water. There is also an area of exacerbated land loss north of the project area (northwest of Dulac, LA). This occurs due to an increase in stage in this area caused by a change in flow patterns from the presence of the project. There are also far-field effects evident in year 30 (south of Turtle Bayou) which are likely due to salinity inconsistencies in version 1 of the ICM code (ICM_v1).[5] Salinity instabilities in the Avoca Island Cutoff region of the model, as well as a model compartment in central Terrebonne in ICM_v1, may have been dampened due to the changed flow patterns in this central Terrebonne region, resulting in these far field differences. Figure 201 shows the difference in salinity with the project compared to FWOA for the hydro compartment just north of the project area.

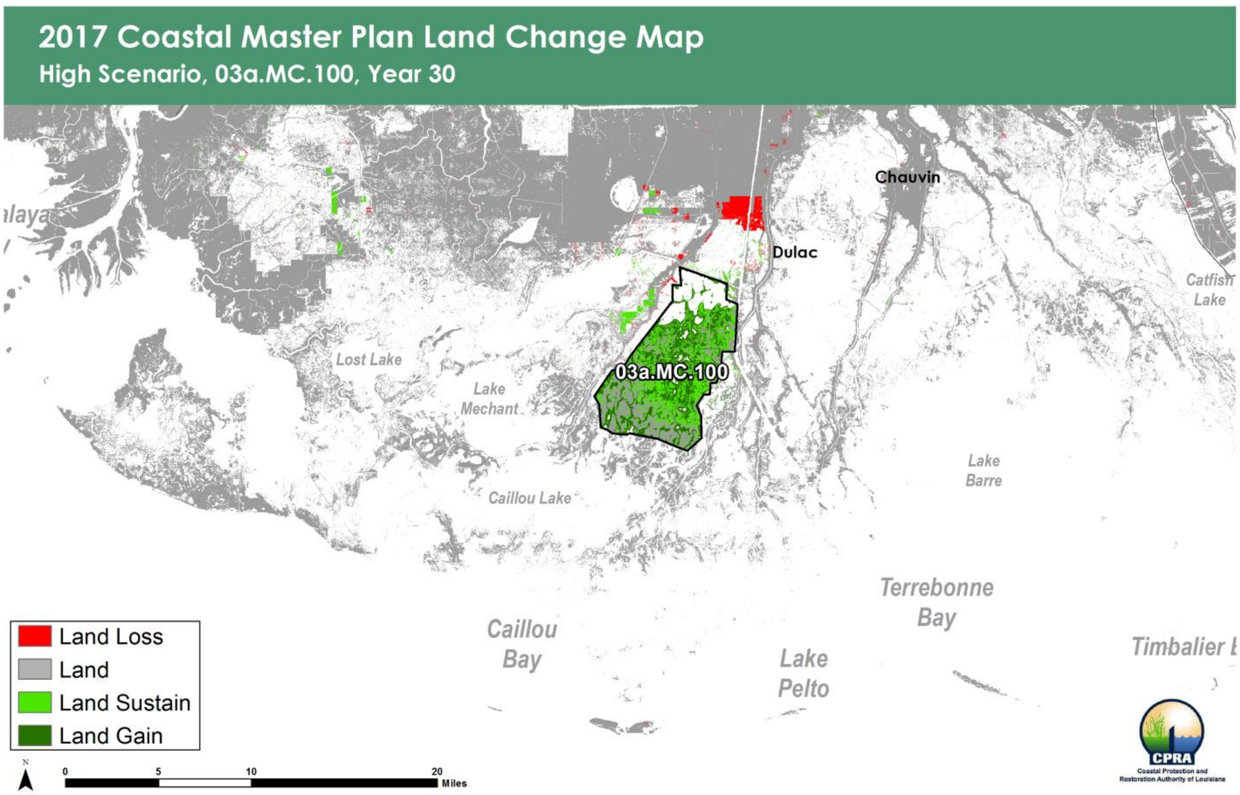

Figure 200: Land Change from the South Terrebonne Marsh Creation Relative to FWOA (year 30; high scenario).

[5] For information on the ICM_v3 salinity/calibration adjustments, refer to Attachment C3-23: ICM Calibration, Validation, and Performance Assessment.

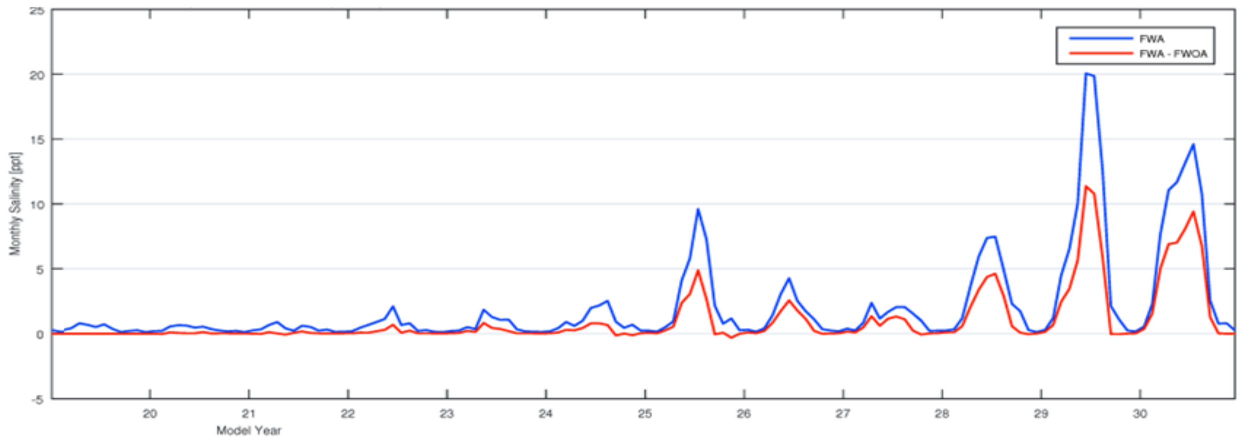

Figure 201: Monthly Salinity (ppt) for the ICM Hydrology Compartment North of the South Terrebonne Marsh Creation Area between Years 19 and 30 of the Simulation. The blue line indicates salinity with the project, and the red line is the difference between the project and FWOA.

By year 50, much of the initial benefit in the form of land gained or sustained is lost (Figure 202). The area is projected to mostly convert to open water under both FWOA and FWA conditions. Also by year 50, some of the far-field effects such as the hastened land loss northwest of Dulac are no longer evident, suggesting the area will experience loss eventually regardless of project implementation.

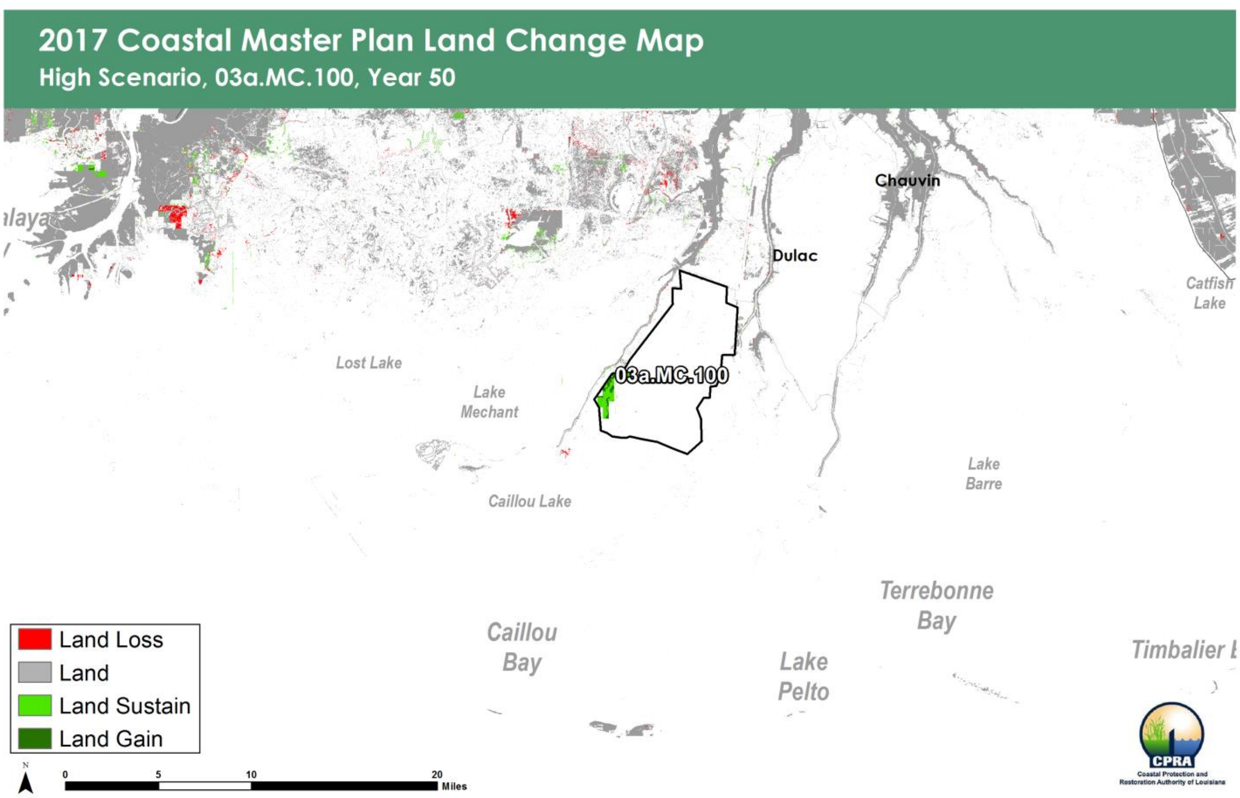

Figure 202: Land Change from the South Terrebonne Marsh Creation Relative to FWOA (year 50; high scenario).

Considering the overall project life, there is a substantial benefit to net land area as compared to FWOA; however, the duration of these benefits is limited. Model output indicates accretion is insufficient to maintain marsh elevations over time. The limited availability of mineral sediments needed to support prolonged accretion in this region (less than 150 g/m^2 are deposited on the constructed marsh surface during any given model year) contributes to an elevation deficit relative to relative sea level rise (RSLR). This deficit leads to loss of elevation relative to water level which leads to prolonged depth and duration of marsh inundation, eventually triggering the marsh collapse threshold and the conversion of that marsh to open water.

The land area benefits, which are maintained through the end of the 50-year simulation, are all areas containing the vegetation type "bare ground/upland." Bare ground occurs when the change in environmental conditions is too rapid for the model's vegetation dispersal mechanism (i.e., there is no vegetation that can tolerate the conditions within the dispersal distance). In ICM_v1, bare ground areas were not subject to a collapse criterion. These areas would likely convert to another vegetation type and then be lost in subsequent years if the modeling period were extended.

The effects due to the project in the low and medium scenarios are far more persistent, with the majority of the land gained or sustained persisting through the end of the modeling period. A land sustaining effect is more evident in the medium scenario indicating these areas would have been lost due to RSLR if not for the additional elevation due to project implementation.

4.3.2 Fish, Shellfish, and Wildlife

In general, the South Terrebonne Marsh Creation project transforms fragmented marsh into an area of relatively solid marsh. This change in landscape configuration results in a decrease in habitat suitability for small juvenile brown shrimp, adult spotted seatrout, largemouth bass, green-winged teal, and American alligator, all of which primarily utilize fragmented marsh habitats with a high degree of marsh edge. There are, however, some areas of fragmented marsh that are maintained in the northern part of the project area, which results in localized increases in habitat suitability for most of these species when compared to FWOA (e.g., small juvenile brown shrimp and largemouth bass; Figures 5 and 6).

As previously mentioned, this project also appears to modify the local hydrology, as evidenced by higher salinities within and around the project area as compared to FWOA (Figure 201). Consequently, the existing low-salinity areas north of the project area become less suitable for largemouth bass and alligator and more suitable for brown shrimp and spotted seatrout (Figure 203 and Figure 204). At the same time, the saline areas south and east of the project area become less suitable for eastern oyster and brown shrimp (Figure 203), both of which are more common at salinities between approximately 10 and 20 ppt (Attachments C3-12 and C3-13, respectively).

By the end of the 50-year simulation, the widespread saltwater intrusion and wetland loss associated with the high scenario eliminates the project's effects, resulting in essentially no difference between the project and FWOA with regard to habitat suitability (Figure 203 and Figure 204). Very little highly suitable habitat remains in the project area in the high scenario for the majority of the species.

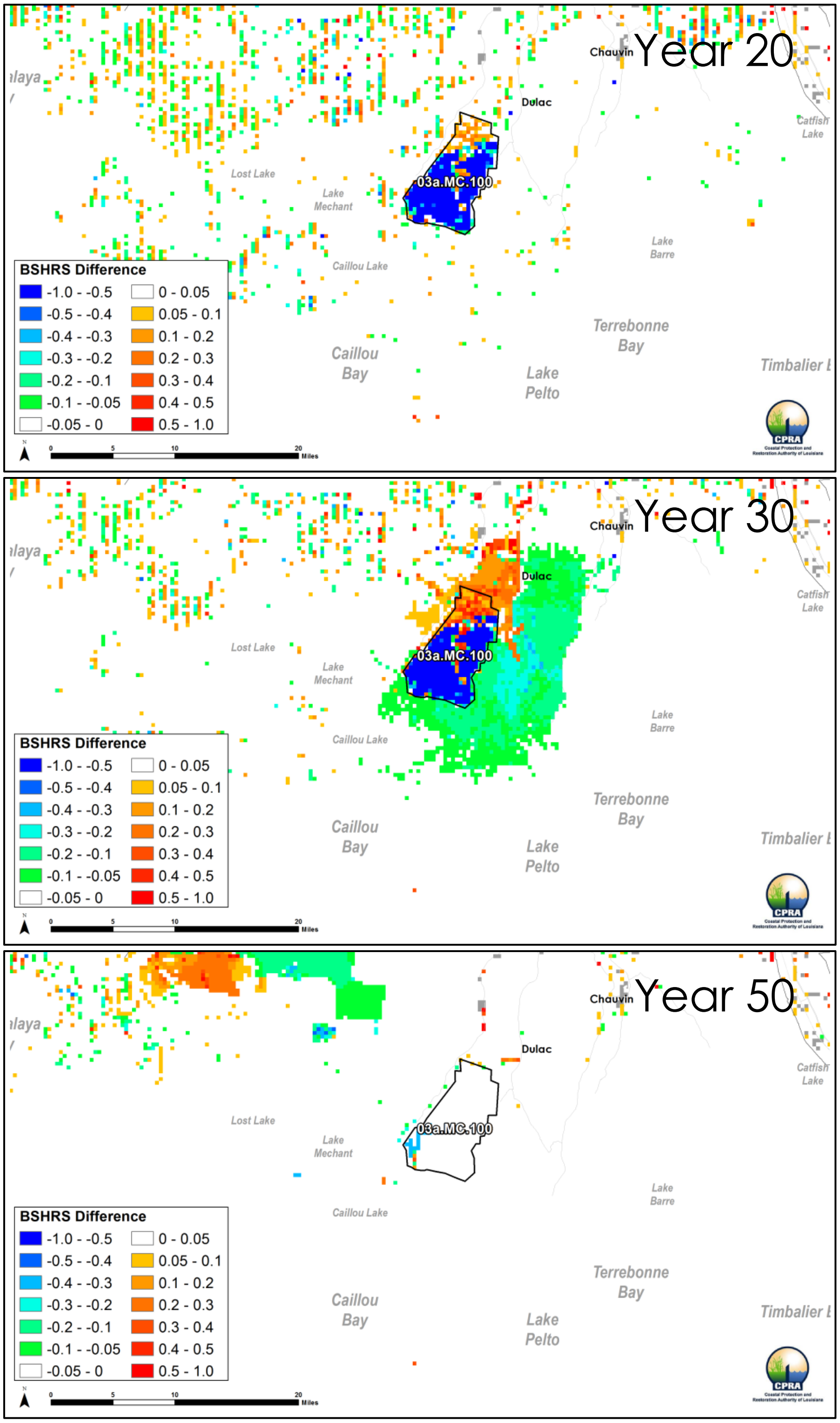

Figure 203: Difference in Small Juvenile Brown Shrimp Habitat Suitability Associated with the South Terrebonne Marsh Creation Relative to FWOA (years 20, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the project. Land areas are removed to better show the changes in suitability.

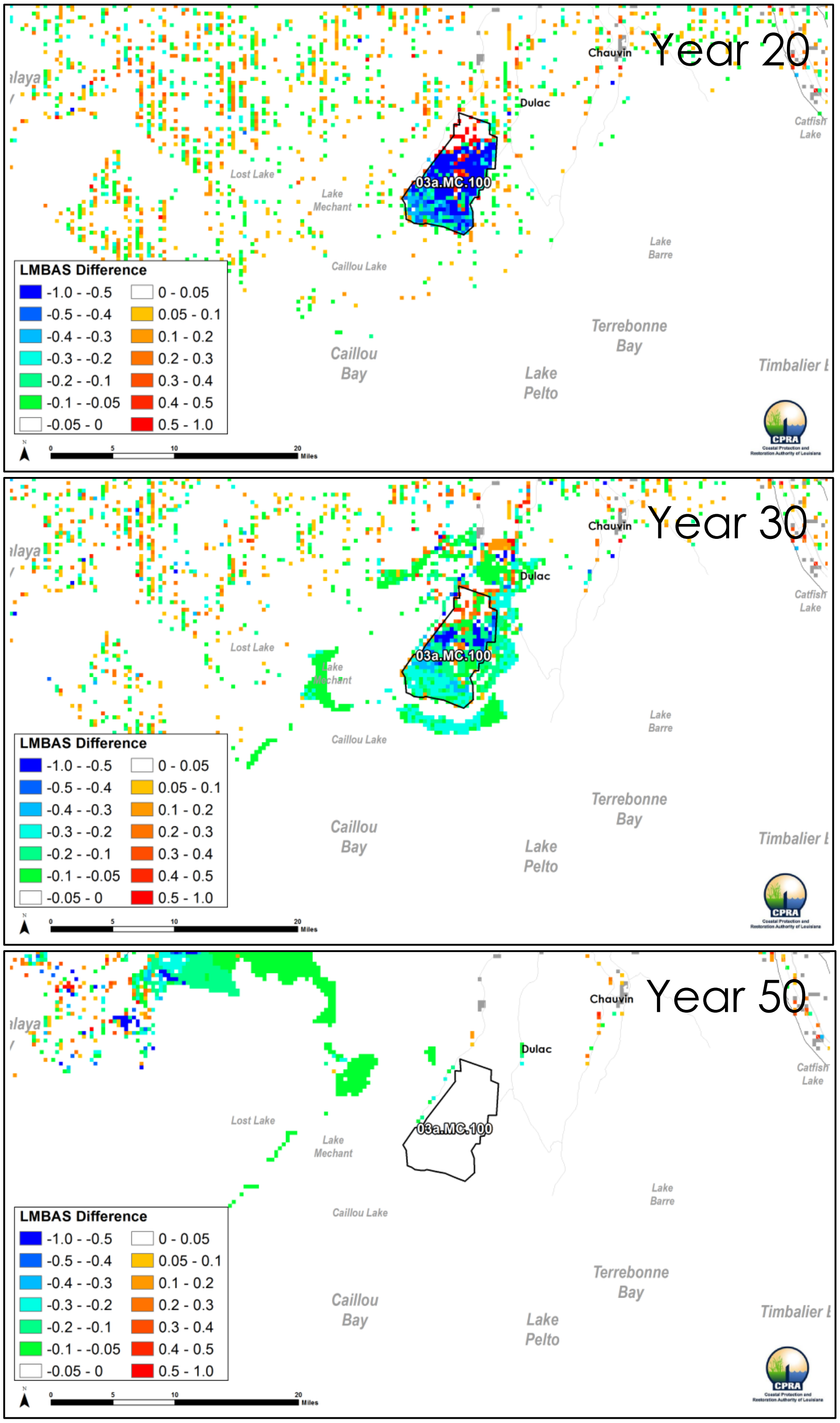

Figure 204: Difference in Largemouth Bass Habitat Suitability Associated with the South Terrebonne Marsh Creation Relative to FWOA (years 20, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the project. Land areas are removed to better show the changes in suitability.

4.4 Calcasieu Ship Channel Salinity Control Measures (004.HR.06)[6]

The goal of the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project is to reduce saltwater intrusion into Calcasieu Lake and surrounding wetlands, thus helping to sustain the wetlands and the ecosystem benefits they provide. The project consists of an array of earthen berms and water control structures that will be built along the length of the Calcasieu Ship Channel in Calcasieu Lake and at key waterways leading into interior marshes, such as Alkali Ditch and Kelso Bayou. The project is implemented in year 4 of the ICM simulation.

4.4.1 Landscape

In the high scenario, this project has a strong impact, reducing mean annual salinity in the southern section of Lake Calcasieu by ≥5 ppt in year 10 (Figure 205). In addition, mean annual salinity is lowered by at least 0.5 ppt from the Sabine freshwater impoundment in the west to areas 8 km east of Highway 27 and as far north as Lake Charles (Figure 205). However, these changes in hydrology have no effect on land change in the region in year 10 (Figure 206). The salinity changes do affect the vegetation, and there is 67 km^2 yr^{-1} more fresh marsh and 3 km^2 yr^{-1} more forested wetland in the Calcasieu/Sabine ecoregion with the project than in FWOA, while brackish (- 40 km^2 yr^{-1}) and saline marsh (- 30 km^2 yr^{-1}) extent both decline in year 10 (Figure 207).

At year 20, there is a positive effect on land change in the Calcasieu/Sabine ecoregion (Figure 208), which is due to wetland areas sustained along the Gulf Intracoastal Waterway (GIWW). The project also induces some land loss in the area just north of Lower Mud Lake, where fresh marsh occurs among Chenier ridges with the project thus more vulnerable to salinity intrusion (see year 20 land change map in Attachment C4-4). In FWOA, this area is brackish and less sensitive to salinity increases. At year 20, the project induces land loss in the Mermentau Lakes, which is primarily due to a small increase (<2 cm) in mean annual water level. Therefore, the overall effect of the project on land along the western coast is negative at this point in the simulation (Figure 208).

[6] Decadal animations of the 50-year simulation outputs can be found in Attachment C4-4: Calcasieu Ship Channel Salinity Control Measures (004.HR.06), including stage, salinity, land, vegetation, HSIs, and EwE.

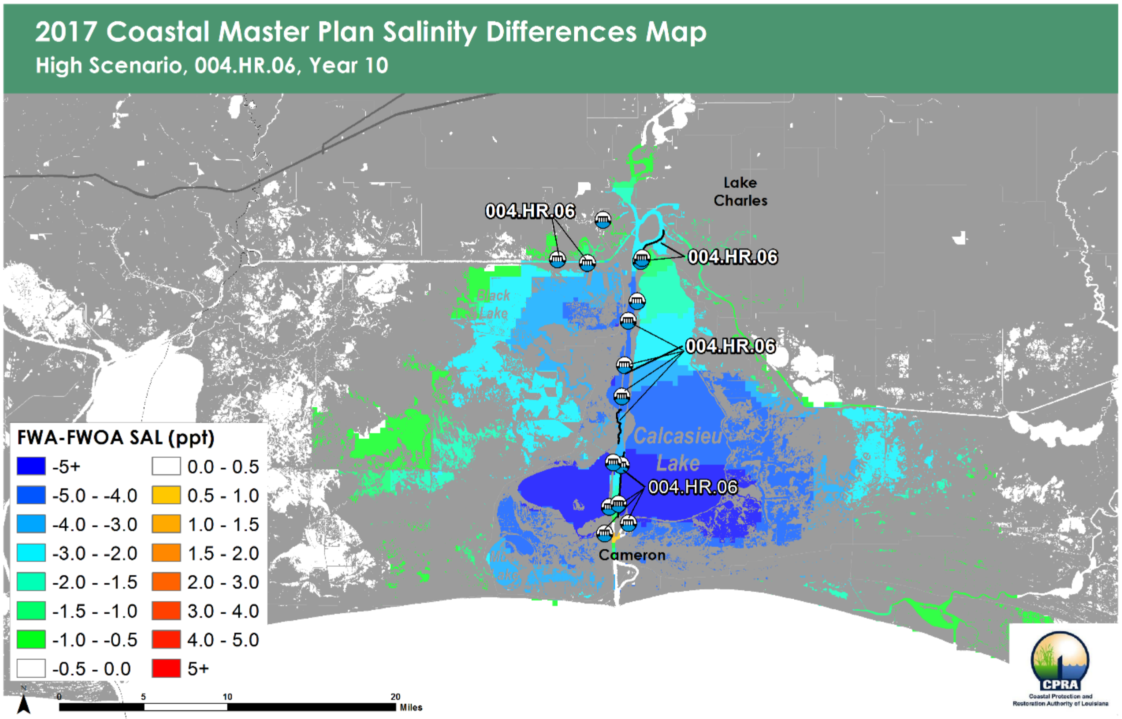

Figure 205: Change in Salinity from the Calcasieu Ship Channel Salinity Control Measures Project Relative to FWOA (year 10; high scenario).

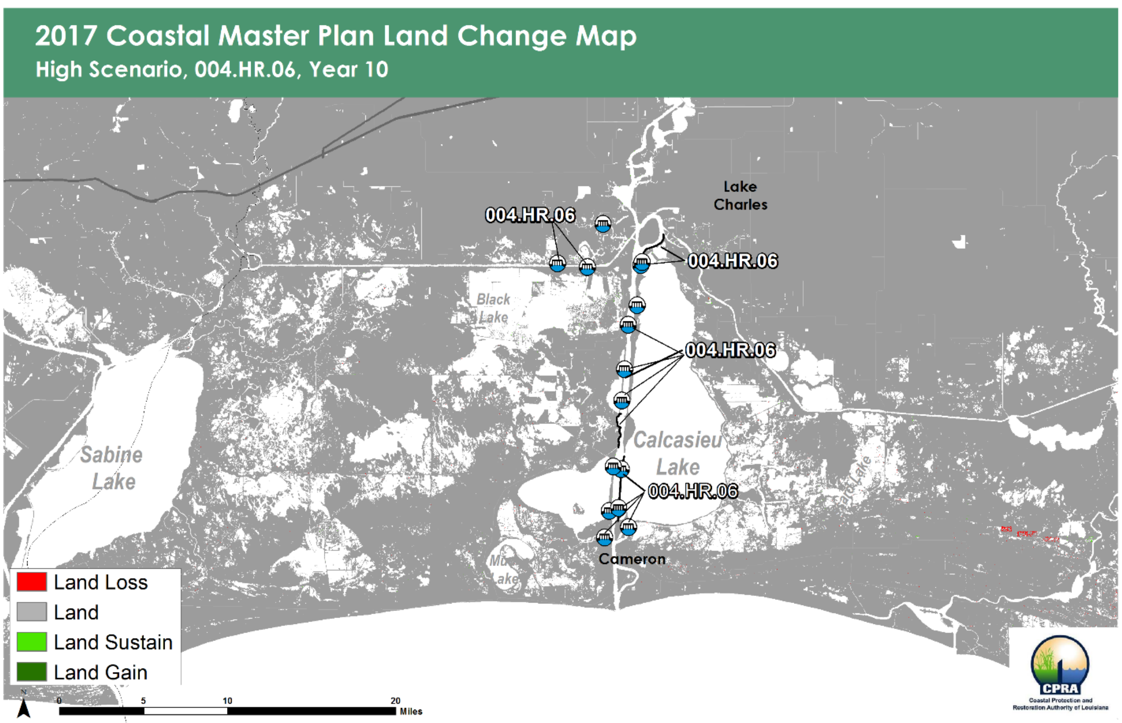

Figure 206: Land Change from the Calcasieu Ship Channel Salinity Control Measures Project Relative to FWOA (year 10; high scenario).

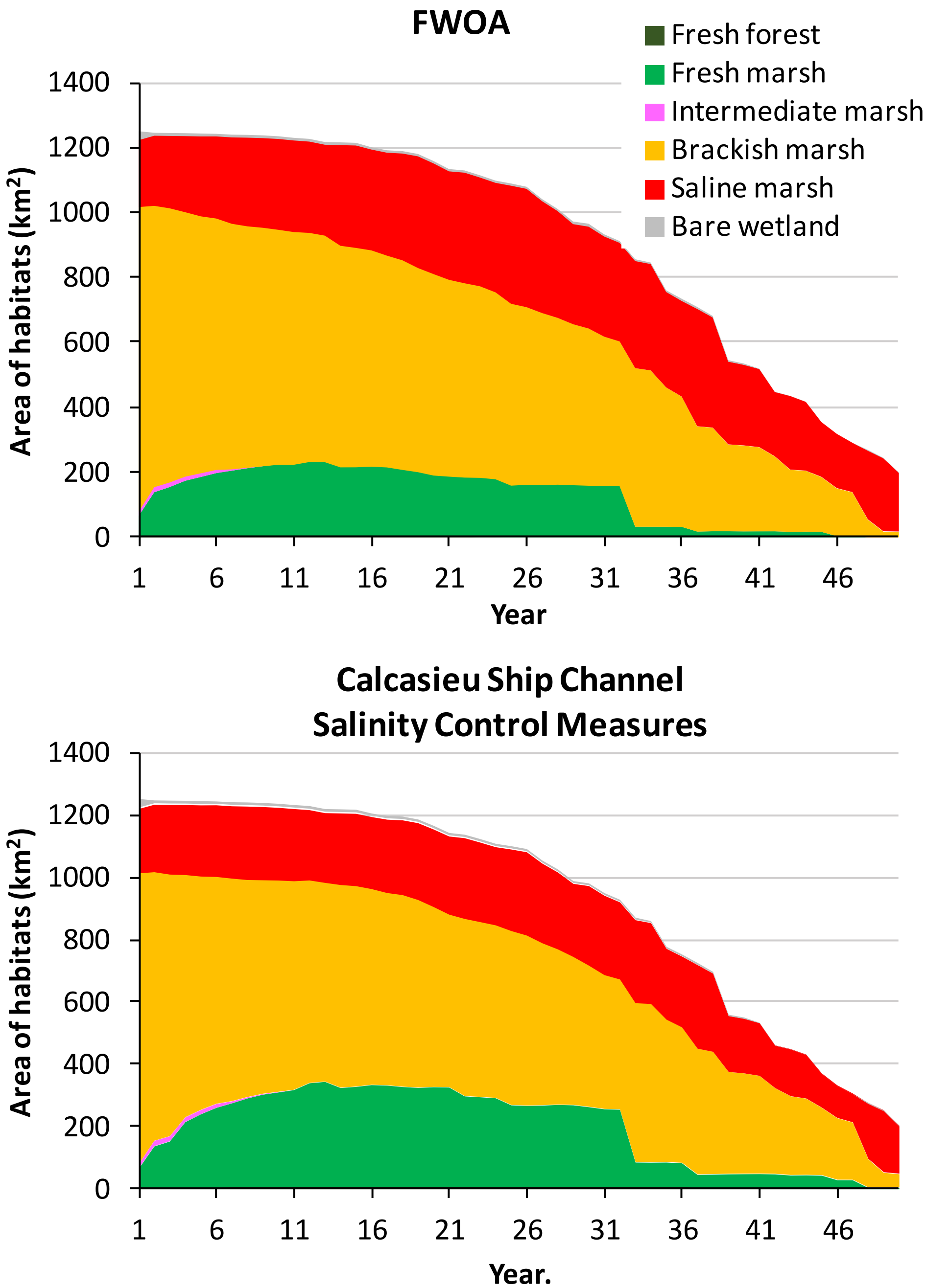

Figure 207: Change in Wetland Habitat over Time within the Calcasieu/Sabine Ecoregion in FWOA and with the Calcasieu Ship Channel Salinity Control Measures Project (high scenario).

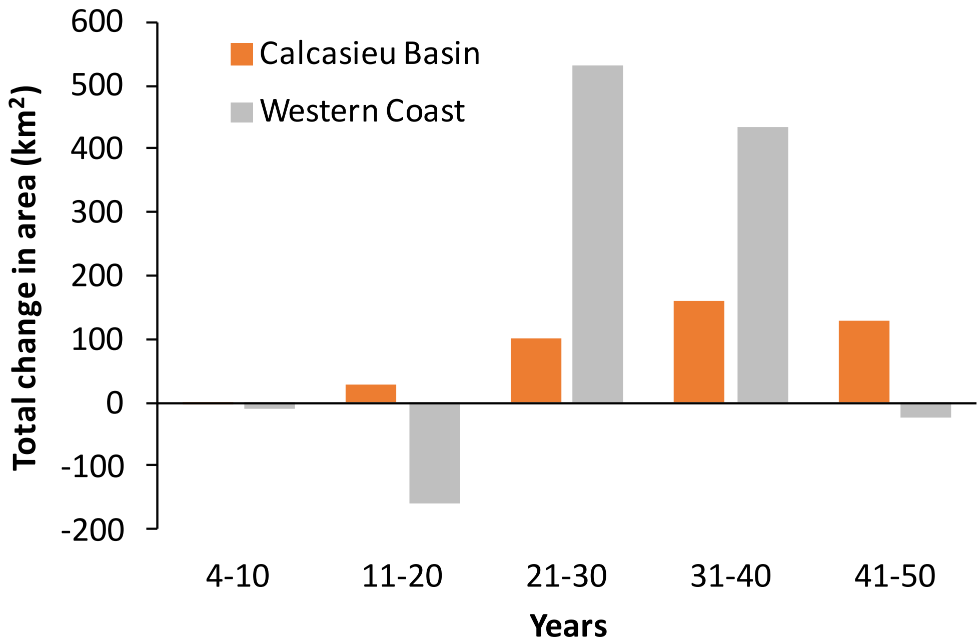

Figure 208: Change in Land Area within the Calcasieu/Sabine Ecoregion and in the Western Coast in Response to the Calcasieu Ship Channel Salinity Control Measures Project (relative to FWOA; high scenario).

At year 30, the project has positive effects on land change both in Calcasieu/Sabine ecoregion and the western coast (Figure 208). In the Calcasieu/Sabine ecoregion, sustained land is scattered throughout, but in the Mermentau Lakes ecoregion more land is sustained than lost (Figure 209). Most of the land loss due to the project occurs in year 24 of the simulation. A large swath of marsh is maintained as fresh marsh with the project through year 23. In year 24, increased sea level rise combined with land loss in the region allows for more overland flow and thus more saline water to penetrate deeper into the coast, and these fresh marsh areas are lost. In FWOA, the marsh in this region is already brackish and therefore less susceptible to the salinity increase associated with the increased overland flow. The areas sustained include fresh water marshes north of the GIWW, where salinity is changed less than 0.5 ppt and where water levels are lowered by less than 2 cm (Figure 210 and Figure 211). The marshes sustained in the Calcasieu/Sabine ecoregion primarily occur in areas of high (>4 ppt) reduction in salinity, adjacent to Black Lake and Sweet Lake.

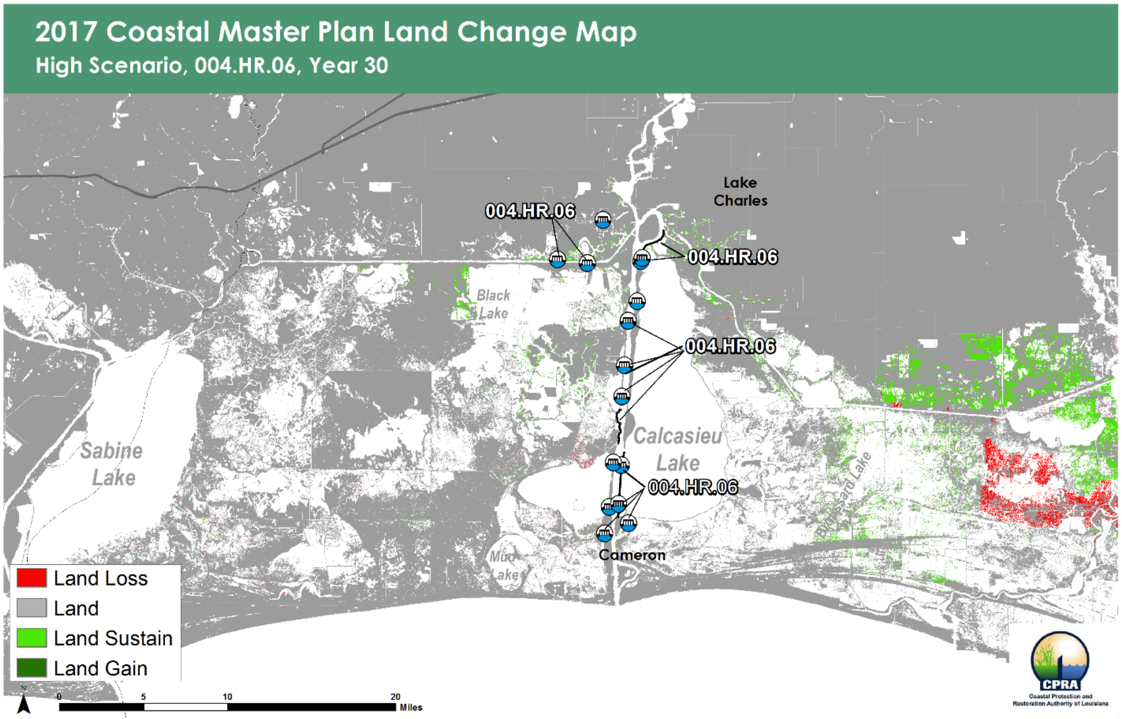

Figure 209: Land Change from the Calcasieu Ship Channel Salinity Control Measures Project Relative to FWOA (year 30; high scenario).

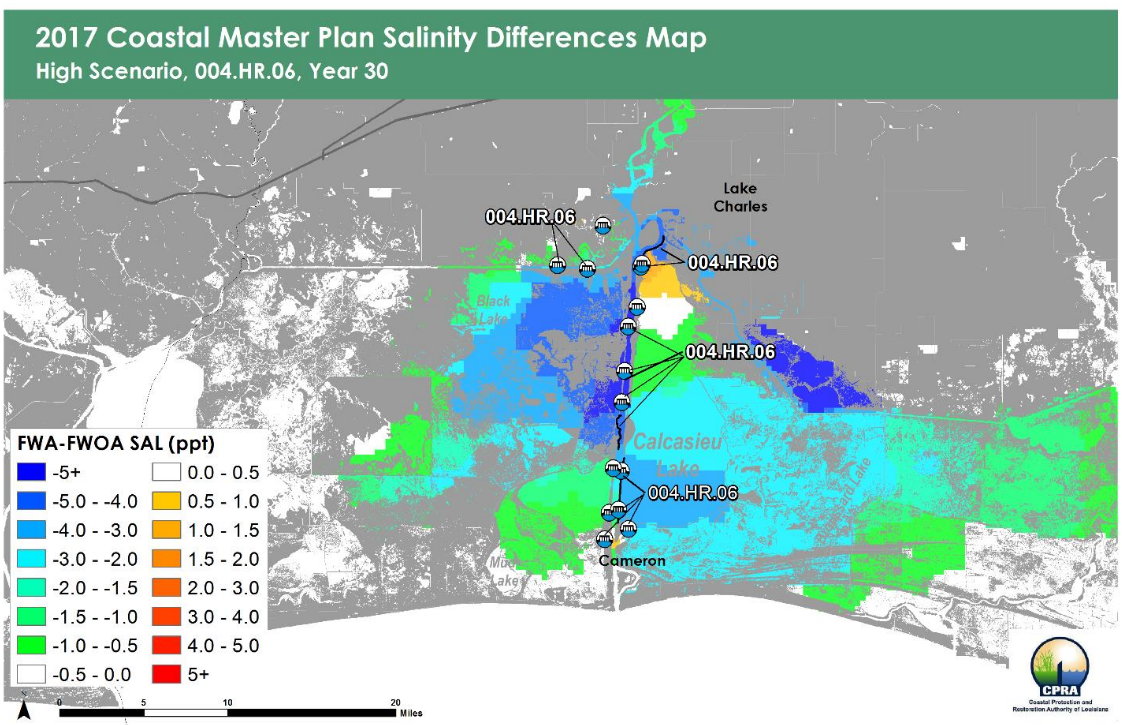

Figure 210: Change in Salinity Resulting from the Calcasieu Ship Channel Salinity Control Measures Project Relative to FWOA (year 30; high scenario).

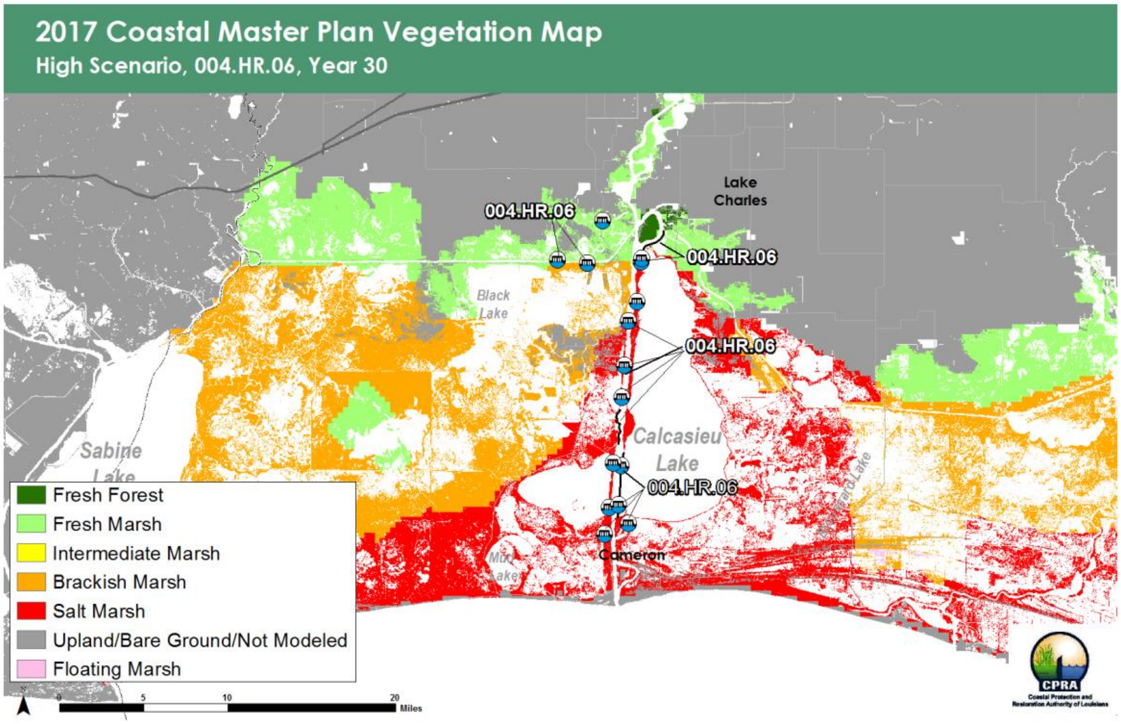

Figure 211: Wetland Habitat Distribution Associated with the Calcasieu Ship Channel Salinity Control Measures Project (year 30; high scenario).

Under the high scenario, drastic land loss occurs throughout the Calcasieu/Sabine ecoregion by years 40 and 50 (Figure 207 and Figure 208), and similar rates of loss also occur in the Mermentau Lakes and Eastern Chenier ridge ecoregions. The presence of the Calcasieu Ship Channel Salinity Control Measures project allows some wetland areas to be sustained longer than in FWOA, which results in the land gain associated with the project in years 40 and 50. However, by year 50, most of the wetlands in the area have converted to open water either with or without the project (Figure 212).

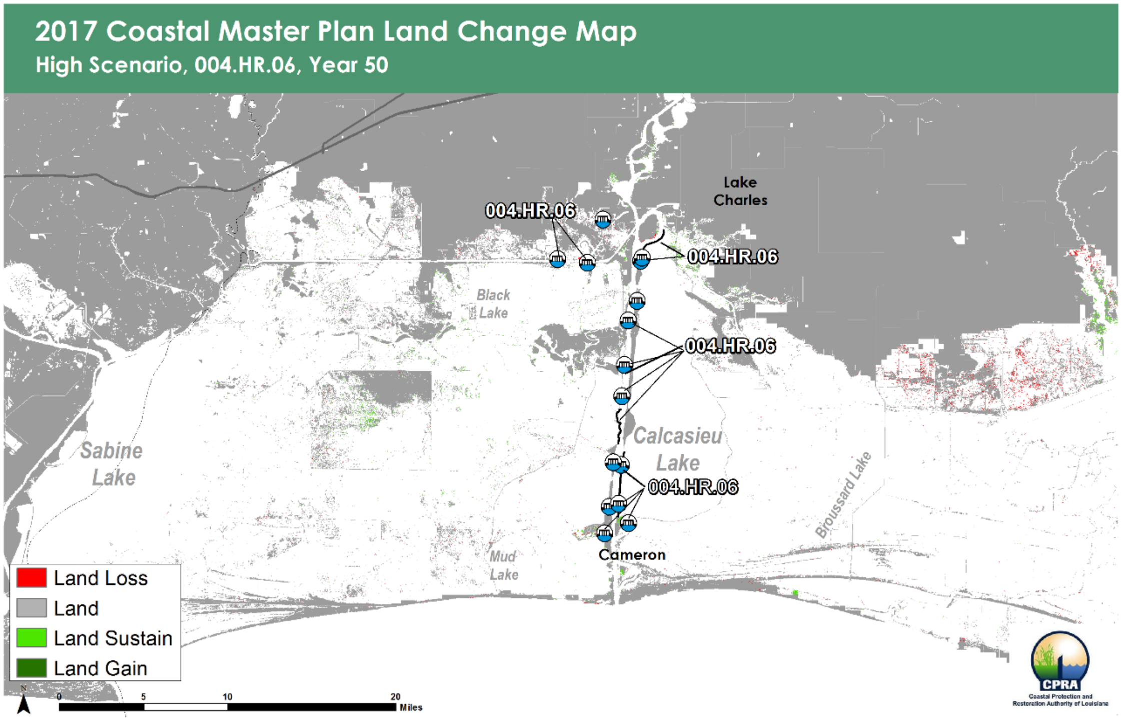

Figure 212: Land Change from the Calcasieu Ship Channel Salinity Control Measures Project Relative to FWOA (year 50; high scenario).

Under the medium scenario, habitat change the Calcasieu/Sabine ecoregion is much lower than under the high scenario (Figure 207 and Figure **213**). Under the medium scenario, the project has a positive impact on land change throughout the western coast especially in the last 30 years of the model run (Figure 214). In the Calcasieu/Sabine ecoregion, when comparing average annual land gain relative to FWOA under the two scenarios, the project has a greater average amount of land gained over the 50-year simulation under the high scenario (41.5 $km^2\ yr^{-1}$) compared to the medium scenario (34.9 $km^2\ yr^{-1}$).

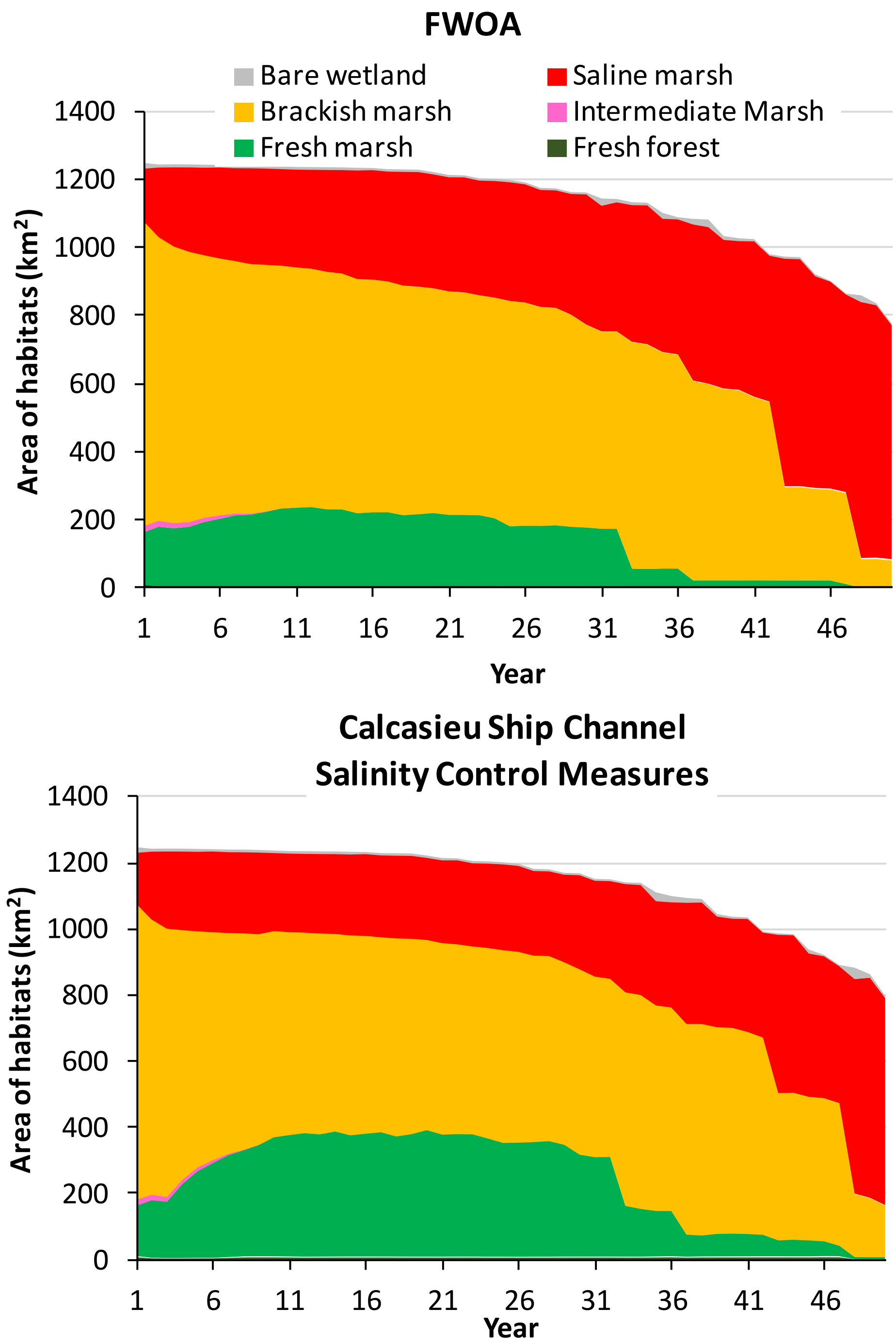

Figure 213: Change in Wetland Habitat over Time within the Calcasieu/Sabine Ecoregion in FWOA and with the Calcasieu Ship Channel Salinity Control Measures Project (medium scenario).

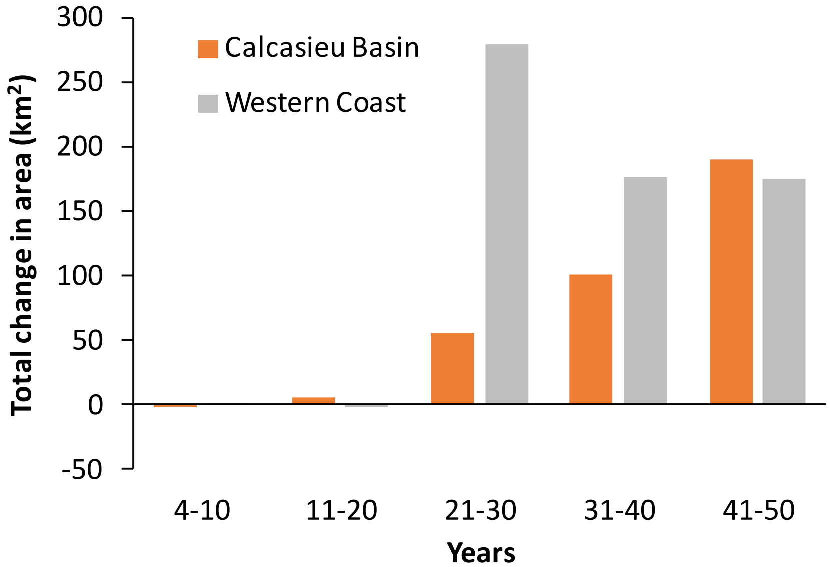

Figure 214: Change in Land Area within the Calcasieu/Sabine Ecoregion and in the Western Coast in Response to the Calcasieu Ship Channel Salinity Control Measures Project (relative to FWOA; medium scenario).

Under the medium scenario, water level changes are similar to the high scenario in amplitude and extent, but the area where salinity is dropped by >2 ppt is larger in extent under the medium scenario compared to the high scenario (
Figure **215**). Despite the impact of the project, most of the remaining wetland area in the Calcasieu/Sabine ecoregion is saline marsh under either scenario at year 50 (Figure 207 and Figure **213**). Only a slight increase in brackish marsh at year 50 occurs due to the Calcasieu Ship Channel Salinity Control Measures project.

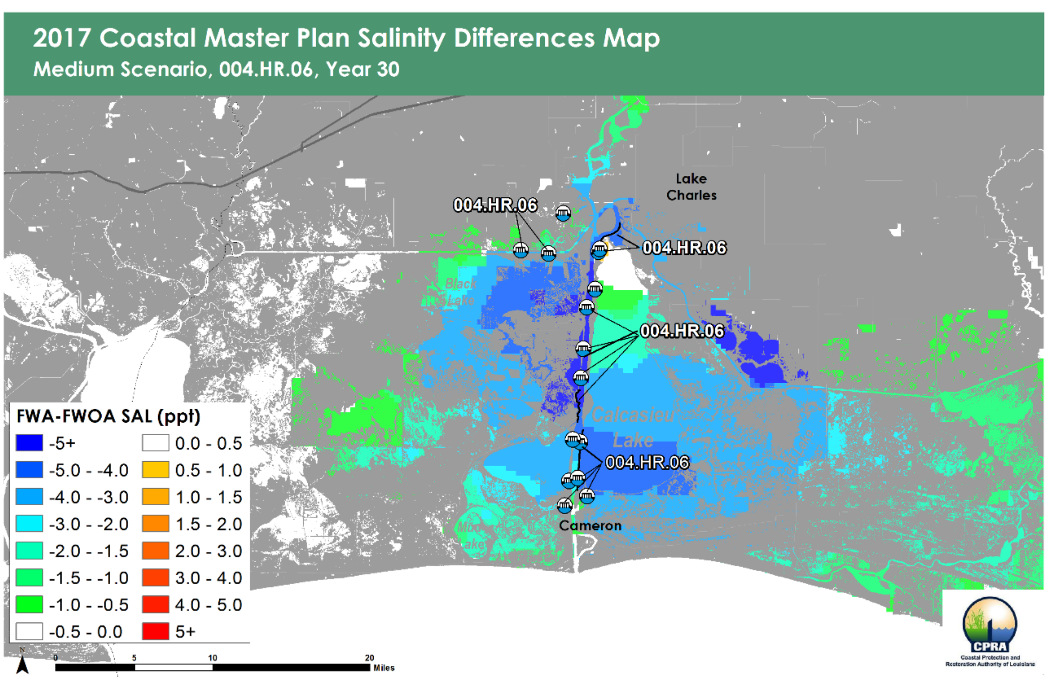

Figure 215: Change in Salinity from the Calcasieu Ship Channel Salinity Control Measures Project Relative to FWOA (year 30; medium scenario).

4.4.2 Fish, Shellfish, and Wildlife

The salinity reduction associated with the Calcasieu Ship Channel Salinity Control Measures project generally decreases habitat suitability relative to FWOA for small juvenile brown shrimp, adult spotted seatrout, and oysters throughout much of the project influence area. The decrease in habitat suitability for brown shrimp and spotted seatrout is relatively small (mostly <0.2 decrease in HSI relative to FWOA) due to these species' broader salinity tolerances (Attachments C3-13 and C3-16). Larger decreases in suitability are observed for oysters, particularly in the southern part of Calcasieu Lake, where salinity reduction is greatest and the majority of cultch substrate is located (Figure 216). In the northern part of Calcasieu Lake, the minimal amount of cultch assumed for this area increases in suitability relative to FWOA (Figure 216). This is because the project also reduces the negative effect that seasonal, low-salinity flooding events have on oyster habitat in northern Calcasieu Lake (Attachment C3-12).

In contrast, the salinity reduction increases habitat suitability relative to FWOA for largemouth bass, green-winged teal, and American alligator. Consistent with these species' habitat utilization patterns, the interior fragmented marshes generally show the greatest increases in suitability (e.g., largemouth bass; Figure 217). Alligator, however, primarily utilize areas with a high proportion of wetland and do not utilize habitat classified as salt marsh (Attachment C3-10); therefore, increases in alligator habitat suitability are less extensive than for bass and teal.

The high rate of RSLR associated with the high scenario overwhelms the project's effects on salinity and thus habitat suitability during the latter part of the 50-year simulation. Consequently, there is little difference in species' habitat suitability between the project and FWOA at year 50 (e.g., oyster and largemouth bass; Figure 216 and Figure 217). However, the project does maintain lower salinities in the northern part of the project area near the Calcasieu River, resulting in areas of high habitat suitability for largemouth bass and alligator (Figure 217).

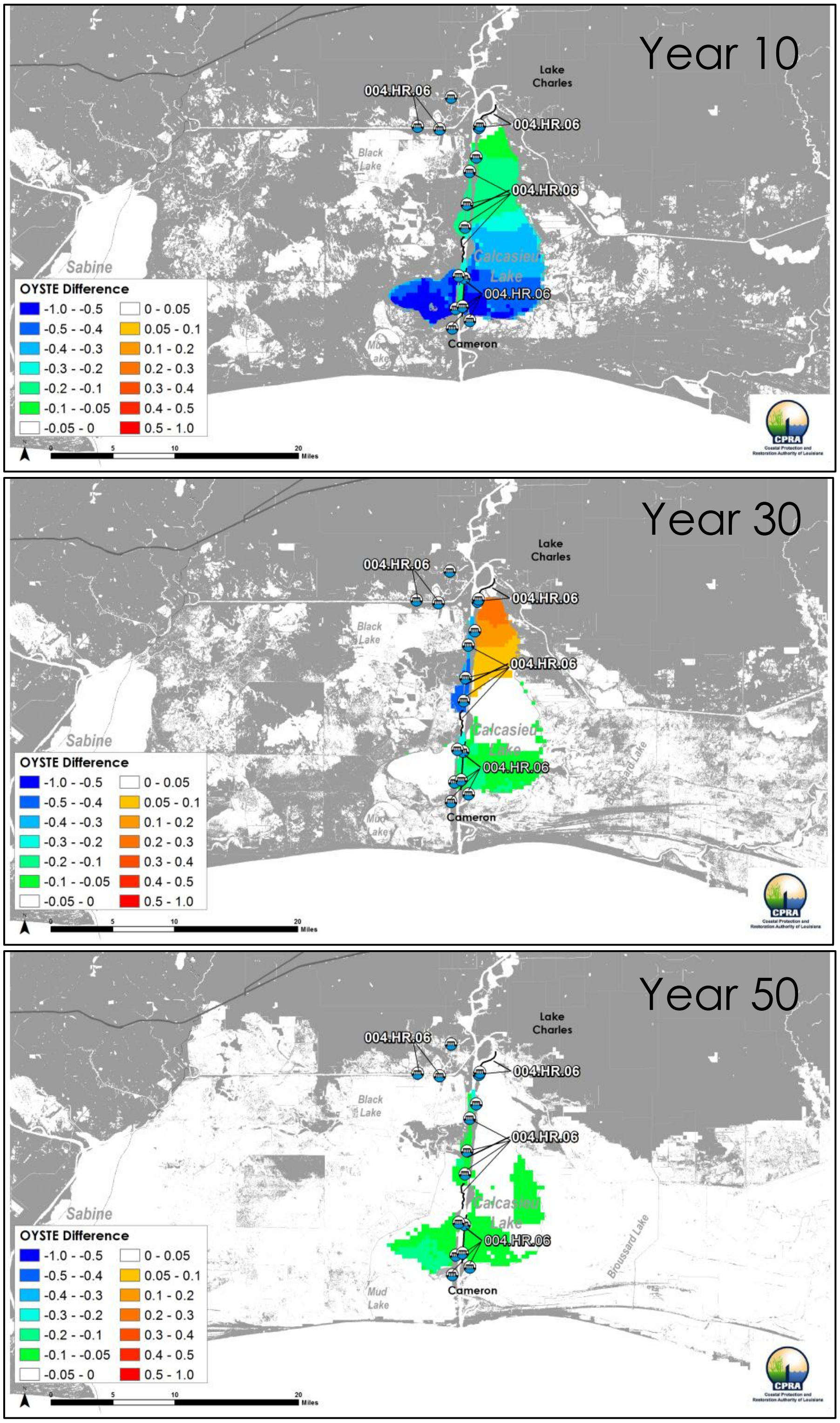

Figure 216: Difference in Eastern Oyster Habitat Suitability Associated with the Calcasieu Ship Channel Salinity Control Measures Project Relative to FWOA (years 20, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the project.

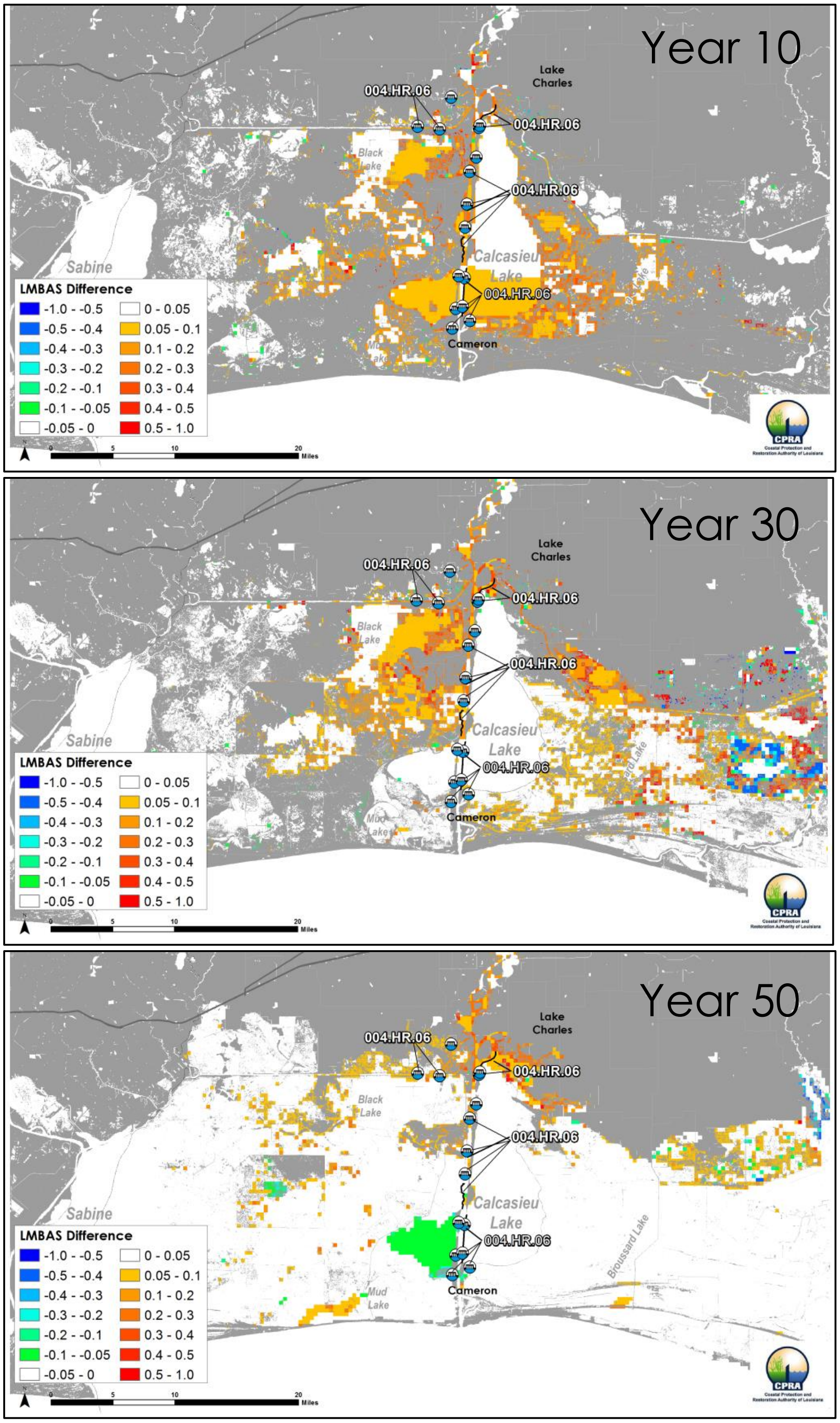

Figure 217: Difference in Largemouth Bass Habitat Suitability Associated with the Calcasieu Ship Channel Salinity Control Measures Project Relative to FWOA (years 20, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the project.

4.5 Lake Hermitage Shoreline Protection (002.SP.100)[7]

The Lake Hermitage Shoreline Protection (002.SP.100) project (implemented in year 5) is located in Plaquemines Parish, Louisiana around Lake Hermitage. The project includes shoreline protection using rock breakwaters of approximately 2,343 m around the southern shore of Lake Hermitage to preserve shoreline integrity and reduce wetland degradation from wave erosion.

In the high scenario, the effects in year 10 are the most extreme effects over the 50-year simulation, even though the change is minimal (Figure 218). There is a very small area of sustained land (as compared to FWOA) in a small pond south of Lake Hermitage near the shoreline protection project. Just south of that small area of sustained land, there is an equally sized area of land loss.

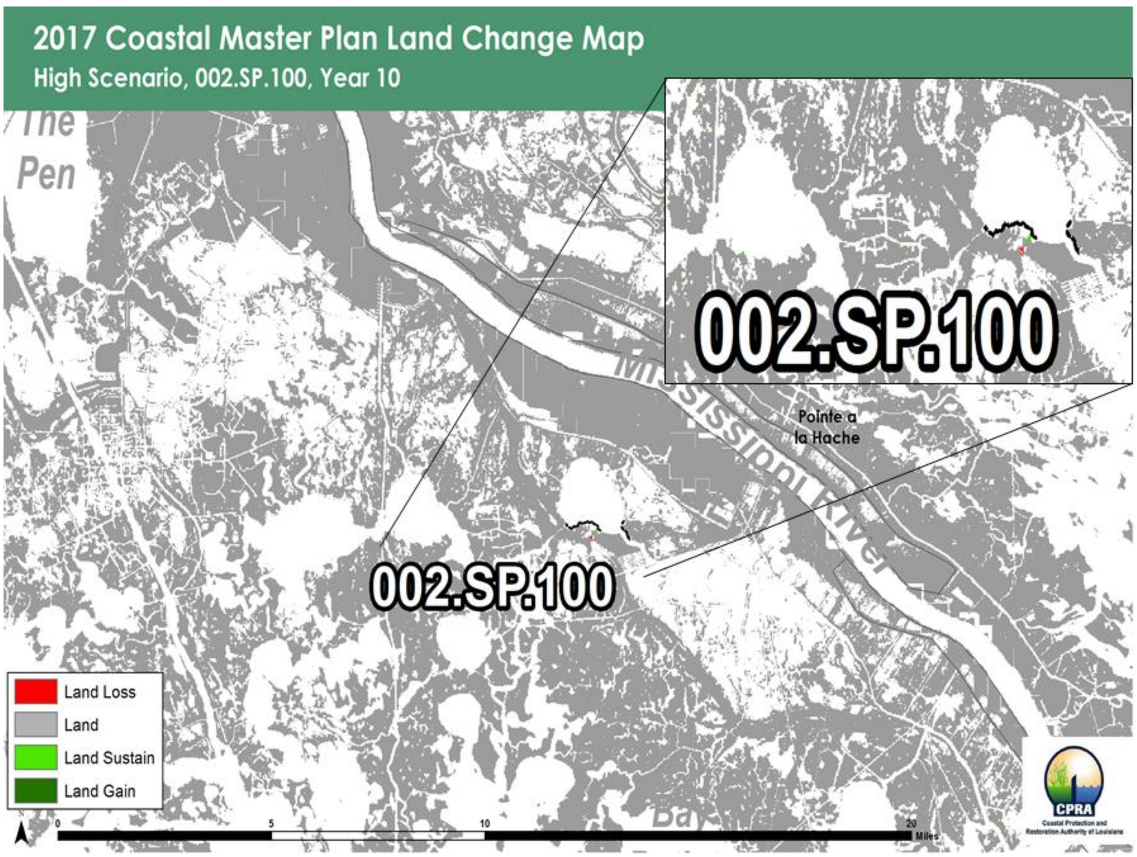

Figure 218: Land Change from Lake Hermitage Shoreline Protection Relative to FWOA (year 10; high scenario). The project is represented by the black line on the southern shore of Lake Hermitage.

[7] Decadal animations of the 50-year simulation outputs can be found in Attachment C4-5: Lake Hermitage Shoreline Protection (002.SP.100), including land.

The small area of land loss south of Lake Hermitage is not present in the results for the low scenario. In year 20, there are less scattered, minor areas of land loss in the low scenario versus the high scenario. In years 30 through 50 for the low scenario, there is no project-induced land change, as was also observed in the high scenario. With the exception of the results at year 20, there is no noticeable difference in project effect between the low and medium scenario. In year 20, there is more scattered land loss in the medium scenario than in the low scenario in the area west of the project site. Otherwise, the project effects are very similar between the low and medium scenario. The low scenario is the only simulation in which the project has land adjacent to it in year 50, and thus it represents the only conditions simulated under which the project seems to have any effect.

The overall lack of project effects observed is likely in part due to the spatial resolution of the model.

4.6 Grand Lake Bank Stabilization (004.BS.01)[8]

The Grand Lake Bank Stabilization (004.BS.01) project (implemented in year 8) is located in Cameron Parish, Louisiana, around Grand Lake and Mallard Bay. The project includes bank stabilization through earthen fill placement, high performance turf reinforcement mat, and vegetative plantings of approximately 91,048 m of perimeter shoreline at Grand Lake to preserve shoreline integrity and reduce wetland degradation from wave erosion.

In the high scenario, the project effects in year 10 (two years after project implementation) are minimal, with minor land sustained (as compared to FWOA) in two small ponds along the western edge of Grand Lake and along the southeast/east edge of Grand Lake (where the project was placed). In year 20, there is more area along the eastern edge of the lake in which land was sustained (Figure 219).

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[8] Decadal animations of the 50-year simulation outputs can be found in Attachment C4-6: Grand Lank Bank Stabilization (004.BS.01), including land.

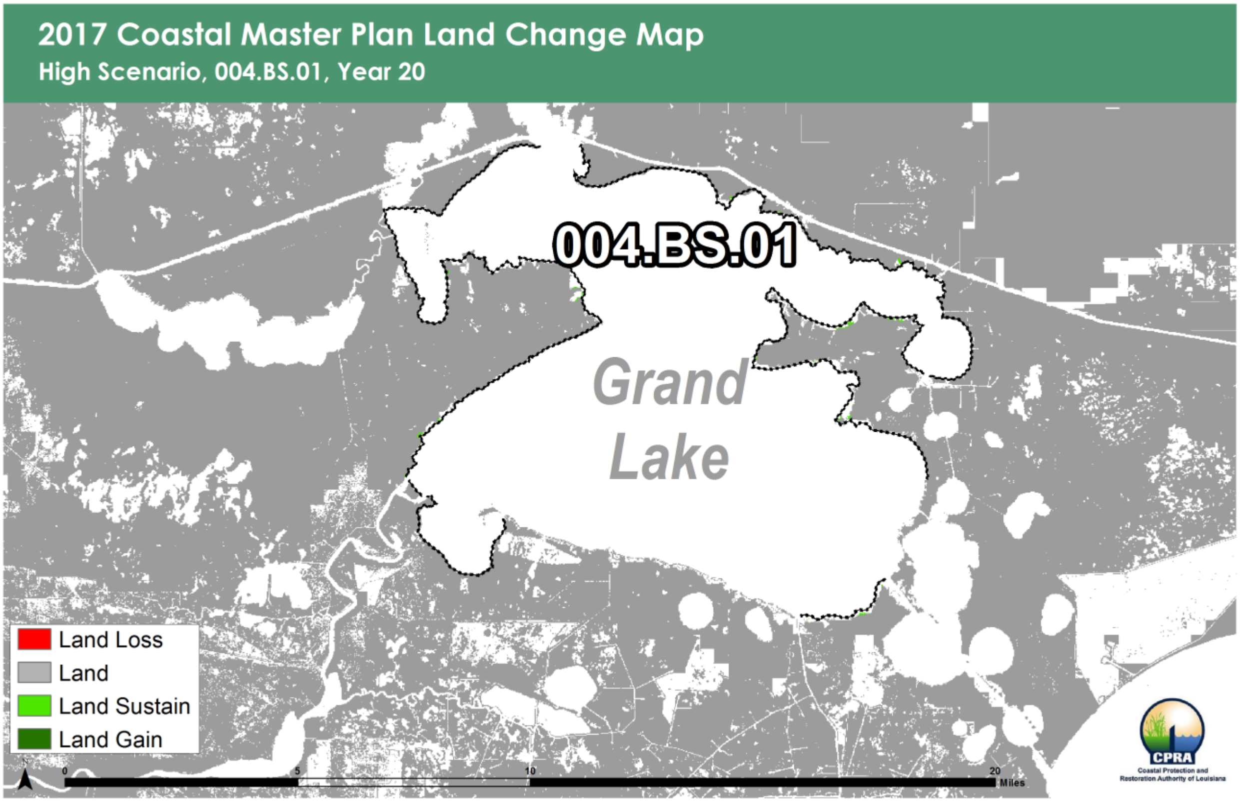

Figure 219: Land Change from Grand Lake Bank Stabilization Relative to FWOA (year 20; high scenario). The project is represented by the black line along the perimeter of Grand Lake.

In year 30, the land surrounding the lake has undergone major losses due to marsh collapse rather than the edge erosion the project is designed to limit. The project seems to have lost what little positive effect it previously had on the region due to the surrounding land loss. Small areas of sustained land can be seen in two locations on the west side of Grand Lake. The land difference observed north of Grand Lake, due to slightly altered hydrology, falls within the model uncertainty, and thus is not considered a major project effect.

In year 40, the banks of Grand Lake are barely detectable among the surrounding deteriorated land (Figure 220). No areas of sustained land or land gain due to the project are visible; however, small areas of land loss are seen in the region north of Mallard Bay.

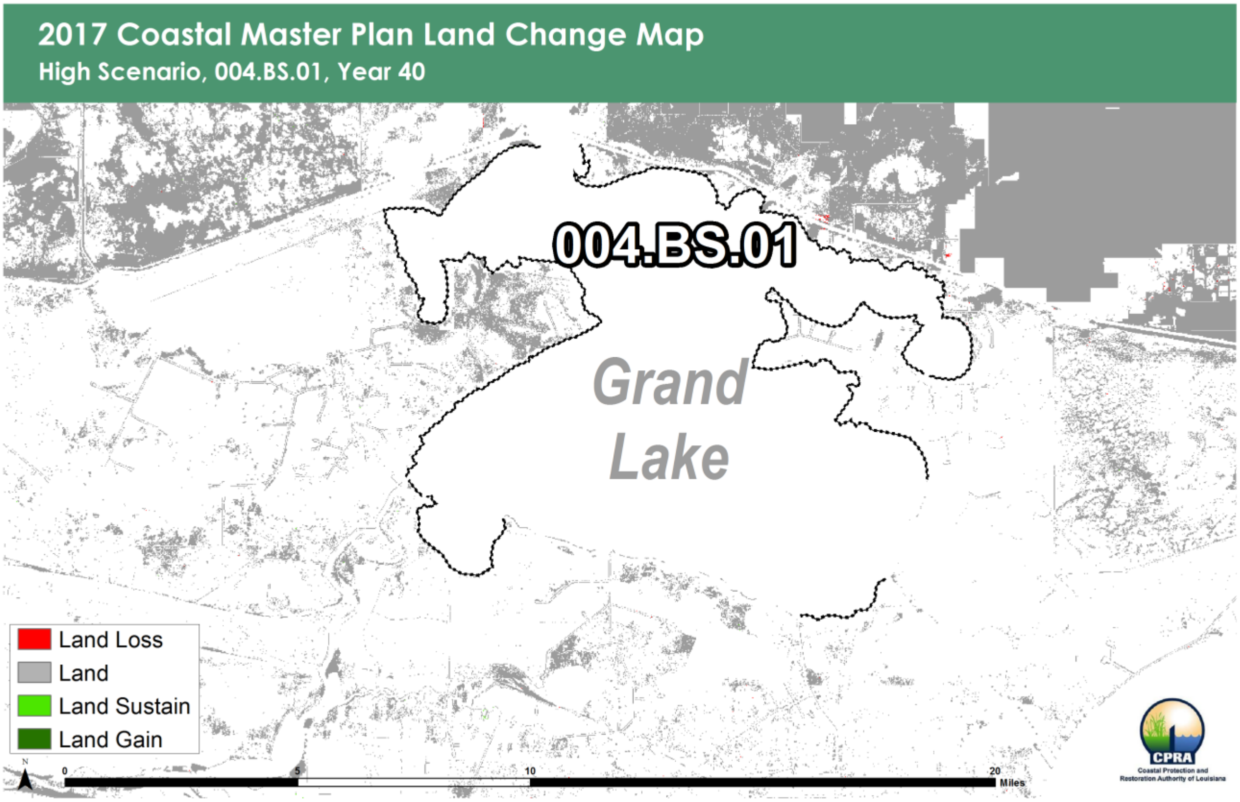

Figure 220: Land Change from Grand Lake Bank Stabilization Relative to FWOA (year 40; high scenario). The project is represented by the black line along the perimeter of Grand Lake.

Similar results are seen in year 50 in the high scenario. By this time in the simulation, the land south of the GIWW is lost in both FWOA and with the project in place, with only a few residual land fragments remaining. A small area of land loss due to the project is observed north of Mallard Bay.

There is little to no change in effects due to the project in the low scenario versus the high scenario in years 10 and 20. In years 30 through 50, the land loss north of Mallard Bay seen in the high scenario is not visible in the low scenario, which verifies that this land loss is associated with marsh collapse (as opposed to marsh edge erosion). In the low scenario, land sustained in years 30 through 50 is still evident. The medium scenario shows effects similar to the low scenario; however, some very small areas of land difference north of Mallard Bay are seen in years 40 and 50. The results indicate that the project performs as intended (by protecting the land in the immediate vicinity of the stabilization project) prior to major land loss in the surrounding area due to marsh collapse processes. The greater the rate of ESLR prescribed within each scenario, the more quickly the project loses its protective capabilities.

The overall lack of project effects observed is likely in part due to the spatial resolution of the model.

4.7 Bayou Decade Ridge Restoration (03a.RC.01)[9]

The Bayou Decade Ridge Restoration (03a.RC.01) project (implemented in year 5) is located in Terrebonne Parish, Louisiana from Lake Decade to Lost Lake. The project includes the restoration of approximately 12,986 m of historic ridge along Bayou Decade to provide coastal upland habitat, restore natural hydrology, and provide wave attenuation.

In the high scenario, the effects in year 10 are minimal, with minor land loss (as compared to FWOA) south of the project between the project site and Lake Mechant. In year 20, there is minor land loss in the same area, but more exaggerated losses north of the project near Lost Lake, Lake Penchant, and Lake Decade (Figure 221). This is likely due to altered hydrologic connections in the model. In year 30, the ridge is surrounded by deteriorated and fragmented land. Spatially variable regions of land loss and sustained land under project implementation compared to FWOA are seen approximately 8 km northeast and 8 km northwest of the project. No clear or substantive pattern of land change is evident. In year 40, the project is entirely surrounded by water due to continued land loss (Figure 222), though some fringe marsh is present between the project and offshore. The area around Lake Mechant and Bayou Dularge shows the greatest amount of sustained land during the simulation. There is also an area of land loss closer to Lake Mechant (again, likely due to altered hydrologic connections in the model). In year 50, additional land is lost north of the project, and the land sustained near Bayou Dularge continues from year 40.

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[9] Decadal animations of the 50-year simulation outputs can be found in Attachment C4-7: Bayou Decade Ridge Restoration (03a.RC.01), including land.

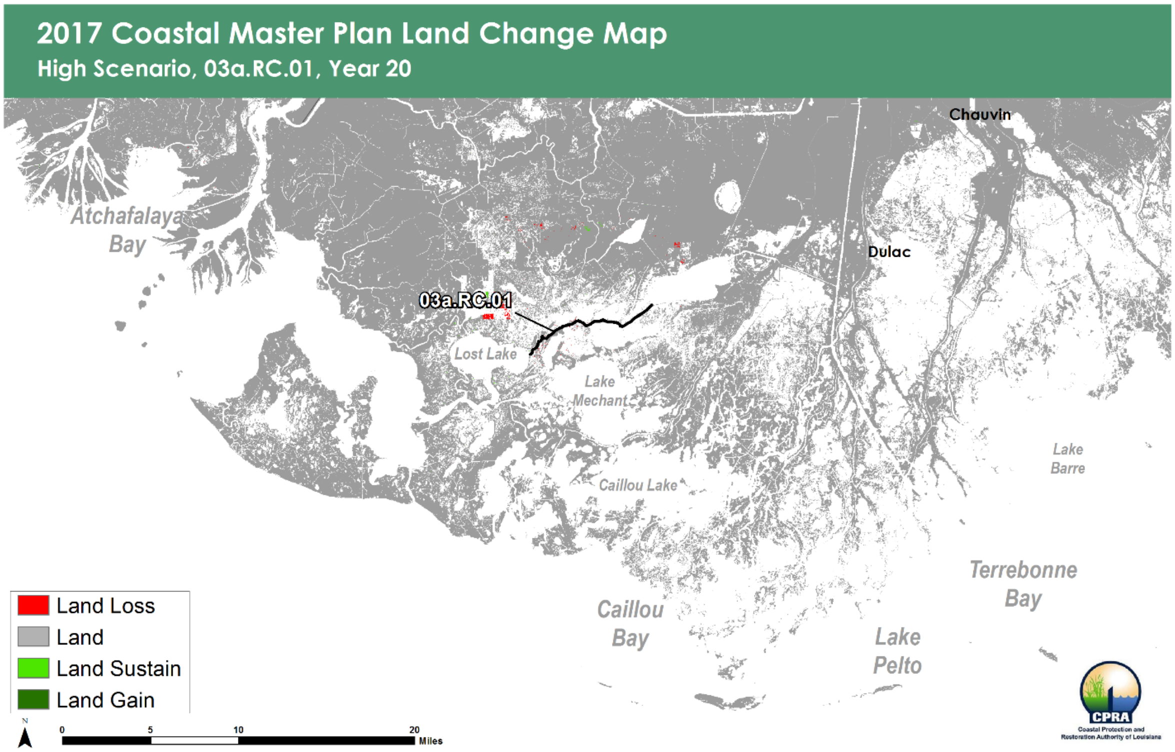

Figure 221: Land Change from Bayou Decade Ridge Restoration Relative to FWOA (year 20; high scenario).

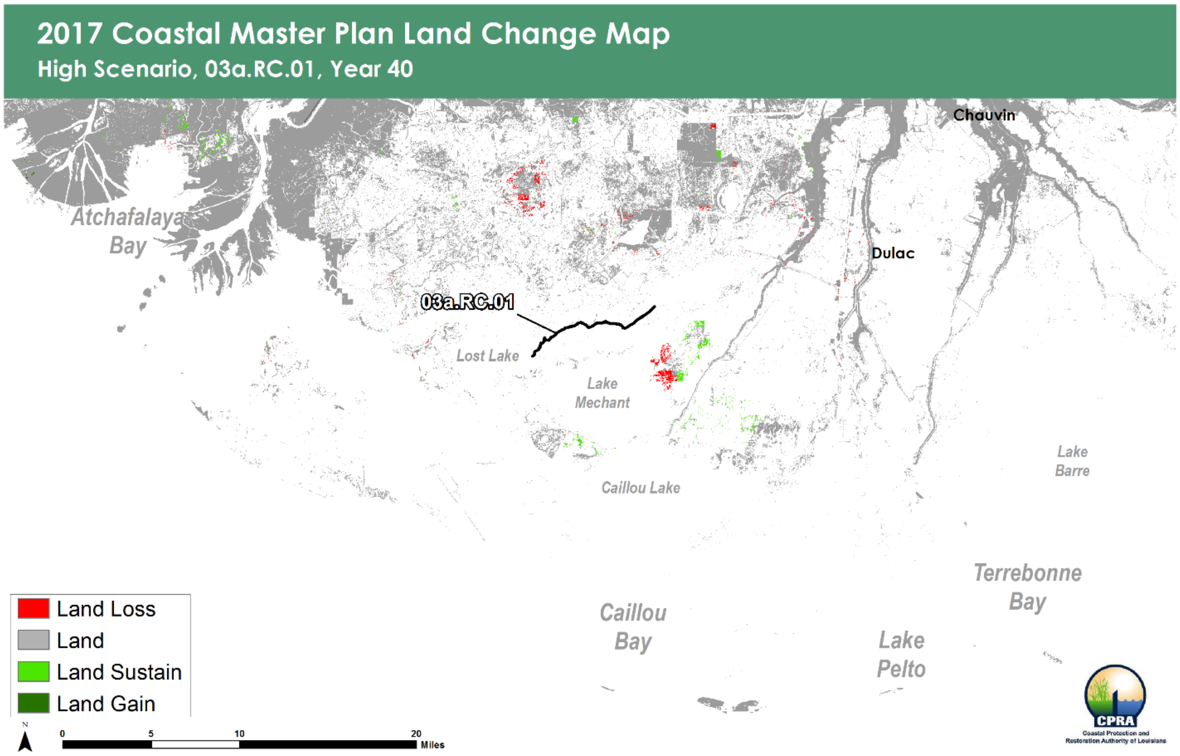

Figure 222: Land change from Bayou Decade Ridge Restoration relative to FWOA (year 40; high scenario).

Overall, during the 50-year simulation, there is no substantive, consistent, or spatial pattern of sustained, gained, or lost land except for an apparent trend of sustained land in the area around Bayou Dularge. The region shows a general shift from saline marsh to bare ground between years 30 and 40 in the high scenario and a complete loss of land with both project implementation and FWOA by year 50. The sustained land areas in year 50 all contain the vegetation type "bare ground/upland." In ICM_v1, bare ground areas were not subject to a collapse criterion. This meant that the hydrologic conditions were not suitable to nearby vegetation species that could disperse into the area, and the loss of vegetated cover occurred prior to any collapse mechanism being triggered within the morphology subroutine. Therefore, while it appears that some land may be sustained at year 50, it is likely unsuitable for any modeled vegetation specie to establish there. These areas of persistent bare ground were handled differently in ICM_v3; a collapse mechanism was put in place to account for these areas. For more information regarding these adjustments made to the code of ICM_v3, refer to Attachment C3-22.

There are some far-field land changes that are likely due to differences in salinity calculations. While some of the difference is potentially due to hydraulic flow constrictions post-project, it is likely also a function of salinity calculation instability in later years when hydraulic flow paths are substantially different than those present on the landscape during the model calibration/validation period. For more details on these instabilities (which were resolved in ICM_v3), please refer to Attachment C3-23.

The effects due to the project in the low scenario are minimal, with the majority of the land change being spatially variable. The area of primary change in the high scenario (northeast of Lake Mechant) shows no change in the low scenario for project implementation compared to FWOA. This implies that the conditions in the high scenario are more conducive to larger project effects. Results in the low and the medium scenarios are similar, but the medium scenario does show a slightly greater occurrence of land sustained throughout the 50 years. Land loss similar to that seen in the high scenario, but at a smaller scale, can be seen in the area northeast of Lake Mechant in the medium scenario.

The overall lack of project effects observed is likely in part due to the spatial resolution of the model.

4.8 Barataria Pass to Sandy Point Barrier Island Restoration (002.BH.04)[10]

The restoration of the barrier islands between Barataria Pass and Sandy Point is intended to provide beach, dune, and back barrier marsh habitat and to provide storm surge and wave attenuation for the Barataria Basin. It is implemented in year 7 of the ICM simulation.

The barrier island model (BIMODE subroutine - Attachment C3-4) simulates the effects of long-shore sediment transport, silt loss, bayside erosion, and RSLR on an annual basis. The results of the simulations for implementing this project are compared to those for FWOA; all analyses discussed herein are for the high scenario and focus on the Chaland Headland portion of the project. While these processes and functions result in similar barrier shoreline erosion and landward migration trends, the restored barrier islands experience less shoreline erosion and migration. The primary reasons are two-fold. First, a restored island subjected to the same wave field experiences less shoreline erosion than an unrestored island due to the raised beach berm elevation which increases the effective profile height (Attachment C3-4). Second, the BIMODE assumes that the sediment utilized for restoration is coarser than the existing island's native beach; thus, the percent silt loss is reduced for a restored island reducing net erosion (Attachment C3-4).

Figure 223 depicts a plan view of shoreline change on decadal time steps through year 20 for the eastern segment of the Chaland Headland. The island was restored in year 7 as part of the Barataria Pass to Sandy Point Barrier Island Restoration (002.BH.04) project, which is shown by the movement of the bayside shoreline between year 1 and year 10. Incremental landward retreat of the gulf side shoreline and erosion of the bayside shoreline occurs with corresponding island width and land area reductions over time. The trends are similar to those under FWOA although at lower rates as discussed below.

[10] Decadal animations of the 50-year simulation outputs can be found in Attachment C4-8: Barataria Pass to Sandy Point Barrier Island Restoration (002.BH.04), including land and pelican HSI.

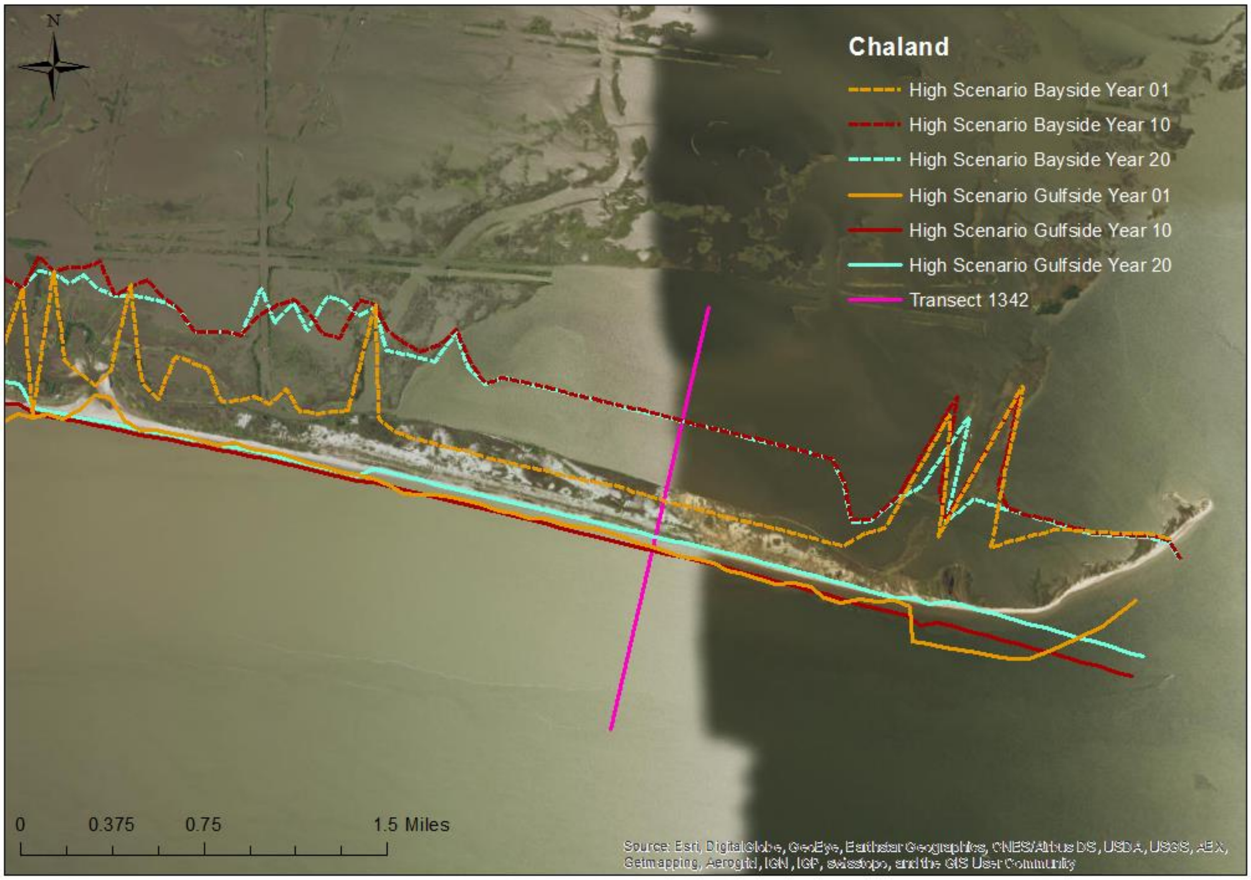

Figure 223: Plan View of Chaland Headland Shoreline Changes through Year 20 with Project Implementation.

Figure 224 depicts a representative cross section for the Chaland Headland for FWOA and with the project in place through year 20, corresponding to the plan view depiction (Figure 223). The shoreface erosion and silt loss on the gulf side, erosion of the bayside shoreline, and vertical lowering of the profile to account for the effects of RSLR is shown in both FWOA and with the project. The unrestored island experienced greater erosion, loss of berm elevation, and profile change than the restored island. For example, at Profile 1342, between year 10 and year 20, the erosion rates measured at the 0.8 m contour were -9.6 m/yr and -8.6 m/yr, and the mean berm elevation change was -0.5 m and -0.4 m, for FWOA and with the project, respectively.

Figure 224: Representative Cross Sectional Comparison of Eastern Chaland Headland through Year 20 for FWOA and with the Project (FWA); Year 1 FWOA and with the Project are the Same Profile.

Cross-shore sediment transport and breaching were modeled during years when storms impacted the barrier shorelines. While the restored islands experience erosion of the gulf side shoreface, beach berm, dune, and marsh platform resulting in land loss, overwash is reduced because of higher restored beach and dune elevations compared to FWOA. Figure 225 and Figure **226** depict a plan view of pre-storm and post-storm shorelines and pre-storm and post-storm profiles, respectively, for the Chaland Headland which was restored in year 7 as part of the Barataria Pass to Sandy Point Barrier Island Restoration project. Storm 143 was modeled in year 35 and passed within 80 km of Chaland Headland. Overwash occurs as shown between the range of 600 m and 650 m in FWOA by higher berm elevations in year 35, equal to 1.0 m^3/m compared to year 34; while, minimal overwash is observed with the project in place between the range of 400 m and 450 m, equal to 0.3 m^3/m.

Figure 225: Plan View of Pre- and Post-Storm Shorelines for Chaland Headland at Years 34-35 with Project Implementation.

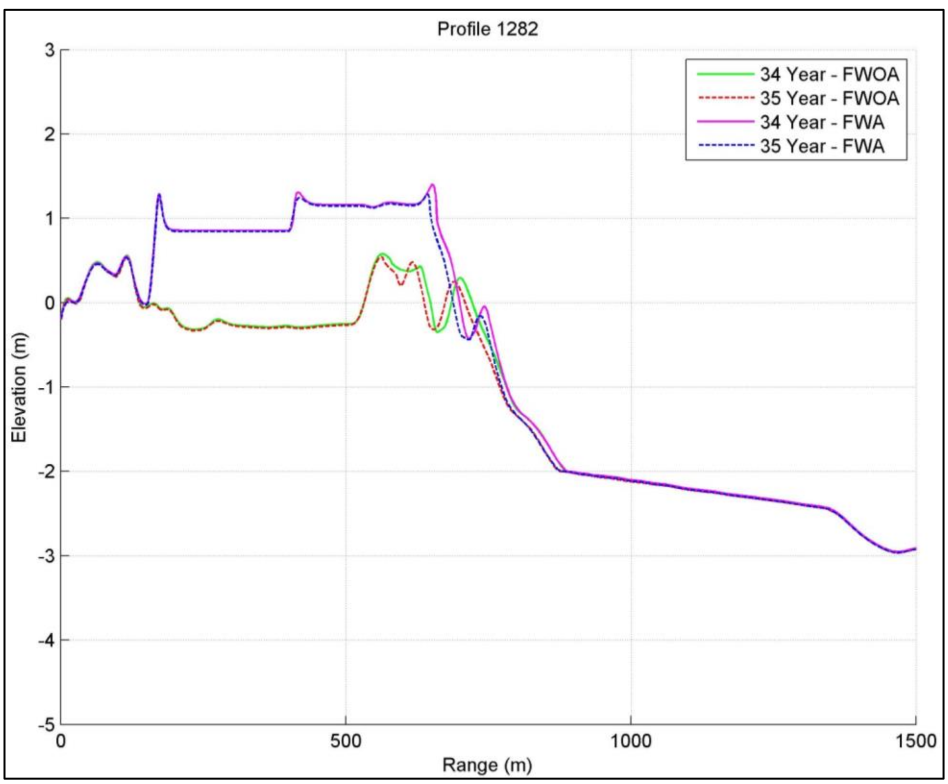

Figure 226: Pre- and Post-Storm Cross Sectional Comparison for Chaland Headland at Years 34-35 for FWOA and with the Project (FWA).

Significant reductions in breaching are observed on the restored islands within the 50-year period. Figure 227 and Figure 228 depict a plan view and a corresponding representative cross section for the central segment of the Chaland Headland for FWOA and with the project in place through year 20. While breaching occurs on the unrestored island in FWOA, which is shown by the gap in both the gulf side and bayside shorelines in year 20 in the plan view, the restored island did not breach. The individual islands within the project area experience 18 breaches under FWOA versus no breaches with the project in place, within the 50-year simulation.

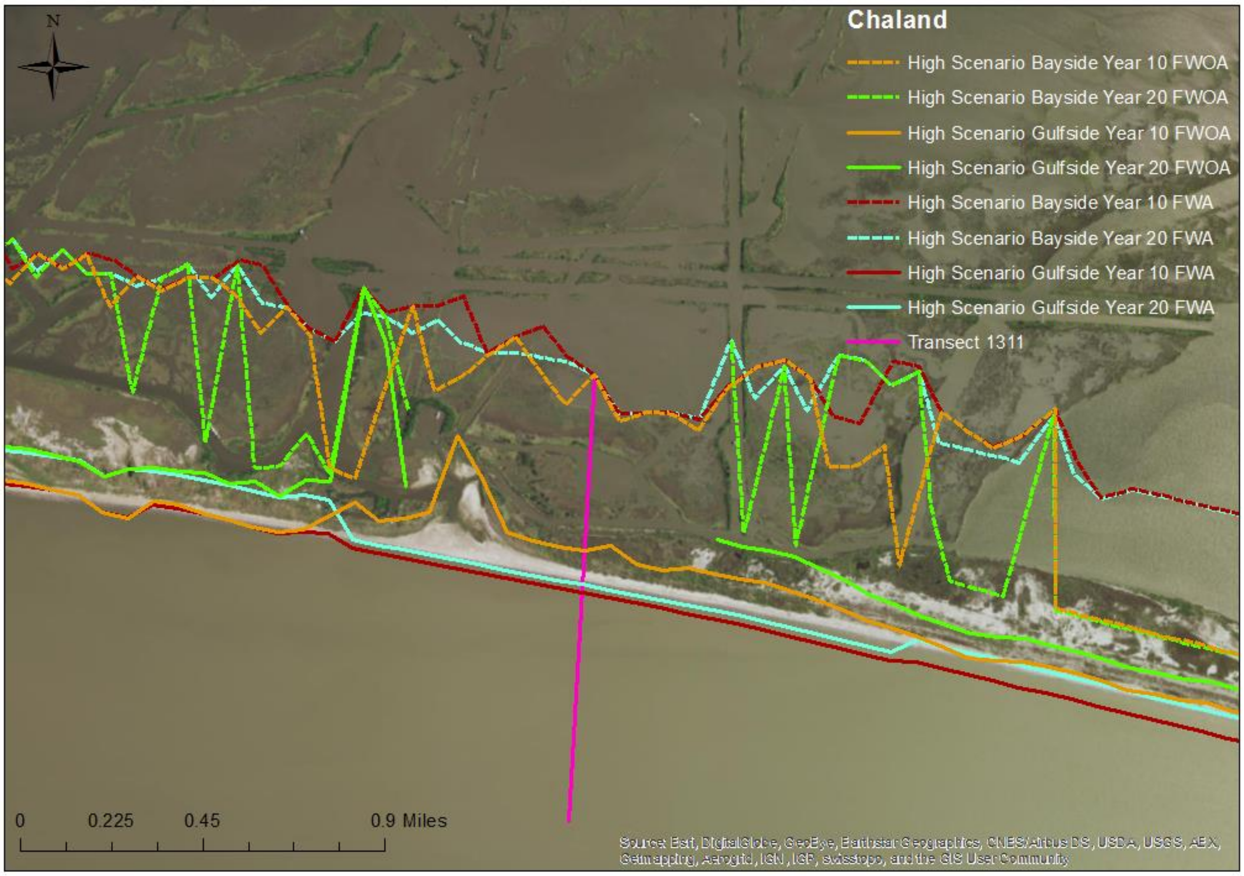

Figure 227: Plan View of Central Chaland Headland Shoreline Changes through Year 20 for FWOA and with the Project (FWA).

Figure 228: Representative Cross Sectional Comparison of Central Chaland Headland through Year 20 for FWOA and with the Project (FWA).

Land area changes were computed in 5-year increments over the 50-year period with the project in place. The FWOA land area changes (Chapter 4 – FWOA Section) were subtracted from the with-project land area changes to compute the barrier island restoration "effect," that is, the land area benefits attributed to the restoration project, over the 50-year period. Figure 229 presents the land area project benefits over time for the islands restored with the Barataria Pass to Sandy Point Barrier Island Restoration project. The average benefits over the 50-year period for comparison equaled over 14 km^2.

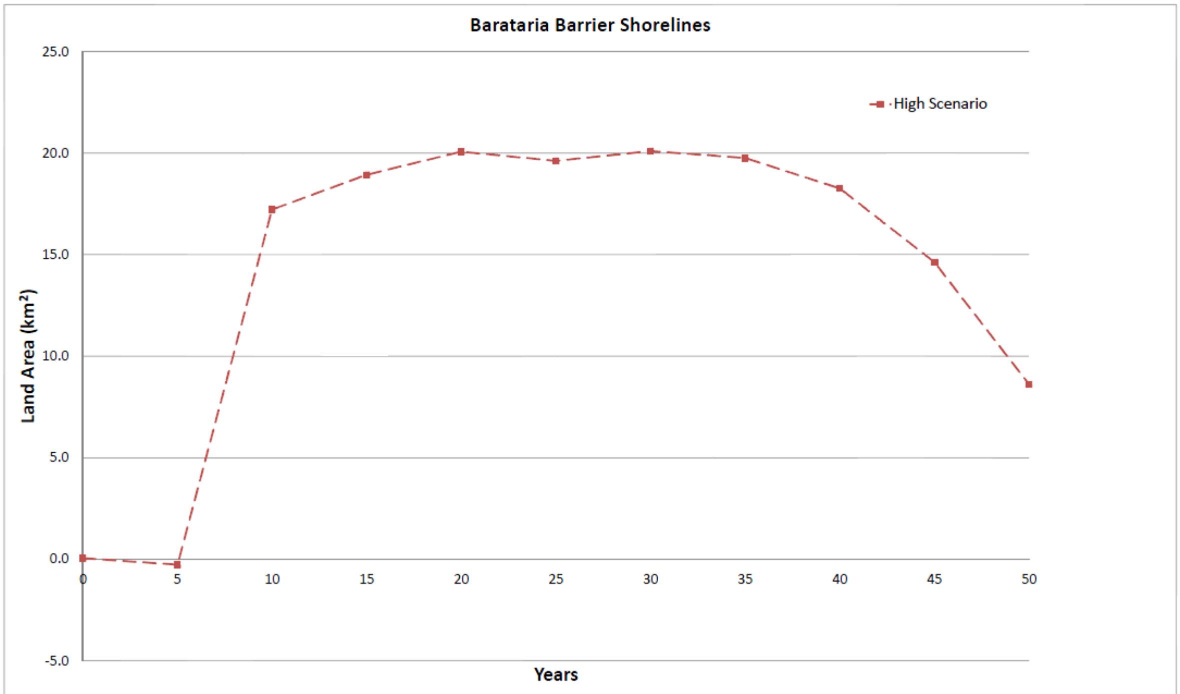

Figure 229: Net Change in Land Area over Time for the Barataria Pass to Sandy Point Barrier Island Restoration Project.

4.9 Biloxi Marsh Oyster Reef (001.OR.01a)[11]

The Biloxi Marsh Oyster Reef (001.OR.01a) project is located in St. Bernard Parish, Louisiana, north of Drum Bay in the Biloxi Marsh. The project includes the creation of approximately 34,231 m of oyster barrier reef along the eastern shore of the Biloxi Marsh. In addition to protecting nearby shorelines from wave-driven erosion, the goal of the project is to augment local oyster habitat by introducing suitable hard substrate upon which new oyster colonies may develop. This project is implemented in year 7 of the ICM simulation.

4.9.1 Landscape

In all scenarios (low, medium, and high), there is no observed change in land due to the project in any year (Figure 230 and Figure 231). The effects of ongoing land loss processes are clearly visible over time, but as determined by a comparison against FWOA, there is no change due to the project. This result is reasonable since oyster reef projects are implemented offshore and are represented in the model solely as a reduction in marsh edge erosion rates. The oyster reef project reduces edge erosion rates for marsh areas that are completely exposed to sea level rise. Other shoreline protection projects tend to show some minor impact in earlier years if the adjacent land area remains and is protected from wave erosion by the project.
However, the oyster reef projects are implemented in an environment that is more similar to the

[11] Decadal animations of the 50-year simulation outputs can be found in Attachment C4-9: Biloxi Marsh Oyster Reef (001.OR.01a), including land and oyster HSI.

later decades of the shoreline protection projects, where inundation-driven land loss results in no net project impact, with respect to land area.

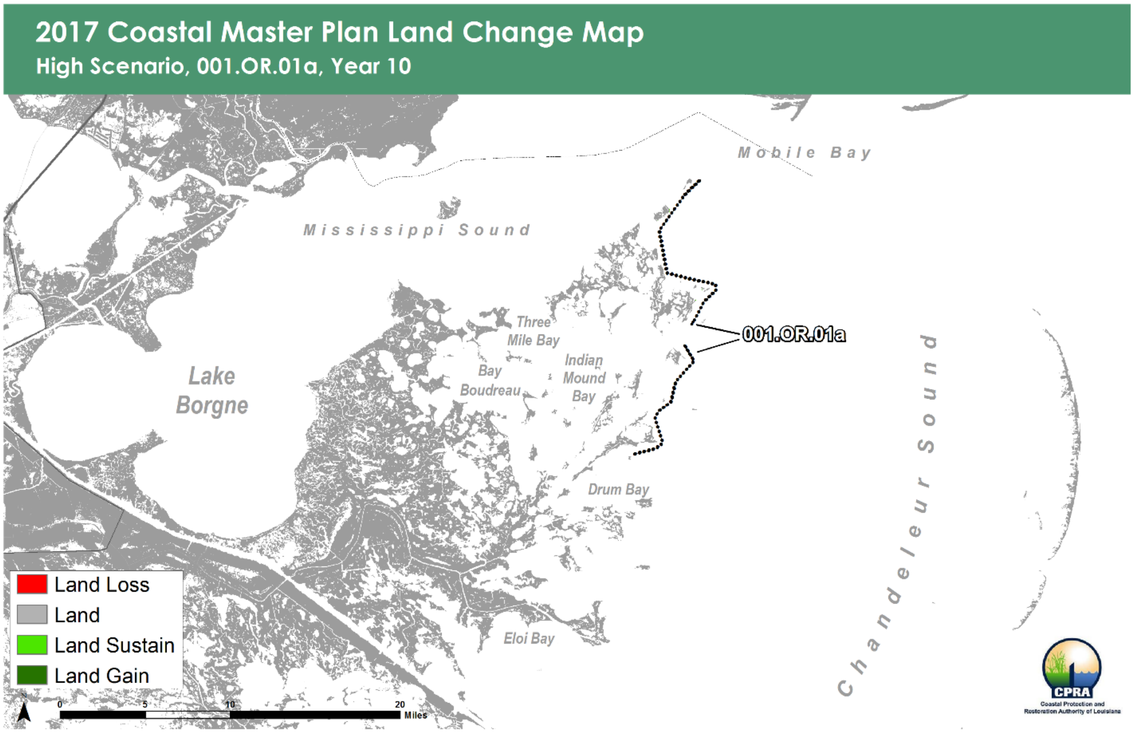

Figure 230: Land Change from Biloxi Marsh Oyster Reef Relative to FWOA (year 10; high scenario).

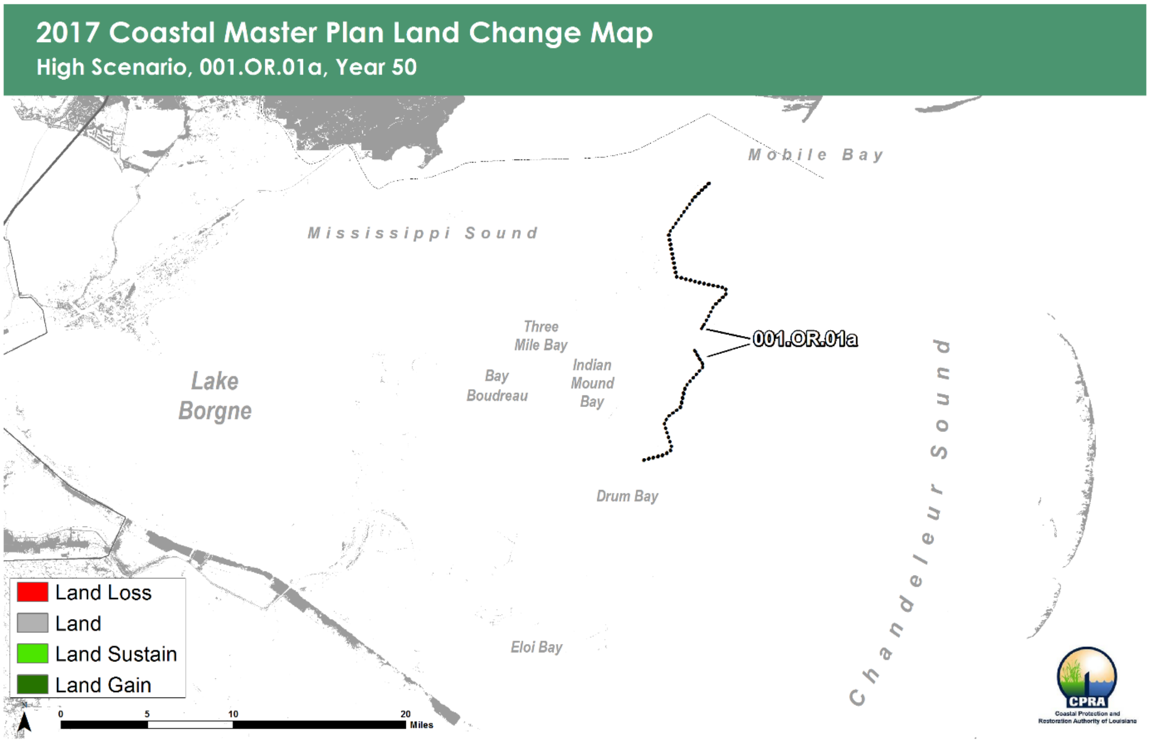

Figure 231: Land Change from Biloxi Marsh Oyster Reef Relative to FWOA (year 50; high scenario).

4.9.2 Oyster Habitat Suitability

The hard substrate provided by the Biloxi Marsh Oyster Reef project results in an increase in oyster habitat suitability relative to FWOA, but primarily during the latter half of the 50-year simulation (Figure 232). During the first half of the model run, there are frequent low-salinity flooding events that greatly reduce the suitability of the project for oyster (Attachment C3-12), particularly in year 10 of the simulation (Figure 232). These events do not occur during the latter half of the simulation because sea level rise generally increases salinities, and as a result, conditions are more suitable for oysters.

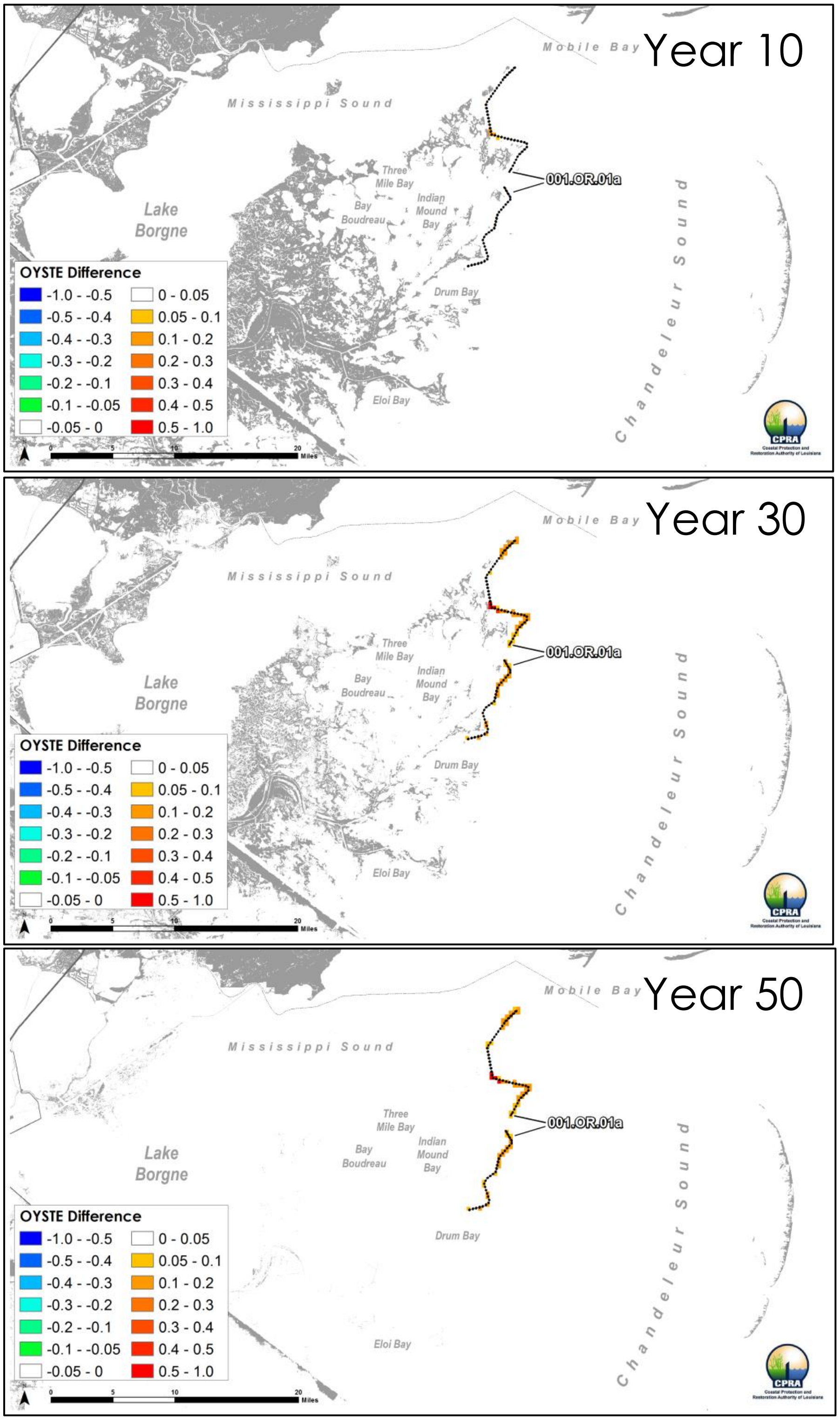

Figure 232: Difference in Eastern Oyster Habitat Suitability Associated with the Biloxi Marsh Oyster Reef Relative to FWOA (years 20, 30, and 50; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease in suitability with the project.

4.10 Upper Barataria Risk Reduction (002.HP.06)

The Upper Barataria Risk Reduction project alignment (002.HP.06) is shown on Figure 233. For the purposes of modeling efficiency, this project and the Lake Pontchartrain Barrier project alignment (001.HP.08) are simulated simultaneously. The two projects do not alter water surface elevation or waves in the same areas.

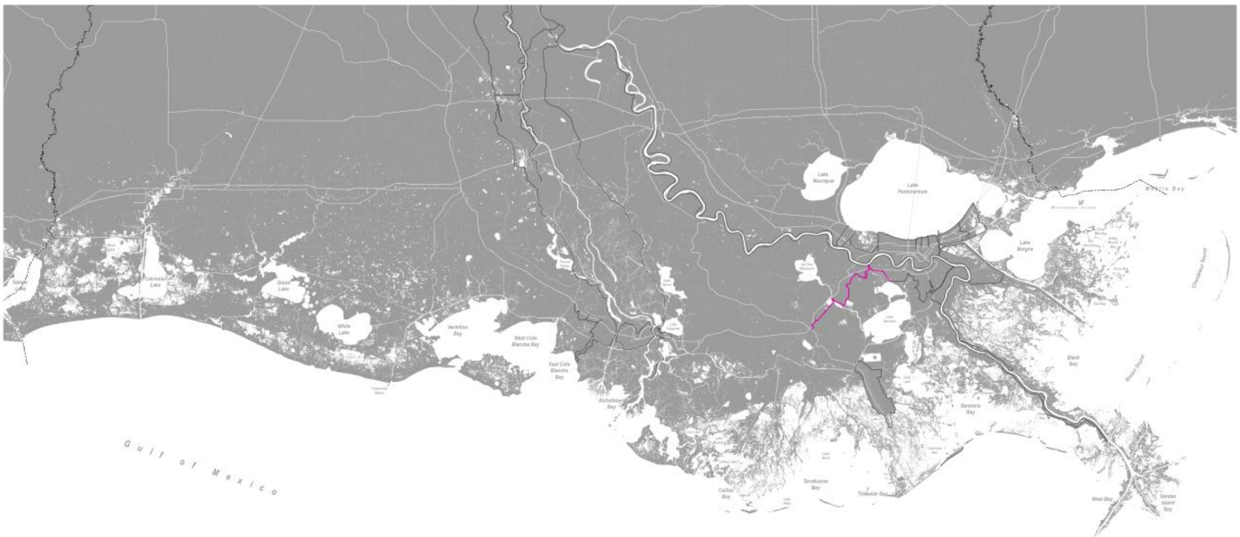

Figure 233: Upper Barataria Risk Reduction Alignment, as Indicated by the Pink Line.

Figure 234 and Figure 235 show the changes in maximum water surface elevation resulting from project implementation for two hurricanes of different strengths under the high scenario for the year 50 FWOA landscape. Figure 234 shows a moderately sized storm, Storm 012, generating storm surge in the area. The project provides benefits to the Upper Barataria region as well as areas along the West Bank of the Mississippi River. Like Figure 234, Figure 235 shows water surface elevation reduction in the upper reaches of the Barataria Basin but for a much larger storm, Storm 018. Storm surge builds against both the Upper Barataria Risk Reduction project and the HSDRRS levee system, eventually increasing water levels on the interior of HSDRRS. It should be noted that the West Bank area is flooded both with and without the Upper Barataria Risk Reduction project for Storm 018; however, with the project in place, water levels are increased by approximately 0.5 m.

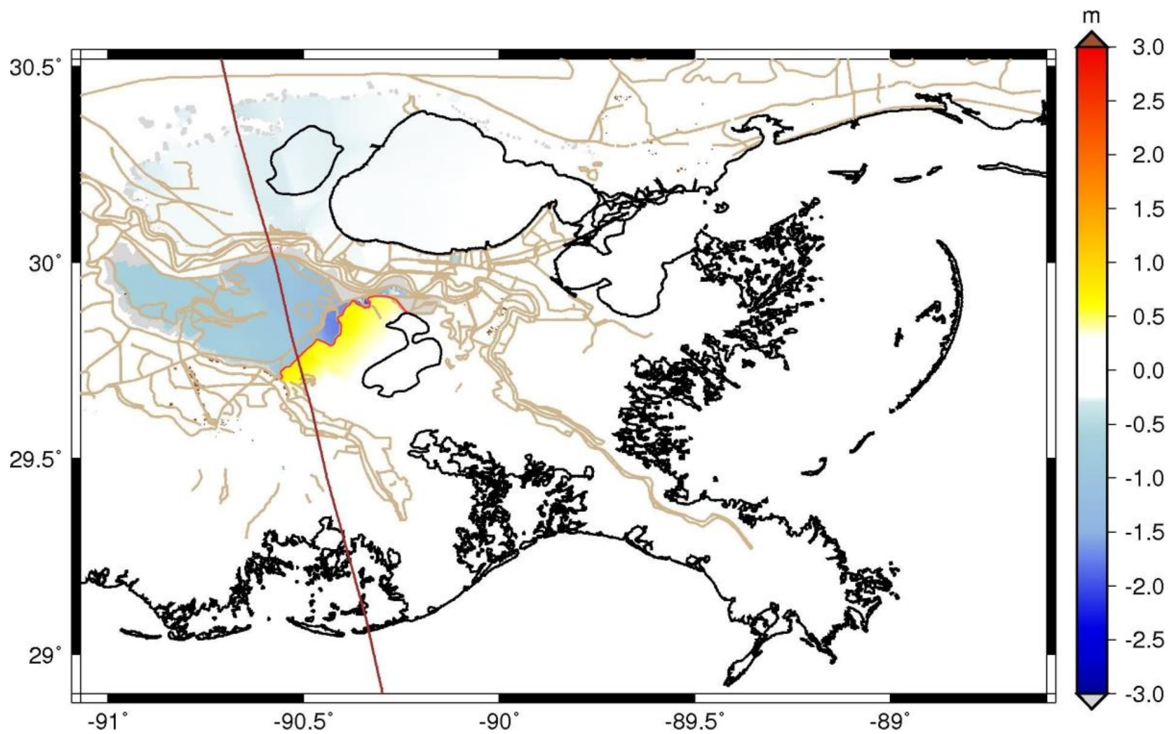

Figure 234: Differences in Maximum Water Surface Elevation (m) due to Implementation of the Upper Barataria Risk Reduction Project (year 50; high scenario) during Storm 012. Positive values denote an increase with the project in place. The project alignment is shown in red and the storm track is shown in brown.

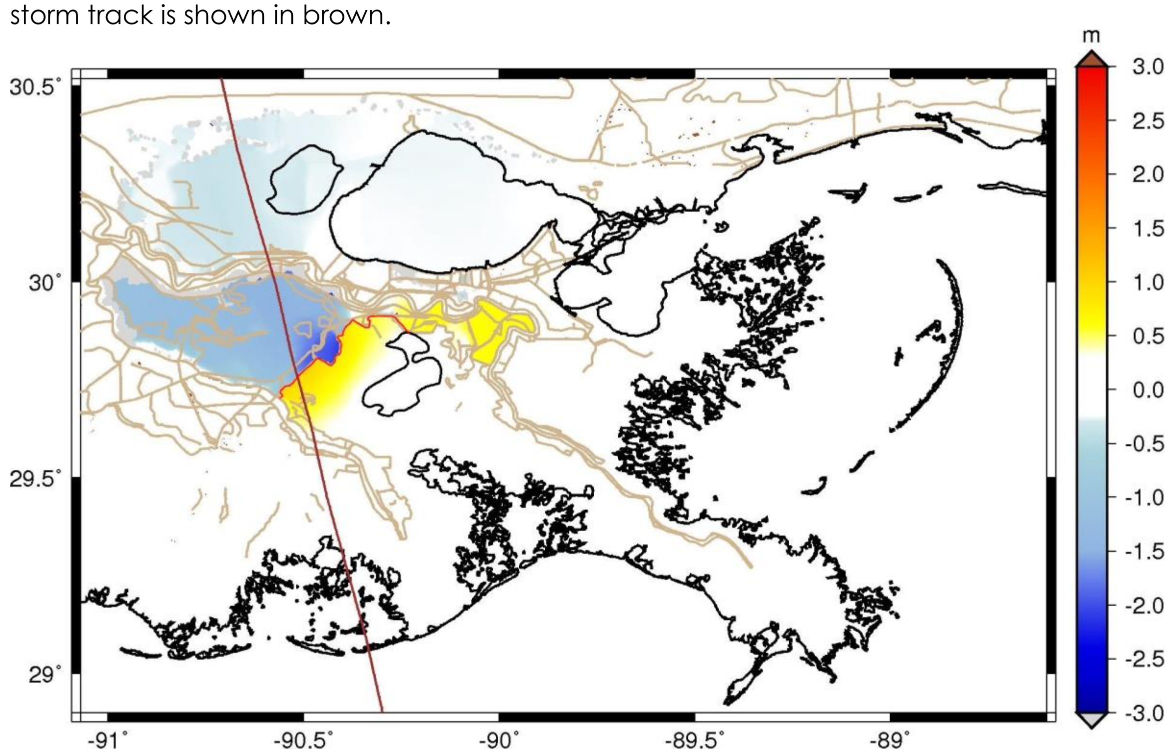

Figure 235: Differences in Maximum Water Surface Elevation (m) due to Implementation of the Upper Barataria Risk Reduction Project (year 50; high scenario) during Storm 018. Positive values denote an increase with the project in place. The project alignment is shown in red and the storm track is shown in brown.

Figure 236 shows the impact of the Upper Barataria Risk Reduction project on 100-year flood depths in year 50 of the high scenario as compared to FWOA. The figure shows the CLARA model median estimates using the IPET fragility curve in enclosed areas, which encounter some induced flooding (in red) on the West Bank HSDRRS system. General reductions (in green) of 1-2 m are evident at the100-year return period throughout the Upper Barataria basin behind the project alignment when compared to FWOA. The largest reductions, approximately 2.5 m, are in the Des Allemands area; reductions are generally smaller in communities along the ridges on the outer boundaries of the green region from the figure, such as Thibodaux and Raceland on the southern ridge and Vacherie in the north on the west bank of the Mississippi River.

The magnitude and geographic distribution of flood depth reductions are very similar at the 50- and 500-year return periods, except in the northwest corner of the basin where 50-year flood depths are less than a meter (not shown). In the low and medium scenarios, 100-year flood depths in Des Allemands are reduced by 3-4 m. In other parts of the basin that are protected by the alignment, reductions are generally smaller than in the high scenario, less than 1 m in the low scenario and less than 1.5 m in the medium scenario. In the high scenario, project effects in Des Allemands are greater in year 25 (reductions of 3-4 m), but the geographic extent of both flood depth reductions and increases is considerably smaller.

The project also induces increased flooding at the 100-year return period in the high scenario over a large region in front of the levee alignment, extending all the way to Lafitte to the east and Larose to the south. The large majority of the induced flooding is in unpopulated wildlife management areas near Lake Salvador, but one important exception is the potential for induced flooding on the West Bank of HSDRRS.

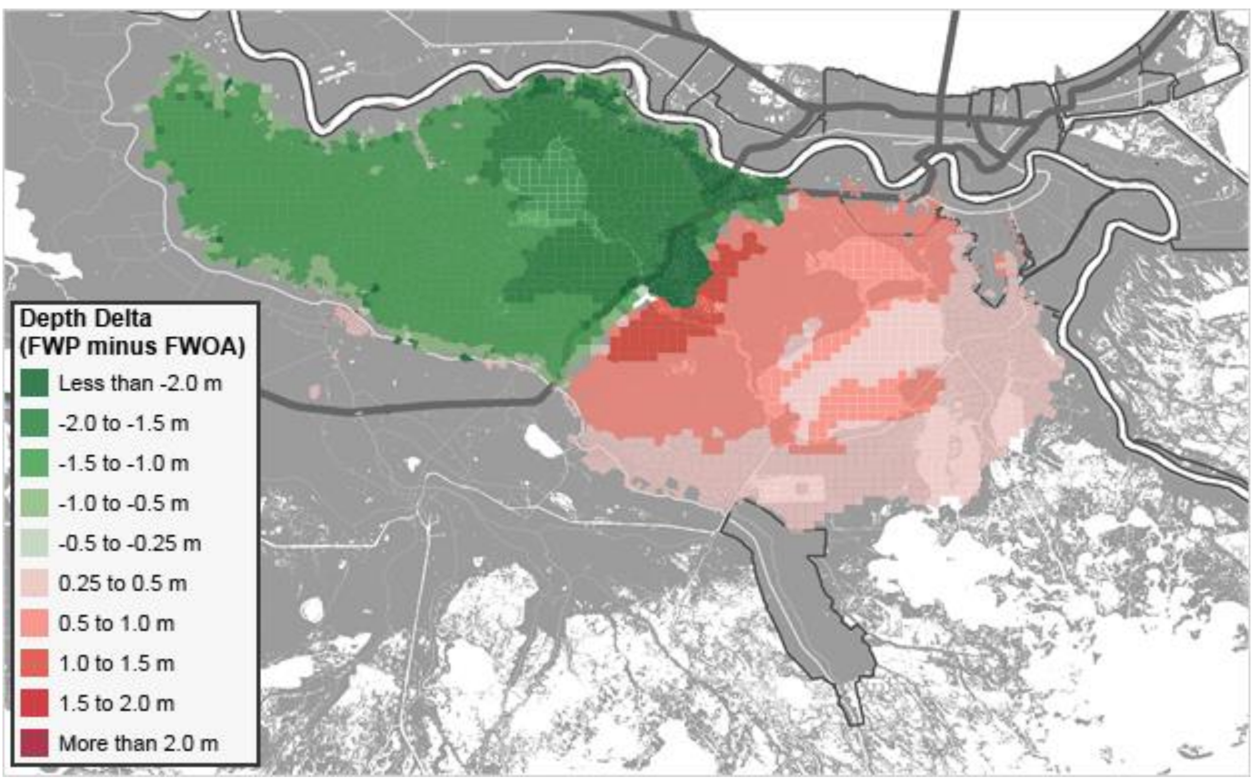

Figure 236: Difference in Median 100-Year Flood Depths due to Implementation of the Upper Barataria Risk Reduction Project (FWP) compared to FWOA (year 50; high scenario). IPET fragility scenario shown in enclosed areas.

The EAD in year 50 of the high scenario is reduced by an estimate of $618 million in the impacted area shown in Figure 237, with the Upper Barataria Risk Reduction project in place (under the IPET fragility assumption and historic growth population scenario) as compared to FWOA. Benefits accrue primarily to the St. Charles Parish region that includes Des Allemands, where flood depth reductions are also the greatest. The rest of the communities along the ridges also benefit from the project, with the exception of some induced damage in Thibodaux (as also shown with the small pink shaded region just south of the ridge in Figure 236). In this scenario, induced damage is $237 million on the West Bank of HSDRRS in Jefferson Parish (JEF.04R risk region), followed by $52 million within the Larose to Golden Meadow protection system (LAF.02R). The full set of EAD impacts is presented by risk region in Figure 237.

In year 25, corresponding to the smaller extent of flood depth impacts, net EAD benefit in this scenario is $507 million, with a reduction of $503 million in the St. Charles region. Induced damage in the Larose to Golden Meadow region is $31 million. Impacts in all other regions are small and not statistically significant.

In the medium scenario, net benefits are $646 million in year 50, greater than the high scenario. This is due to an absence of induced damage in HSDRRS. In year 25, the benefits are $335 million due to lower baseline FWOA damage.

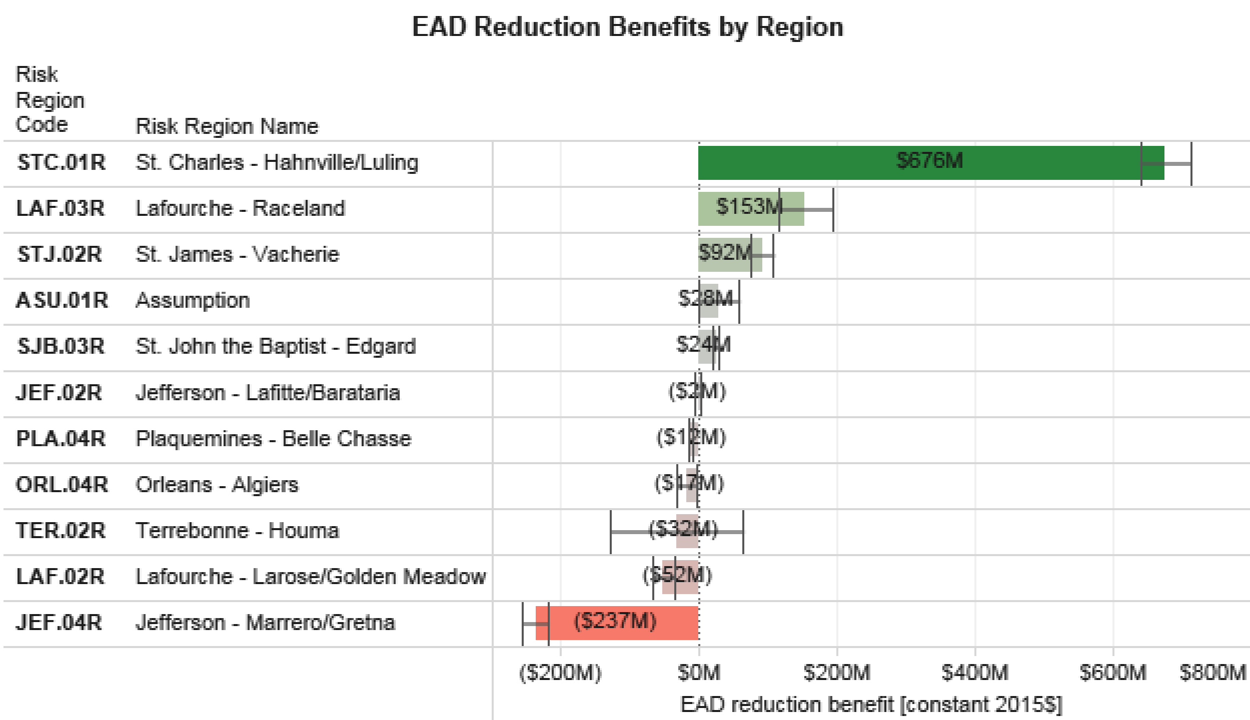

Figure 237: Change in EAD from Implementation of the Upper Barataria Risk Reduction Project (year 50; high scenario; historical growth; IPET fragility scenarios). Colored bar and labels show mean change in EAD; lines show an estimate of the 95% confidence interval.

4.11 Iberia/St. Mary Upland Levee (03b.HP.14)

The Iberia/St. Mary Upland Levee alignment (03b.HP.14) is shown on Figure 238. For the purposes of modeling efficiency, this project and the Morgan City Back Levee (03a.HP.20) are simulated simultaneously. The two projects do not alter water surface elevation or waves in the same areas.

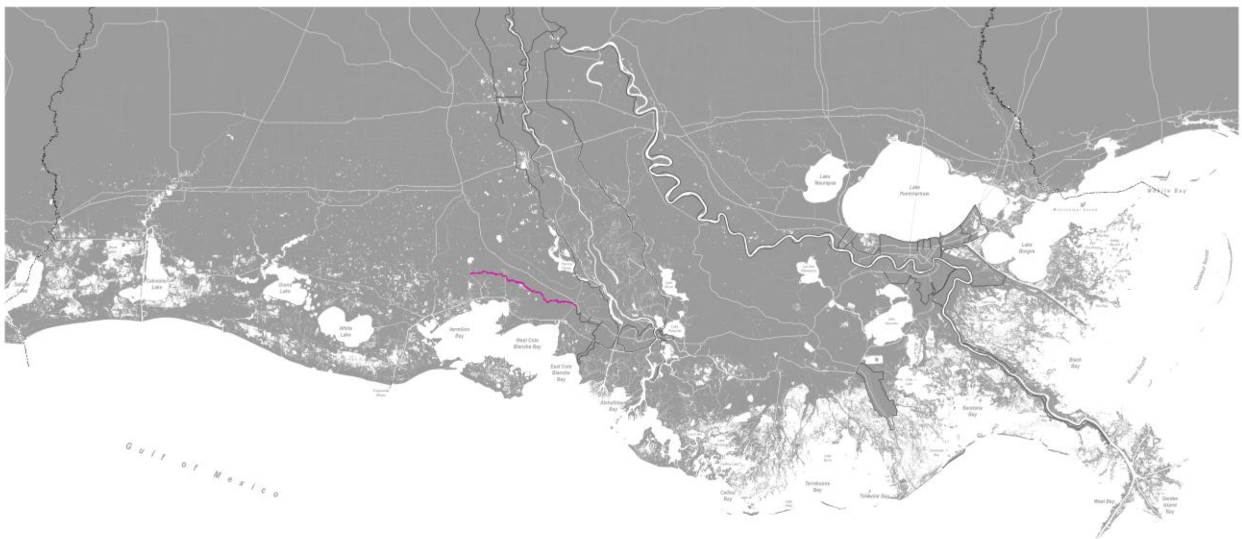

Figure 238: Iberia/St. Mary Upland Levee Alignment, as Indicated by the Pink Line.

Figure 239 and Figure 240b show the changes in maximum water surface elevation that occur when implementing the project for two storms of different strengths and tracks west of the project. The simulations are for the year 50 FWOA landscape for the high scenario. Storm 223 (Figure 239) makes landfall near Lake Calcasieu, while Storm 232 (Figure 240) makes landfall closer to the project and near White Lake. For storms that make landfall east of and far to the west of the project, such as Storm 223, the project is generally able to provide significant storm surge reduction to all areas behind the levee; storm surge runaround is limited for these storm tracks. However, many storms that make landfall nearer to the project, including Storm 232, lead to storm surge runaround at the western extents of the project. The areas behind the project alignment that experience storm surge runaround are illustrated within the red circles in Figure 240a and b. The western reach of the project experiences a reduction of approximately 0.5 m; however, water surface elevations are still nearly 3.5 m due to the significant flooding caused by runaround.

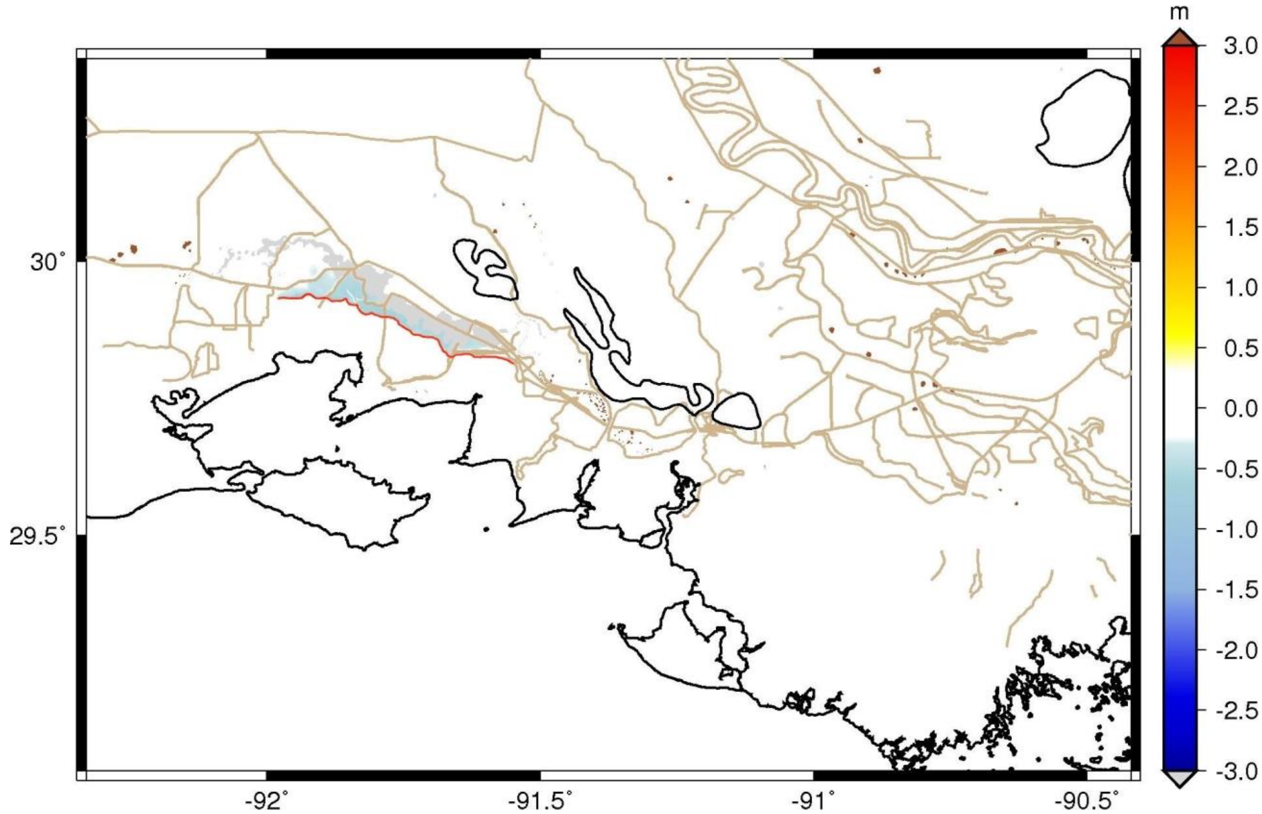

Figure 239: Differences in Maximum Water Surface Elevation (m) due to Implementation of Iberia/St. Mary Upland Levee Alignment (year 50; high scenario) during Storm 223. Positive values denote an increase with the project in place.

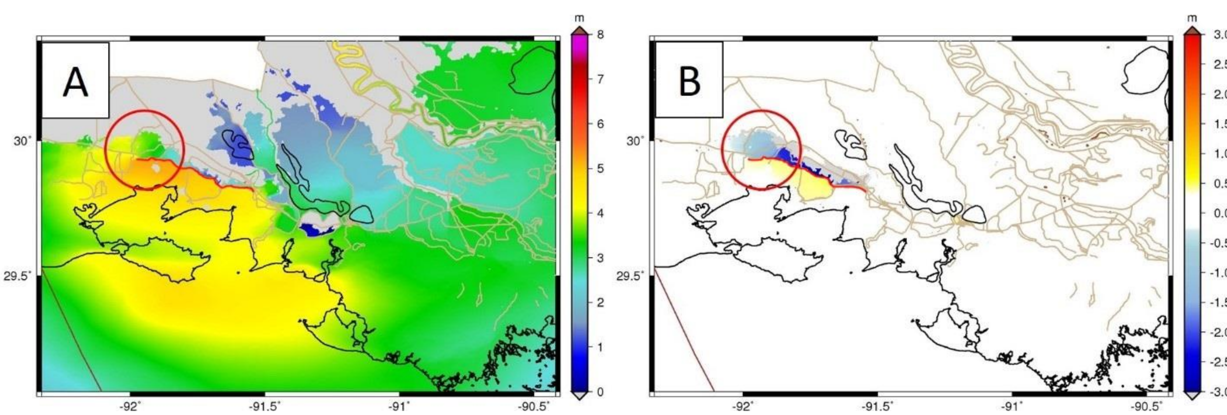

Figure 240: (A) Maximum Water Surface Elevation (m, NAVD88) and (B) Differences in Maximum Water Surface Elevation (m) due to Implementation of Iberia/St. Mary Upland Levee Alignment (year 50; high scenario) during Storm 232. Positive values denote an increase with the project in place. Red circle denotes area where storm surge runaround has occurred. The project alignment is shown in red and the storm track is shown in brown.

Figure 241 illustrates the difference in median 100-year flood depths associated with implementation of the Iberia/St. Mary Upland Levee Alignment in year 50 of the high scenario. Flood depth reductions extend all the way from the project's western terminus in Delcambre to Baldwin in the east, where the alignment would tie in to the Franklin and Vicinity levee system. The 100-year flood depths are reduced by 2-3.5 m in some areas between the alignment and

Highway 90. Despite the evidence of surge runaround produced by specific storms, when examining the statistical results, reductions of 0.5 m or less extend slightly beyond the western end of the alignment. In a small number of grid points near New Iberia and Baldwin, reductions also extend north beyond Highway 90.

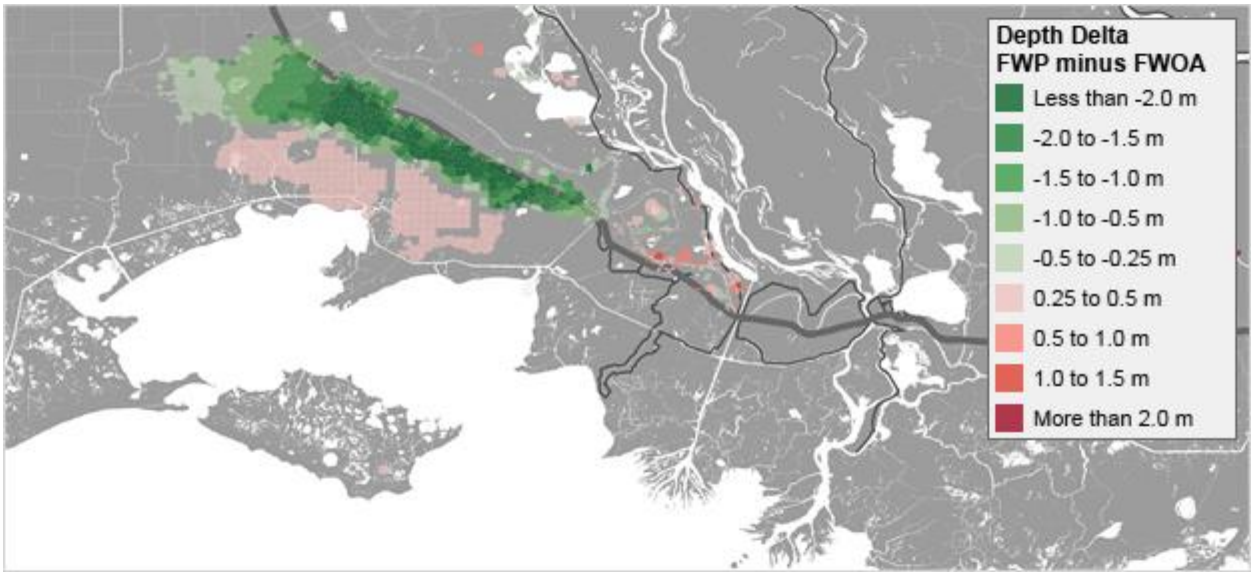

Figure 241: Difference in Median 100-Year Flood Depths from the Iberia/St. Mary Upland Levee Alignment Project (FWP) Compared to FWOA (year 50; high scenario).

The induced flood depths in front of the alignment are typically less than 0.5 m at the 100-year return period, although a small number of points east of the project and north of the highway see larger increases. Virtually no additional flooding is induced at the 50-year return period (not shown). The differences in 500-year flood depths with the project are very similar to the 100-year differences.

Reductions in the 100-year flood depths are similar in magnitude and extent in the medium scenario. In the low scenario, reductions are generally about 0.5 m smaller in magnitude, disappearing at some higher-elevation areas near Highway 90. Impacts in year 25 of the high scenario are similar to those in year 50 of the low scenario; the lower FWOA flood depths and extent of flooding place a limit on the reduction that can occur.

The EAD in year 50 of the high scenario is reduced by a mean estimate of $250 million with the Iberia/St. Mary Upland Levee Alignment project in place (IPET fragility assumption, historic growth population scenario) as compared to FWOA. Benefits of $211 million accrue to the Iberia Parish region south of Highway 90, where flood depth reductions are also the greatest. A smaller EAD reduction of $40 million is seen in St. Mary Parish for assets along Highway 90 from Jeanerette to Franklin. Impacts on Vermilion Parish, to the west of the project alignment, are not statistically significant. The full set of EAD impacts is presented by risk region in Figure 242.

In year 25 of the high scenario, corresponding to the smaller extent of flood depth impacts, net benefit is $134 million, with $116 million of that impact located in Iberia Parish. Induced damage in year 25 is negligible. In the medium scenario, net benefit is $155 million in year 50, again with the large majority of benefit ($142 million) in Iberia Parish. In Year 25, net benefit is $103 million, due primarily to a lower level of baseline risk in FWOA.

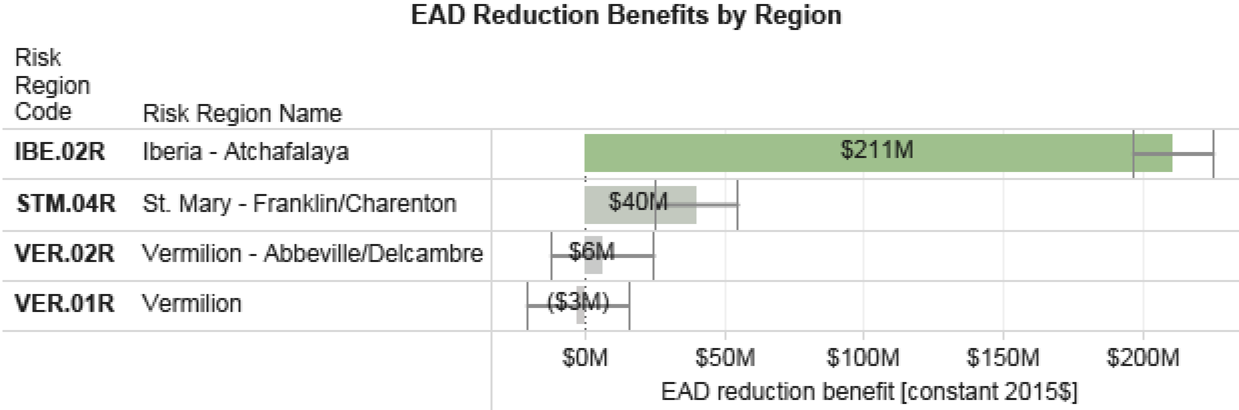

Figure 242: Change in EAD from the Iberia/St. Mary Upland Levee Alignment Project (year 50; high scenario; historical growth; IPET fragility scenarios). Colored bar and labels show mean change in EAD; lines show an estimate of the 95% confidence interval.

4.12 Nonstructural Risk Reduction Project (Jefferson Parish – Lafitte/Barataria; JEF.02N)

JEF.02R is a small risk region consisting of the area within the proposed Lafitte Ring Levee risk reduction project (002.HP.07). Approximately 2,046 structures in the region are eligible for nonstructural risk reduction in the JEF.02N project. Forty-two percent of households are low to moderate income, and 765 of the structures are in locations that have experienced repetitive loss or severe repetitive loss in the past.

The flood depth standard for nonstructural risk reduction in the region is based on median 100-year flood depths in year 10 of the high scenario, which range from 1.5 to 4 m and are shown in Figure 243. Under initial conditions, the 100-year values are generally 1.2-2 m; by year 50 this value is over 4.5 m in some points, so flood depths are projected to increase significantly over time.

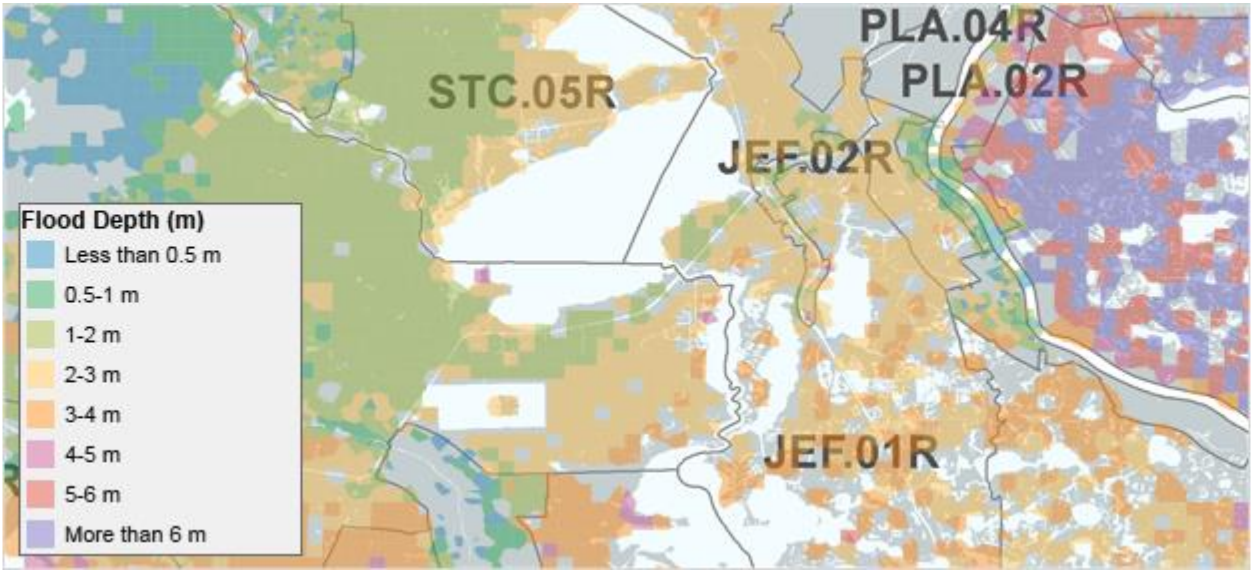

Figure 243: Median 100-Year Flood Depths in the Vicinity of the Jefferson Parish - Lafitte/Barataria Region (year 10; high scenario).

The CLARA model's mean estimate of current EAD in the region is $91 million. With the nonstructural risk reduction project JEF.02N implemented, EAD is reduced by a mean of $24 million in year 10 compared to FWOA, $27 million in year 25, and $16 million in year 50 of the high scenario (historic growth scenario). Risk reduction is achieved primarily through residential elevation, with 1,237 structures elevated, compared to only nine flood-proofed structures and two structure acquisitions. This represents mitigation of 61% of the total structures eligible for nonstructural risk reduction. Total costs are estimated at $201 million with a 5-year duration to complete construction. While benefits were modeled only in year 10, year 25, and year 50, they would accrue in all subsequent years after implementation of the project.

4.13 Nonstructural Risk Reduction Project (Lower Terrebonne; TER.01N)

TER.01R represents the region of Terrebonne Parish south of the proposed Morganza to the Gulf structural protection alignment (03a.HP.103). Given that the Morganza to the Gulf system alignment is intended to reduce risk for population centers within Terrebonne and other adjacent parishes, the number of nonstructural-eligible structures in Lower Terrebonne south of the alignment, 796, is small. Sixty-one percent of the households in the region are low to moderate income, and 455 of the structures are in locations that have experienced repetitive loss or severe repetitive loss in the past.

The flood depth standard for nonstructural protection in the region is based on median 100-year flood depths in year 10 of the high scenario. Exposed assets are primarily in unincorporated communities such as Theriot and Cocodrie, where year 10, 100-year depths range from 2.5-5 m as shown in Figure 244. Under initial conditions, the 100-year values are generally 2.5-4.5 m; by year 50 this value is over 5 m in some points, a statistically significant increase over time.

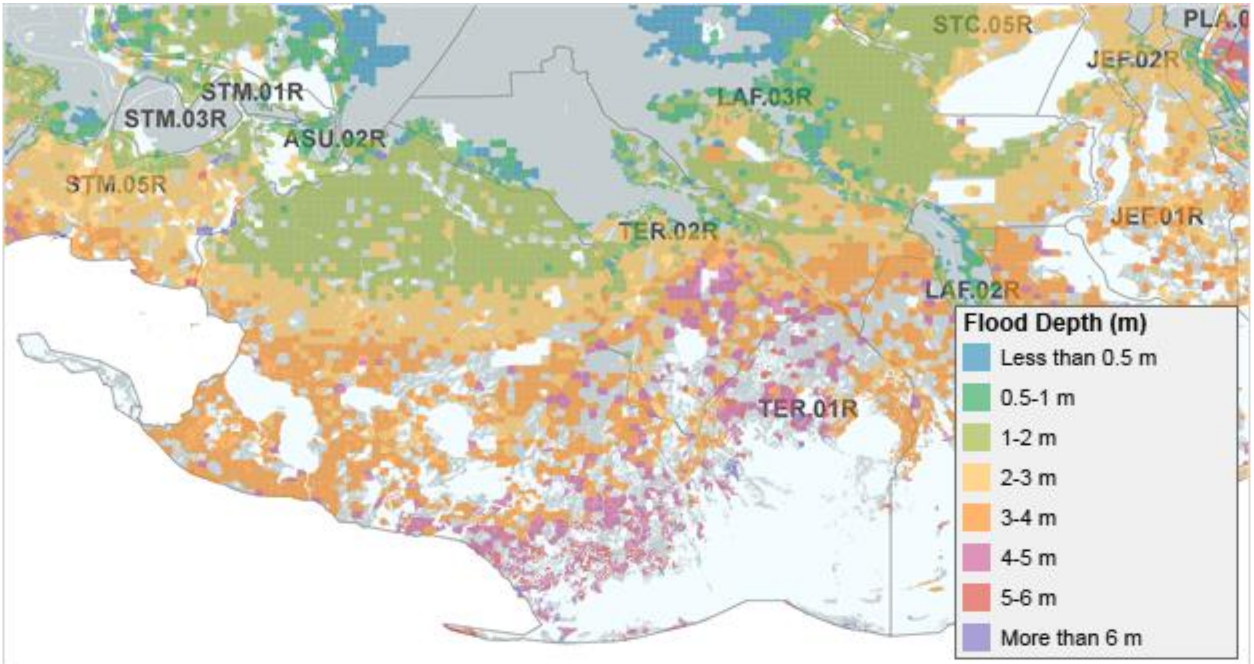

Figure 244: Median 100-Year Flood Depths in the Vicinity of the Lower Terrebonne Region (year 10; high scenario).

The CLARA model's mean estimate of initial condition EAD in the region is $88 million. With the nonstructural risk reduction measures in place, EAD is reduced by a mean of $8 million in year 10 compared to FWOA, $9 million in year 25, and $9 million in year 50 of the high scenario, under historic growth assumptions. Risk reduction is achieved through a mixture of acquisitions and elevations, with 262 structures elevated, 121 acquisitions, and only two flood-proofed structures. This represents mitigation of 48% of the total structures eligible for nonstructural risk reduction. Total costs are estimated at $87 million, and the project has assumed construction duration of three years. While benefits were modeled only in year 10, year 25, and year 50, they would accrue in all subsequent years after implementation of the project.

4.14 Nonstructural Risk Reduction Project (Vermilion – Abbeville/Delcambre; VER.02N)

VER.02R represents the upland portion of Vermilion Parish ranging from Delcambre on the eastern boundary of the parish west to Abbeville, north of the proposed Abbeville and Vicinity structural risk reduction project (004.HP.15). Approximately 2,438 structures in the region are eligible for nonstructural risk reduction. Forty percent of households are low to moderate income, and 965 of the structures are in locations that have experienced repetitive loss or severe repetitive loss in the past.

The flood depth standard for nonstructural protection in the region is based on median 100-year flood depths in year 10 of the high scenario, which range from no flooding to 3 m and are shown in Figure 245. In initial conditions, the 100-year flood depths range from no flooding to 2.5 m; by year 50 the 100-year flood depths range up to 4.2 m in some points, so flood risks are projected to increase significantly over time. The CLARA model's mean estimate of current EAD in the region is $45 million.

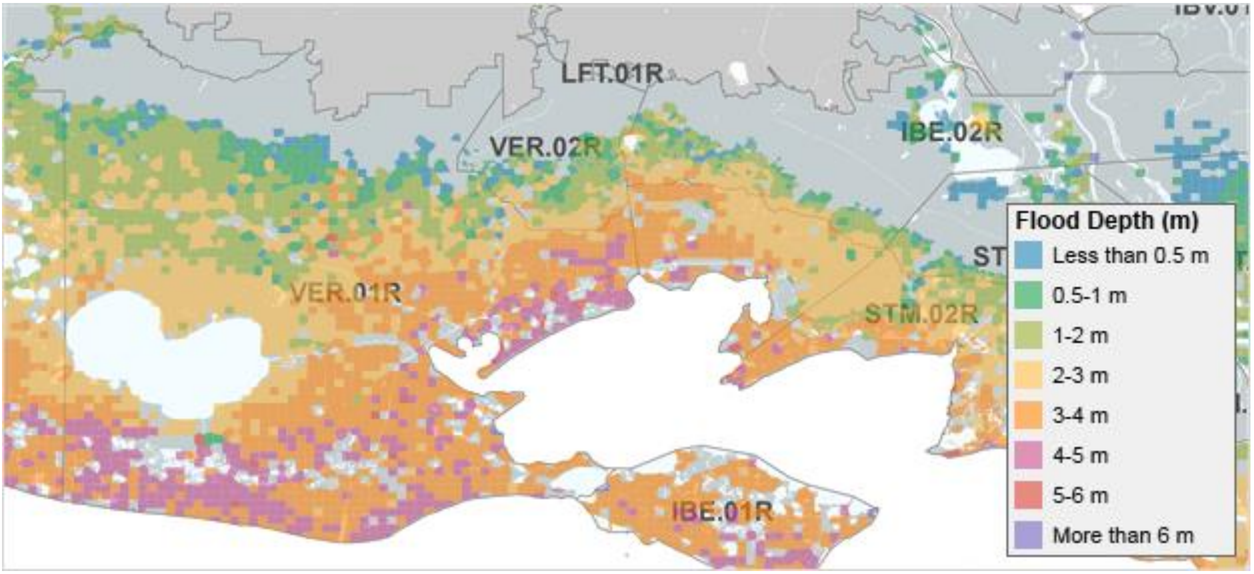

Figure 245: Median 100-Year Flood Depths in the Vicinity of the Vermilion – Abbeville/Delcambre Region (year 10; high scenario).

With the nonstructural risk reduction measures in place, the EAD is reduced by a mean of $24 million in year 10 compared to FWOA, $38 million in year 25, and $46 million in year 50 of the high scenario, under historic growth assumptions. A total of 710 structures receive nonstructural risk mitigation over the assumed four-year implementation period, for a total cost of $156 million. The risk reduction is achieved through a mixture of elevation and flood-proofing, with 635 residences elevated and 60 commercial properties flood proofed. Only 14 properties are acquired; this represents mitigation of 29% of the total structures eligible for nonstructural risk reduction. While benefits were modeled only in year 10, year 25, and year 50, they accrue in all subsequent years after implementation of the project.

5.0 Project Interactions and Interpretations

5.1 Introduction

Each of the candidate restoration and structural protection projects is evaluated using the systems models described above. For restoration projects, the results are summarized for each of the 11 ecoregions for each scenario (Figure 74) and provided to the Planning Tool team. For protection projects, the project level results are defined for 54 risk regions (Attachment C-25). CLARA calculates flood depths at selected AEP intervals and EAD at years 10, 25, and 50 for each scenario, and characteristics of nonstructural projects in these regions are also defined, e.g., the number of structures flood-proofed, elevated, acquired, and estimated cost. These results are used by the Planning Tool (Appendix D) to define a set of "alternatives." Each alternative is comprised of the set of projects that build the most land and reduce the most flood risk while meeting funding, other planning constraints (such as sediment availability and project incompatibilities/dependencies), and other defined conditions, e.g., project dependencies where if one project is selected, another one also has to be selected (Appendix

D provides more information). Within an alternative, projects are implemented in one of three periods, driven primarily by the availability of funds and their expected effectiveness over time.

This section describes the results of taking the projects within alternatives and analyzing them using the systems models. There are several key differences between this analysis and the project-level analysis described above:

- In the project level analysis, restoration projects are implemented "on the landscape" after sufficient time has elapsed for engineering, design, and construction, assuming that these activities begin at the start of the planning period. The "duration" defines this period for each project. In an alternative, the duration beings at the start of the implementation period (IP) to which the project is assigned. IP begins at year 1, IP2 begins at year 11, and IP3 begins at year 31. Thus, a project with a nine-year duration assigned to IP2 is implemented in the model simulation at year 20.
- Some projects are modified or the modeling approach adjusted between project-level simulations and the alternatives analysis, either to better reflect on-the-ground conditions or as a result of the Planning Tool analysis. Examples include:
    - Several of the sediment diversions are modified to include a minimum discharge through the diversion during times of low Mississippi River flow;
    - Large marsh creation projects are considered in increments in the Planning Tool and in many cases not all increments are included in an alternative, resulting in the initial project footprint being smaller than during the project-level analysis;
    - Nonstructural projects are defined by different elevation standards depending on the IP to which they are assigned;
    - The elevation to which marsh creation projects are 'built' in the ICM is adjusted to account for sea level rise and subsidence for IP2 and IP3[12];
- In the project-level analysis, each restoration and protection project is modeled independently, interacting only with FWOA conditions. In the alternatives, projects interact as they would in the landscape with conflicting or synergistic effects shown in the resulting land, risk, and other metrics. This also means, however, that the interaction of any specific set of projects cannot be readily separated from the rest of the alternative.

An additional difference is an adjustment to the ICM which is described in more detail below. This chapter also summarizes some results of specific ICM analysis conducted to examine specific project interactions. Example results for alternatives modeling include comparisons among the following alternatives as well as FWOA:

- **G301** - this alternative "Modified Maximize Risk Reduction and Maximize Land" is based on the results of the Planning Tool analysis with specific modifications identified by CPRA to make the alternative more consistent with ongoing project implementation and to reflect the impact of changing environmental conditions over time on project performance. It includes restoration projects, structural protection projects and

[12] Sediment needs are adjusted accordingly in the Planning Tool analysis.

nonstructural projects, and has been analyzed using the landscape/ecosystem models (ICM, HSIs, and EwE), the surge (ADCIRC), and risk (CLARA) models.

- **G303** - this alternative includes only the structural protection and nonstructural projects in G301. Landscape/ecosystem analysis was conducted to ensure the effects of the structural protection projects on the landscape were considered in the surge/wave and risk modeling. Output and interpretations are provided for landscape/ecosystem and surge/risk modeling.
- **G304** - this alternative includes only the restoration projects included in G301. Output and interpretations are presented only for landscape/ecosystem modeling.

All sections following the sections explaining the differences between ICM FWOA_v1 and FWOA_v3 (i.e., after Section 1.3 below) reflect outcomes of FWOA_v3 analysis.

5.2 Changes in Landscape Modeling: ICM FWOA_v3 vs FWOA_v1

5.2.1 Overview of ICM v3 update

After completing several multi-decadal model runs under a variety of environmental scenarios, it became clear that several aspects of the ICM required adjustment to ensure appropriate response to changing environmental conditions. The changes were focused on predominantly three issues: adjustments to the salinity mass balance algorithm and further salinity calibration efforts, a new method for determining when floating marsh was converted to open water in the model, and the application of collapse criteria on areas of persistent bare ground. A discussion of these changes is provided in Section 4 of Attachment C3-22, and more detail as well as the impact on model performance is provided in Section 6 of Attachment C3-23. This section describes the results of the FWOA_v3, which is then compared to FWOA_v1.

5.2.2 ICM_v3 Stage and Salinity

Stage results for FWOA are intuitive across the coast. Nearly all compartments indicate a rise in mean water level across each 50-year scenario. A rise of ~0.4 m is evident under the low scenario, and a rise of ~0.8 m can be seen under the high scenario. A few compartments do not indicate much change in water level throughout the run, and they are typically near the Mississippi River distributaries (e.g., Davis Pond compartments) or are within levee protected regions. The hydrographic signals seen under FWOA_v3 (G300) do not differ dramatically from FWOA_v1 (G001).

Areas that are initially fresh water generally remain fresh throughout the 50-year low scenario run, with some periods of slightly higher salinity during the last simulated decade. However, the predominant regime would still be considered fresh, since the periodic increases in salinity do not drive the annual mean salinity to higher values. There are many areas across the coast (in the more brackish and saline areas) where a largely variable salinity with extreme highs and lows at the start of the model run, over time has a smaller amplitude but an overall higher salinity.

There are a few compartments that have a counterintuitive response in which it appears that salinity is less variable in later years and the long term average is slightly fresher than in the beginning of the run. Eloi Bay, which is immediately adjacent to MRGO, is a good example of this phenomenon. The slight apparent freshening through time can be explained by the location of the compartments. In all cases where this was seen, the compartment immediately downstream was initially 100% open water (e.g. open bay/Gulf). Through time, the connectivity to landward compartments (e.g. fresh source) was increased due to loss of upstream marsh areas, whereas the downstream connectivity remained constant (e.g., all open water all of the time). Therefore, the ratio of fresh connectivity to saline connectivity increased over time. Additionally, as land area decreased in this compartment through time, the volume of water increased. Therefore, the constant saline mass (from the unchanged downstream connectivity) was being diluted into a larger volume while also likely receiving more freshwater flow from the upstream connectivity. Given the higher rates of RSLR in the medium and high scenarios, this apparent freshening in transitional areas does not occur; it is evident in some compartments in the low scenario.

In addition to the salinity dynamics explained above, the intermittent salinity spikes that were occurring in compartments with small open water areas, relative to the marsh and upstream area within the compartment, during FWOA_v1 (G001), no longer occur.

5.2.3 ICM_v3 Land Change

Overall, the patterns of wetland area change under FWOA_v3 (G300) are intuitive across the low (Figure 246 and Figure 247), medium (Figure 248 and Figure 249), and high (Figure 250 and Figure 251) scenarios, and reflect the various subsidence and sea level rise parameters tested. Under the 50-year FWOA_v3 (G300) simulations, a projected net loss of 3,160, 5,870, and 10,690 km^2 across the entire model domain occur under the low, medium, and high scenarios, respectively. What follows is a general description of patterns in the eastern, central, and western areas of the coast over the 50-year simulation.

Wetland loss in the western region of coastal Louisiana is less than that of the eastern region (as a percent of beginning wetland area) but more than that of the central region. Wetland change is somewhat limited and sporadic through the first 20 years or so of the model simulation. In year 24, there is a rapid collapse of the area southeast of Broussard Lake and northeast of Creole under the low scenario. Between years 24-40 the loss in this area expands rapidly to encompass the area west southwest of Lake Misere. In the final 10 years of the 50-year simulation, wetland loss becomes more expansive throughout the Chenier Plain as would be expected considering the sea level rise and subsidence parameter values in the low scenario.

The central region of the coast experiences the least amount of loss under the low scenario FWOA_v3 (G300). Gain is evident in the Wax Lake Delta and there is a notable net stability in many areas of this region. Areas such as the marshes in the vicinity of Cote Blanche are relatively stable throughout the time period. The losses which do occur in this region are more prevalent in areas such as Marsh Island and the areas east of Freshwater Bayou.

Overall, the wetland area in the eastern region experiences the most net wetland loss under the low scenario FWOA_v3. During the first few years, there is loss to the west of Bayou Sauvage National Wildlife Refuge in the vicinity of Big Oak Island, and the entire vicinity of Bayou Sauvage National Wildlife Refuge has been lost. Similar early losses in leveed areas along Bayou Lafourche as well as in the vicinity of Scarsdale and Belle Chasse are also noted. These early losses are probably a result of model adjustment between initial conditions (such as land use/land cover or elevation) and model parameters in compartments covering these protected areas. Loss between years 10-20 is intuitive and seems to occur in lower portions of the basins, in more exposed areas and in some cases, areas experiencing higher rates of sea level rise and subsidence. Loss in years 20-30 follows a similar pattern in most basins (more exposed areas are lost first). The Bird’s Foot Delta begins to experience rapid collapse during these years in the outer extremities of the delta, but simultaneous building in the areas around Main Pass and West Bay.

In other portions of the eastern region, loss continues to move up basins throughout the final model years. Loss is widespread and complete in lower portions of Terrebonne and Barataria basins by year 50. Losses in Breton Sound are not as substantial. This appears to be somewhat a result of a more rapid salinity increase in Barataria and Terrebonne basins than that of Breton Sound; this results in different predominant vegetation types, which in turn alters the collapse threshold which would result in land loss.

The general spatial trends across the coast hold across the three scenarios: the eastern region experiences the most land loss, the central region experiences the least, and the western region loss is somewhere between the two. Similar to the low scenario patterns described above, loss under the medium and high scenarios between years 10-20 is intuitive and seems to occur in lower portions of the basins, in more exposed areas, and areas experiencing higher rates of subsidence. Loss in years 20-30 follows a similar pattern in most basins (more exposed areas are lost first). Under the high scenario, loss becomes widespread and complete throughout the eastern region by year 50. Losses are observed in areas that were not lost in the low and medium scenarios, in particular the forested wetlands in the vicinity of Lake Maurepas and those of upper Barataria Basin. These losses are the result of overwhelming increases in salinity in these areas due to the sea level rise rate imposed in the high scenario.

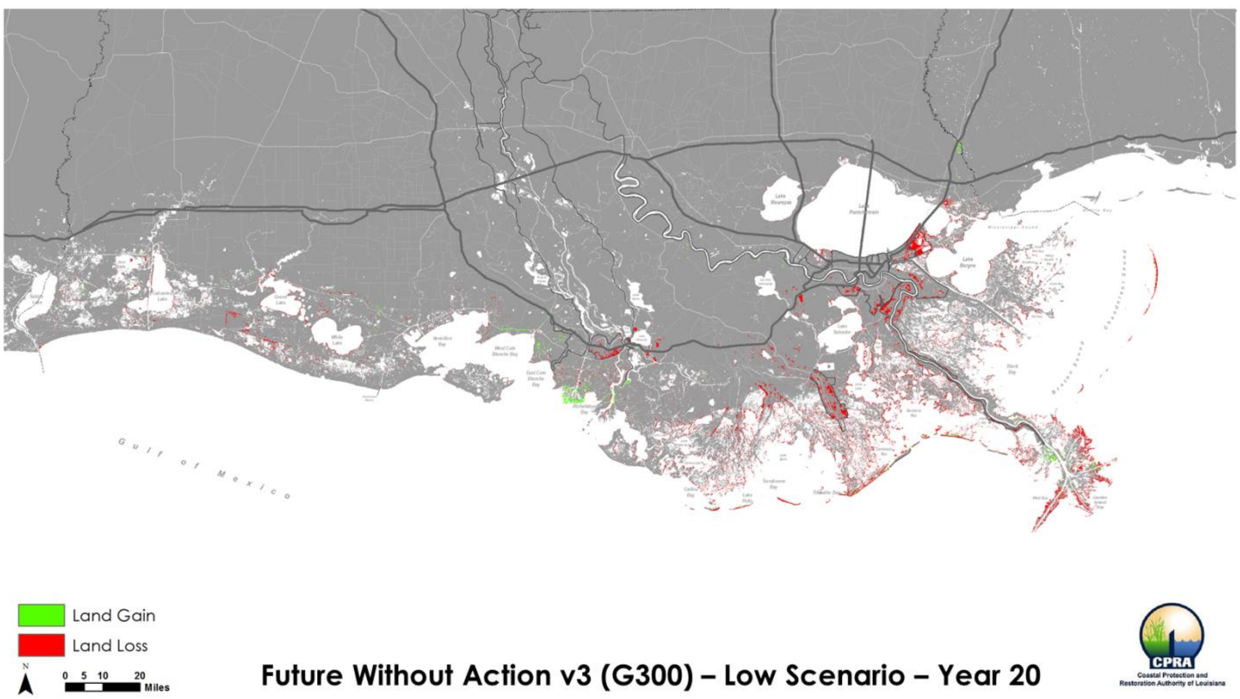

Figure 246: Land Change under FWOA_v3 compared to Initial Conditions (year 20; low Scenario).

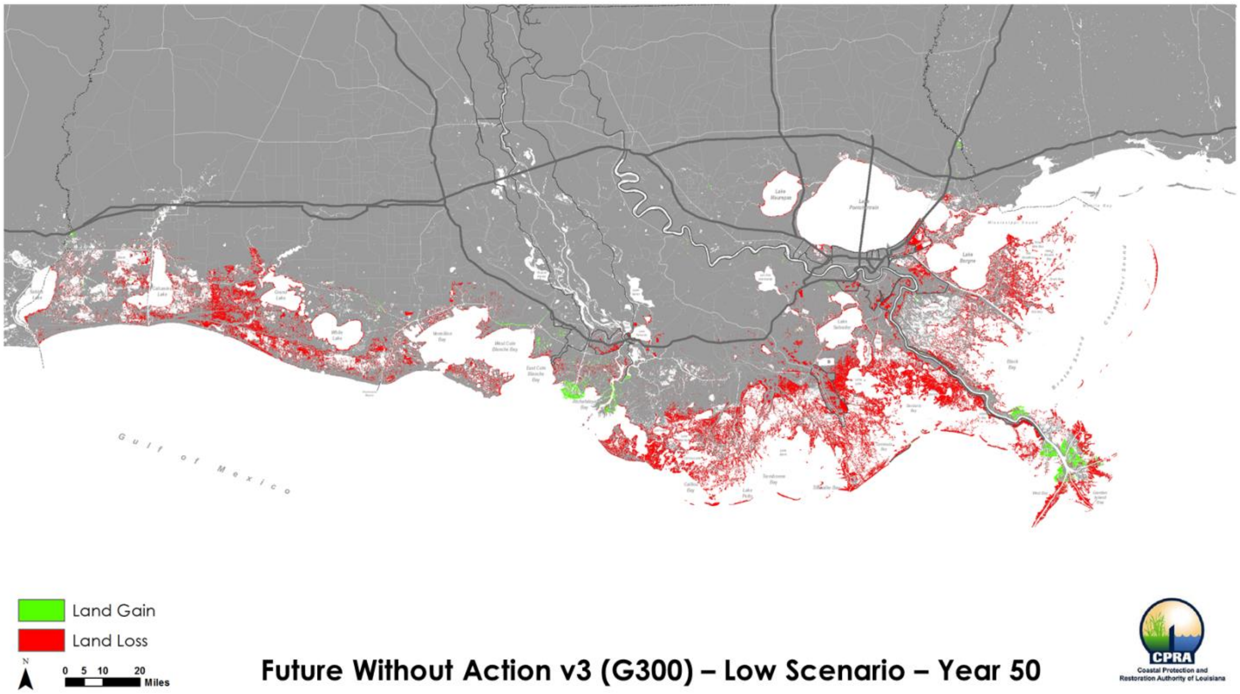

Figure 247: Land Change under FWOA_v3 compared to Initial Conditions (year 50; low scenario).

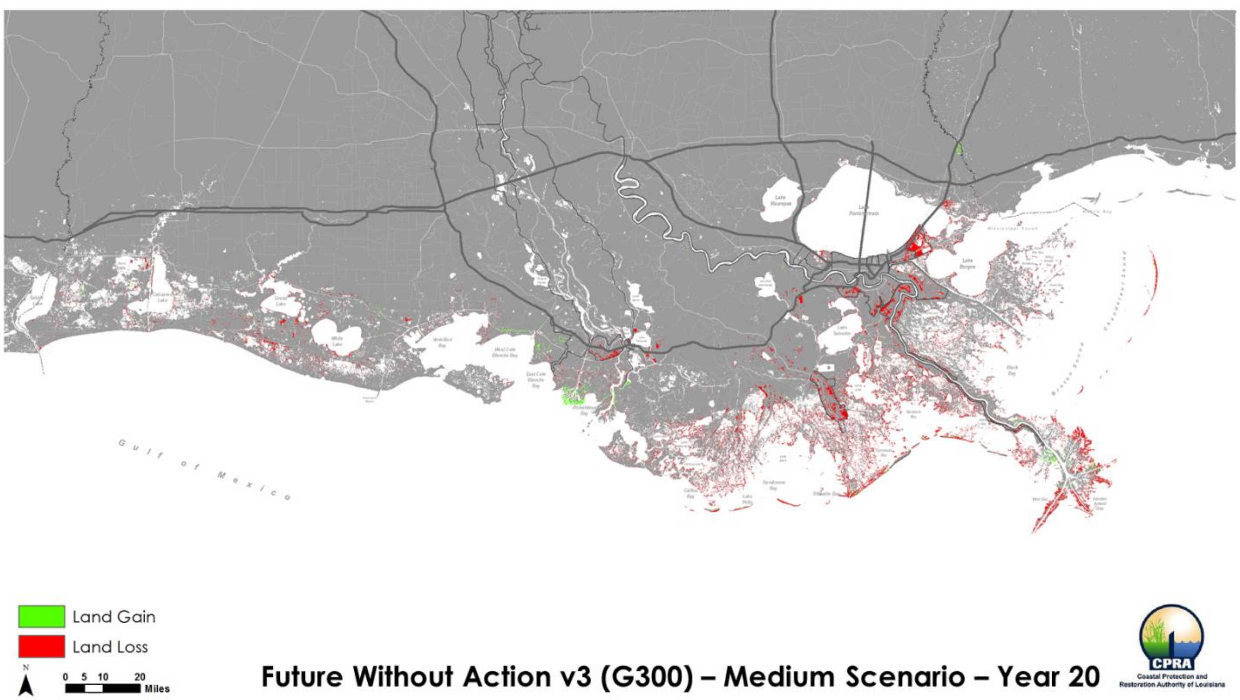

Figure 248: Land Change under FWOA_v3 compared to Initial Conditions (year 20; medium scenario).

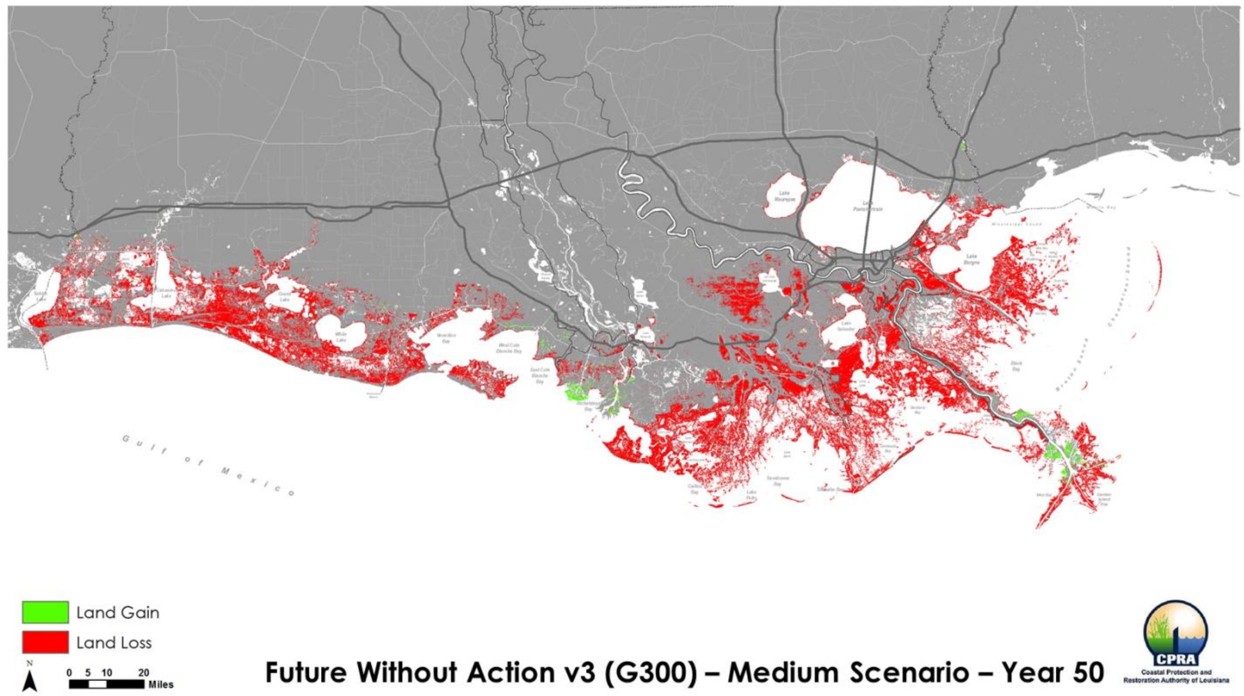

Figure 249: Land Change under FWOA_v3 compared to Initial Conditions (year 50; medium scenario).

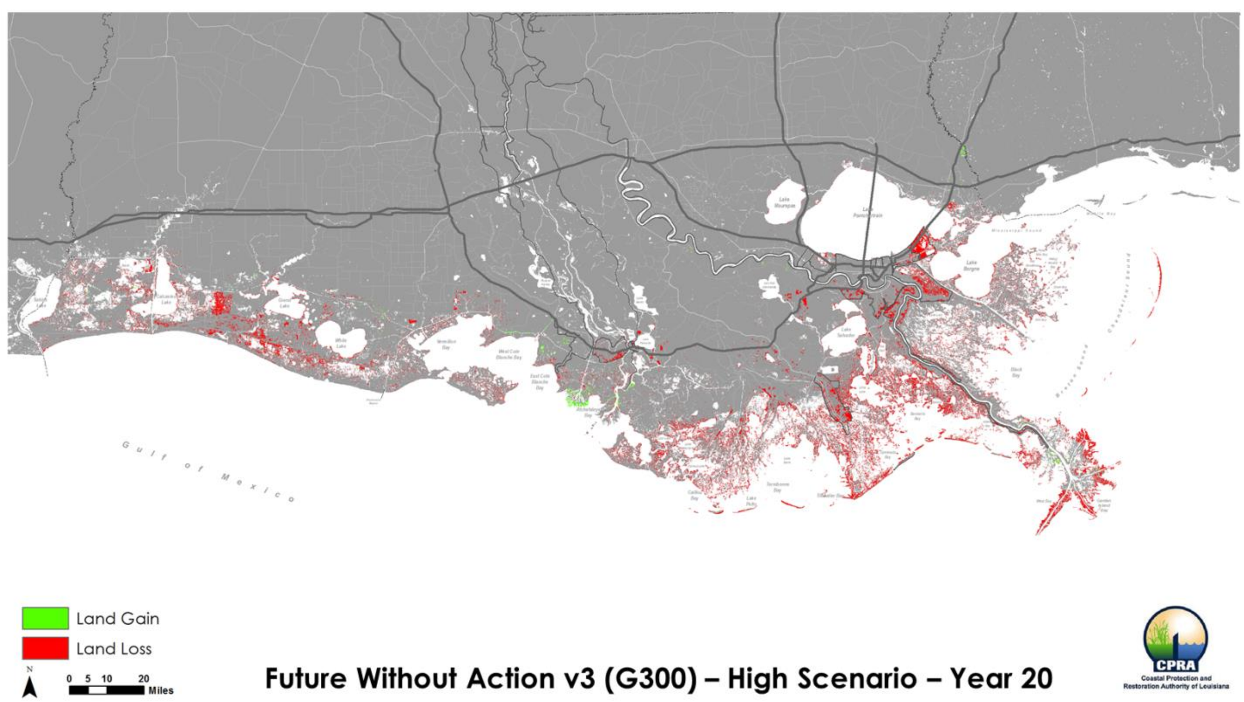

Figure 250: Land Change under FWOA_v3 compared to Initial Conditions (year 20; high scenario).

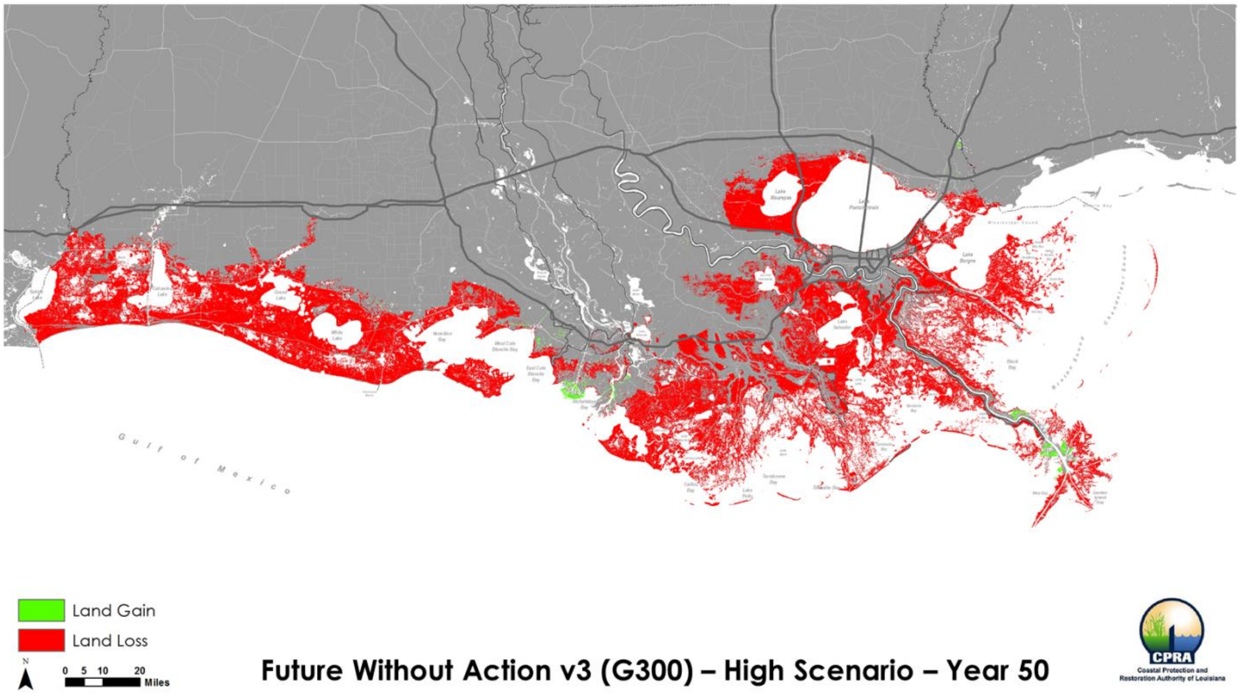

Figure 251: Land Change under FWOA_v3 compared to Initial Conditions (year 50; high scenario).

5.2.4 ICM_v3 Vegetated Cover

Under the low scenario for FWOA (Figure 252 and Figure 253), there is an initial conversion of brackish marsh to salt marsh in the first ten years in the western region of the model domain. The vegetation community remains relatively stable from year 10 through 30, after which there is an expansion of brackish marsh into fresh marsh areas southwest of Grand Lake and in between Sabine and Calcasieu Lakes. These trends continue through the final decade, with salt marsh invading south of Grand Lake and brackish marsh expanding east and north of Sabine Lake. The central region experiences a rapid movement to a new equilibrium where brackish marsh in the Point au Fer, lower Terrebonne areas converts to salt marsh, and there is a small intrusion of brackish marsh into central Terrebonne. For the remaining decades, the area remains largely unchanged, with the only notable exception being a continued conversion of swamp forest to fresh marsh south of Lake Verret. The eastern region experiences a rapid shift in the first five years to a new equilibrium involving a slight inland movement of salt and brackish marsh, a conversion of intermediate marsh to fresh marsh, and the start of conversion of swamp forest to fresh marsh. The marsh types then remain relatively stable until year 40 except for the progressive conversion of swamp forest to fresh marsh in the Maurepas Swamp and upper Barataria regions. By year 50, there is a conversion of fresh marsh to brackish marsh around Lake Salvador, and nearly all swamp forest has been converted to fresh marsh.

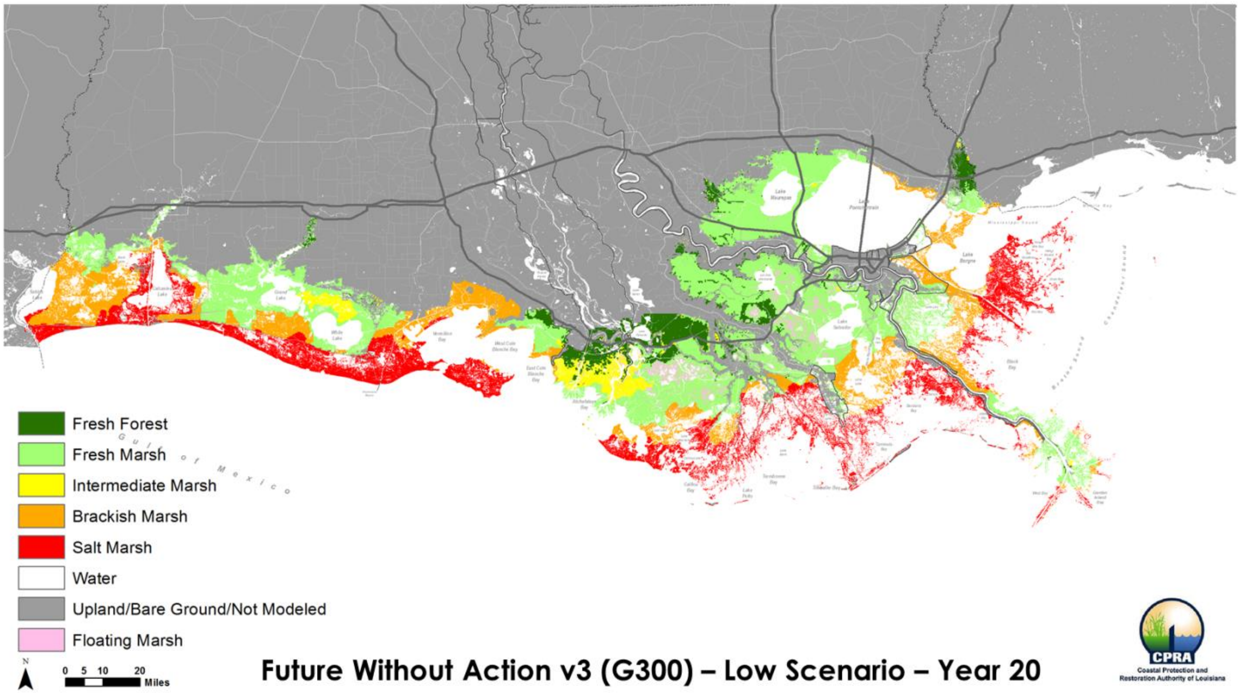

Figure 252: Predominant Vegetation Cover under FWOA_v3 (year 20; low scenario).

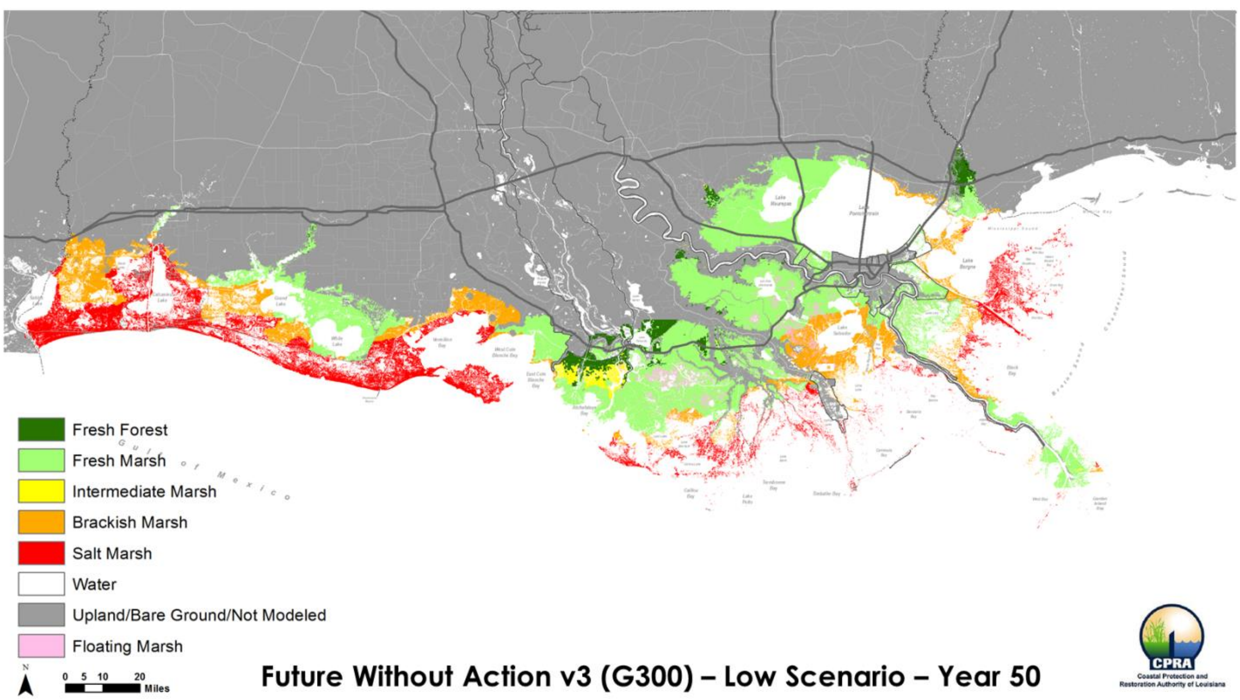

Figure 253: Predominant Vegetation Cover under FWOA_v3 (year 50; low scenario).

Under the medium scenario (Figure 254 and Figure 255), there is an initial conversion during the first five years of brackish marsh to salt marsh in the western region. By year 20, the distribution of community types remains relatively stable with only small expansions of salt marsh. From years 31 to 40, there is an expansion of brackish marsh into fresh marsh areas in the area southwest of Grand Lake and between the Sabine and Calcasieu lakes joined with an expansion of salt marsh into formerly brackish marsh. Between year 40 and 50, these trends continue with salt marsh expanding into areas south of Grand Lake and brackish marsh expanding east and north of Sabine Lake. By year 50, fresh and brackish marsh have been nearly completely replaced with salt marsh with only a remnant area remaining along the northern most portion of the western region. Dynamics in the central region area are very similar to those observed in the low scenario. By year 20, the eastern region shows very similarly patterns under medium scenario as it does under the low scenario. In the Maurepas area, by the end of the 50-year simulation, nearly all swamp forest is converted to fresh marsh. In the upper Barataria Basin, the same loss of swamp forest is observed, but the conversion is to brackish marsh instead of fresh marsh.

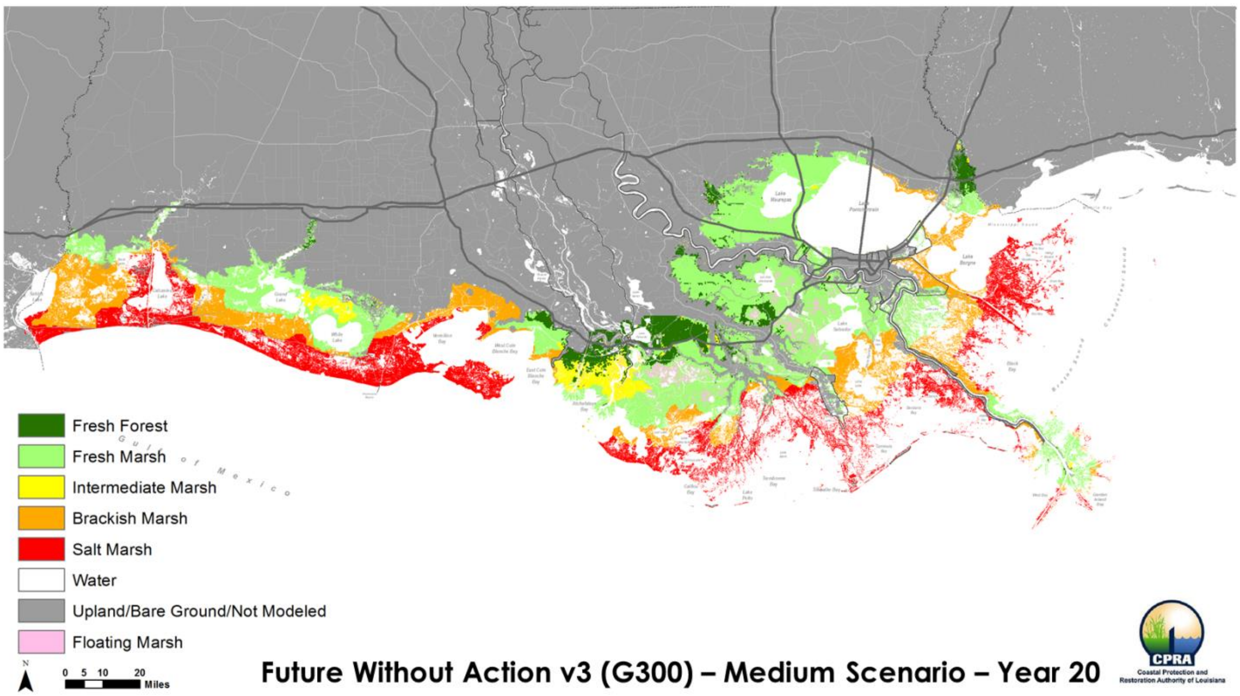

Figure 254: Predominant Vegetation Cover under FWOA_v3 (year 20; medium scenario).

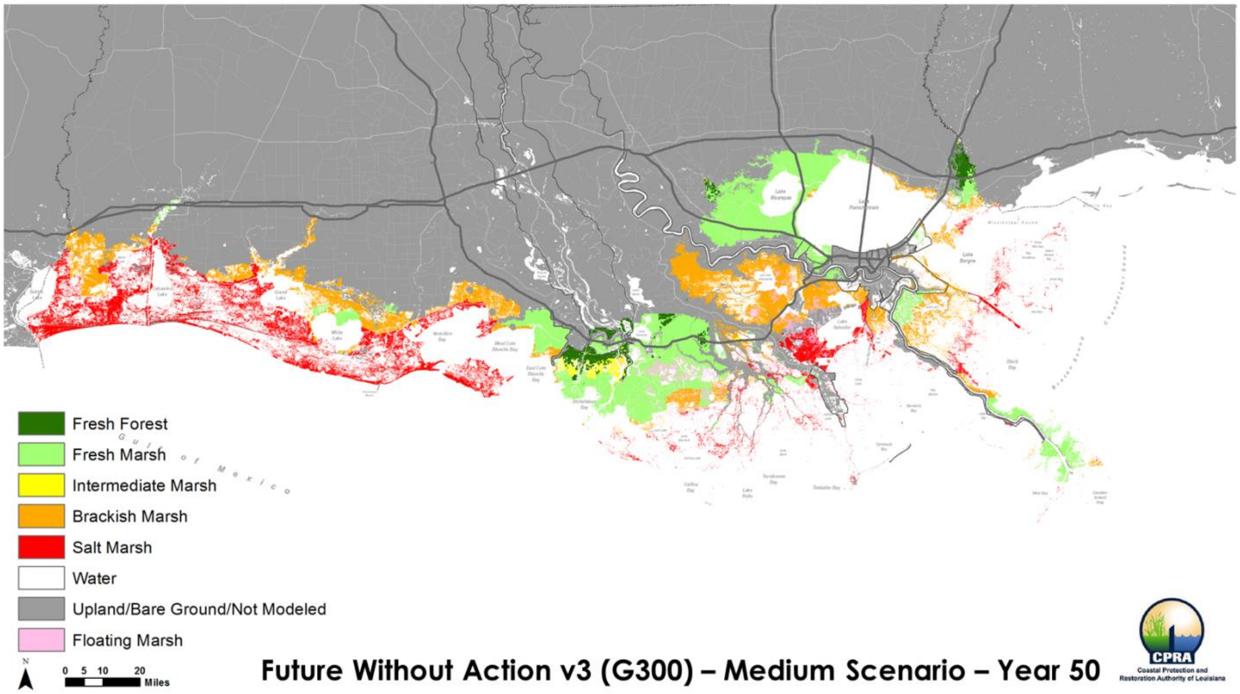

Figure 255: Predominant Vegetation Cover under FWOA_v3 (year 50; medium scenario).

Under high scenario (Figure 256 and Figure 257), the western region of the coast experiences a conversion of brackish marsh to salt marsh in the first five years. During the next 20 years, the distribution of community types remains relatively stable with a progressive conversion of brackish marsh to salt marsh along the brackish/saline boundary. Starting in year 25, land loss begins to dominate change in the landscape, which is correlated with a conversion of brackish marsh to salt marsh and northward movement of brackish marsh into fresh marsh areas. This continues to year 40, at which point most of the area is occupied by open water. Remnants of salt marsh are present throughout most of the area with a thin band of brackish and fresh marsh along the northern most boundary of the area. By year 50, the wetlands have been almost completely replaced with open water with the few remaining areas converted to salt marsh. There appears to be a small area of fresh marsh north of White Lake, but it is completely surrounded by open water. This area is currently an impoundment managed for freshwater marsh.

Under the high scenario in the central region, during the first 10 years, there is a conversion of intermediate to fresh marsh in the lower portion of the Atchafalaya Basin and a conversion of brackish to salt marsh in lower Terrebonne. There is also a contraction of swamp forest as it converts to fresh marsh during the first 10 years. The system remains relatively stable for the next 20 years (years 11 to 30) with some continued conversion of small areas from swamp forest to fresh marsh. From years 31 to 40, there is a major conversion of salt marsh to open water, while at the same time fresh marsh remains stable. By year 50, severe land loss results in the conversion of all marsh types to open water. In areas where marsh persists, there is a direct conversion from fresh to salt marsh followed by collapse of the salt marsh.

Under the high scenario in the eastern region, the most obvious change to vegetated cover is the conversion of swamp forest and intermediate marsh to fresh marsh by year 20. Lower areas of this region experience a small invasion of salt marsh into brackish marsh along the boundary between the two types. During this period, the distribution of marsh types in lower Pontchartrain

Basin remains largely unchanged. Starting in year 20, there begins a rapid conversion of salt marsh to open water. This is followed by an invasion of brackish marsh into the Lake Salvador region by year 30. During the same period (years 20 to 30), lower Pontchartrain remains relatively stable. From years 31 to 40, there is collapse of salt marsh over the entire eastern region with associated intrusion of brackish marsh into the upper basins. In the final decade, brackish marsh intrudes farther into the upper basins and is then converted to open water.

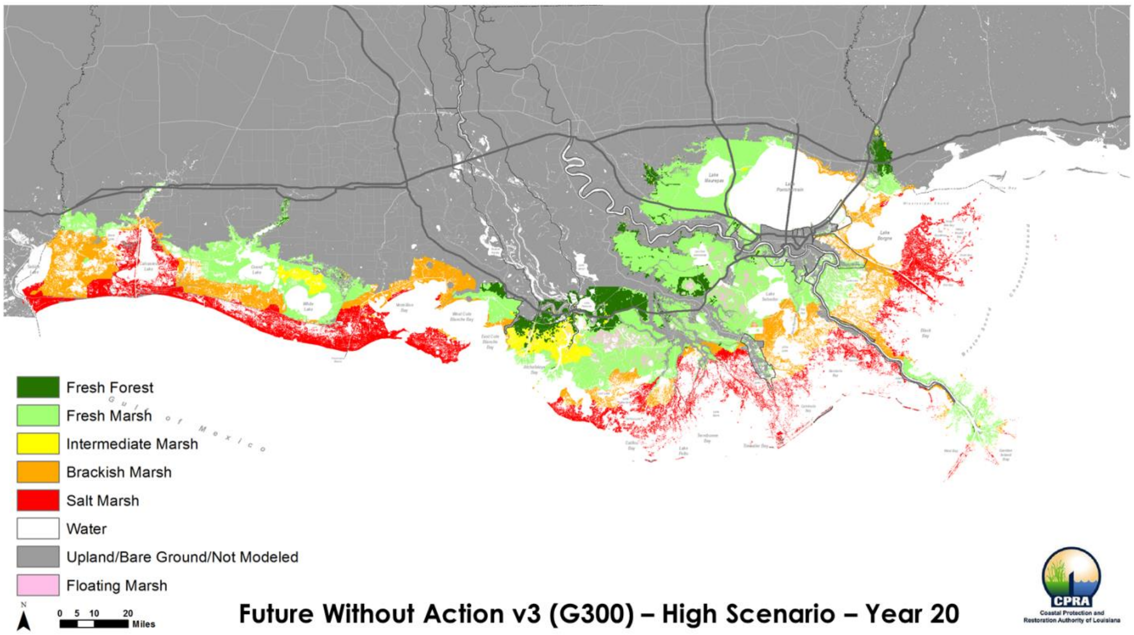

Figure 256: Predominant Vegetation Cover under FWOA_v3 (year 20; high scenario).

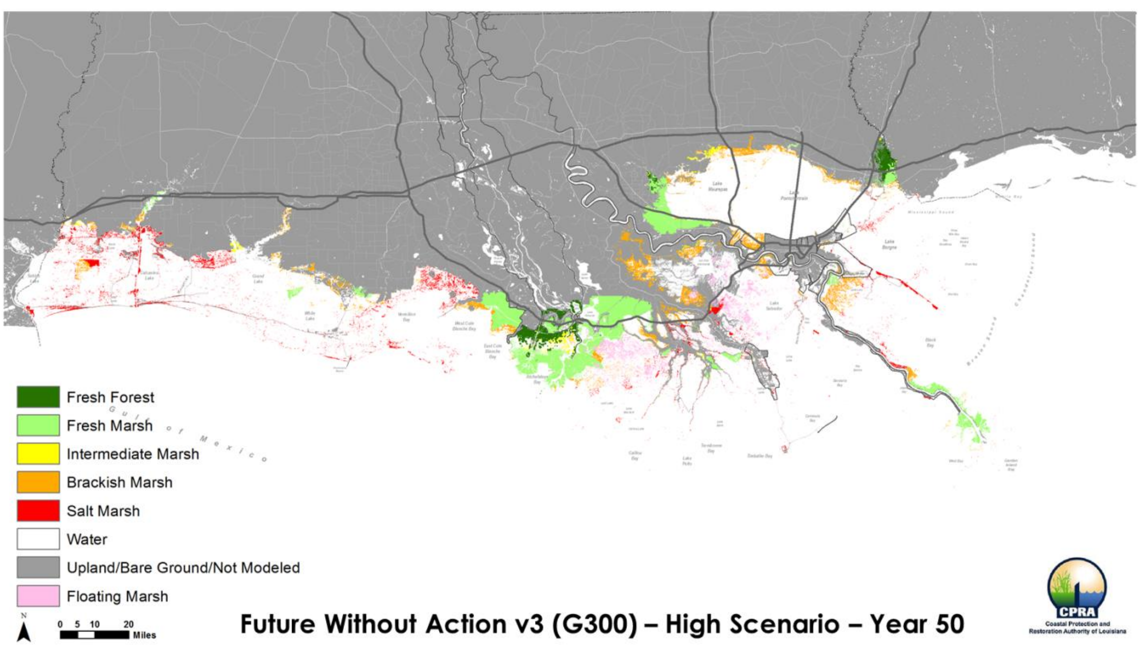

Figure 257: Predominant Vegetation Cover under FWOA_v3 (year 50; high scenario).

5.2.5 FWOA_v3 (G300) vs FWOA_v1 (G001)

5.2.5.1 Landscape and Vegetation Comparison

The majority of the model domain does not experience much change in land or vegetation cover between FWOA_v1 and v3; however, there are several regions where changes are substantial. The most pronounced changes are evident in areas subjected to salinity instabilities under FWOA_v1. Most changes are evident predominantly in three regions of the model: Maurepas Swamp, upper Barataria Basin, and western Terrebonne Basin.

Once the salinity instabilities were corrected in the Maurepas Swamp under FWOA_v3, the fresh wetlands persisted longer in this area (Figure 249 and Figure 255), as opposed to conversion to brackish marsh under FWOA_v1 (Figure 258 and Figure 259). Even at year 50, under both the low and medium scenarios, there are still large areas of fresh marsh present near Lake Maurepas. Fresh marsh is not subjected to an inundation collapse criteria; therefore, regardless of the sea level rise and subsidence rates modeled in these two scenarios, this land remained fresh marsh and did not collapse into open water areas as it did under FWOA_v1. Under the high scenario, however, the wetlands surrounding Lake Maurepas convert to intermediate and brackish marshes (Figure 257 and Figure 260) and collapse due to inundation stress by the later decades of the simulation. These different behaviors between the low/medium scenarios compared to the high scenario explain much of the different behavior in land loss over time seen in Figure 261, Figure 262, and Figure 263. By year 50 under the high scenario, any changes to the landscape as a result of salinity predictions under FWOA_v3 are mostly outweighed by the high rates of sea level rise and subsidence, resulting in a year 50 land area value that is not substantially different than the FWOA_v1 value.

In the upper Barataria Basin, upstream of Lac des Allemandes and near Raceland, there is substantial difference in vegetation type at year 50 between FWOA_v1 and FWOA_v3 for both the low and medium scenarios. Under FWOA_v1, these regions are fresh and brackish marsh under the low scenario, with some areas of bare ground (Figure 258). However, under FWOA_v3, these regions remained fresh marsh at year 50 under the low scenario (Figure 253). Under the medium scenario at year 50, these regions are predominantly brackish marsh or bare ground under FWOA_v1 (Figure 259), however with the salinity recalibration in place, these regions are either brackish marsh or open water under FWOA_v3 (Figure 255). Since this area is not subjected to collapse in FWOA_v1 (i.e., bare ground has no collapse criteria), there is an increase in land loss in this region during FWOA_v3.

The third region where there are noticeable differences in model output between FWOA_v1 and FWOA_v3 is in western/central Terrebonne; where the differences are predominantly evident in the vegetation type at year 50. Under FWOA_v1, by year 50, there is intrusion of brackish and salt marsh into the lower reaches of Terrebonne Basin (due east of the Atchafalaya Delta; Figure 258, Figure 259, and Figure 260). Under FWOA_v3, the influence of fresh water from the Atchafalaya appears to be driving this region to remain fresher during later decades under the low and medium scenarios (Figure 253 and Figure 255). By year 50 under the high scenario, there is still fresh marsh adjacent to the Atchafalaya River; however, brackish marsh has established much more than under the low and medium scenarios (Figure 261).

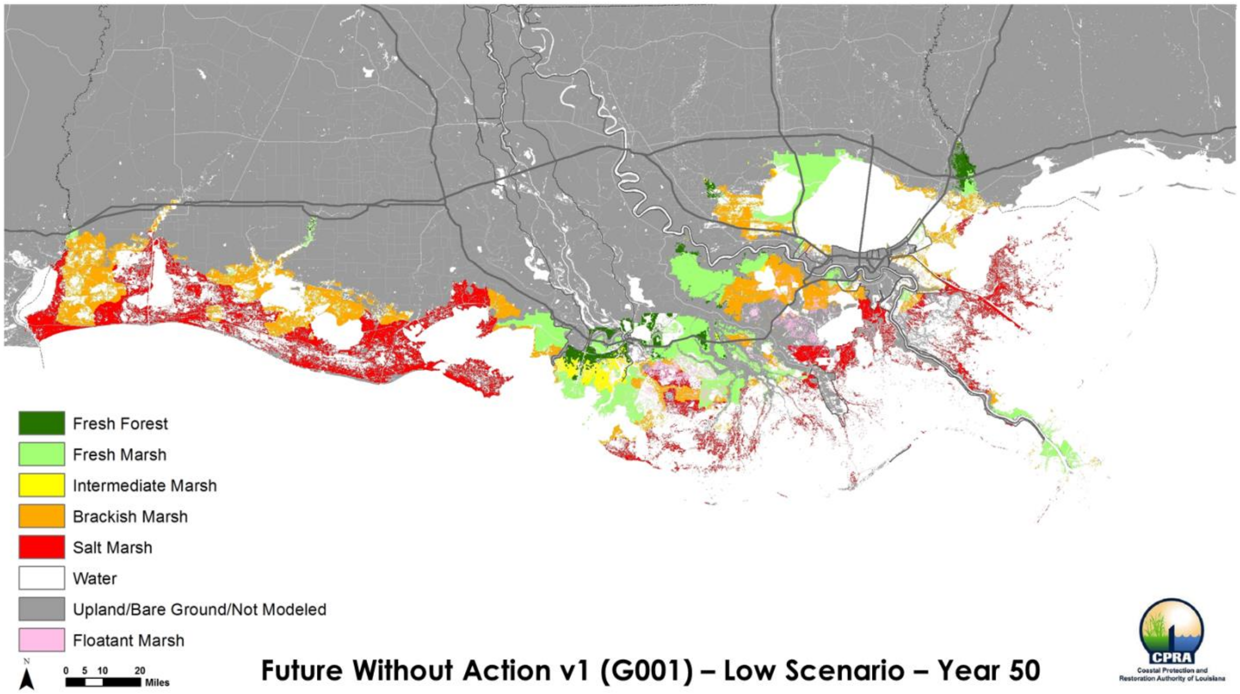

Figure 258: Predominant Vegetation Cover under FWOA_v1 (year 50; low scenario).

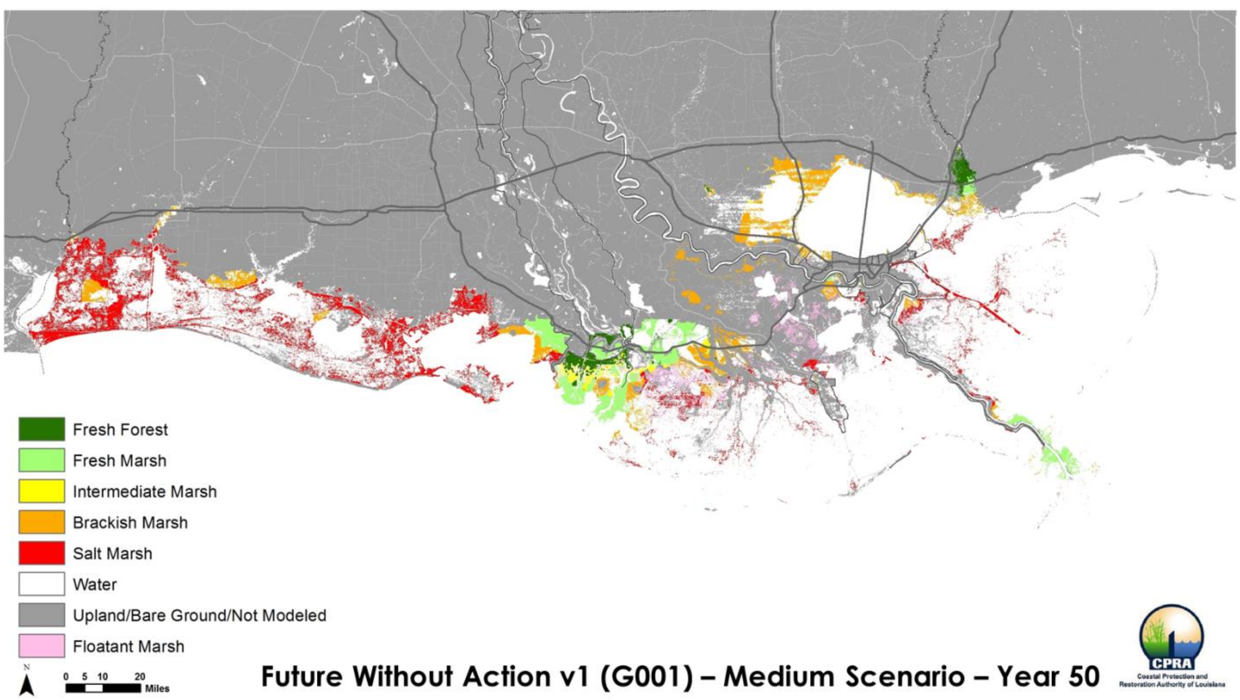

Figure 259: Predominant Vegetation Cover under FWOA_v1 (year 50; medium scenario).

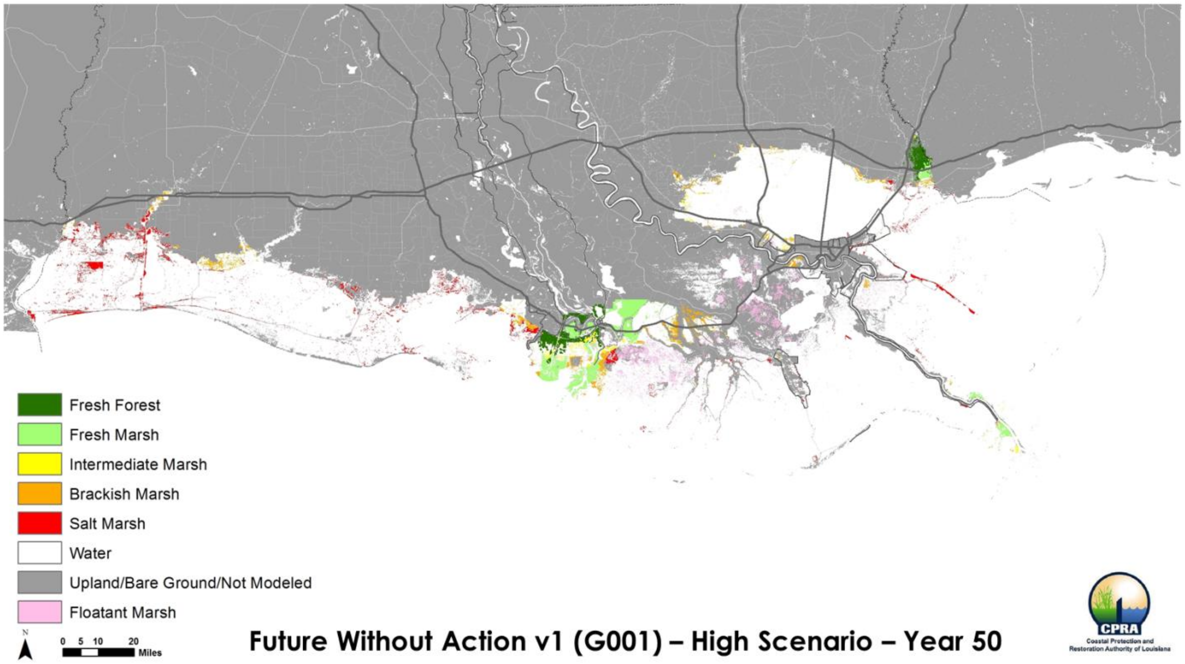

Figure 260: Predominant Vegetation Cover under FWOA_v1 (year 50; high scenario).

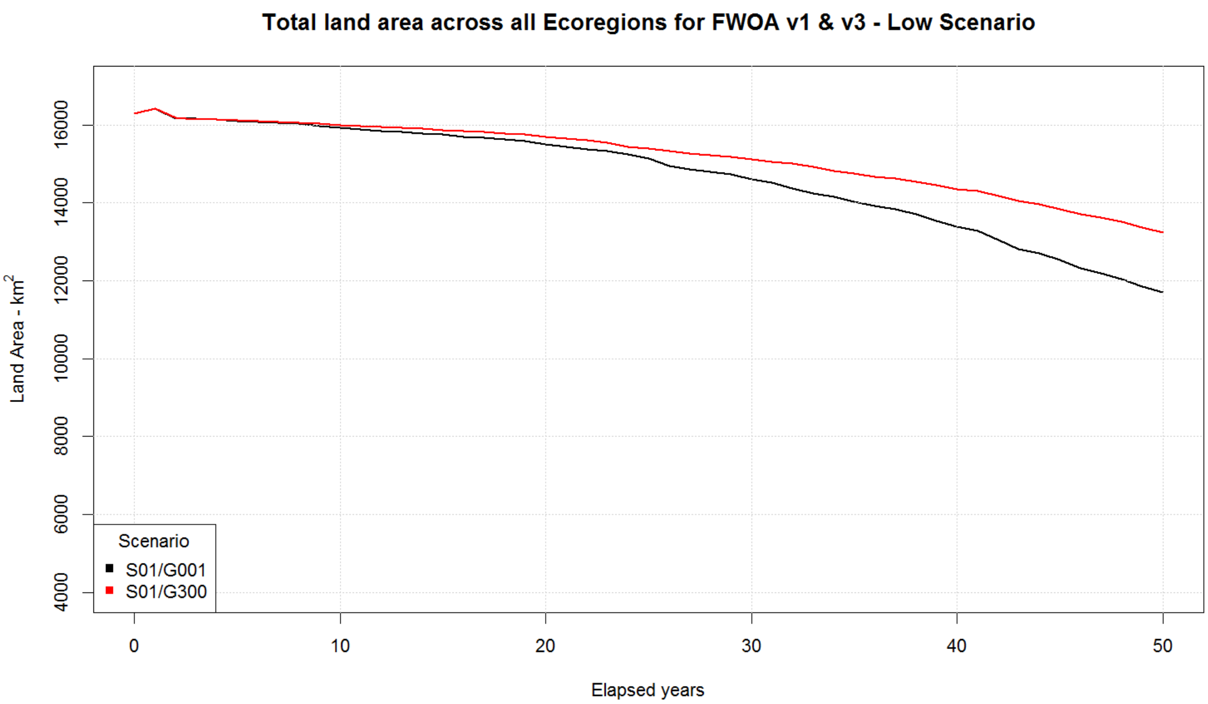

Figure 261: Land Area for FWOA_v1 (G001) and FWOA_v3 (G300; full coast; low scenario).

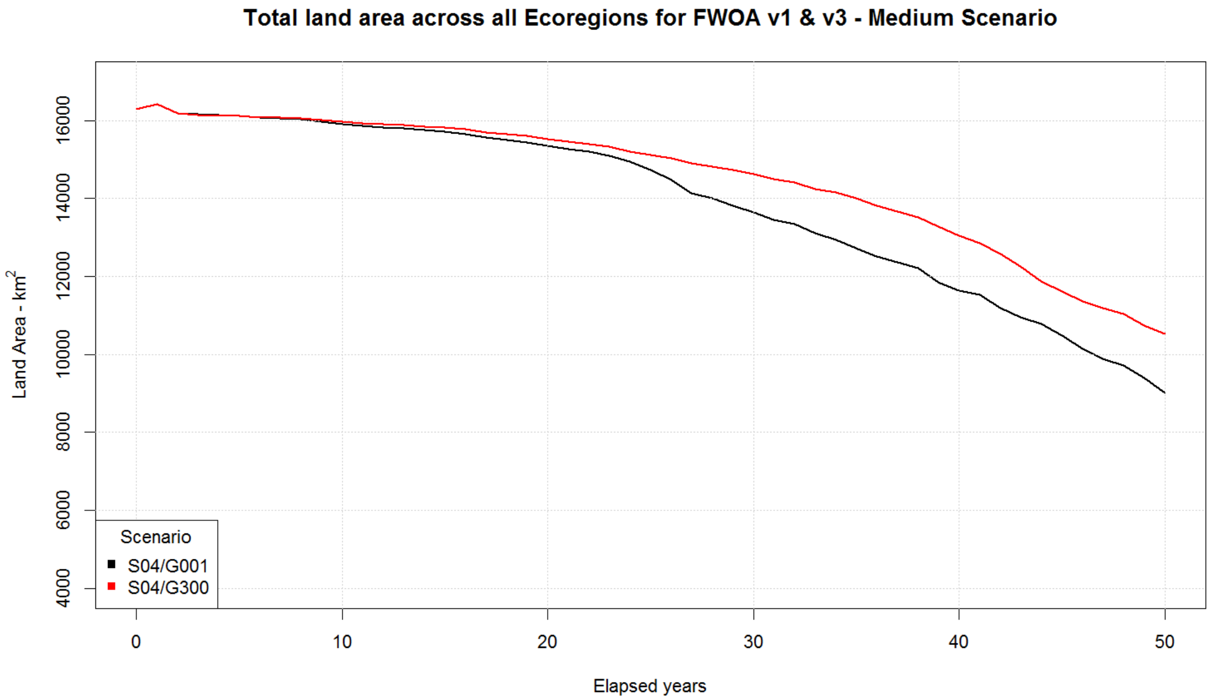

Figure 262: Land Area for FWOA_v1 (G001) and FWOA_v3 (G300) (full coast; medium scenario).

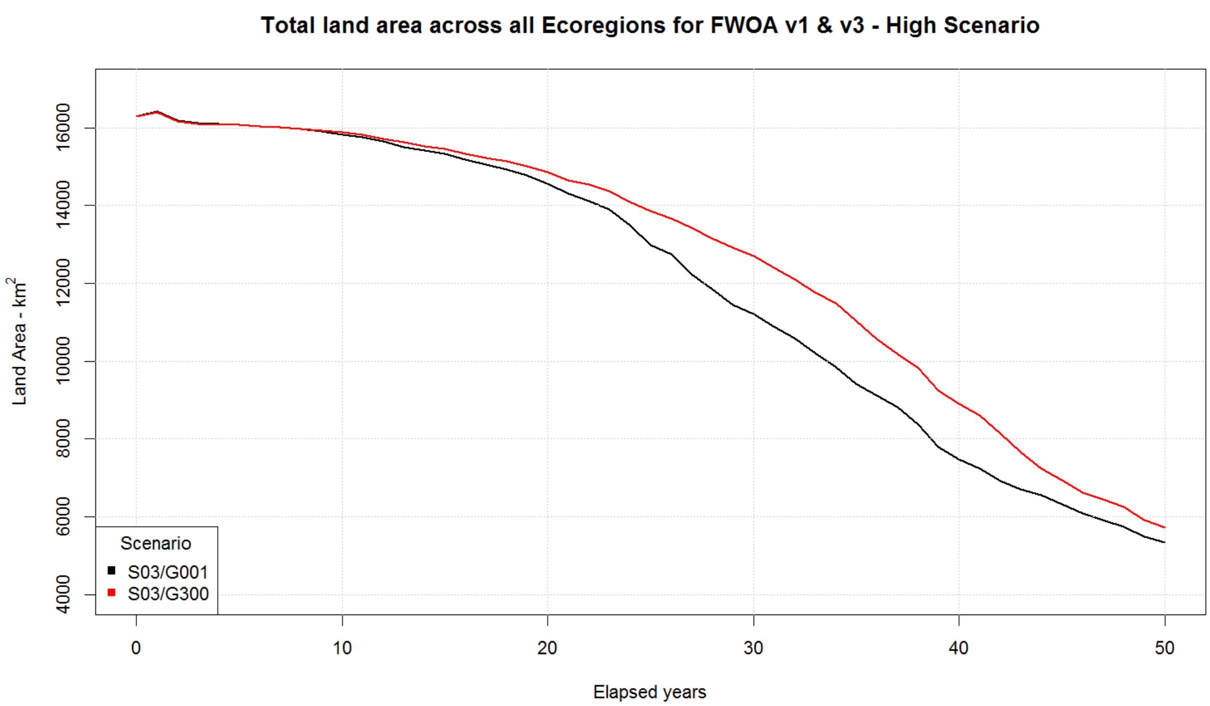

Figure 263: Land Area for FWOA_v1 (G001) and FWOA_v3 (G300) (full coast; high scenario).

5.2.5.2 HSIs and EwE Comparison

The changes in the FWOA_v3 compared to FWOA_v1 resulted in minor effects on the spatial-temporal patterns of habitat suitability for fish, shellfish, and wildlife. Because saltwater intrusion is less pronounced in the FWOA_v3, most interior areas are not as suitable for higher-salinity species, such as brown shrimp, as is seen in the FWOA_v1. Conversely, these areas are maintained as suitable habitat for low-salinity species, such as largemouth bass, for a longer time period in the FWOA_v3. These differences are more apparent for the medium scenario than for the high scenario, which by the end of the 50-year simulation exhibits similar habitat suitability patterns between the two versions.

There are larger changes in the EwE between FWOA_v1 and FWOA_v3 simulations as a result of the improvements made to the ICM. These changes are due to the aforementioned changes in the salinity regime and to modifications made to the TKN input data, which is an important factor driving phytoplankton production, and thus fish and shellfish biomass, in the EwE model. As a consequence, simulated biomasses in the FWOA_v3 are generally lower in magnitude and the spatial distribution patterns are different for many species. For example, the inland expansion of biomass of higher-salinity species is considerably less evident than in FWOA_v1, while the majority of the biomass remained in the lower basins and nearshore where TKN-driven food resources are greatest (e.g., juvenile brown shrimp; Figure 264).

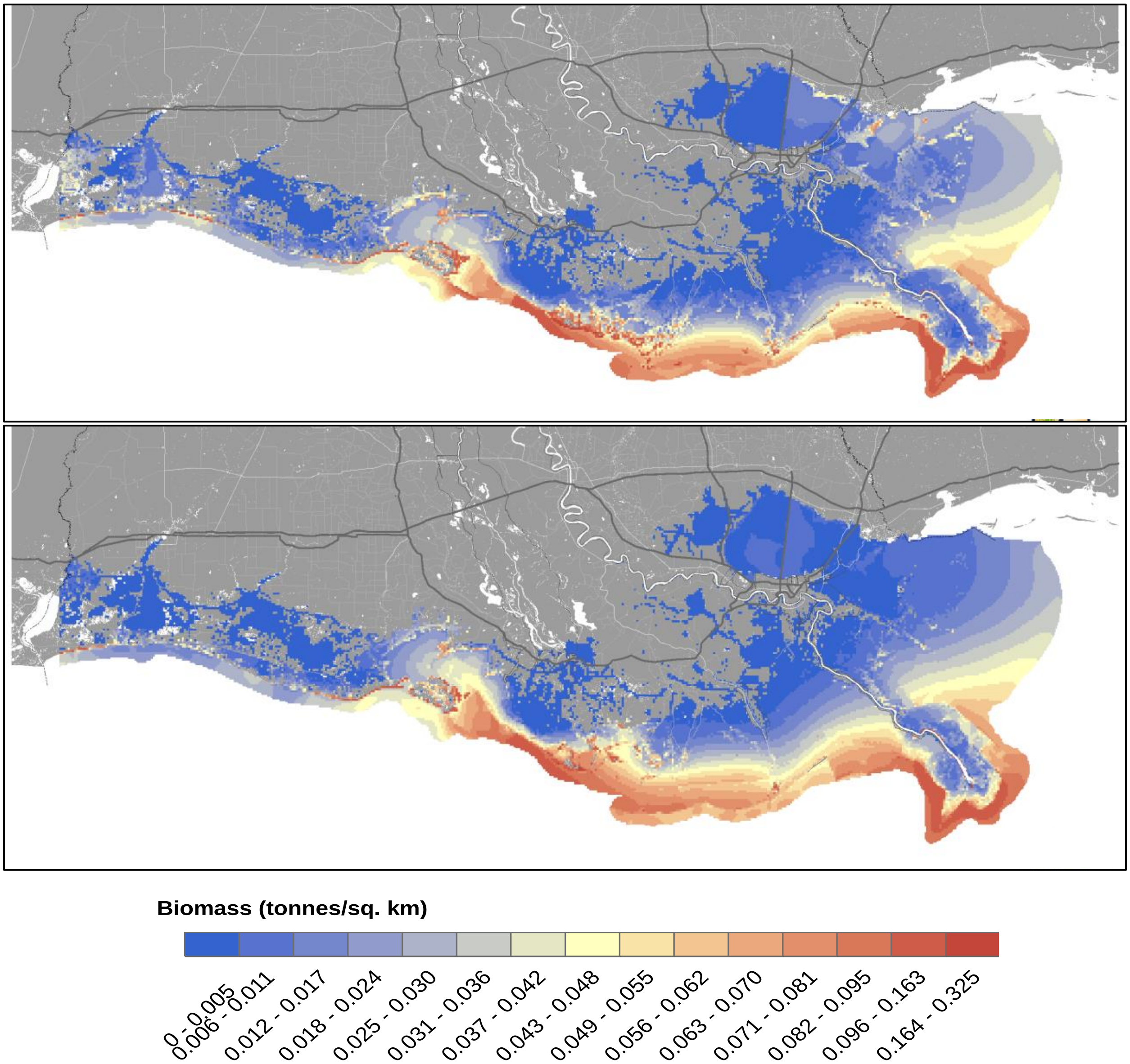

Figure 264: EwE Juvenile Brown Shrimp Biomass Distribution in FWOA_v3 (April year 25 [top] and year 50 [bottom]; medium scenario).

5.3 Project Interactions - Landscape and Ecosystem

The local project interactions section uses FWOA_v1 for comparison purposes. All subsequent sections refer to analysis using FWOA_v3.

5.3.1 Local Project Interaction Examples

Synergies among restoration projects are anticipated at a number of spatial and temporal scales. To assess this, several numerical experiments were conducted to evaluate how small groups of projects designed to address different aspects of systems dynamics (e.g., salinity control project paired with projects designed to rebuild wetlands) may work together. Two examples are described in this section.

5.3.1.1 Example 1: Calcasieu Ship Channel Salinity Control Measures project (004.HR.06), Calcasieu Lake West Bank Marsh Creation (004.MC.104), and East Calcasieu Lake Marsh Creation (004.MC.19)

In the Chenier Plain, the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project, Calcasieu Lake West Bank Marsh Creation (004.MC.104), and East Calcasieu Lake Marsh Creation (004.MC.19) were modeled independently and also together in a single model run where the salinity control project was implemented in IP1 and increments of the marsh creation projects were implemented in IP2.

The effect of the salinity control project on the mean annual salinity, compared to FWOA conditions is shown for the high scenario for year 25 in Figure 265 and for year 50 in

Figure 266. By year 25, the effects of the project are to reduce salinity across the influence area; however, by year 50, the prevention of salinity penetration into Lake Calcasieu and interior areas, compared to FWOA, causes a localized increase in salinity of up to 3 ppt in the area south of the Lake and west of the Calcasieu Ship Channel.

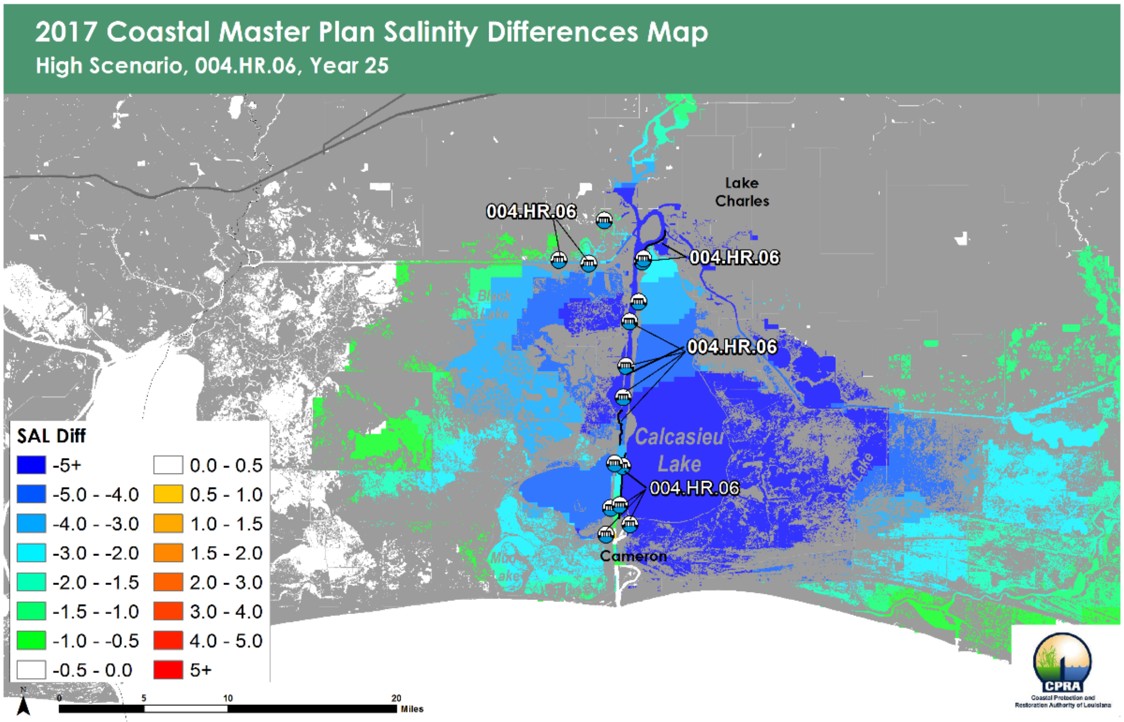

Figure 265: Difference in Mean Annual Salinity with the Calcasieu Ship Channel Salinity Control Measures Project compared to FWOA (year 25; high scenario).

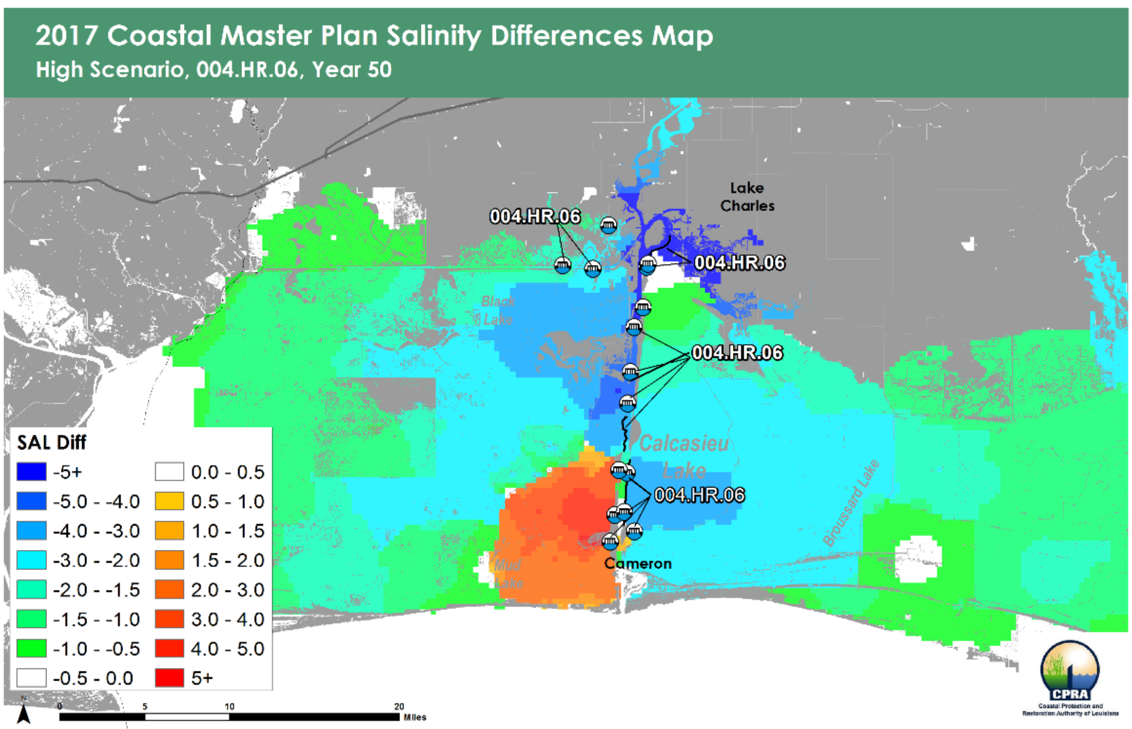

Figure 266: Difference in Mean Annual Salinity with the Calcasieu Ship Channel Salinity Control Measures Project compared to FWOA (year 50; high scenario).

The effect of these changes on land change by year 50 are negligible as extensive land loss across the Chenier Plain is not reduced by the project. However, by year 25, some benefits relative to FWOA can be seen east of the project area (Figure 267). Areas of land loss south of GIWW can also be observed. The effect of the project on Chenier plain hydrology appears to be to retain fresh marsh north of GIWW while brackish marshes south of GIWW are impacted by changes in water level resulting in loss.

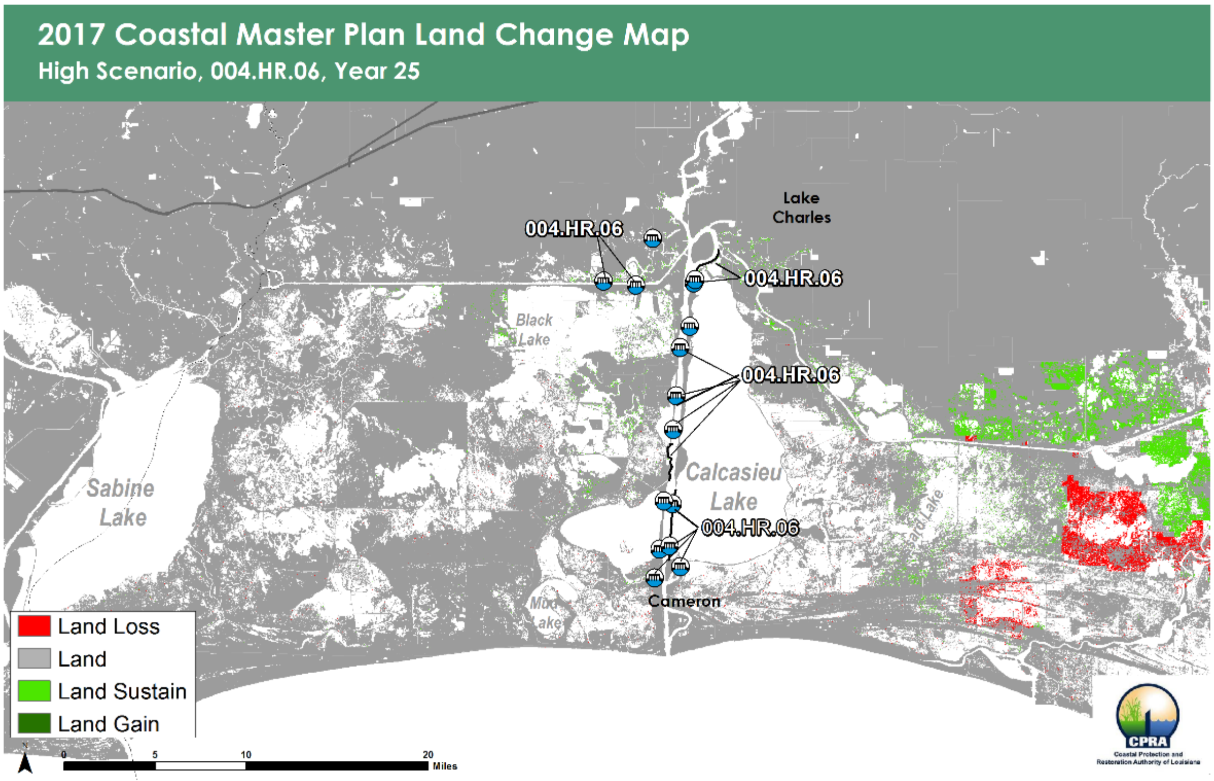

Figure 267: Land Change with the Calcasieu Ship Channel Salinity Control Measures Project compared to FWOA (year 25; high scenario).

When implemented in IP1, both marsh creation projects still showed substantial change in land compared to FWOA by year 25, but benefits are eliminated by year 50. When implemented in the second IP and in combination with the salinity control project, the marsh created within the project footprints still does not persist until year 50 (Figure 268). However, the combined project does show some relative gain of land in the east of the project area north of the GIWW. This appears to be due to retaining an area of intermediate marsh and could be a result of the marsh creation project limiting the penetration of saline water in the later decades of the combined simulation and allowing fresh marsh to convert to intermediate gradually. Intermediate marsh is only lost in the ICM due to a change in water level (not a change in salinity), indicating that the effect is probably due to the impact of the marsh creation project on regional hydrology rather than the salinity control project.

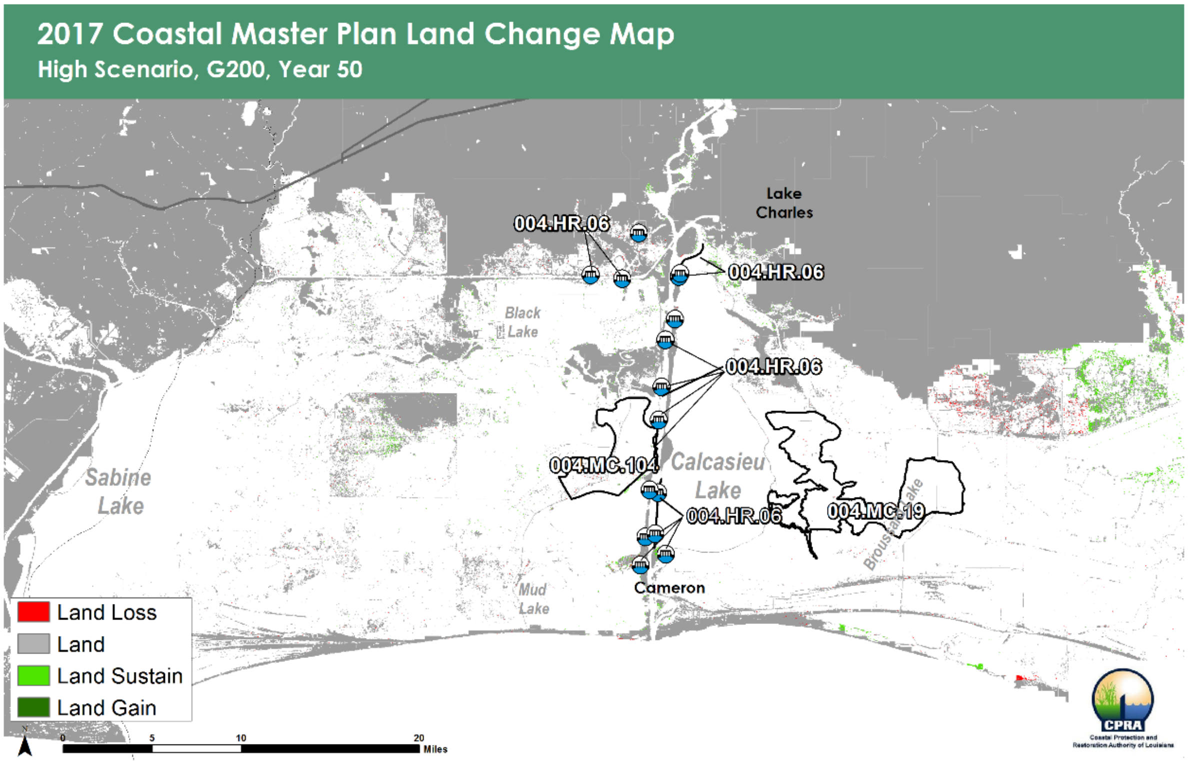

Figure 268: Land Change with the Calcasieu Ship Channel Salinity Control Measures Project compared to FWOA (year 50; high scenario).

While this discussion focuses on the factors influencing land-water conditions, the net effect on salinity by year 50 of the combined project simulation (Figure 269) is greater in the extent and intensity of salinity reduction compared to the salinity control project alone (

Figure 266). This likely has additional consequences for fish and wildlife habitat.

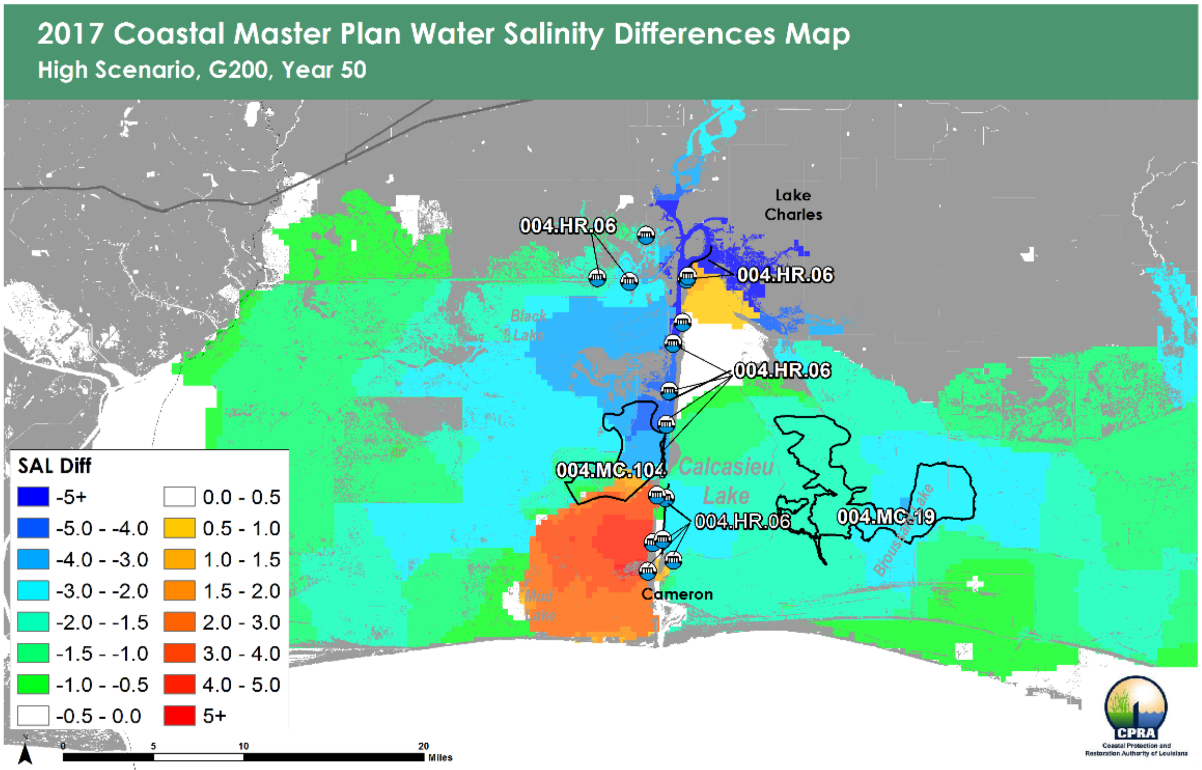

Figure 269: Difference in Mean Annual Salinity with the Calcasieu Ship Channel Salinity Control Measures, Calcasieu Lake West Bank Marsh Creation, and East Calcasieu Lake Marsh Creation Projects compared to FWOA (year 50; high scenario).

For the medium scenario, the effects of the combined projects on salinity at year 50, compared to FWOA, is a greater decrease of up to 3-4 ppt in the area east of the lake. The increase in salinity south of the lake on the west side of the ship channel is also lessened. Under the medium scenario, the combination of the salinity control and the marsh creation, as well as the later implementation of the marsh creation, leads to land gain by year 50 within the marsh creation project footprints as well as land gain to the east and west of the areas shown in Figure 270.

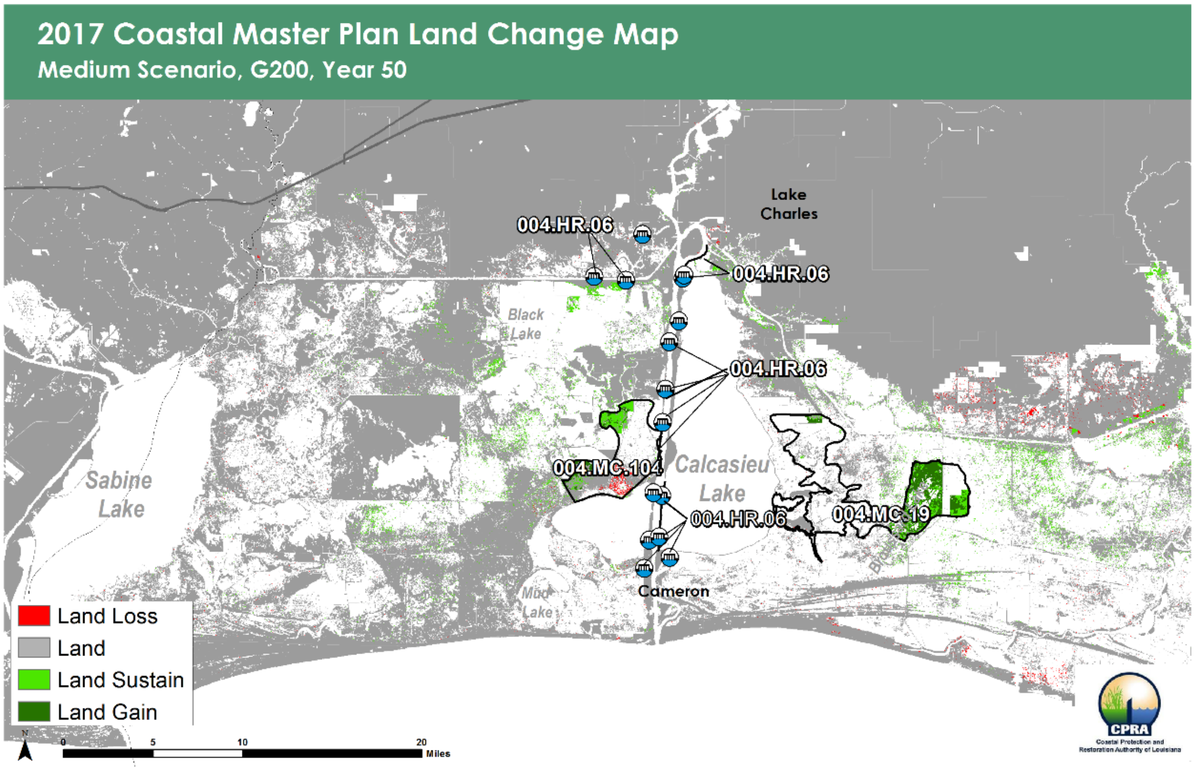

Figure 270: Land Change with the Calcasieu Ship Channel Salinity Control Measures, Calcasieu Lake West Bank Marsh Creation, and East Calcasieu Lake Marsh Creation Projects compared to FWOA (year 50; medium scenario).

The net effect of the project interactions on land change is shown for the high and medium scenarios in Figure 271. These graphs show that for both scenarios, the effects of the individual project and the combined implementation shows greater benefits in the decades prior to year 50, and for the medium scenario, the benefits are continuing to increase relative to FWOA before a steep decline in year 50.

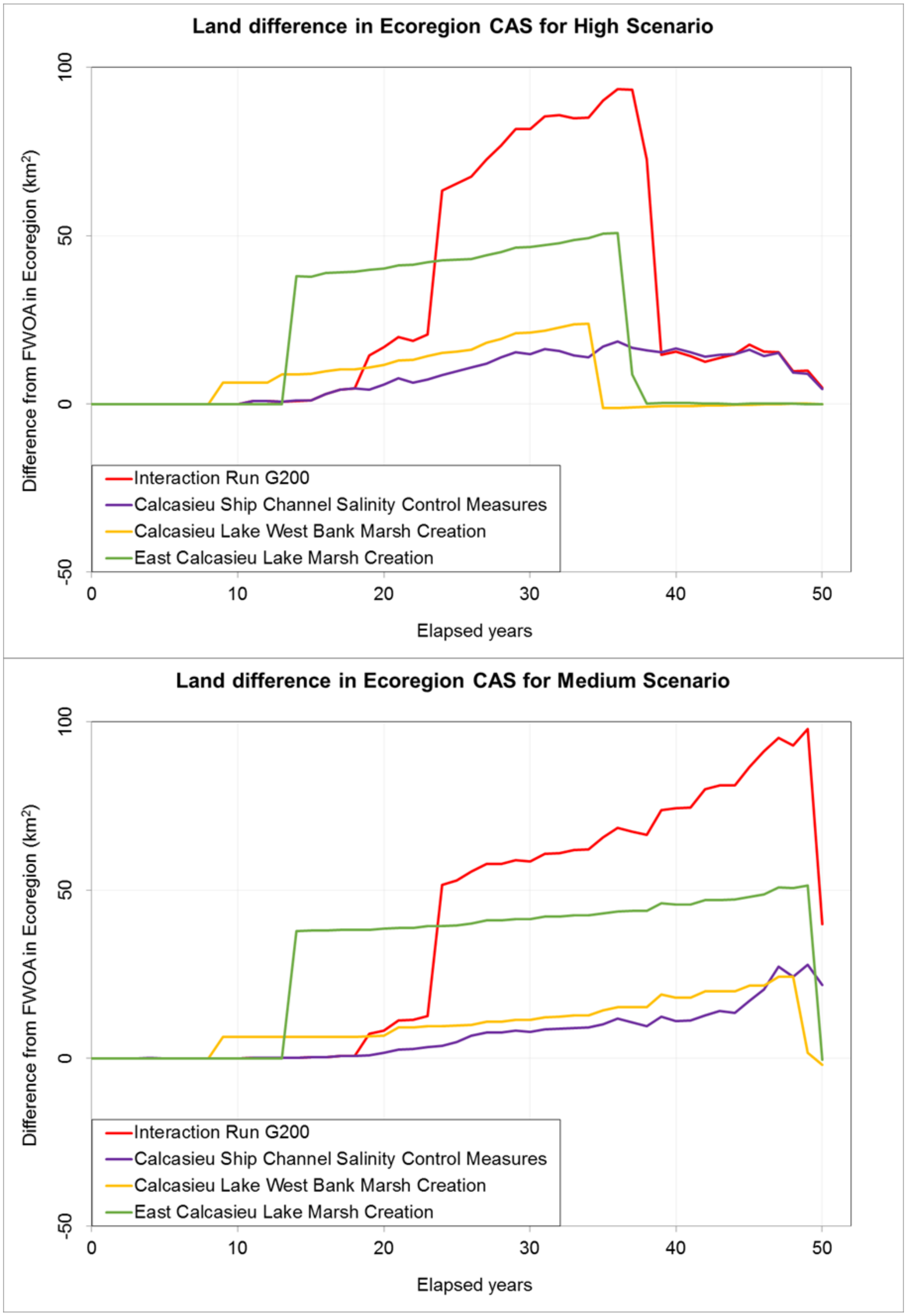

Figure 271: Net Effect of the Calcasieu Ship Channel Salinity Control Measures, Calcasieu Lake West Bank Marsh Creation, and East Calcasieu Lake Marsh Creation Projects together on Land Change compared to the Individual Projects (high scenario [top]; medium scenario [bottom]).

5.3.1.2 Example 2: Mid-Barataria Diversion (002.DI.03) and Large-Scale Barataria Marsh Creation - Component E (002.MC.05e)

In Barataria Basin, the Mid-Barataria Diversion (002.DI.03) and the Large-Scale Barataria Marsh Creation - Component E (002.MC.05e) project were modeled independently and also included in a single model run where the diversion was implemented in IP1 and increments of the marsh creation project were implemented in IP2.

When implemented alone under the high scenario, the diversion results in a complex pattern of land change – sustaining, building and loss – in Barataria Basin, extending to a lesser extent to parts of the Terrebonne Basin via the GIWW. By year 25, the sustaining effects are shown largely to the south of the diversion location and loss occurs to the north – presumably due to increases in water level impacting non-fresh wetlands (Figure 272). By year 50 (Figure 273), the land gain adjacent to the diversion location is more extensive but compared to FWOA there is extensive loss in the upper part of the basin. This is due to operation of the diversion that requires discharge to be reduced to zero when Mississippi River flow is below 5,663 cms. This occurs during the last decade of the simulation and marshes that have been maintained and sustained as fresh by the diversion are impacted by salinity incursion when the diversion is turned off[13].

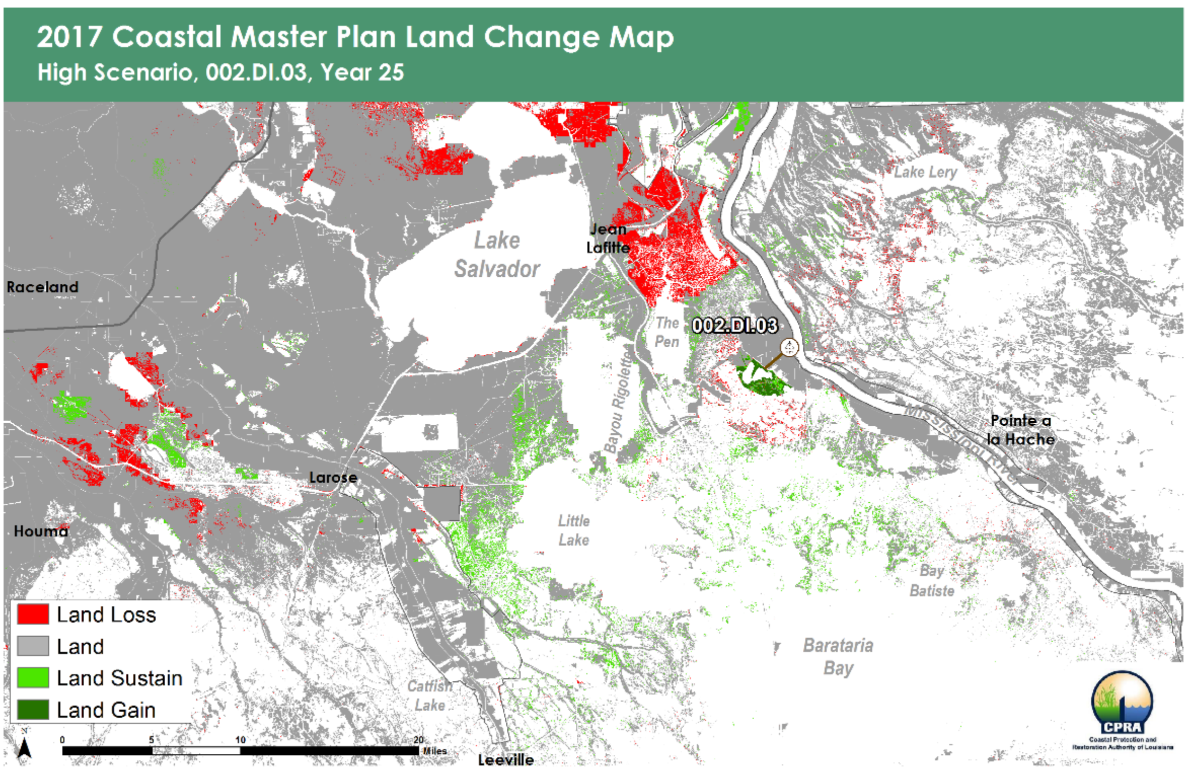

Figure 272: Land Change with Mid-Barataria Diversion compared to FWOA (year 25; high scenario).

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[13] Note that recognition of this effect led to a modified operation of the Mid-Barataria Diversion in subsequent simulations to ensure a base flow of fresh water even when Mississippi River flow is low.

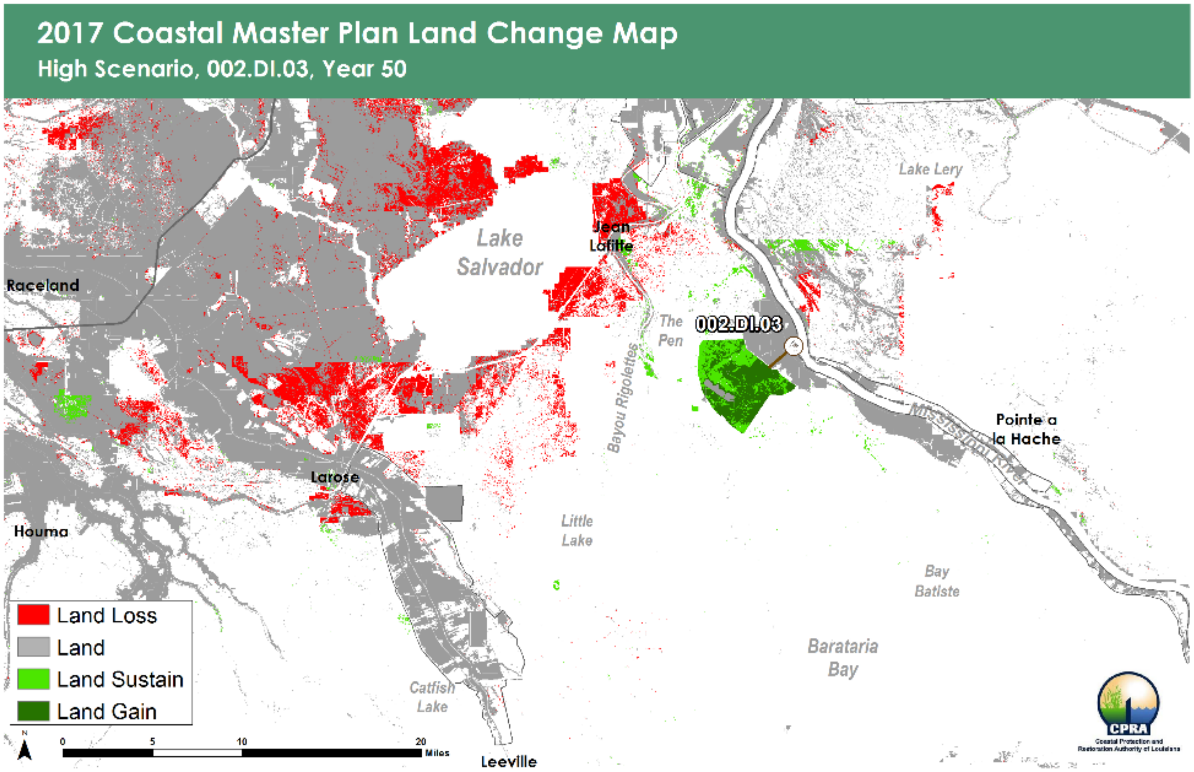

Figure 273: Land change with Mid-Barataria Diversion compared to FWOA (year 50; high scenario).

The marsh creation project, under the high scenario and when implemented as an individual project during the first IP, includes extensive land gain (relative to FWOA) within the project footprint at year 25, but there is no effect within the footprint by year 50. At year 25, the created marsh does have an effect on mean annual salinity in the basin (Figure 274) with an increase of several parts per thousand to the north and west of the project area.

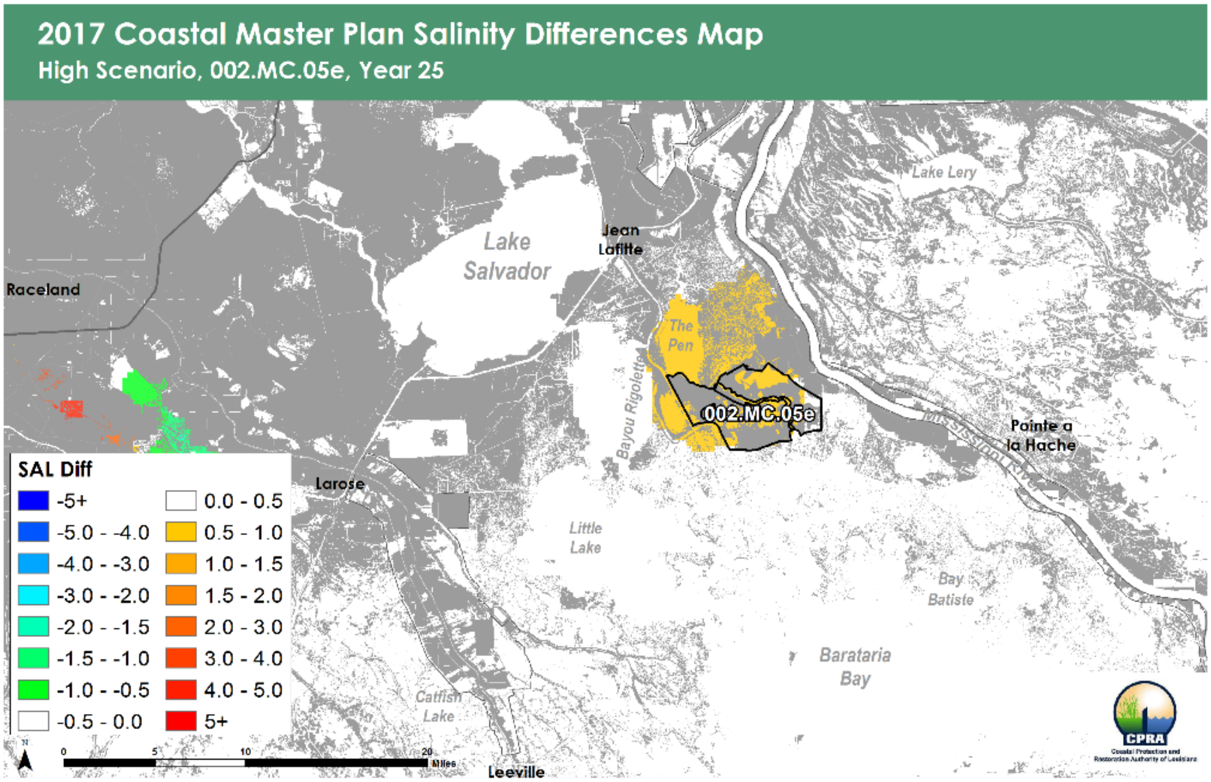

Figure 274: Difference in Mean Annual Salinity with the Large-Scale Barataria Marsh Creation compared to FWOA (year 25; high scenario).

When the two projects are implemented together, the marsh creation project is implemented in the second IP, and for the high scenario some land remains within the marsh creation footprint in year 50 (Figure 275). This may be a result of the later implementation but could also be a result of a nourishing effect from the sediment diversion. The freshening effect of the diversion overrides the effects on salinity of the marsh creation project shown in Figure 274 in year 50 when the basin is 5 ppt or more fresher than under FWOA at year 50. The effect is much less in year 25 as the operational rules for the diversion lead to it being closed for much of the year 25 simulation.

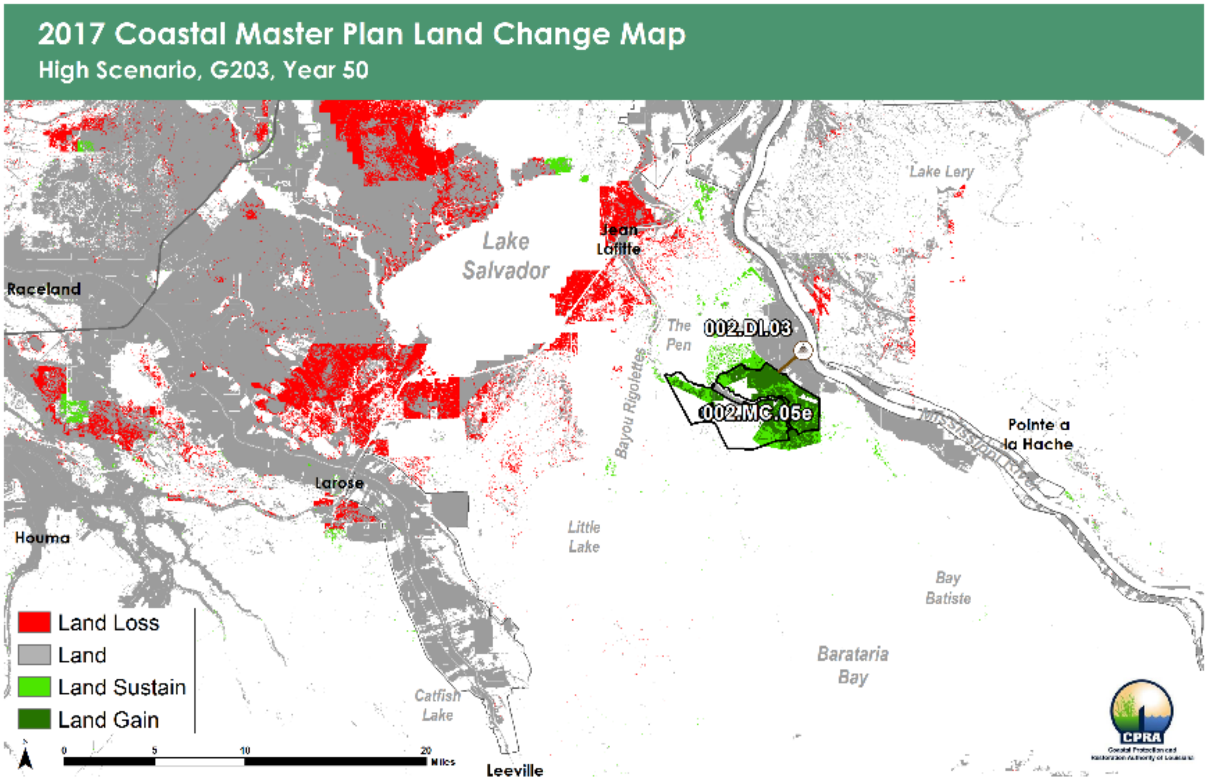

Figure 275: Land Change with the Mid-Barataria Diversion and Large-Scale Barataria Marsh Creation compared to FWOA (year 50; high scenario).

Under the medium scenario, the effect of the combined projects on land compared to the diversion alone is marked. By year 50, the diversion builds and sustains land in the outfall area, but there is loss compared to FWOA in upper parts of the basin and to the west presumably due to the salinity incursion into marshes maintained as fresh described above for the high scenario. This loss is reduced for the combined project run (Figure 276). Figure 276 also shows substantially less land loss at year 50 under the medium scenario compared to the high scenario.

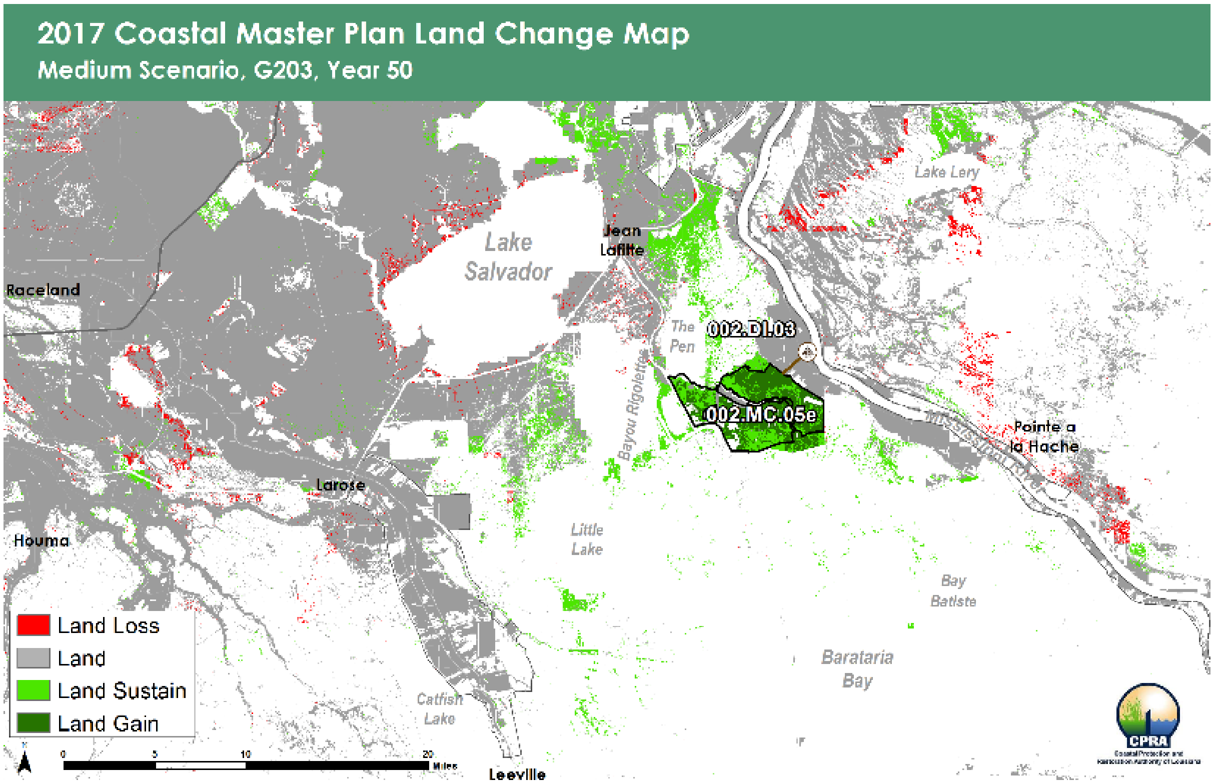

Figure 276: Land Change with the Mid-Barataria Diversion and Large-Scale Barataria Marsh Creation compared to FWOA (year 50; medium scenario).

5.3.2 G301 compared to FWOA

5.3.2.1 Stage

High Scenario

Under the high scenario, annual mean stage effects (for all decades) primarily occur in Barataria, Breton, and Terrebonne basins (Figure 277: and Figure 278). Upper Breton Sound, in the immediate vicinity of sediment diversion outfalls, has the largest increase in water levels compared to FWOA. This is due to the extremely large (7,079 cms) design flowrate of the Upper Breton Diversion (001.DI.17). Water levels increase by more than 3 m in the immediate outfall region. Therefore, regardless of the sediment deposition depth, it is not possible for the deposition to overtake the water level in the outfall area. When examining the time series of water level, a clear signal is evident when diversions are activated in the ICM. The Bayou Lafourche Diversion (03a.DI.01) results in over 1 m increase in mean water level immediately upon implementation, as do the other large diversions off of the Mississippi River. The western region of the coast has no change in mean water level compared to FWOA, due to the lack of diversion projects in this region.

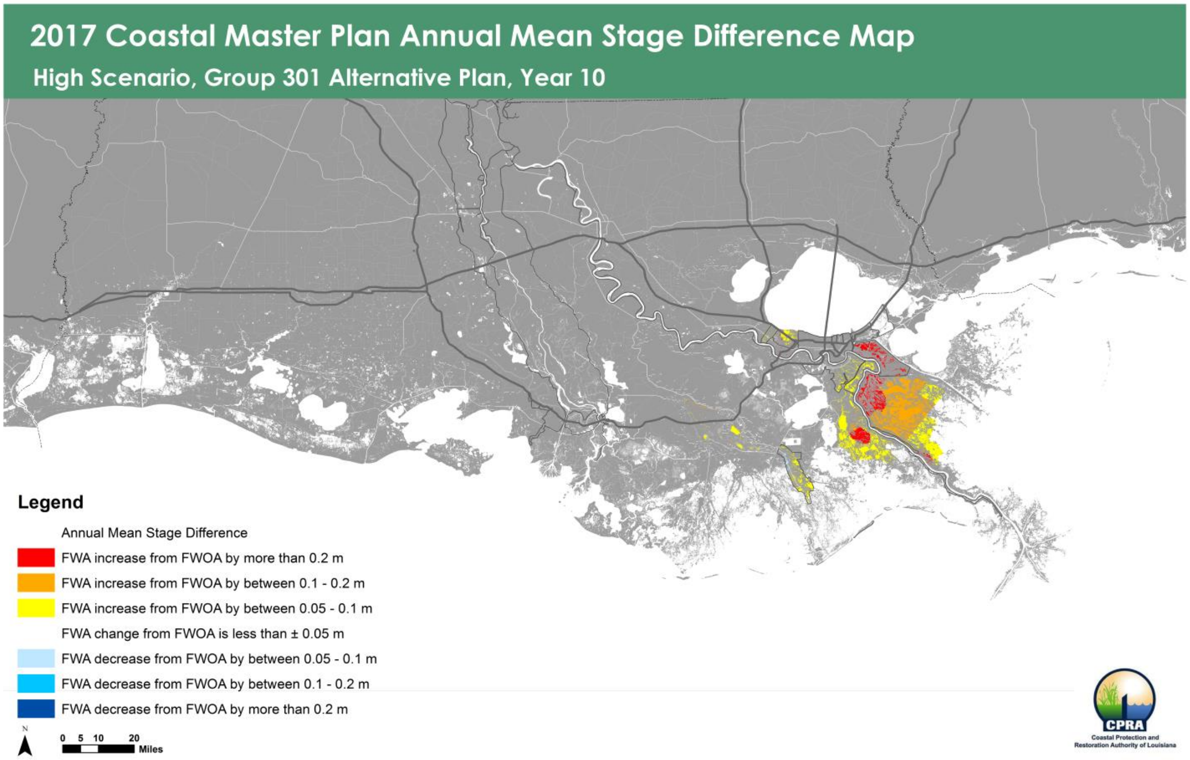

Figure 277: Mean Annual Stage Difference with G301 (FWA) compared to FWOA (year 10; high scenario).

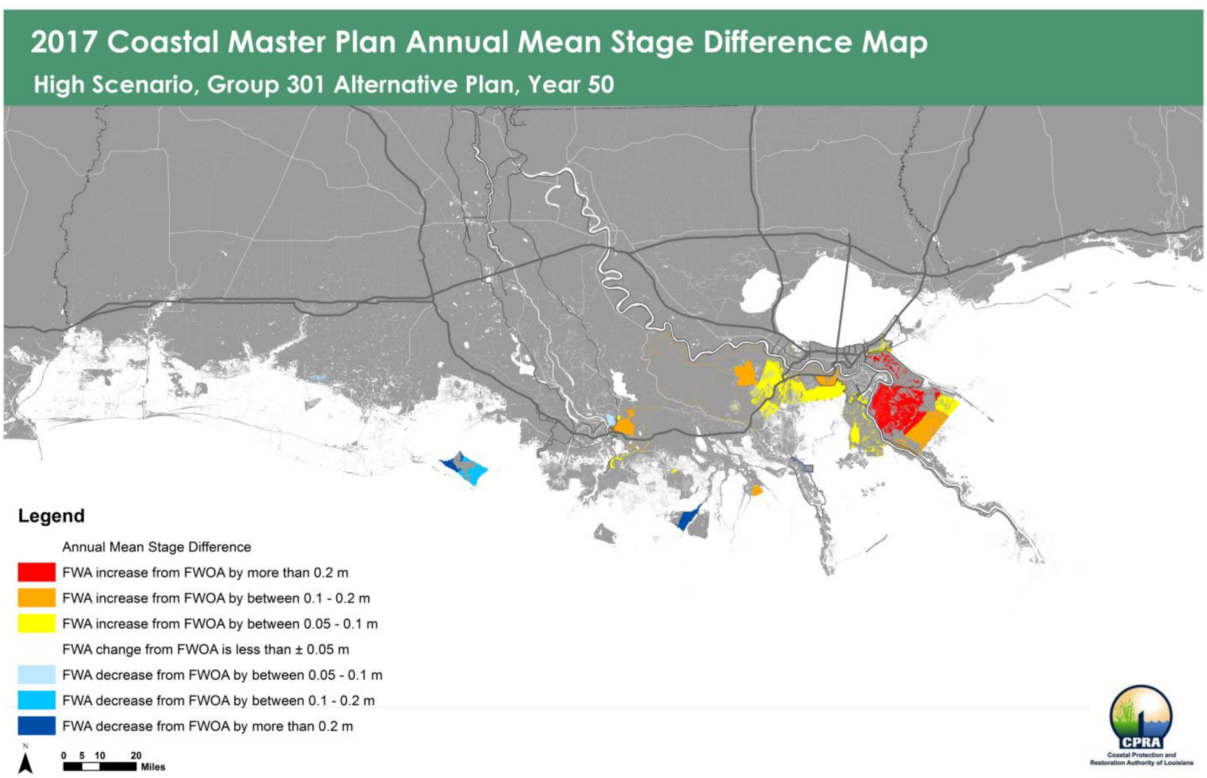

Figure 278: Mean Annual Stage Difference with G301 (FWA) compared to FWOA (year 50; high scenario).

Medium Scenario

The spatial patterns of mean water level change evident under the high scenario are consistent with those seen under the medium scenario (Figure 279 and Figure 280). All evident impacts upon mean water level occur east of the Atchafalaya River. There are some isolated regions of increased water levels in eastern Terrebonne, but the majority of increased water level areas are near the implementation of sediment and freshwater diversion projects. As is seen under the high scenario, the largest magnitude of change is in the upper Breton Basin. While the causes of these increases are the same as under the high scenario, the magnitude of increase in upper Breton is actually higher under the medium than under the high scenario. This phenomenon is due to the fact that the diverted flowrates into the estuary remain constant across scenarios, but the receiving water bodies will have a lower pre-implementation water surface elevation under the medium scenario when compared to the high. The post-implementation water surface elevation is a function predominantly of the diverted flowrate. Therefore, when the water surface in Breton Sound is lower under the medium scenario (due to lower rates of ESLR), the impact of the project upon the mean water level is greater than it is when the ESLR rate is higher under the high scenario.

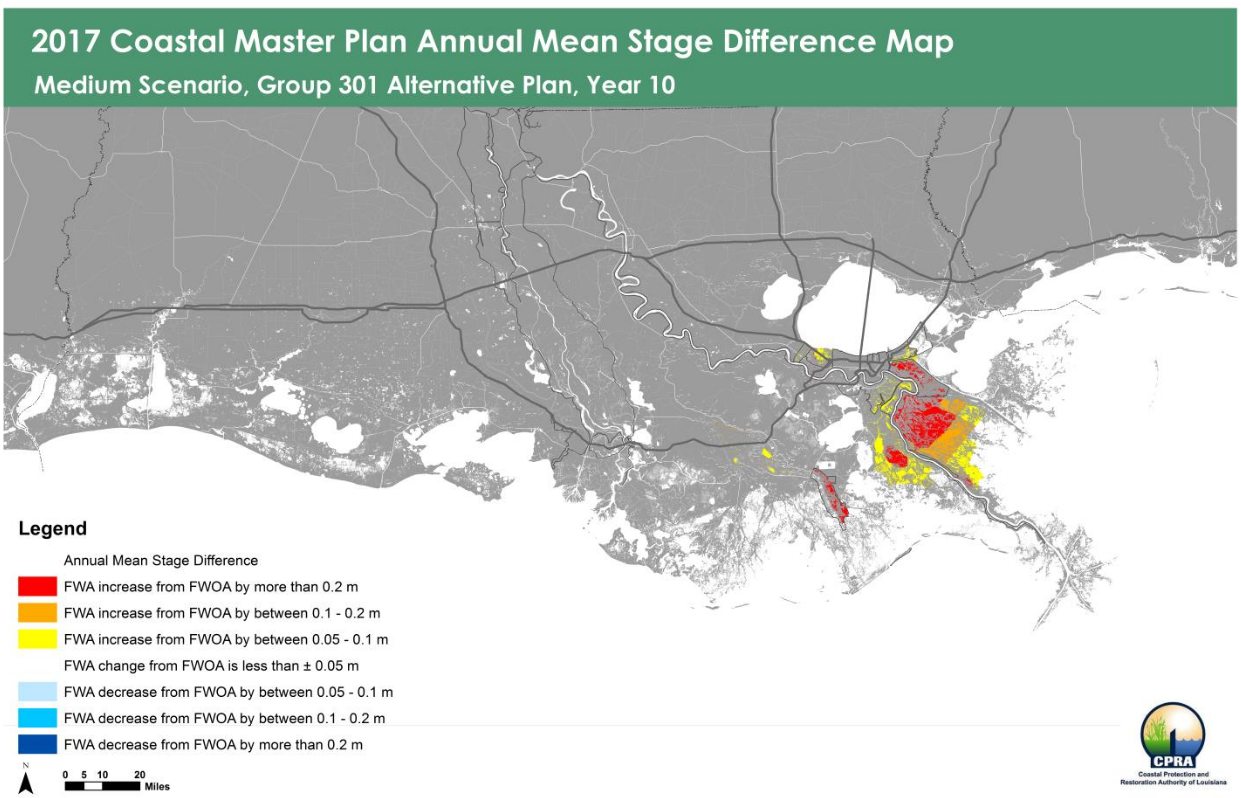

Figure 279: Mean Annual Stage Difference with G301 (FWA) compared to FWOA (year 10; medium scenario).

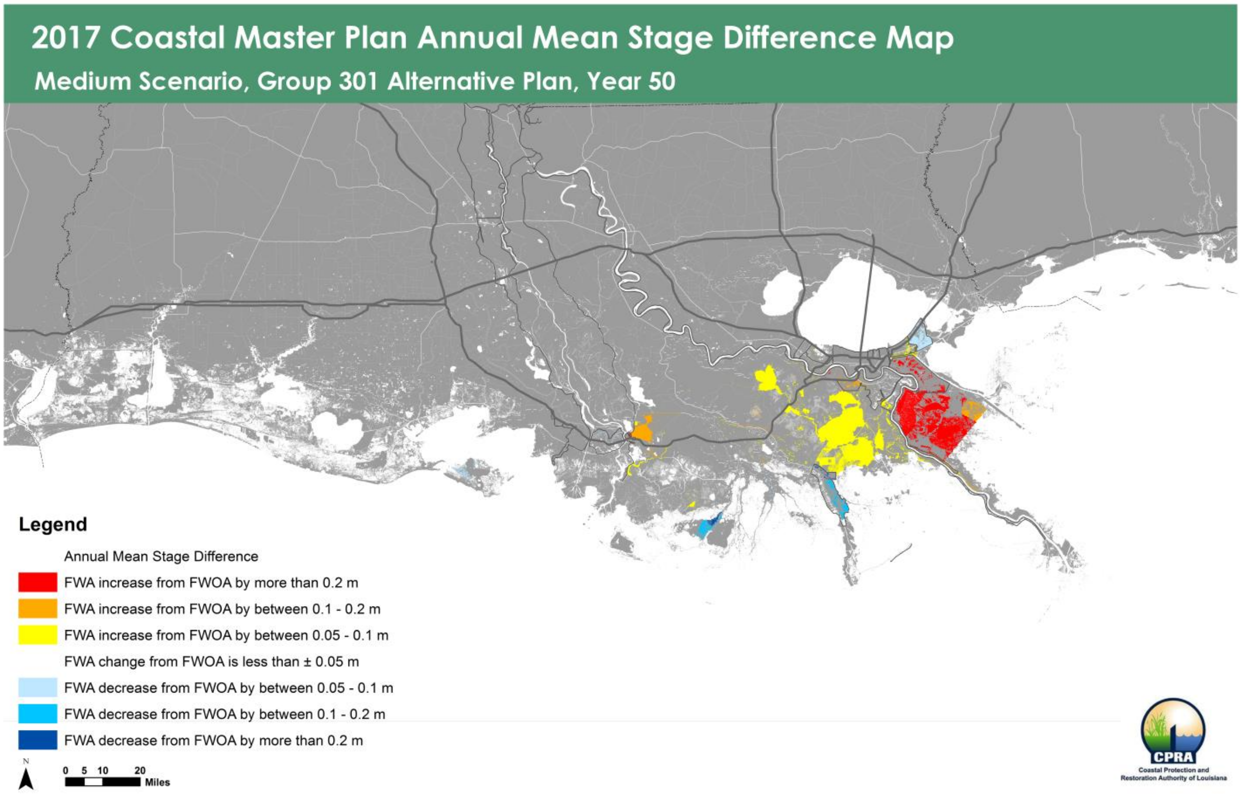

Figure 280: Mean Annual Stage Difference with G301 (FWA) compared to FWOA (year 50; medium scenario).

5.3.2.2 Salinity

High Scenario

Spatial patterns of salinity change are internally consistent and highly effected by diversion projects. In year 10, the largest reduction in salinity is within Barataria Bay, while there are smaller magnitude reductions in the upper reaches of Barataria Basin (essentially bounded by the GIWW), eastern Terrebonne Basin, and Breton Sound (Figure 281). The drivers of these salinity reductions are likely the numerous diversions into Breton Sound and Barataria Basin, as well as the Bayou Lafourche Diversion (03a.DI.01). The Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project is also active in this simulation and results in fairly widespread reductions in salinity throughout Calcasieu Lake, with smaller magnitude reductions in the surrounding wetland areas (both east and west of the Lake).

These patterns remain in year 30; however, the reduction in salinity (compared to FWOA) due to the diversion projects increases in both magnitude and spatial extent, as compared to year 10. In year 30, more diversion projects from the Mississippi River are implemented, which begins to result in a slight increase in average annual salinity at the Bird's Foot Delta compared to FWOA. The Increase Atchafalaya Flow to Terrebonne Diversion (03b.DI.04) also decreases salinity somewhat during year 30. There is slight freshening east of the Atchafalaya River and a slight increase in salinity to the west. The extent of this pattern is amplified when the maximum two-week mean salinity is analyzed, as compared to the annual mean salinity. The impact of the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project is approximately the same at year 30 as at year 10; however, there is a larger area of reduced salinity in the wetlands surrounding Calcasieu Lake.

In year 50, there are widespread changes in mean annual salinity values across the entire model domain (Figure 282). Barataria Bay, as well as upper Barataria Basin, shows substantial reduction in salinity. Similar reduction in salinity is evident in Breton Sound, while a smaller magnitude reduction can be seen in the central Terrebonne and upper Pontchartrain/Maurepas areas. The combination of the Lake Pontchartrain Barrier (001.HP.08) project and the numerous freshwater additions to the Maurepas Swamp area result in a freshening in upper Pontchartrain and a subsequent inverse effect on the Gulf east of the Pearl River and north of Lake Borgne where a widespread area of increased salinity is seen. There are still some areas of freshening in the western portion of the model domain, due to the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project; however, the extent is much smaller than during earlier years of the simulation. The largest reduction in salinity appears to be focused along the GIWW at the northern end of Lake Calcasieu. There are some areas of slight increased salinities in the Mermentau region in later years of the simulation. This is likely due to the implementation of numerous marsh creation projects near Freshwater Bayou, that likely reduce the connectivity of this area to flow pathways, while at the same time reducing the volume of water bodies and therefore their buffering capacity when receiving intermittent flow from saline sources (e.g. during high water events in the Gulf).

Salinity in the area of the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project shows substantial freshening; however, there is a seasonal pattern to the amplitude of freshening, which tends to dampen the impact when long-term (e.g., annual) means are used for spatial comparison purposes. Salinity reduction is apparently of greatest magnitude in summer months, when the FWOA salinity is increasing. During the winter months when the FWOA salinity decreases, there is a reduction in the freshening impact, simply due to the flat-line behavior of salinity after this project is implemented. These semi-annual trends are, obviously, not evident when examining the project impacts upon annual mean salinity values.

Medium Scenario

The changes in salinity patterns seen under the medium scenario generally follow the same behavior as the high scenario, particularly in earlier years of the simulation. In later years, when relative sea level is not as high as under the high scenario, the freshening compared to FWOA is generally smaller in magnitude than it is under the high scenario. This is an intuitive response; the FWOA salinities are not as high under the medium scenario as under the high scenario, and therefore the introduction/management of freshwater via either diversions or the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project does not have as dramatic an effect on salinity. Similarly, the areas of increased salinity (compared to FWOA) in the medium scenario are similar in location, but smaller in magnitude, and are therefore less noticeable than under the high scenario.

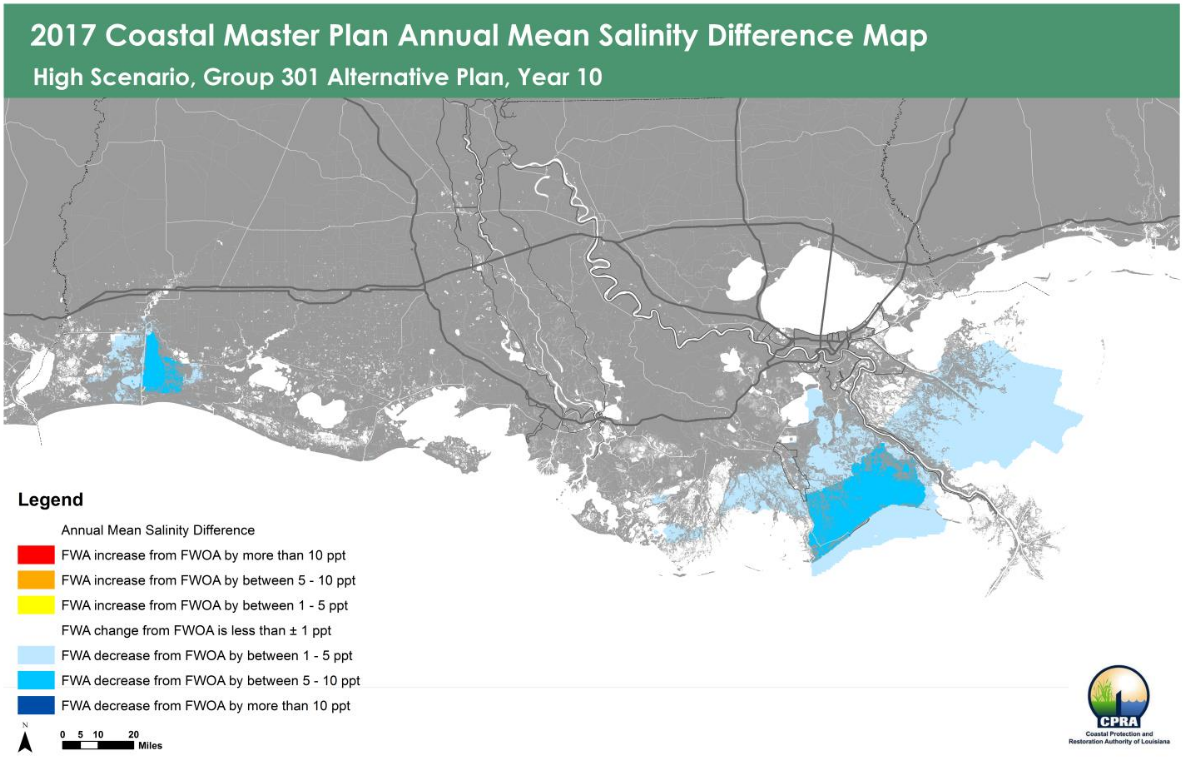

Figure 281: Mean Annual Salinity Difference with G301 (FWA) compared to FWOA (year 10; high scenario).

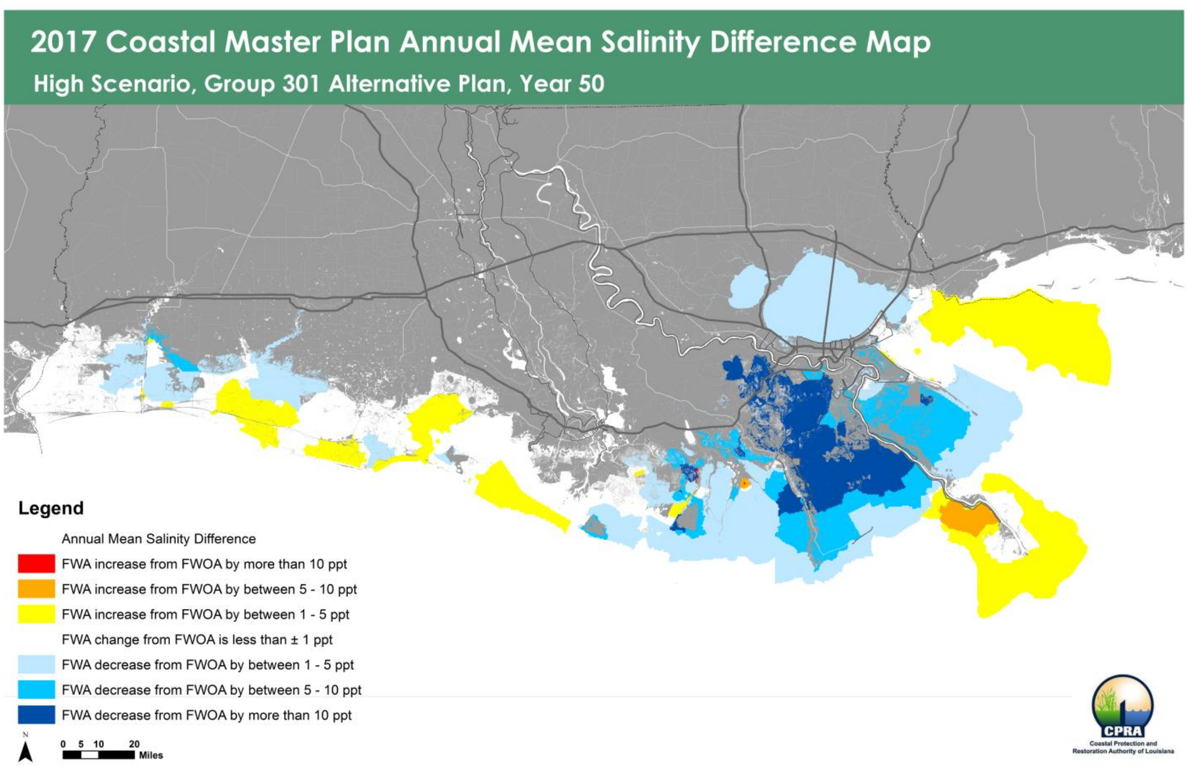

Figure 282: Mean Annual Salinity Difference with G301 (FWA) compared to FWOA (year 50; high scenario).

5.3.2.3 Land Change

High Scenario

Overall, G301 predicts approximately 2,663 km^2 of net land area benefit (floating marsh included) compared to FWOA at the end of the 50-year simulation (and Figure 283). This figure includes both land sustained and new land built. At year 25, the land building effects of projects in this group are more prevalent (Figure 284); whereas by year 50, the land sustaining effects of projects in this group are more prevalent (Figure 285). Again, while the net land area benefit compared to FWOA is positive (2,663 km^2) at year 50, total land area over the modeling period is projected to decrease (-8,019 km^2;). It is important to note that this is far less loss than is observed under FWOA (-10,682 km^2;). There is more net land area benefit in the high scenario compared to the medium scenario (high: 2,663 km^2 at year 50; medium: 1,996 km^2 at year 50), despite this scenario including higher rates of RSLR (). This occurs as a result of the much higher rate of land loss under the high scenario as compared to medium. For example, in a few locations, vegetation transition and eventual land loss is seen in FWOA under the high scenario which is not projected to occur under the medium scenario (Figure 285). One such region is near the Maurepas Swamp. This occurs as a result of the combined effects of freshwater diversion projects (e.g., Union Diversion (001.DI.102), Manchac Landbridge Diversion (001.DI.100), and Labranche Wetland Hydrologic Restoration (001.HR.100), and the Lake Pontchartrain Barrier (001.HP.08) project. The barrier project is designed to limit storm surge entering the lake, but during later years of the simulation the frequency of gate closure increases as sea level rise and subsidence increase water level and the stage criteria for closure is met more often. This is especially seen under the high scenario, and the barrier therefore prevents high salinity water from entering Lake Pontchartrain. Under the medium scenario in FWOA, salinity does not exceed levels which would cause collapse of freshwater wetlands (7-8 ppt depending on the wetland type). In FWOA under the high scenario, those thresholds are exceeded and loss is projected. Project implementation, including the barrier, mitigates that loss.

Examining patterns by region, the majority of benefits in the western region are attributable to marsh creation projects. Net land area benefit from project implementation is projected to be approximately 269 km^2 by year 25, decreasing to 152 km^2 by year 50, indicating that some of the benefit originally put in place in this scenario is lost due to the higher RSLR. At year 25, the high scenario results in more benefit compared to the medium scenario (year 25: 180 km^2) for the previously mentioned reasons regarding marsh creation implementation. However, the project-related benefits are less persistent in this scenario (medium: 382 km^2 at year 50; high: 152 km^2 at year 50;). As would be expected, the higher RSLR of the high scenario contributes to less sustainability of project benefits.

The central region contains a series of marsh creation and shoreline protection projects, two diversions, and several hurricane protection features. Similar to the western region, the majority of those benefits are attributable to marsh creation projects. Net land area benefit from project implementation is projected to be approximately 72 km^2 by year 25, increasing to 335 km^2 by year 50. Similar to the western region, these benefits are more than those projected in the medium scenario (medium: 49 km^2 at year 50; high: 194 km^2 at year 50) for the previously discussed reasons regarding implementation of marsh creation projects.

The eastern region contains marsh creation, ridge restoration, shoreline protection, and hurricane protection features. However, this region also contains nine diversions. Net land area benefit from project implementation is projected to be approximately 498 km^2 by year 25, increasing to 2,175 km^2 by year 50.

There is a negative effect from implementing the Upper Breton Diversion (001.DI.17) and Mid-Breton Diversion (001.DI.23) under this scenario which is explained in the following sections (Figure 284 and Figure 285). The negative land area impact in the Bird's Foot Delta is also observed in this scenario (Figure 284 and Figure 285). Additionally, there is a large amount of benefit projected in the Maurepas Swamp region in this scenario that is not observed in the medium scenario. This occurs as the land is not lost in the medium scenario, and as such, no benefit is possible, but under the high scenario, collapse which is projected under FWOA is mitigated by project implementation.

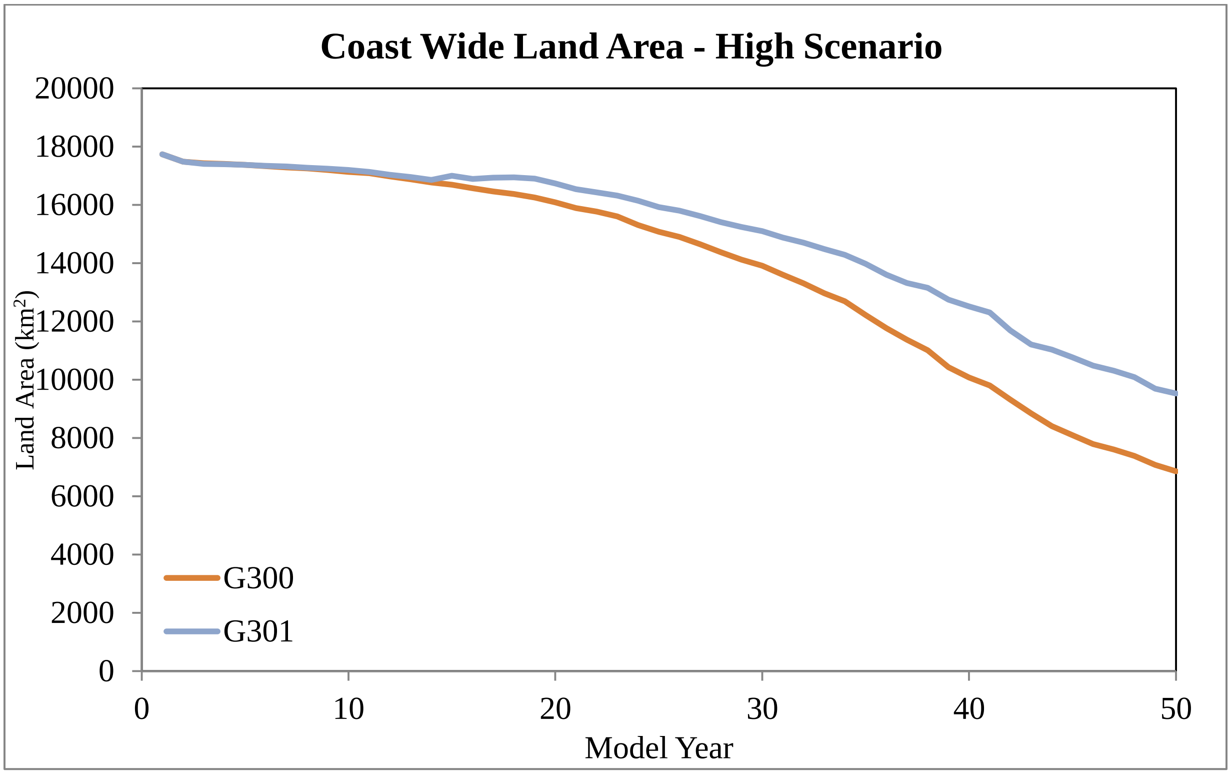

Figure 283: Land Area Change Over Time for G301 and FWOA (high scenario).

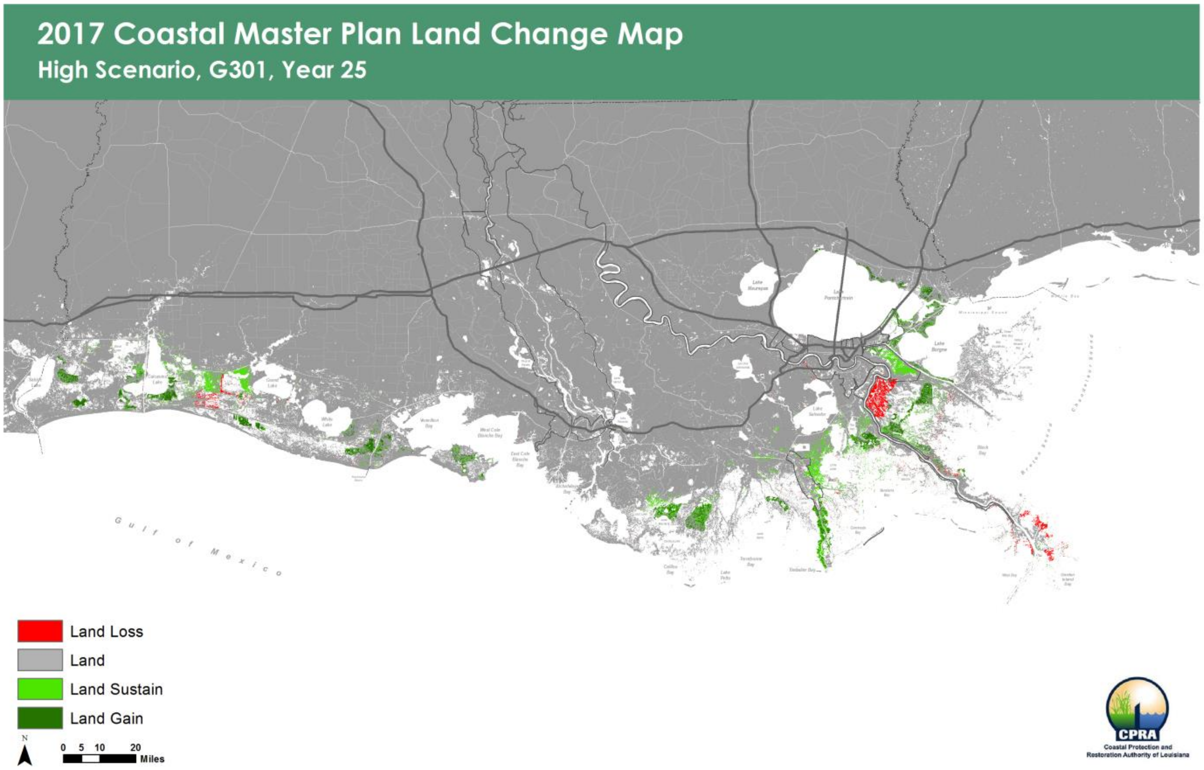

Figure 284: Land Change for G301 compared to FWOA (year 25; high scenario).

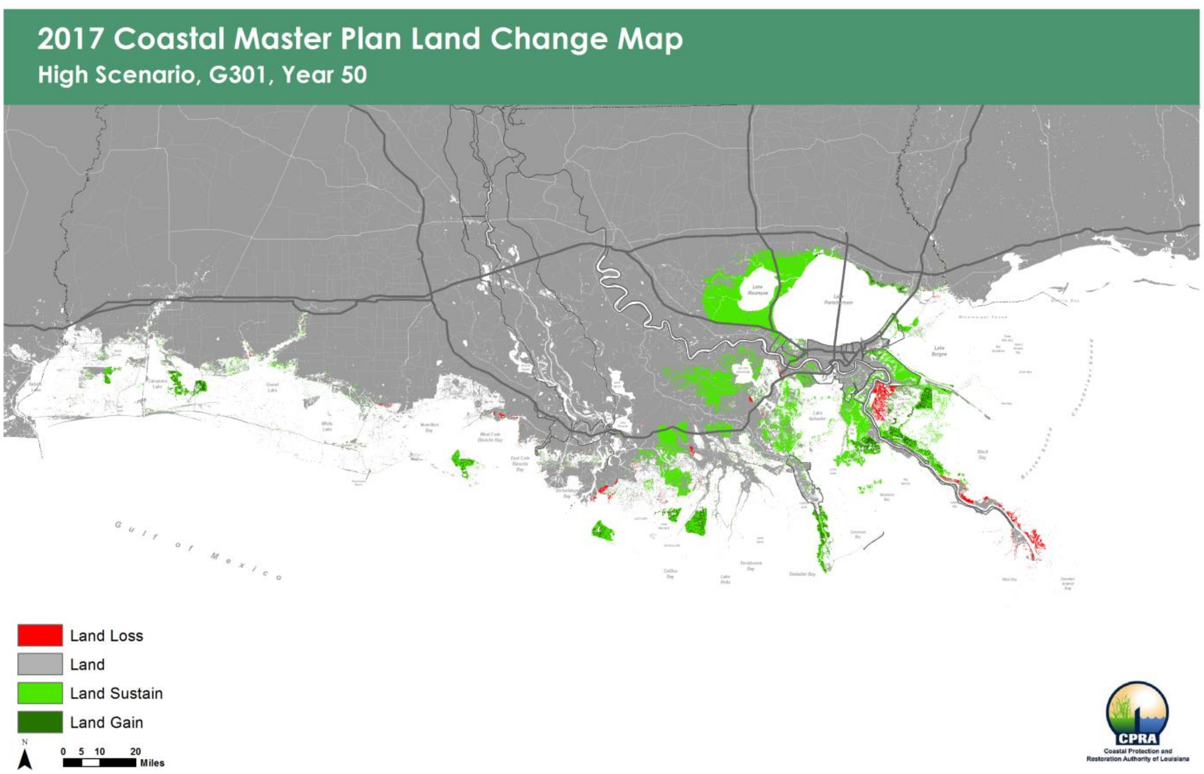

Figure 285: Land Change for G301 compared to FWOA (year 50; high scenario).

Medium Scenario

G301 (which includes both protection and restoration projects) predicts approximately 1,996 km^2 of net land area benefit (floating marsh included) compared to FWOA at the end of the 50-year simulation (Table 12 and Figure 286). This figure includes both land sustained and new land built. While there is positive net land area benefit compared to FWOA, this scenario still forecasts an overall loss of total wetland area (-3,842 km^2) during the 50-year simulation (Table 12). This is consistent with the findings of previous modeling efforts that indicate that project implementation does not result in "no net loss" at coast wide scales, but will rather mitigate losses which would have occurred in the absence of project implementation. In the absence of any action, the coast is projected to lose 5,837 km^2 in this scenario (Table 12).

Examining patterns in the model output more specifically, the western region contains a series of marsh creation, ridge creation, and shoreline protection projects which are generally observed to have a positive impact on net land area with the majority of benefit attributed to marsh creation projects (Figure 287 and Figure 288). Net land area benefit from project implementation is projected to be approximately 180 km^2 by year 25, increasing to 382 km^2 by year 50 (Table 12 and Figure 286). As this region includes primarily marsh creation projects, the majority of this increase in land area benefit is due to project implementation between years 25 and 50.

Similarly, the central region contains a series of marsh creation and shoreline protection projects, two diversions, and several hurricane protection features. In terms of net land area benefit, the collective effect of the projects is to have an overall positive impact on net land area when compared to FWOA (Figure 287 and Figure 288). Similar to the western region, the majority of those benefits are attributable to marsh creation projects. Net land area benefit from project implementation is projected to be approximately 49 km^2 by year 25, increasing to 194 km^2 by year 50 (Table 12 and Figure 286).

The eastern region contains marsh creation, ridge restoration, shoreline protection and hurricane protection features. However, this region also contains nine diversions. Net land area benefit from project implementation is projected to be approximately 293 km^2 by year 25, increasing to 1,420 km^2 by year 50 (Table 12 and Figure 286).

An immediate observation in the eastern region is the negative effect that implementation of the Upper Breton Diversion (001.DI.17) and Mid-Breton Diversion (001.DI.23) has on land area during the simulation period (Figure 287 and Figure 288). Not only do these features neither sustain nor build land, implementation of these diversions actually causes loss of wetlands which would have been maintained in FWOA. While increased sediment deposition and accretion is observed as a result of these features, it is not enough to overcome the increase in water level which results from implementation of these diversions.

Another negative impact which is a result of diversion implementation occurs in the Bird's Foot Delta (Figure 287 and Figure 288). This occurs as a result of using water and sediment for diversion implementation upstream from the delta, thereby leading to a negative impact on deposition/accretion in this area. This impact leads to elevation deficits which eventually lead to marsh collapse due to inundation thresholds being exceeded in non-fresh wetland types.

Table 12: Land Area for G301 and FWOA. Units are square kilometers**.**

Medium Scenario - Group 301									
	Year 0	Year 25	Difference Year 25 vs. Year 0	FWOA Year 25	Difference with FWOA at Year 25	Year 50	Difference Year 50 vs. Year 0	FWOA Year 50	Difference with FWOA at Year 50
East	8,927	8,068	-859	7,775	293	6,575	-2,352	5,155	1,420
Central	3,516	3,551	35	3,502	49	3,025	-492	2,830	194
West	3,853	3,978	124	3,798	180	2,856	-997	2,474	382
Total	16,297	15,597	-700	15,075	523	12,455	-3,842	10,460	1,996
High Scenario – Group 301									
	Year 0	Year 25	Difference Year 25 vs. Year 0	FWOA Year 25	Difference with FWOA at Year 50	Year 25	Difference Year 25 vs. Year 0	FWOA Year 50	Difference with FWOA at Year 50
East	8,927	7,581	-1,346	7,083	498	5,252	-3,675	3,076	2,176
Central	3,516	3,430	-87	3,358	72	2,115	-1,402	1,779	335
West	3,853	3,633	-221	3,363	269	912	-2,942	760	152
Total	16,297	14,644	-1,653	13,804	840	8,278	-8,019	5,615	2,663

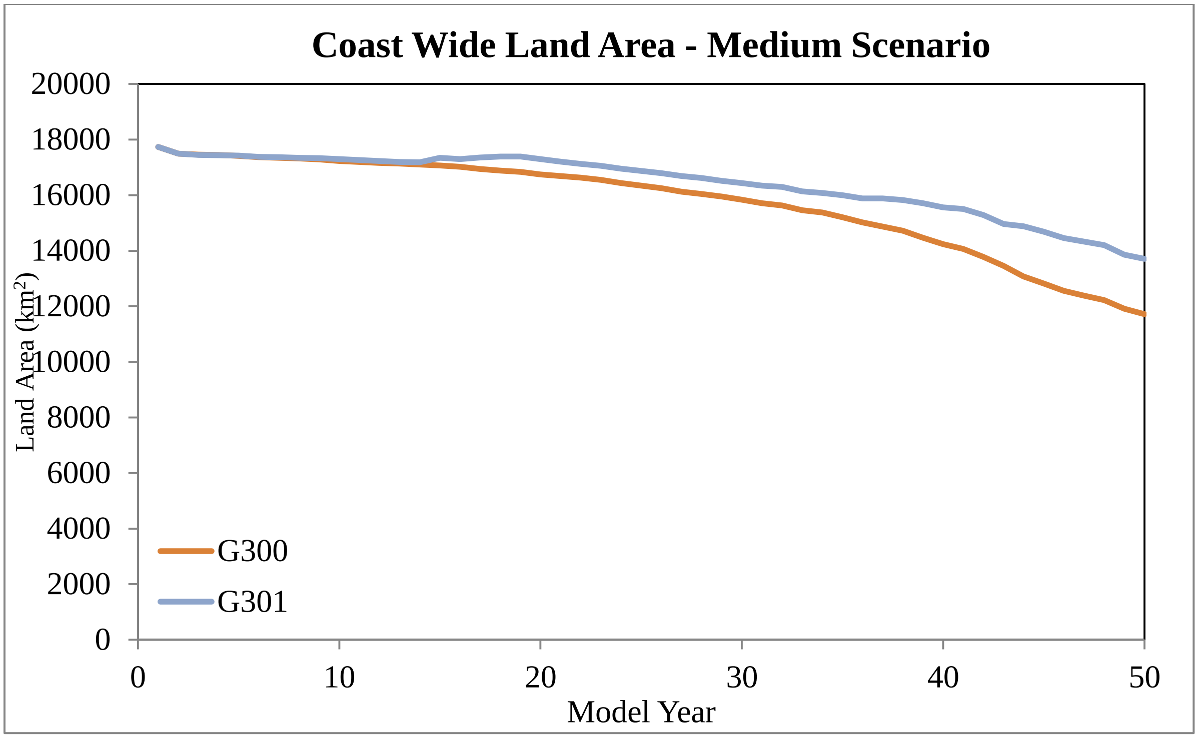

Figure 286: Land Area Change over Time for G301 and FWOA (medium scenario).

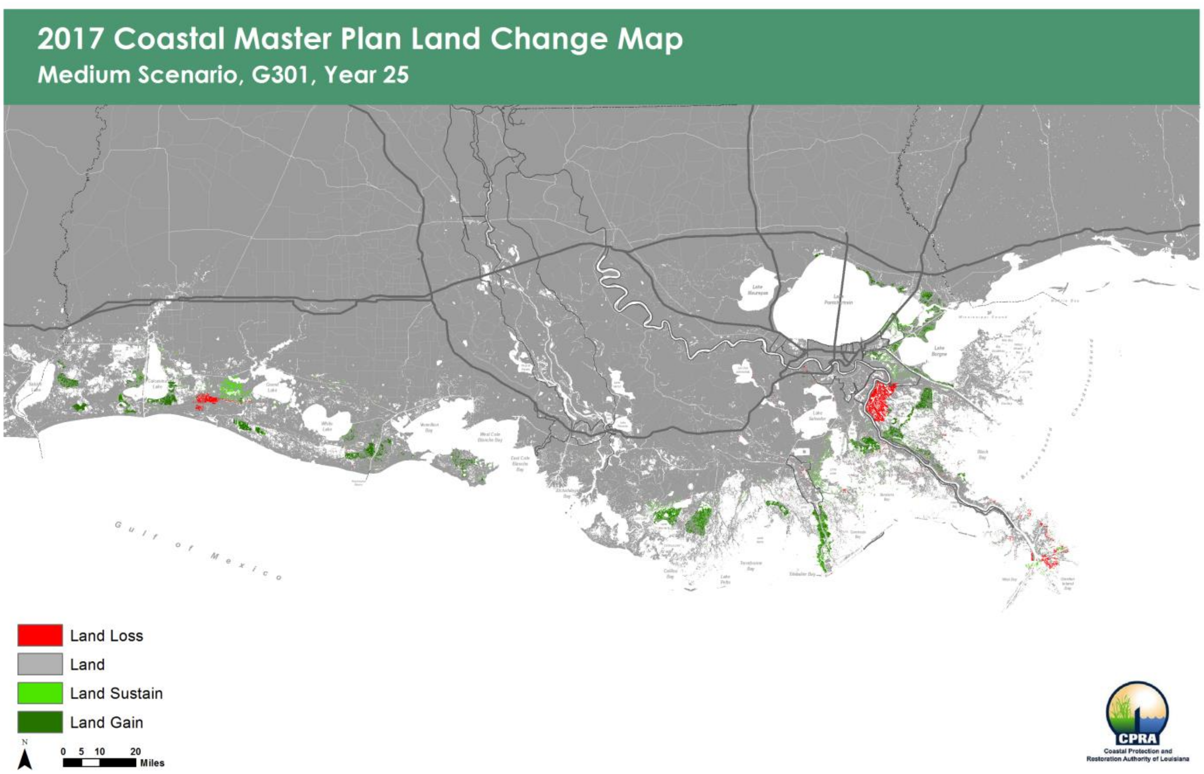

Figure 287: Land Change for G301 compared to FWOA (year 25; medium scenario).

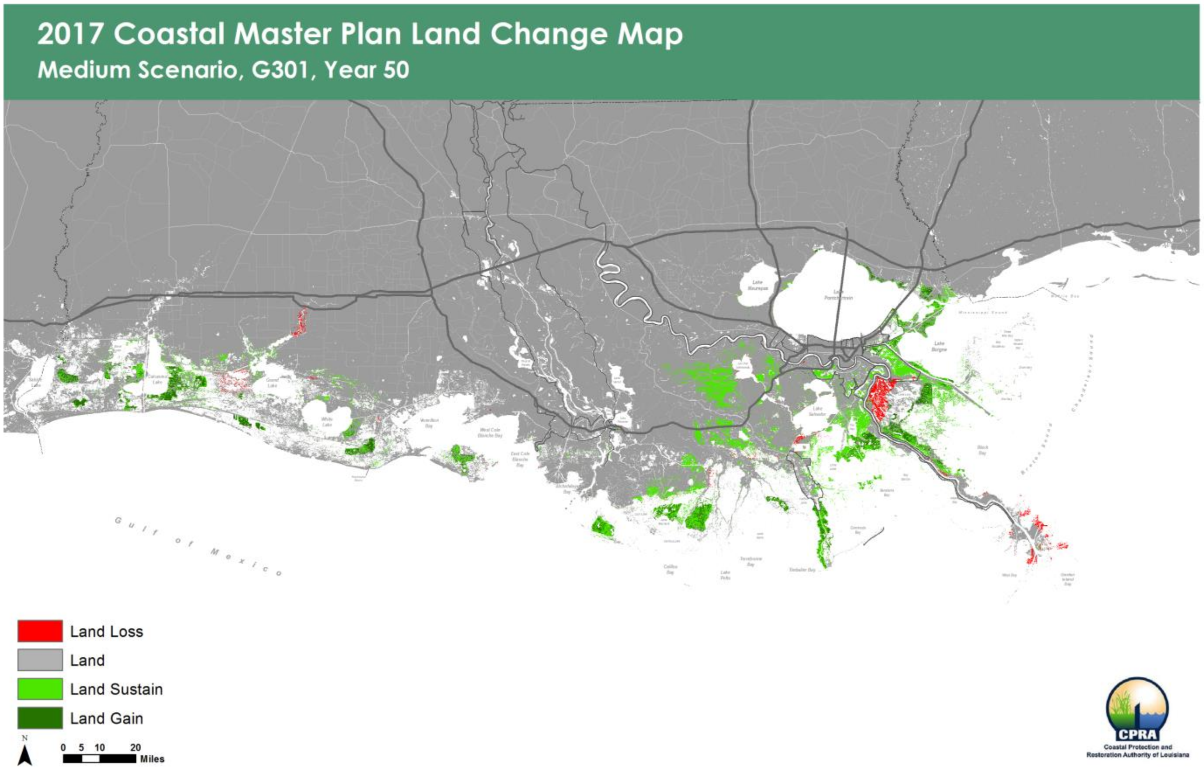

Figure 288: Land Change for G301 compared to FWOA (year 50; medium scenario).

5.3.2.4 Vegetation[14]

High Scenario

In the eastern region of the coast, influence of the diversions compared to FWOA is apparent in vegetation cover by year 25 (Figure 289). Habitats that are brackish in FWOA switch to fresh marsh (Figure 290). By year 25, the eastern region has gained 103 km^2 of forested wetland, 1,004 km^2 of fresh marsh, 7 km^2 of intermediate marsh, and lost 698 km^2 brackish marsh, 84 km^2 salt marsh, and 8 km^2 of bare wetland compared to FWOA. These trends continue through year 50 (Figure 290). By year 50, the eastern region has gained 70 km^2 of forested wetland, 2,282 km^2 of fresh marsh, 67 km^2 of intermediate marsh, and lost 698 km^2 brackish marsh, 41 km^2 salt marsh, and 345 km^2 of bare wetland compared to FWOA.

In the central region of the coast, habitat changes due to this alternative compared to FWOA are more subtle (Figure 291). However, by year 25 all habitat types increase in extent relative to FWOA: 15 km^2 forested wetland, 125 km^2 fresh marsh, 13 km^2 brackish marsh, and 69 km^2 salt marsh. By year 50, there is 29 km^2 less brackish marsh than in the FWOA, but all other habitat types increase in size: 104 km^2 forested wetland, 231 km^2 fresh marsh, 227 km^2 salt marsh, and 12 km^2 bare wetland (Figure 291).

In the western region of the coast, habitat changes compared to FWOA are substantial by year 25 (Figure 289). Large areas that turn to salt marsh in FWOA remain as fresh marsh, and there is

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[14] Changes ≤ 5 km^2 are not discussed.

even an increase in fresh marsh area (Figure 292). This general freshening of the area is due to the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project (see section 1.3.2.2). By year 25, there is a reduction of 149 km^2 salt marsh and 9 km^2 intermediate marsh and an increase of 6 km^2 forested wetland, and 416 km^2 fresh marsh compared to FWOA. By year 50, there is a substantial reduction in land area compared to year 1, but when compared to FWOA, there is an increase in 8 km^2 of fresh marsh, 112 km^2 of brackish marsh, 19 km^2 salt marsh, and 20 km^2 of bare wetland.

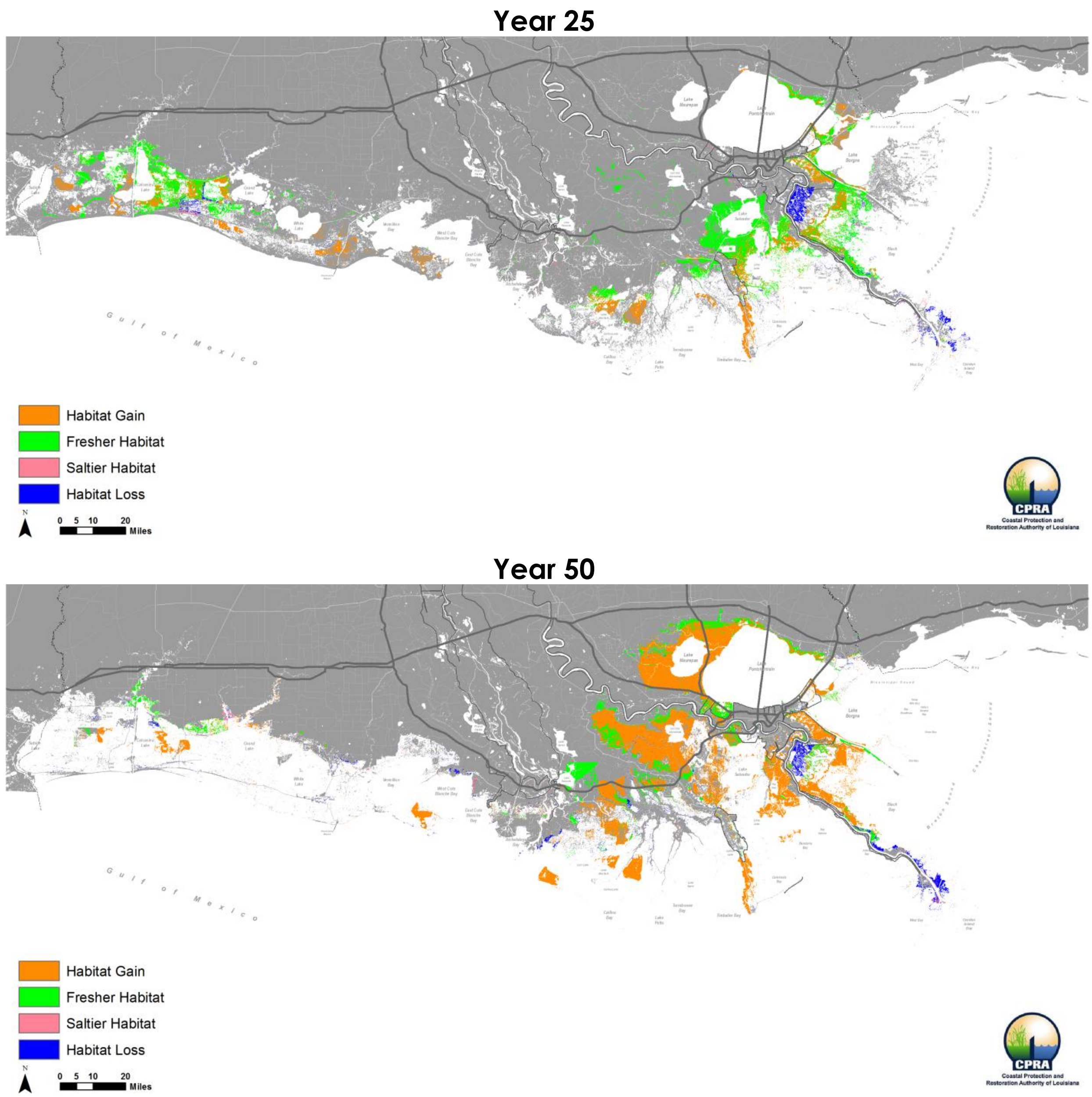


Figure 289: Vegetation Cover by Salinity under G301 compared to FWOA (year 25 [top]; year 50 [bottom]; high scenario).

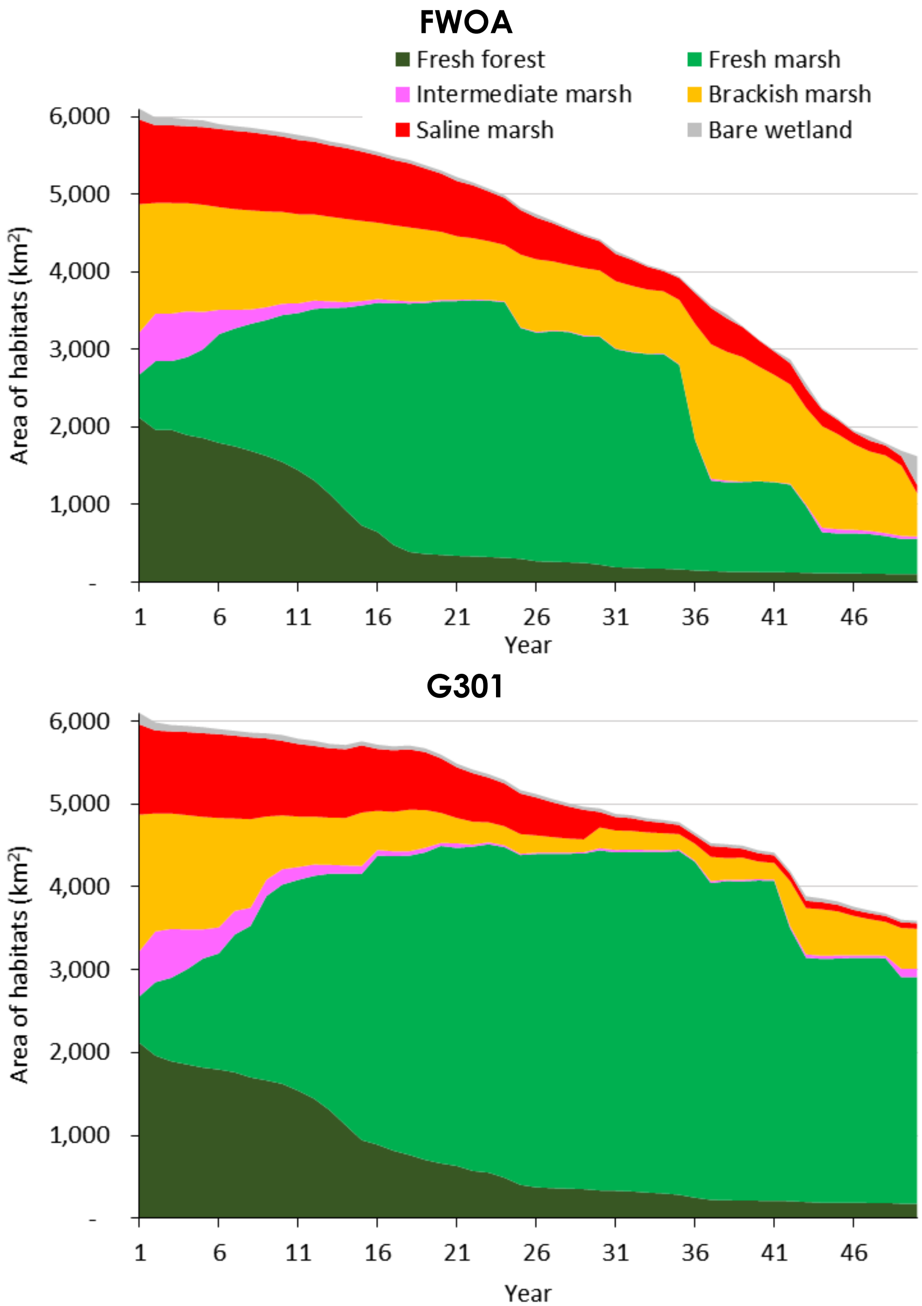


Figure 290: Changes in Marsh Type in the Eastern Coast (FWOA [top]; G301 [bottom]; high scenario).

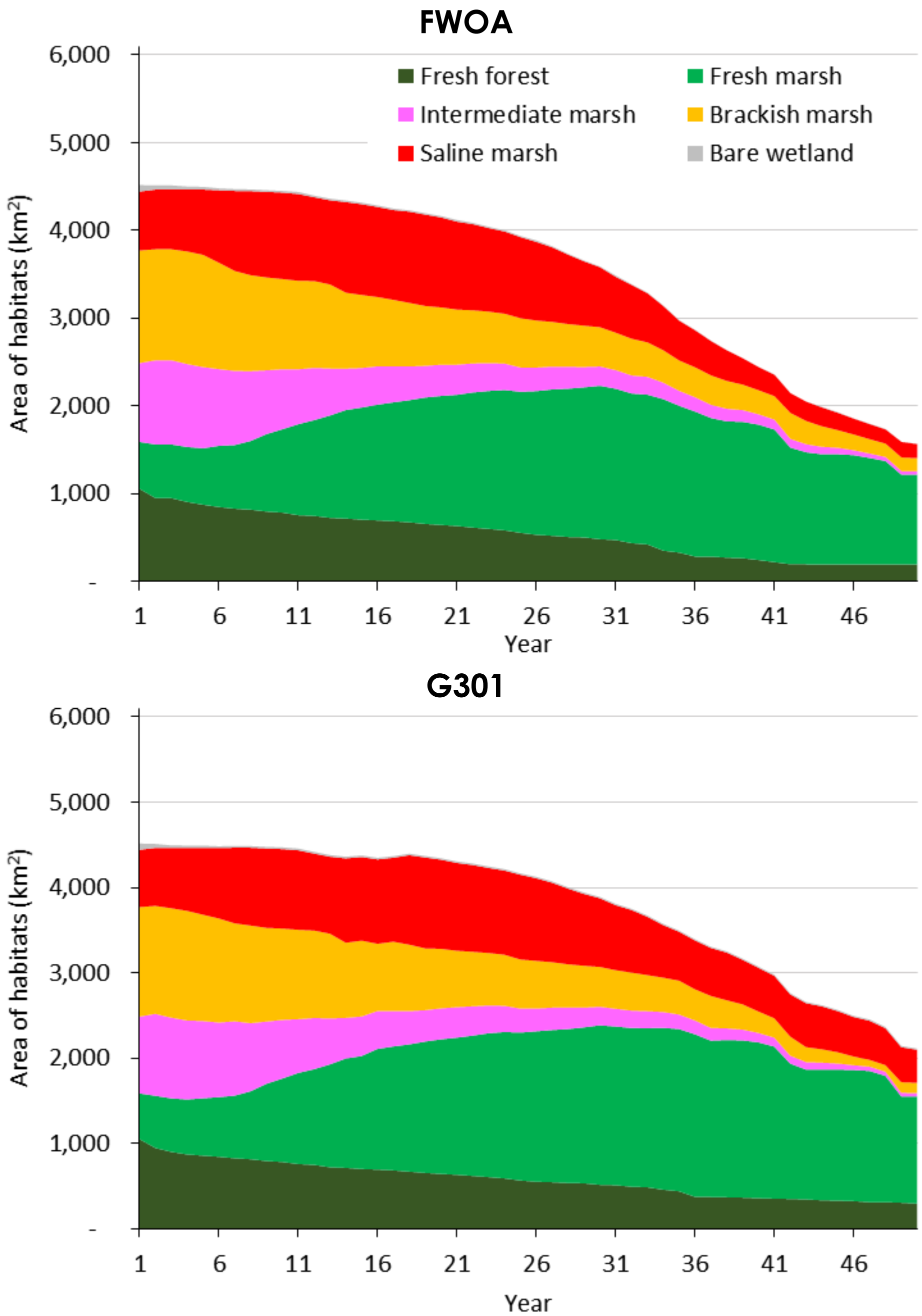


Figure 291: Changes in Marsh Type in the Central Coast (FWOA [top]; G301 [bottom]; high scenario).

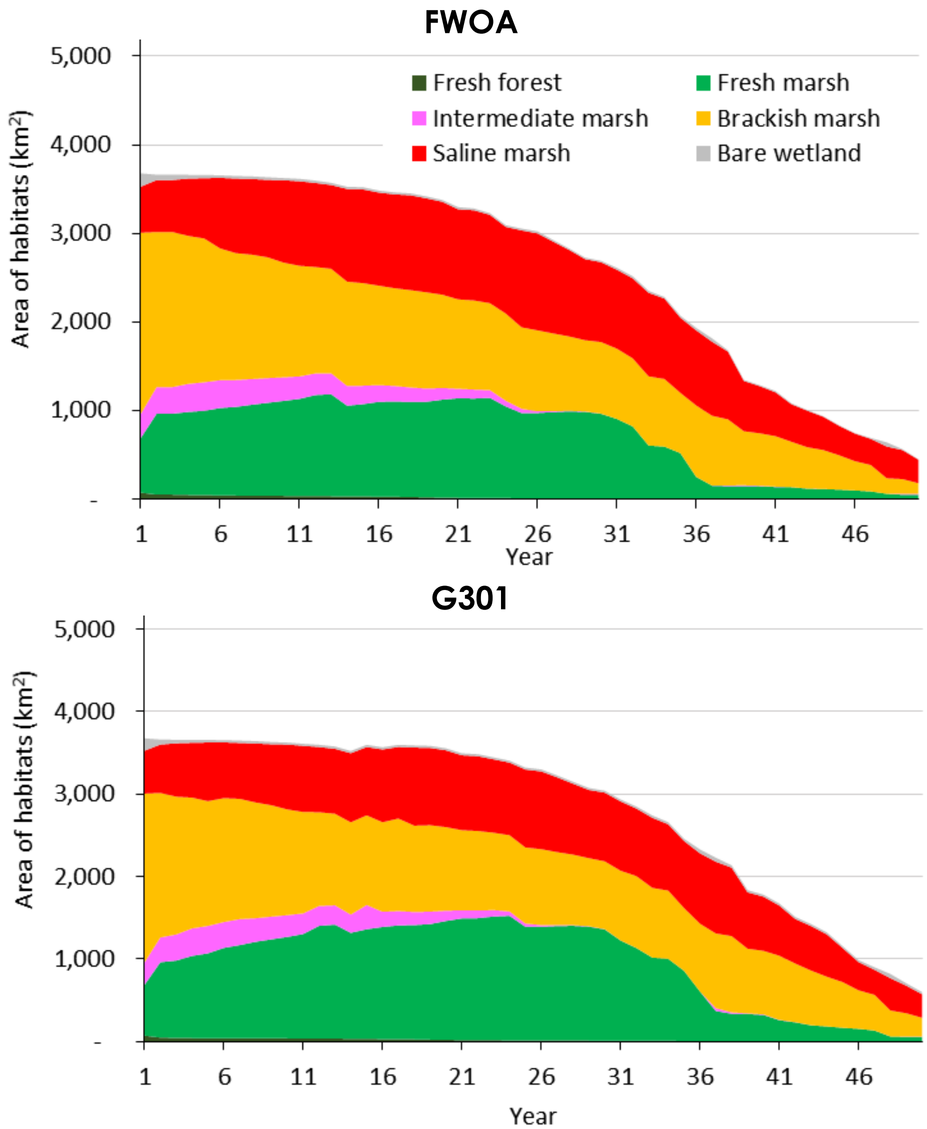


Figure 292: Changes in Marsh Type in the Western Coast (FWOA [top]; G301 [bottom]; high scenario).

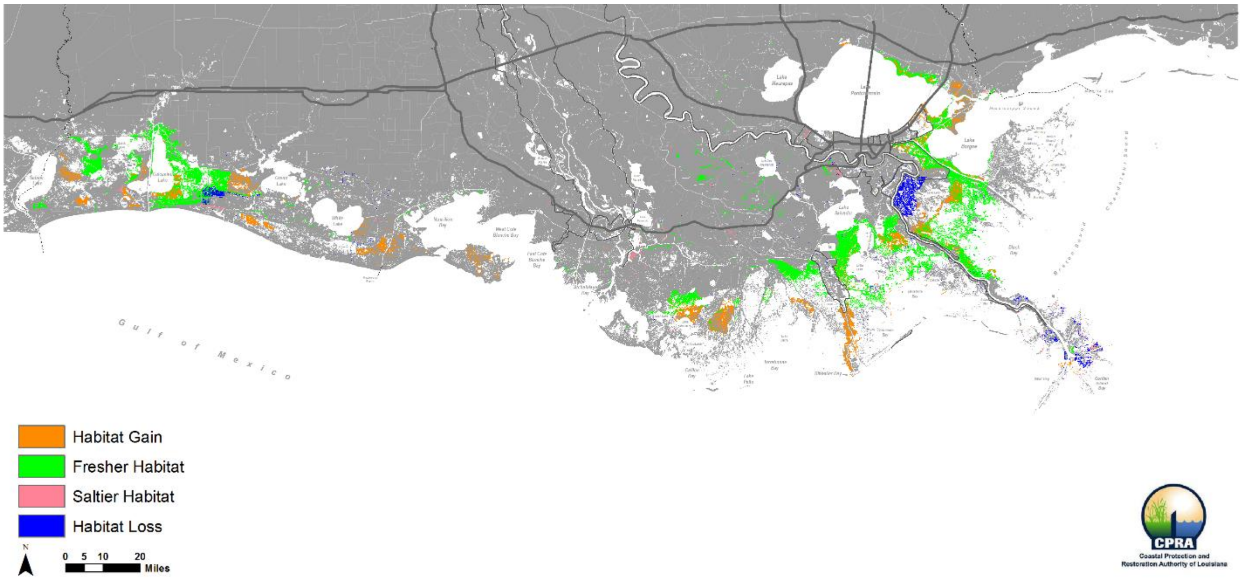
Medium Scenario

At year 25, in the eastern region of the coast, the effect of G301 (Figure 293) is similar to that seen under the high scenario (Figure 289). However, the difference from the FWOA under the medium scenario is more subtle than under the high scenario (Figure 294). By year 25, the eastern region has an increase of 121 km^2 forested wetland, 676 km^2 fresh marsh, 19 km^2 intermediate marsh and 5 km^2 bare wetland, and a reduction of 497 km^2 brackish marsh and 159 km^2 salt marsh compared to the FWOA. However, locally increased wetland loss occurs either due to increased flooding associated with the diversions (e.g., Upper Breton Sound Diversion (001.DI.17)) or reduced sediment input and land loss (e.g., Bird's Foot Delta). This loss is offset by large areas of wetlands that are sustained (Figure 293). These trends continue through year 50 (Figure 294). By year 50, the eastern region has an increase of 120 km^2 forested wetland, 2,177 km^2 fresh marsh, and 35 km^2 intermediate marsh, and a reduction of 909 km^2 brackish marsh, 264 km^2 salt marsh, and 83 km^2 bare wetland compared to the FWOA. It is interesting to note that although stage does not significantly increase in upper Barataria and upper Pontchartrain basins and salinity stays fresh, the ICM predicts significant conversion of swamp forest to fresh marsh in this region. This is most likely due to the loss of elevation (subsidence), which leads to increased flooding and loss of trees. Only projects that increase sediment input can sustain the existing forests.

In the central region of the coast, habitat changes are even more subtle under the medium scenario (Figure 295) than they are in the high scenario (Figure 291). However, by year 25, all habitat types increase in extent relative to FWOA (8 km^2 forested wetland, 142 km^2 fresh marsh, 13 $km^{2,}$ intermediate marsh, and 21 km^2 salt marsh) except for a 8 km^2 decrease in brackish marsh. By year 50, there is a reduction of 68 km^2 brackish marsh and 7 km^2 of intermediate marsh and an increase of 132 km^2 forested wetland, 244 km^2 fresh marsh, 221 km^2 salt marsh, and 11 km^2 bare wetland compared to FWOA (Figure 295).

Under the medium scenario, there is very little effect in the western region of the coast compared to FWOA (Figure 296). By year 25, there is an increase of 7 km^2 forested wetland, 381 km^2 fresh marsh, and 6 km^2 bare wetland, and a reduction of 90 km^2 brackish marsh, and 119 km^2 salt marsh compared to FWOA. By year 50, the effects are even smaller, but all habitat types increase in area relative to the FWOA: 122 km^2 fresh marsh, 154 km^2 brackish marsh, 90 km^2 salt marsh, and 14 km^2 of bare wetland.

Year 25



Year 50

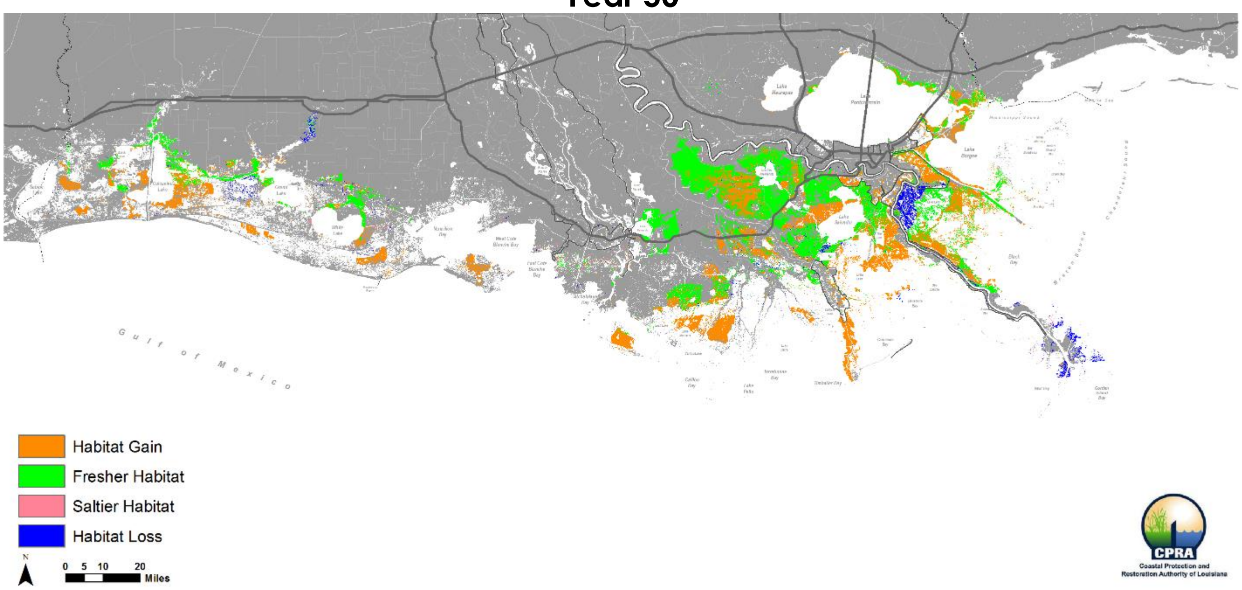


Figure 293: Vegetation Cover by Salinity under G301 compared to FWOA (year 25 [top]; year 50 [bottom]; medium scenario).

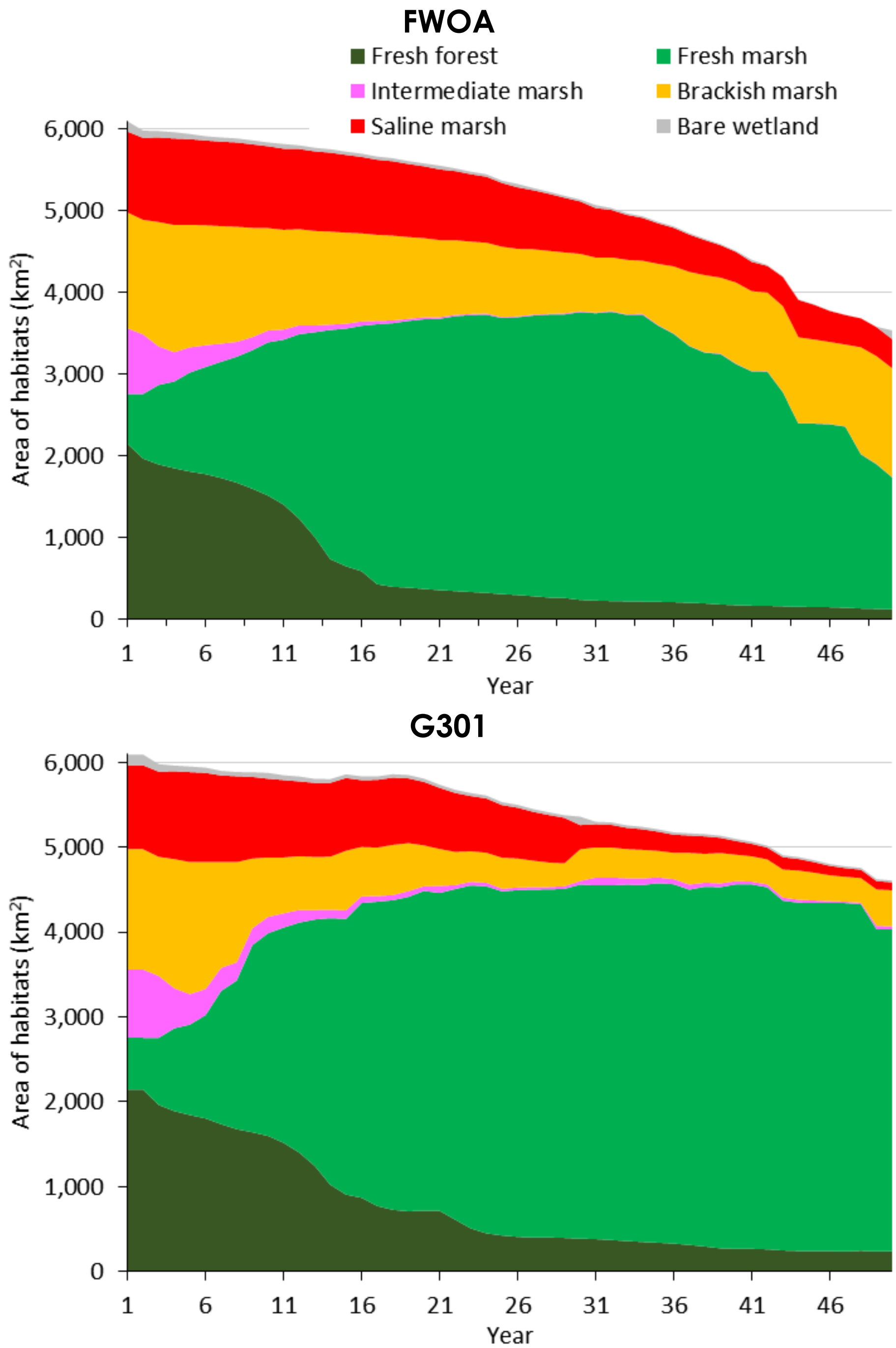


Figure 294: Changes in Marsh Type in the Eastern Coast (FWOA [top]; G301 [bottom]; medium scenario).

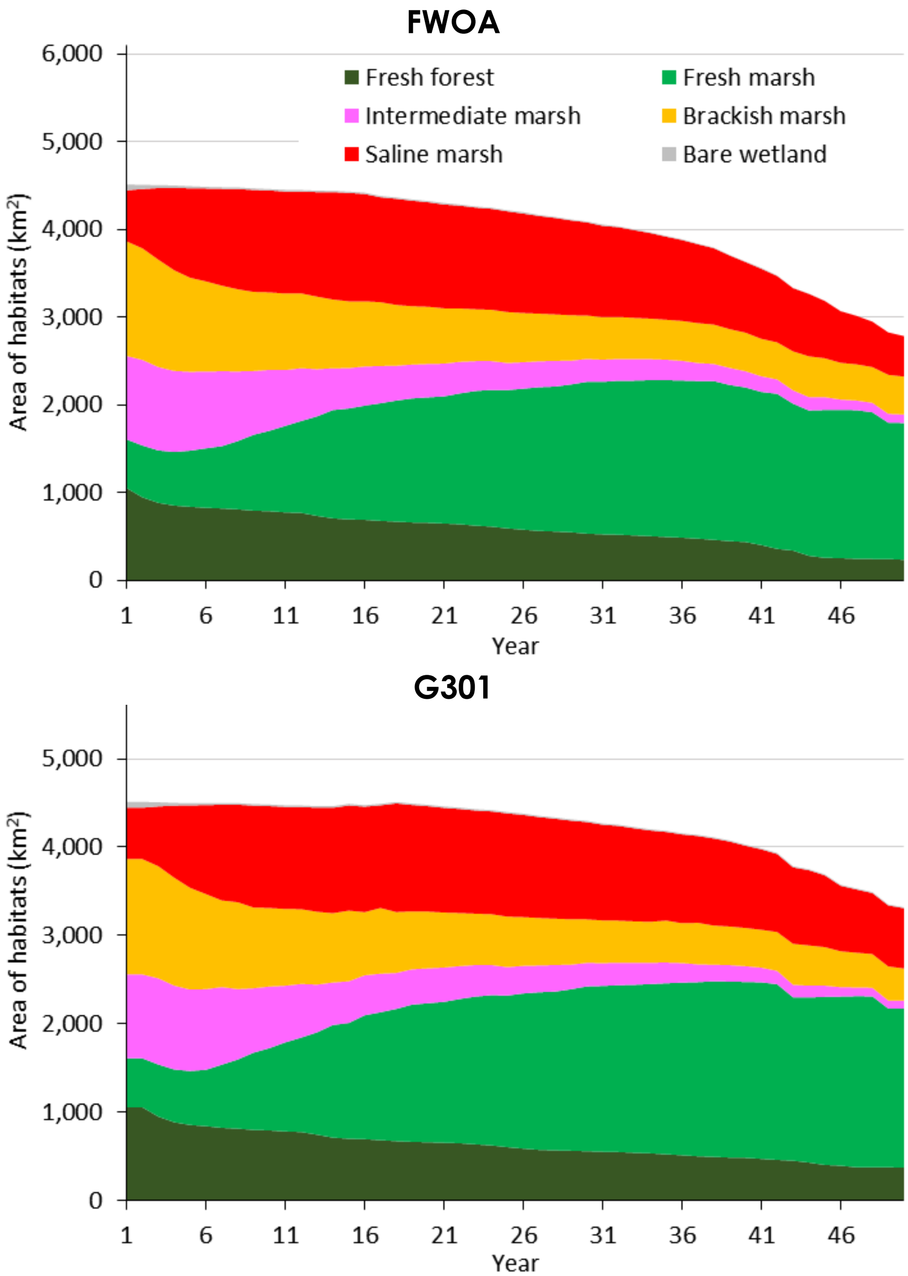


Figure 295: Changes in Marsh Type in the Central Coast (FWOA [top]; G301 [bottom]; medium scenario).

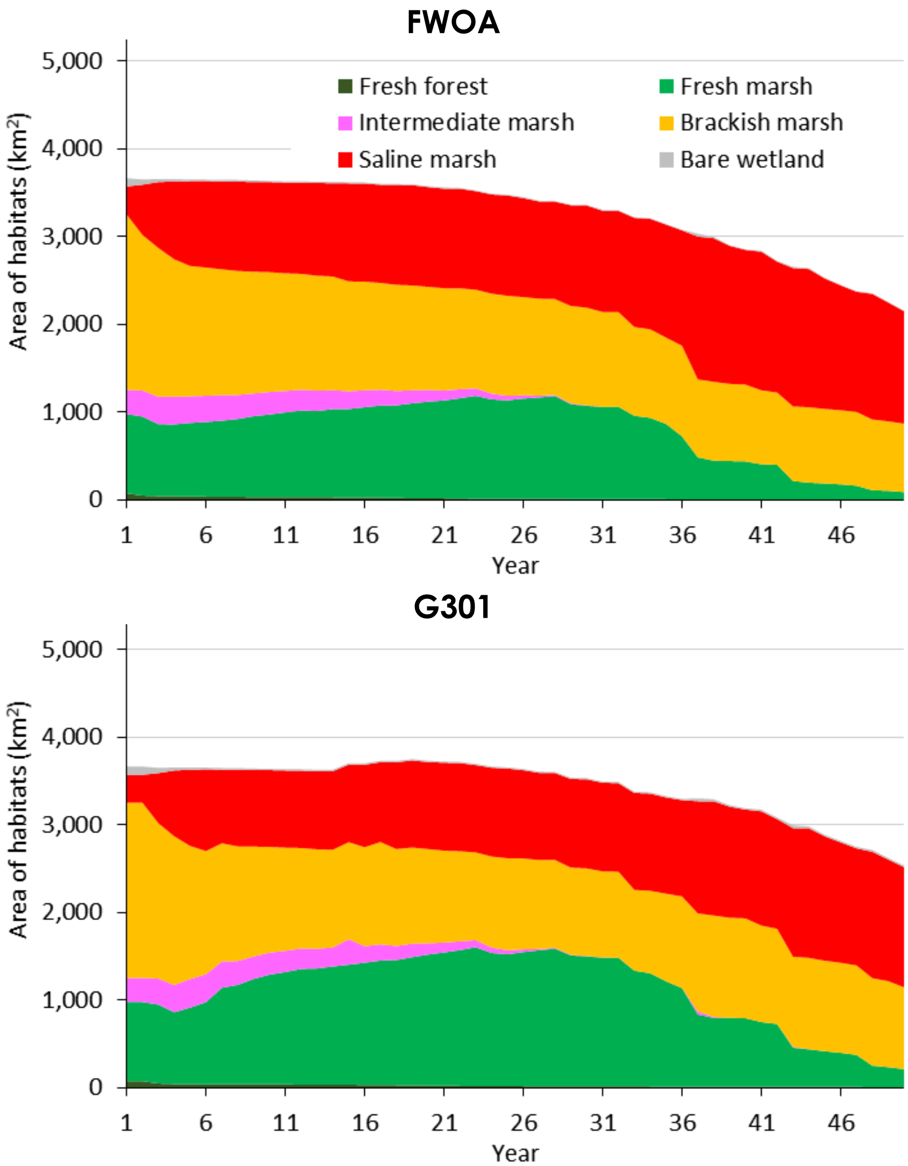


Figure 296: Changes in Marsh Type in the Western Coast (FWOA [top]; G301 [bottom]; medium scenario).

5.3.2.5 HSIs and EwE

Under each environmental scenario, G301 generally decreases habitat suitability for the higher-salinity species: small juvenile brown shrimp, adult spotted seatrout, and oyster. Much of this is due to the alternative's effect on salinity. In the central and western regions, hydrologic restoration projects, in combination with ridge restoration and/or marsh creation projects, reduce saltwater intrusion into interior wetlands, consequently decreasing the suitability of these areas relative to FWOA (e.g., small juvenile brown shrimp; Figure 297 and Figure 298). In the eastern region, sediment diversions introduce large volumes of freshwater that reduce salinities and thus habitat suitability across much of the Pontchartrain, Breton Sound, and Barataria basins (Figure 297 and Figure 298). However, the salinity reduction also increases the suitability, relative to FWOA, of parts of lower Barataria and lower Terrebonne basins for small juvenile brown shrimp and oyster, because salinities in these areas were higher than optimal for these species in FWOA.

In the Bird's Foot Delta, habitat suitability increases relative to FWOA because the reduced discharge from the Delta results in increased salinities. These effects generally become more extensive over time as the difference in salinity compared to FWOA increases in the scenarios.

The landscape changes contribute to the decrease in habitat suitability for small juvenile brown shrimp and adult spotted seatrout. The marsh creation projects replace highly-suitable fragmented marsh with less-suitable solid marsh, resulting in discrete areas of decreased suitability (>0.5 decrease in HSI relative to FWOA; Figure 297 and Figure 298). The alternative also maintains large areas of relatively solid marsh in upper Barataria Basin, upper Terrebonne Basin, and around Lake Maurepas; again resulting in a decrease in suitability relative to FWOA because these areas are converted into more-suitable fragmented marsh and open water habitats in FWOA. This is most evident during the later years of the simulations (particularly in the high scenario) when most of the land loss occurrs in FWOA.

The overall, coast wide effect on habitat suitability for low-salinity species: largemouth bass, green-winged teal, and American alligator, is more varied than for the higher-salinity species. As expected, salinity reduction increases habitat suitability for the low-salinity species in each scenario across large areas of Calcasieu/Sabine, Terrebonne, Barataria, and Breton Sound basins (e.g. largemouth bass; Figure 299 and Figure 300). However, at the same time, suitability decreases in many other areas due to the creation and maintenance of less-suitable solid marsh areas (Figure 299 and Figure 300). In addition, habitat suitability for alligator and green-winged teal decreases compared to FWOA in parts of upper Breton Sound and upper Barataria Basin as a result of increased water levels from multiple diversion discharges.

Fish and shellfish biomasses simulated by the EwE model show somewhat different patterns than those for habitat suitability. Salinity reduction generally results in increased biomass relative to FWOA for low-salinity species (e.g., juvenile largemouth bass; Figure 301 and Figure 302). However, the biomass of higher-salinity species is less negatively affected by the salinity reduction than habitat suitability, particularly in the eastern region (e.g., juvenile brown shrimp; Figure 303 and Figure 304). It is important to remember that the HSI models evaluate effects of projects on potential habitat, whereas the EwE model evaluates effects on actual biomass. Consequently, because the biomass of the higher-salinity species is concentrated in the lower reaches of the basins and nearshore (Figure 264), it is less exposed to low-salinity conditions from the diversion discharge and, therefore, does not decrease appreciably relative to FWOA, except in the Breton Sound Basin. As with the HSI outcomes, biomass in some of these areas increases relative to FWOA because the diversion discharge creates more suitable salinity conditions for the higher-salinity species.

Because EwE is a food web model, the results of the simulations are also affected by factors that influenced food availability. The diversion projects provide inputs of TKN to the Pontchartrain Basin, Breton Sound, and Barataria Basin that subsequently increase phytoplankton production and thus food resources for higher trophic levels. This increased production primarily benefits fish and shellfish in the low-salinity parts of the basins. However, increased production also extends into parts of the lower basins, where it likely contributes to the increased biomass of higher-salinity species observed in these areas.

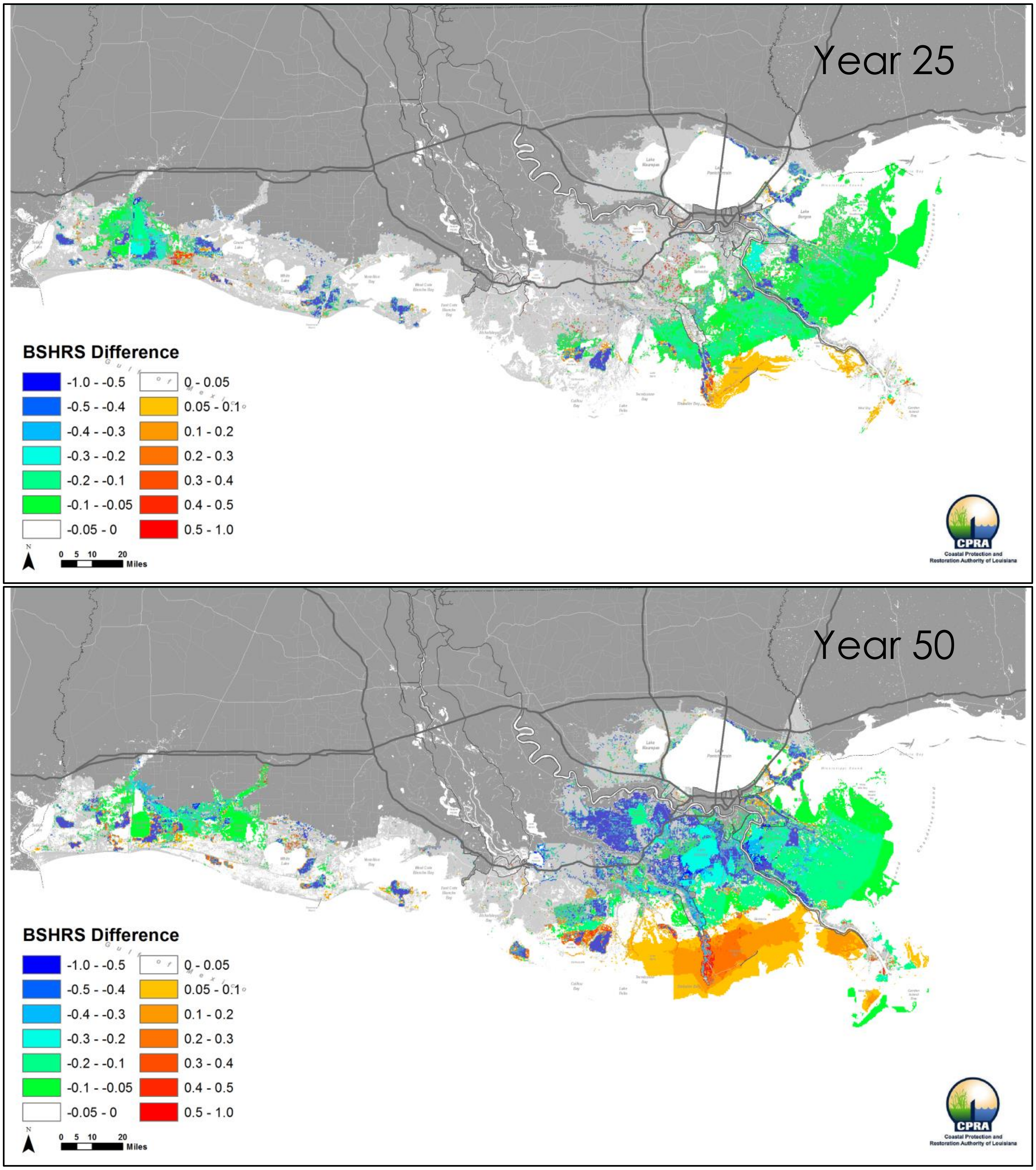
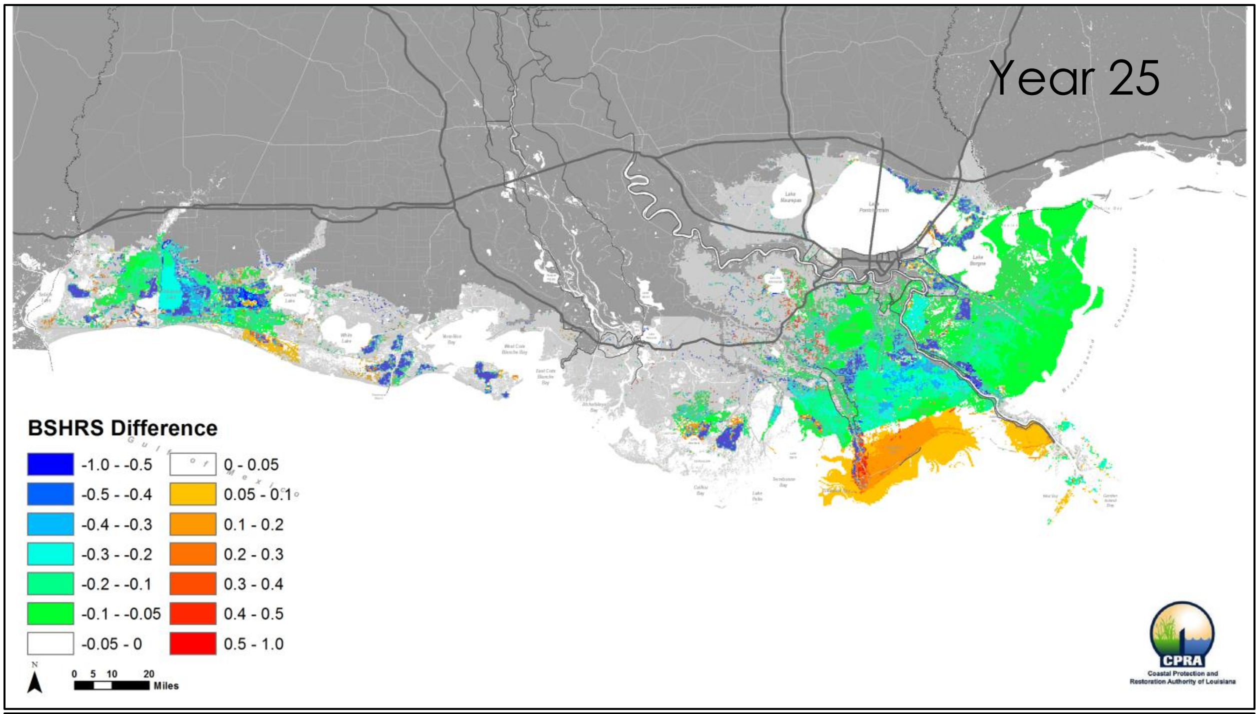


Figure 297: Difference in Small Juvenile Brown Shrimp Habitat Suitability with G301 compared to FWOA (year 25 [top]; year 50 [bottom]; medium scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease with G301.



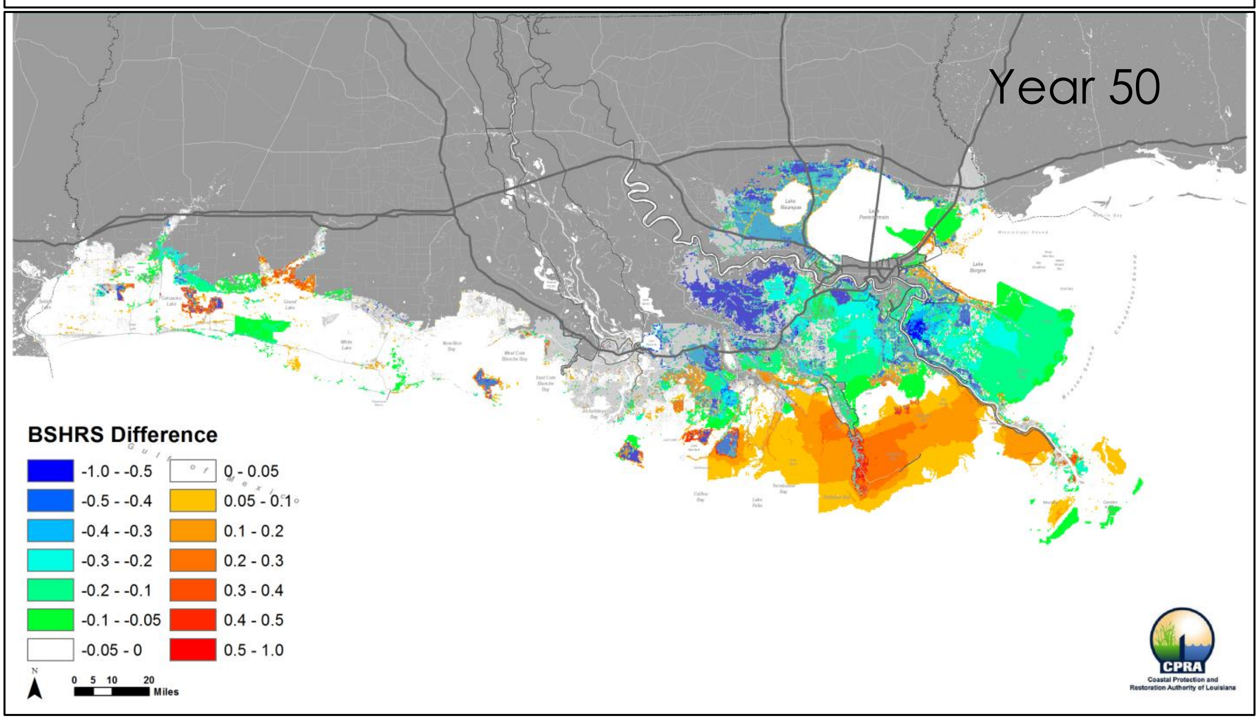


Figure 298: Difference in Small Juvenile Brown Shrimp Habitat Suitability with G301 compared to FWOA (year 25 [top]; year 50 [bottom]; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease with G301.

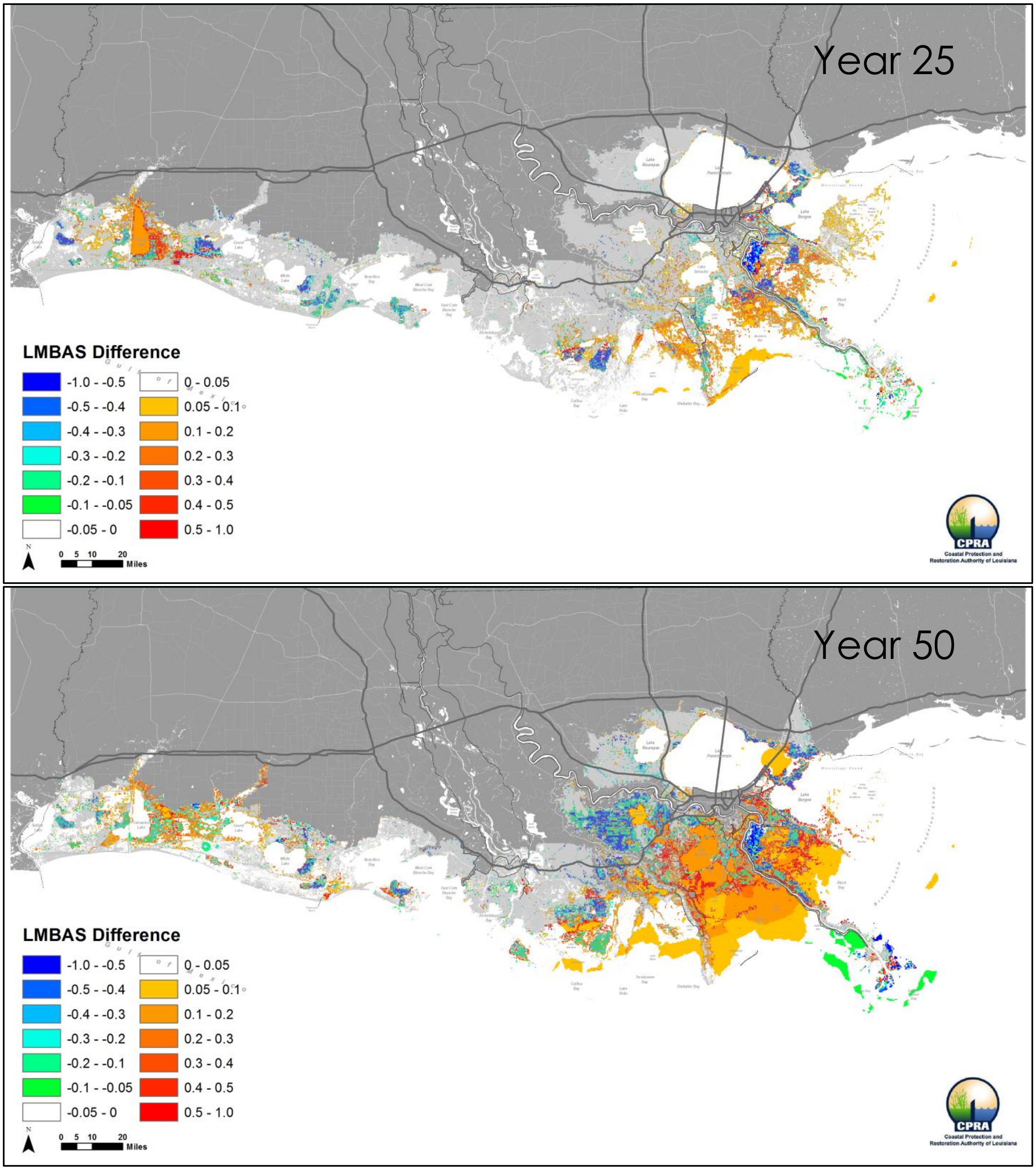
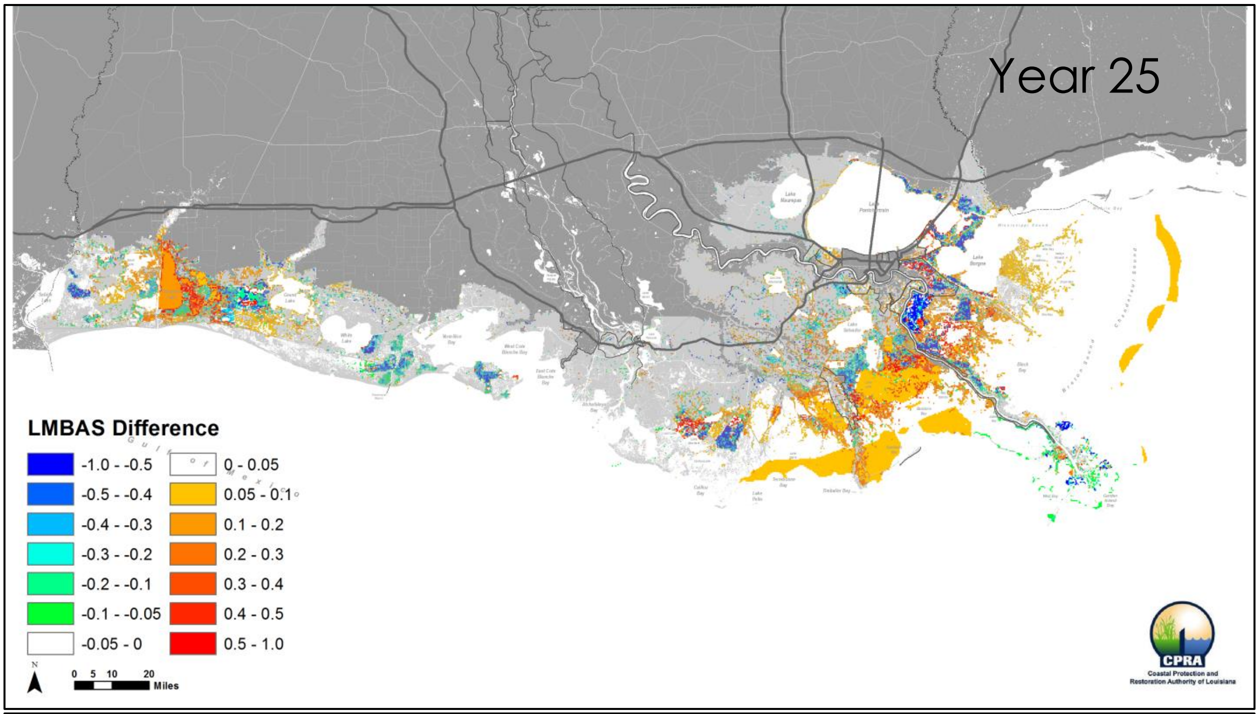


Figure 299: Difference in Largemouth Bass Habitat Suitability with G301 compared to FWOA (year 25 [top]; year 50 [bottom]; medium scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease with G301.



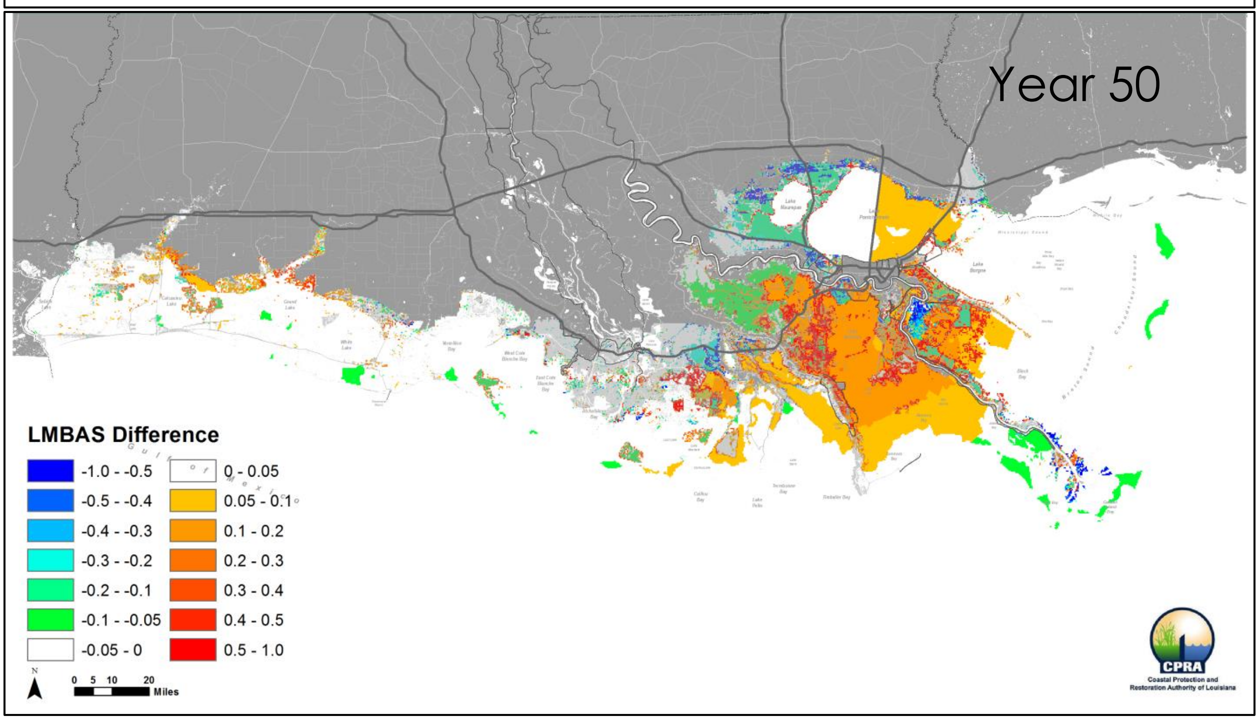
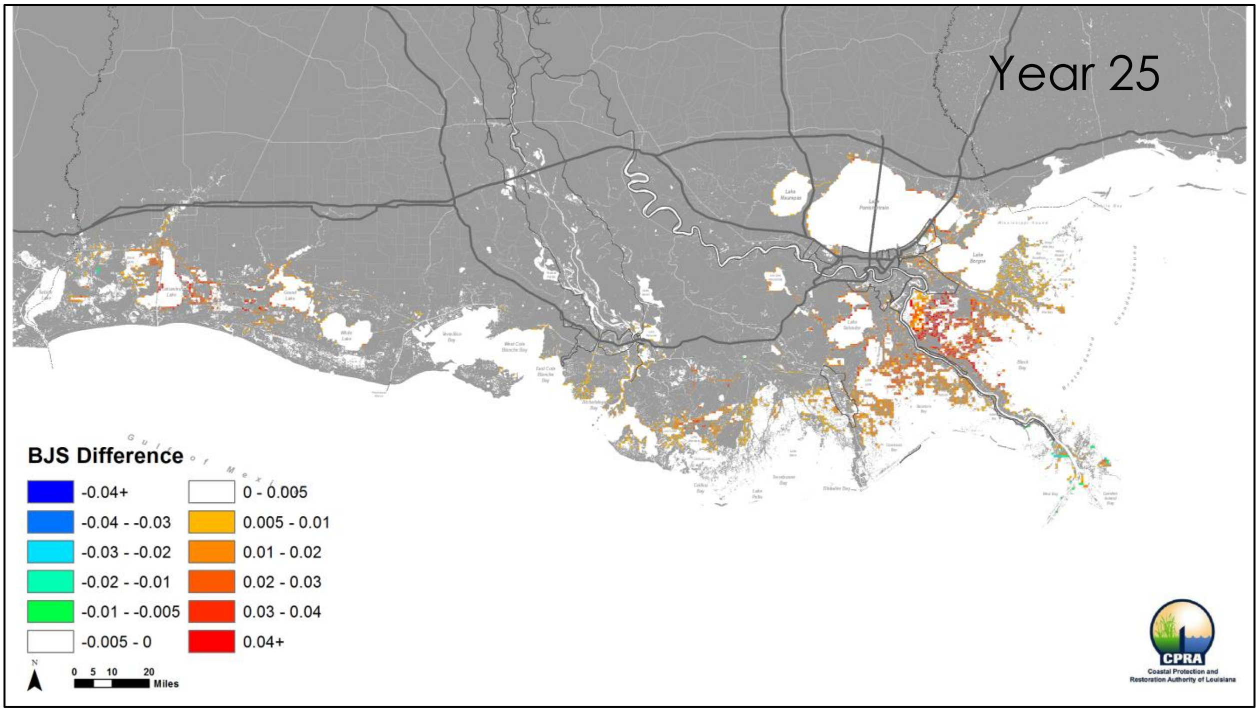


Figure 300: Difference in Largemouth Bass Habitat Suitability with G301 compared to FWOA (year 25 [top]; year 50 [bottom]; high scenario). Warmer colors indicate an increase in suitability and cooler colors indicate a decrease with G301.



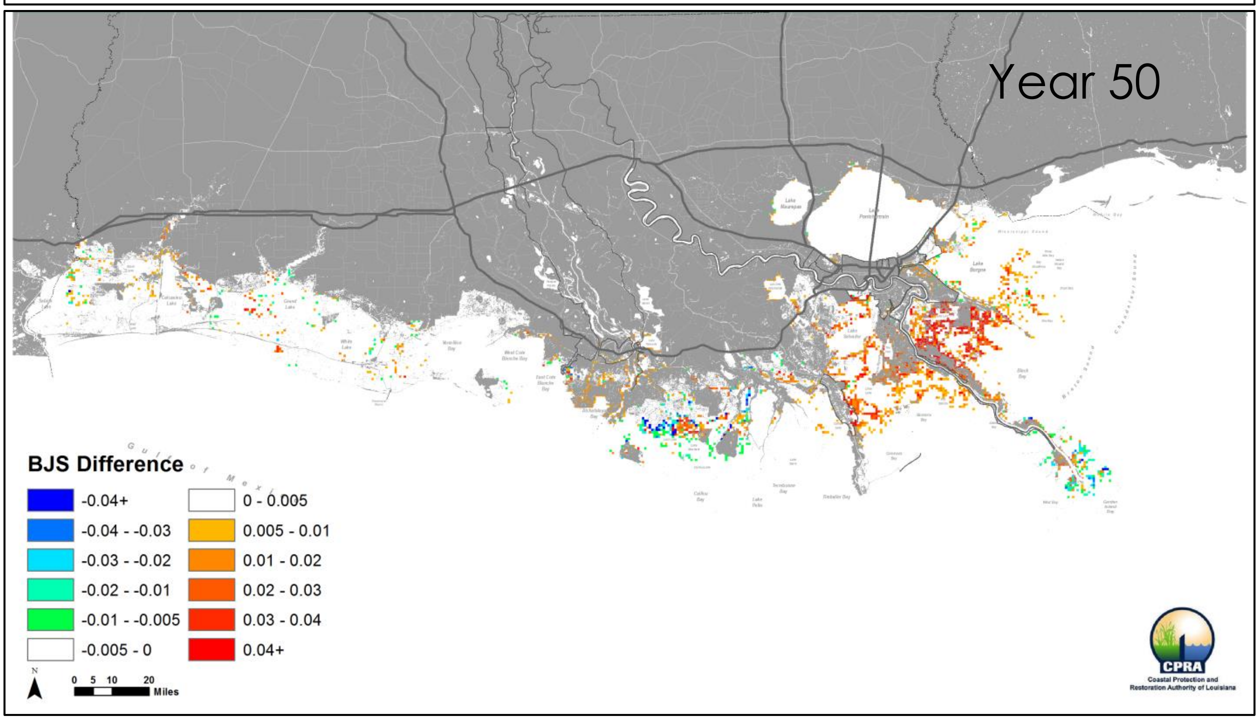


Figure 301: Difference in EwE Juvenile Largemouth Bass Biomass with G301 compared to FWOA in April (year 25 [top]; year 50 [bottom]; medium scenario). Warmer colors indicate an increase in biomass (in tonnes per km^2) and cooler colors indicate a decrease with G301.

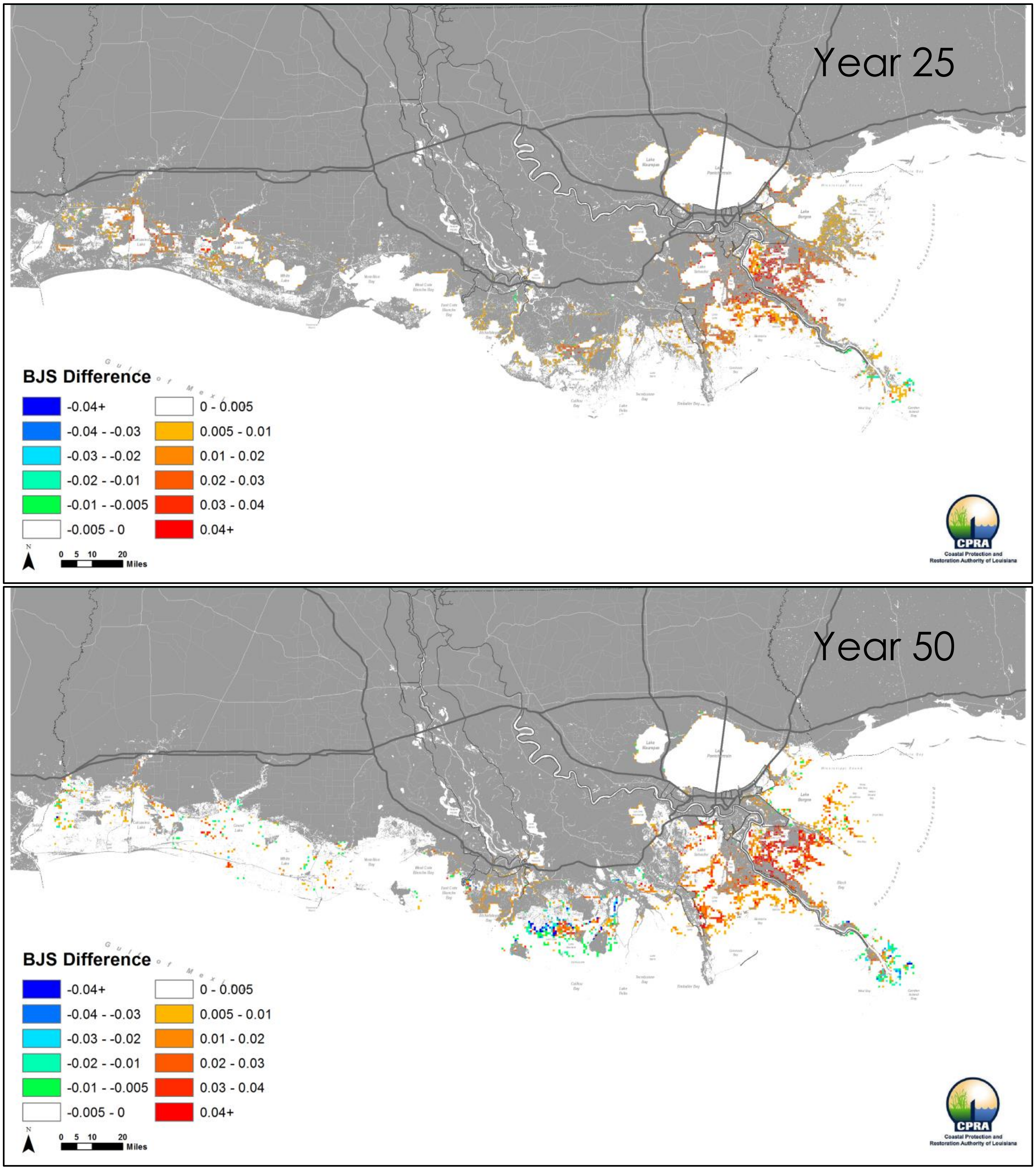


Figure 302: Difference in EwE Juvenile Largemouth Bass Biomass with G301 compared to FWOA in April (year 25 [top]; year 50 [bottom]; high scenario). Warmer colors indicate an increase in biomass (in tonnes per km^2) and cooler colors indicate a decrease with G301.

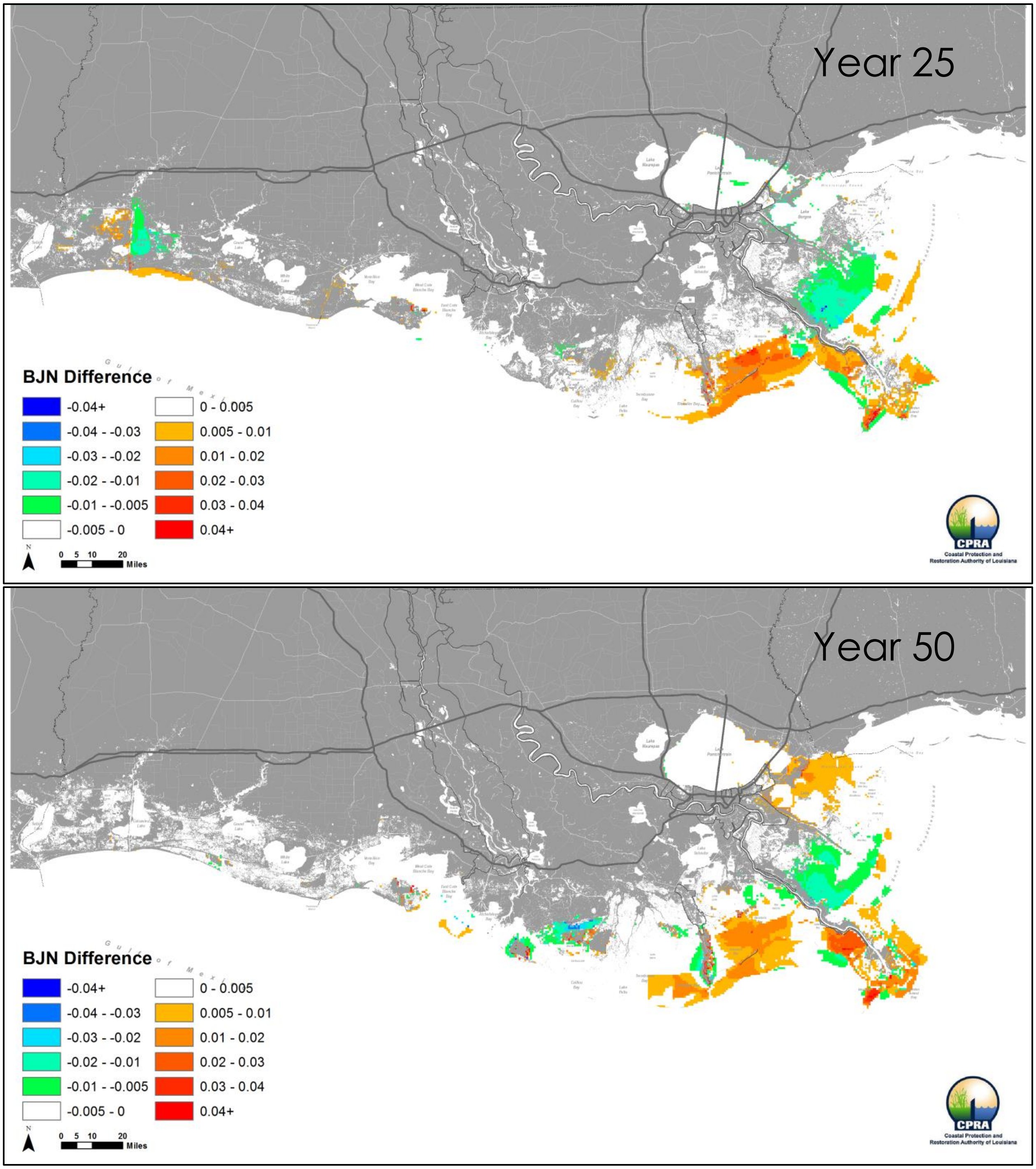


Figure 303: Difference in EwE Juvenile Brown Shrimp Biomass with G301 compared to FWOA in April (year 25 [top]; year 50 [bottom]; medium scenario). Warmer colors indicate an increase in biomass (in tonnes per km^2) and cooler colors indicate a decrease with G301.

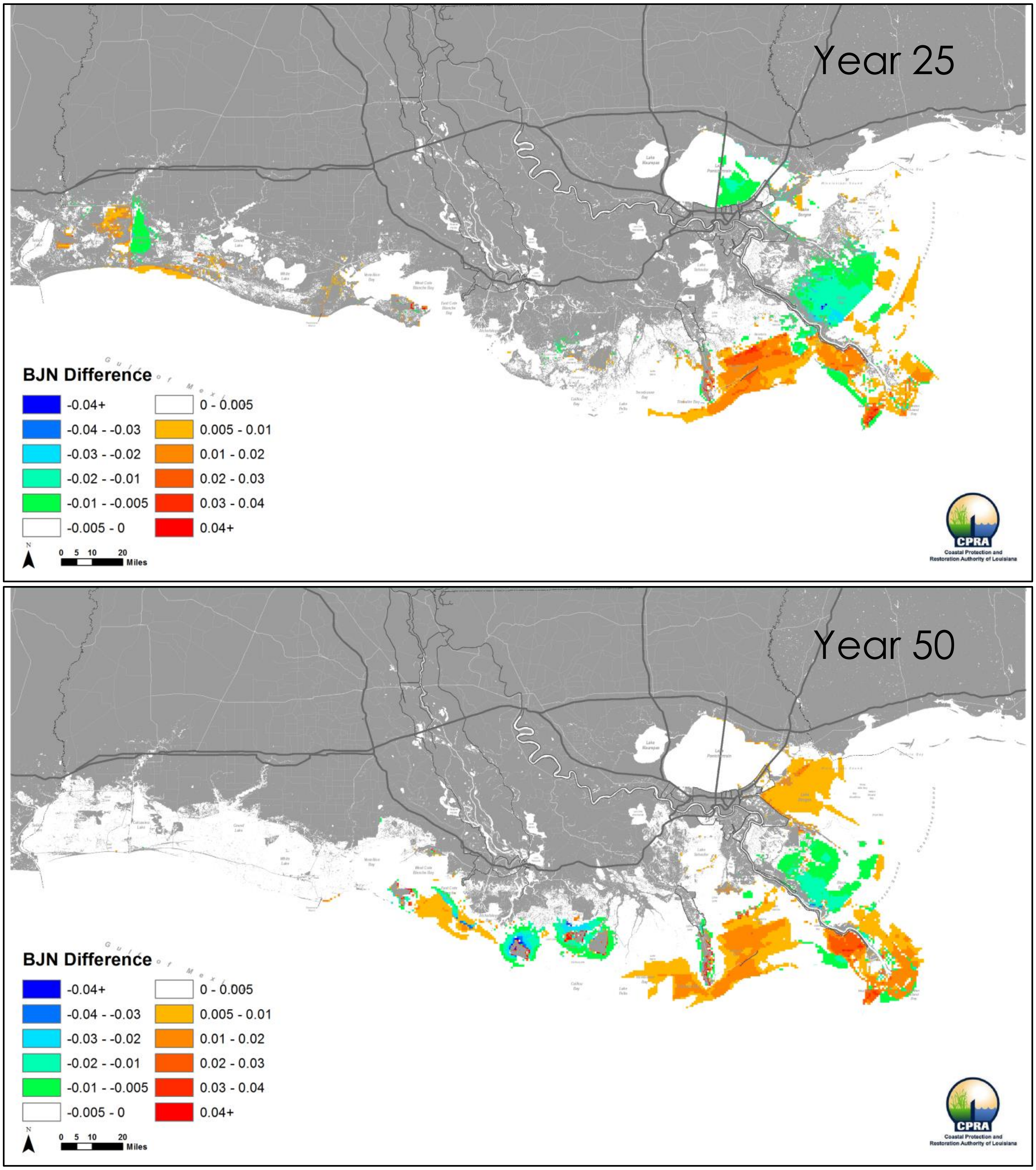


Figure 304: Difference in EwE Juvenile Brown Shrimp Biomass with G301 compared to FWOA in April (year 25 [top]; year 50 [bottom]; high scenario). Warmer colors indicate an increase in biomass (in tonnes per km^2) and cooler colors indicate a decrease with G301.

5.3.3 G303 compared to FWOA

Alternative G303 includes all of the structural protection projects that are in G301 (discussed above), but the restoration projects are not included. This section describes the difference the structural protection projects make on land area and vegetation distribution for comparison with the other alternatives and FWOA.

5.3.3.1 Land Change

Medium Scenario

Under the medium scenario, G304 results in approximately 200 km^2 of net land area benefit (floating marsh included) compared to FWOA at the end of the 50-year simulation (Table 13).

This figure includes both land sustained and new land built. This outcome of this alternative is similar to FWOA with regard to net land area (Figure 306 and Figure 307) but there are areas of loss and gain relative to FWOA.

As the western region contains no protection features, the results of G303 should be identical to FWOA; however, there are small differences in net land area benefit. The central region is projected to realize only 1.5 km^2 of land benefit at year 25 and 25 km^2 of benefit by year 50 compared to FWOA (Figure 305; Table 13). This minimal difference is within the error of the model. This indicates that structural protection features have a minimal effect on land area benefit in this region. Finally, when compared to FWOA, the eastern region has a projected net land area benefit of approximately 29 km^2 by year 25, increasing to 162 km^2 by year 50 (Figure 305). Figure 307 shows a complex pattern of gain and loss associated with changing inundation patterns, but overall there is a net benefit.

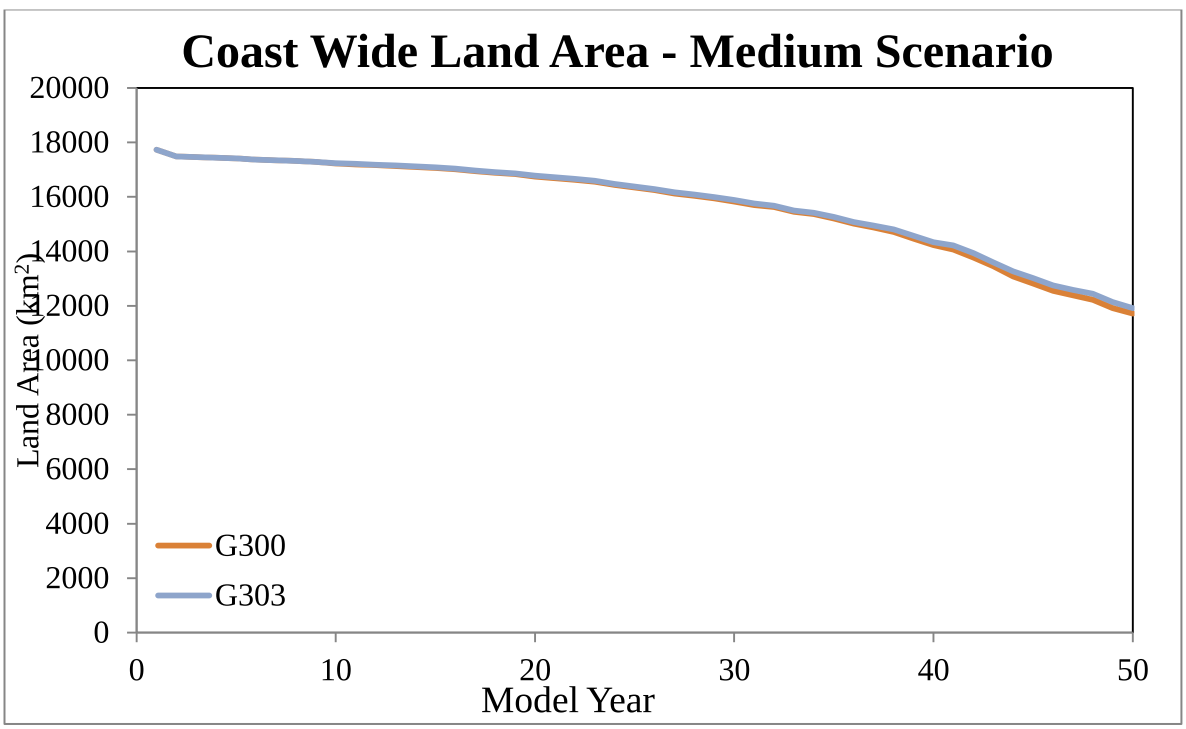


Figure 305: Land Area Change over Time for G303 and FWOA (medium scenario).

Table 13: Land Area for G303 and FWOA. Units are square kilometers.

Medium Scenario - Group 303									
	Year 0	**Year 25**	**Difference Year 25 vs. Year 0**	**FWOA Year 25**	**Difference with FWOA at Year 25**	**Year 50**	**Difference Year 50 vs. Year 0**	**FWOA Year 50**	**Difference with FWOA at Year 50**
East	8,927	7,804	-1,123	7,775	29	5,317	-3,610	5,155	162
Central	3,516	3,504	-13	3,502	2	2,855	-661	2,830	25
West	3,853	3,804	-49	3,798	6	2,487	-1,366	2,474	13
Total	16,297	15,111	-1,186	15,075	37	10,660	-5,637	10,460	200
High Scenario - Group 303									
	Year 0	**Year 25**	**Difference Year 25 vs. Year 0**	**FWOA Year 25**	**Difference with FWOA at Year 25**	**Year 50**	**Difference Year 50 vs. Year 0**	**FWOA Year 50**	**Difference with FWOA at Year 50**
East	8,927	7,147	-1,779	7,083	65	3,969	-4,958	3,076	892
Central	3,516	3,359	-157	3,358	1	1,821	-1,695	1,779	42
West	3,853	3,369	-484	3,363	6	782	-3,071	760	23
Total	16,297	13,876	-2,421	13,804	72	6,573	-9,724	5,615	957

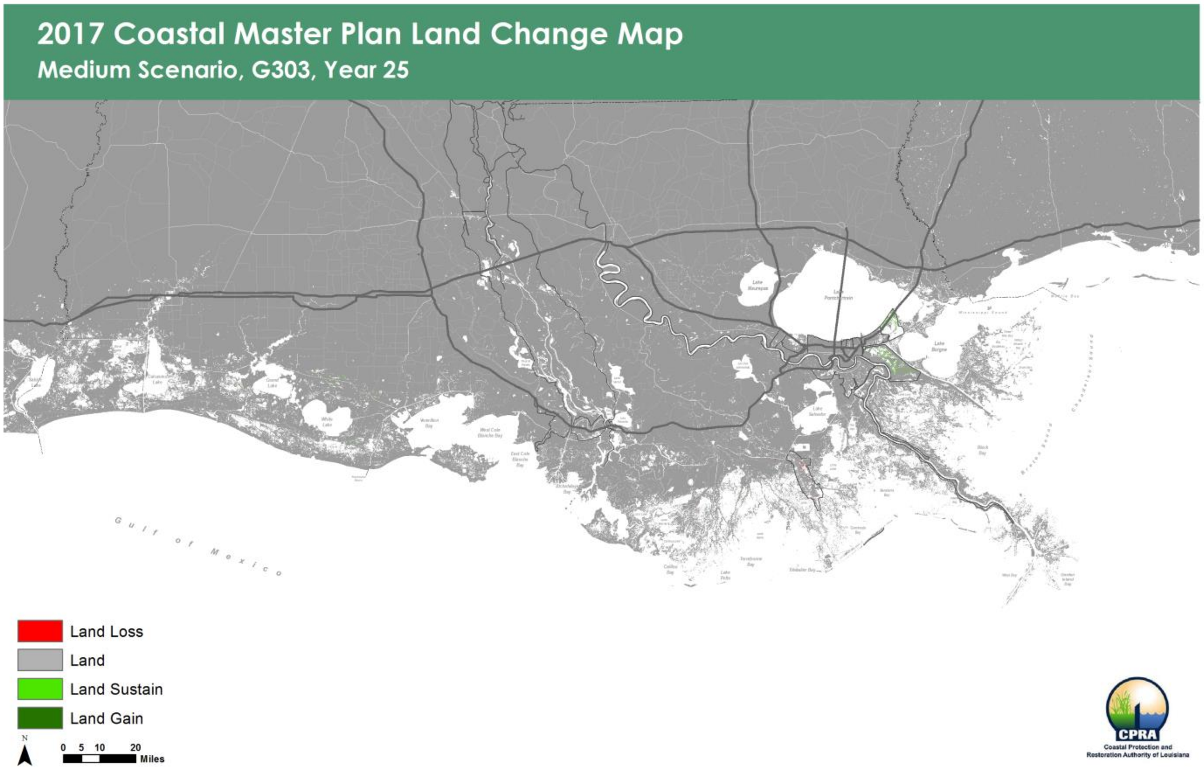


Figure 306: Land Change for G303 compared to FWOA (year 25; medium scenario).

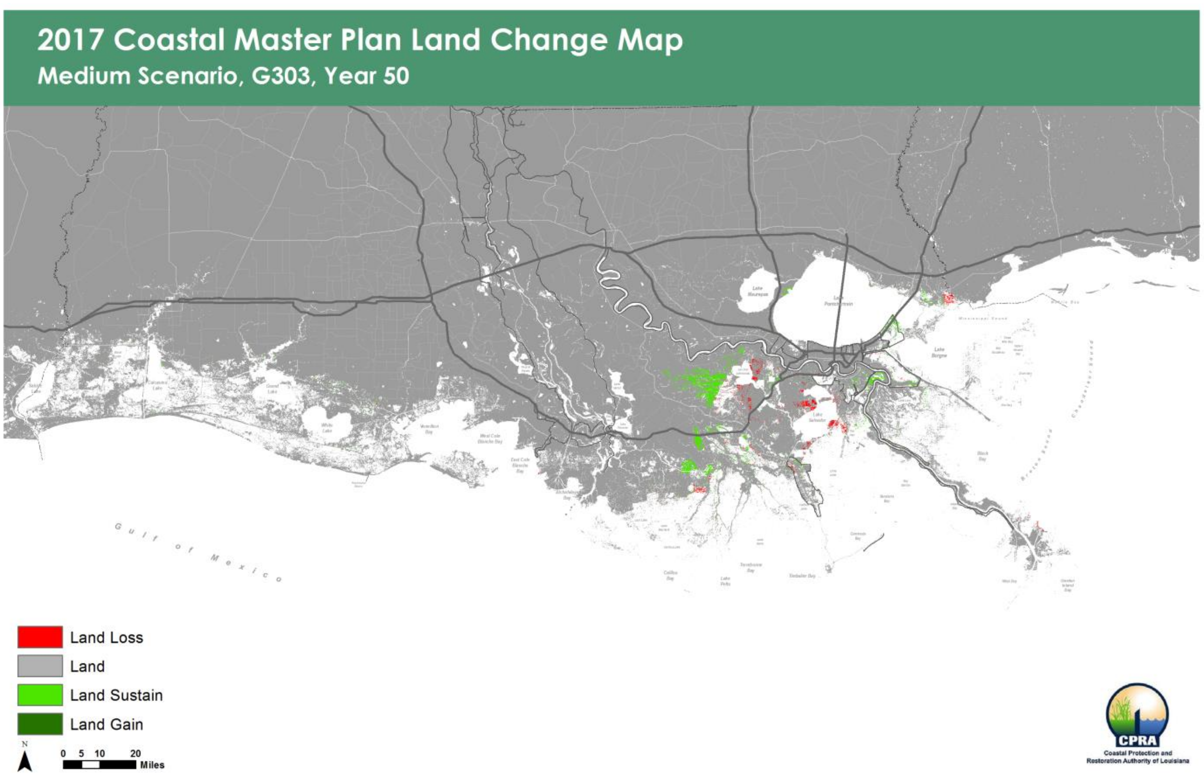


Figure 307: Land Change for G303 compared to FWOA (year 50; medium scenario).

High Scenario

Under the high scenario, G303 results in approximately 957 km² of net land area benefit (floating marsh included) compared to FWOA at the end of the 50-year simulation (Figure 308).

As the western region contains no protection features, the results of G303 are the same as FWOA. There are some small areas of sustained land in the western region, which are likely due to very minor differences in the annual mean water level in this region, which resulted in land areas directly at the edge of the land/water interface responding differently at year 50 between G303 and FWOA. This did not occur in the medium scenario which indicates that the land was not lost under FWOA in that scenario as water levels did not exceed marsh collapse thresholds. The central region is projected to realize only 1 km² of benefit by year 25, which is within the error of the model, and 42 km² of benefit by year 50 compared to FWOA (Figure 309). This indicates that structural protection features have some effect on land area benefit in this region. Finally, the eastern region has a projected net land area benefit of approximately 65 km² by year 25, increasing to 892 km² by year 50 (Figure 310). Again, this increase in benefit indicates the effects of the structural protection projects are most significant in the eastern region and under the high scenario. Most of this benefit occurs in the Maurepas Swamp region due to the previously discussed effects of Lake Pontchartrain Barrier (001.HP.08) project. Similar to the medium scenario, additional benefit is observed behind the Upper Barataria Risk Reduction (002.HP.06) project.

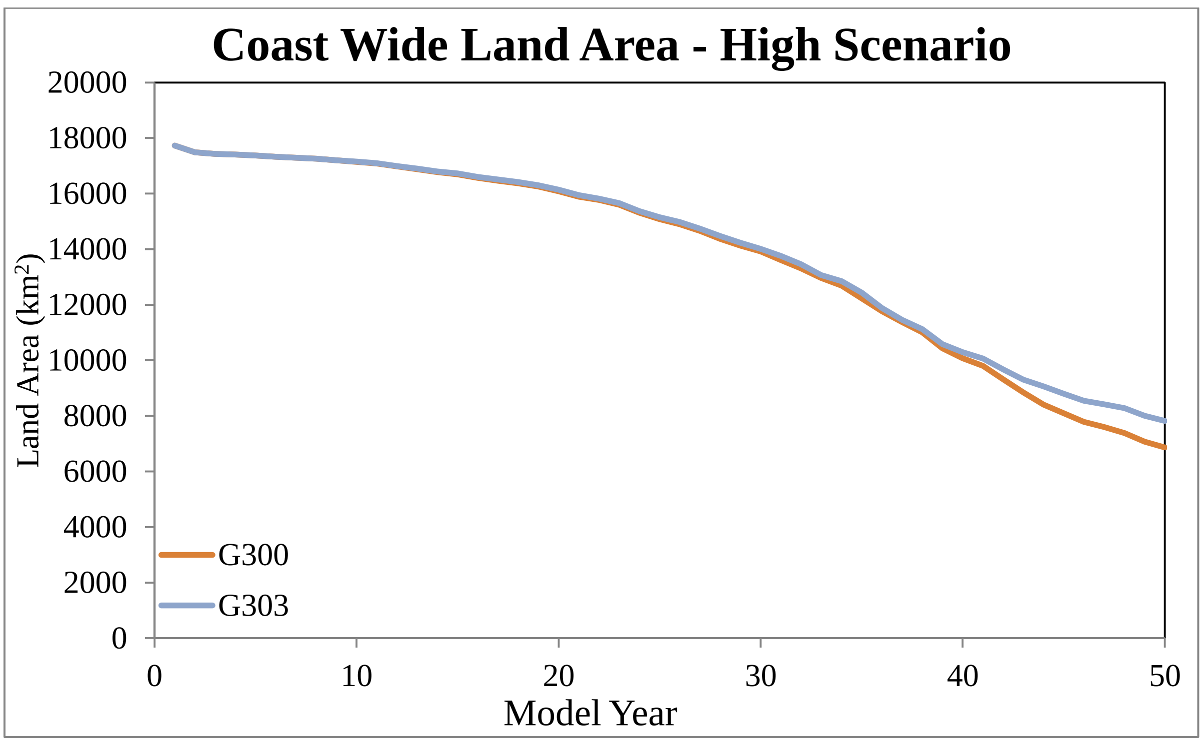


Figure 308: Land Area Change over Time for G303 and FWOA (high scenario).

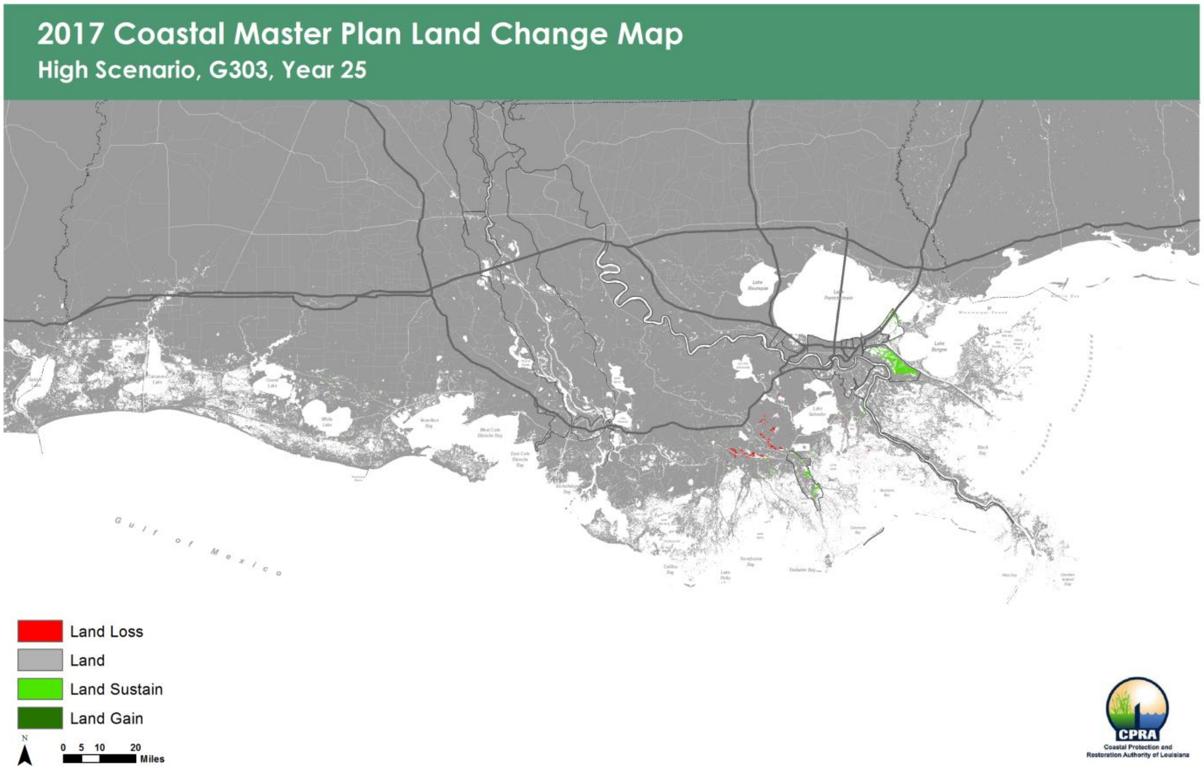


Figure 309: Land Change for G303 compared to FWOA (year 25; high scenario).

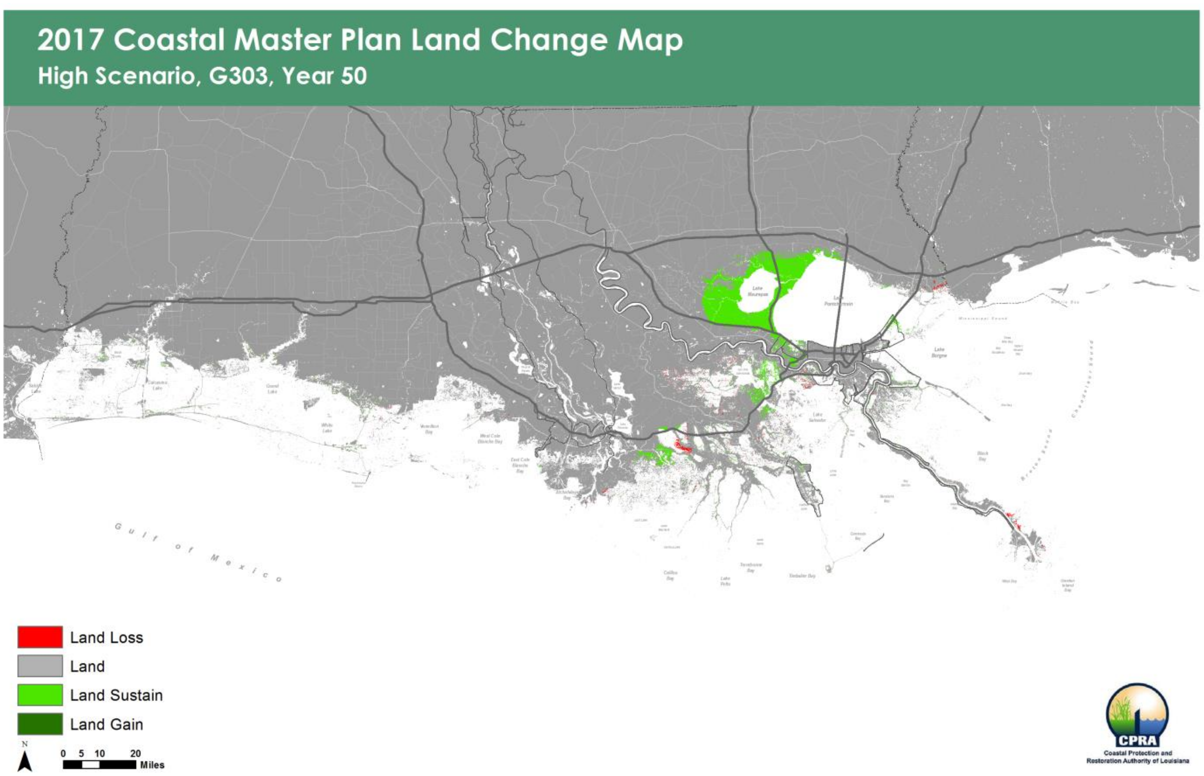


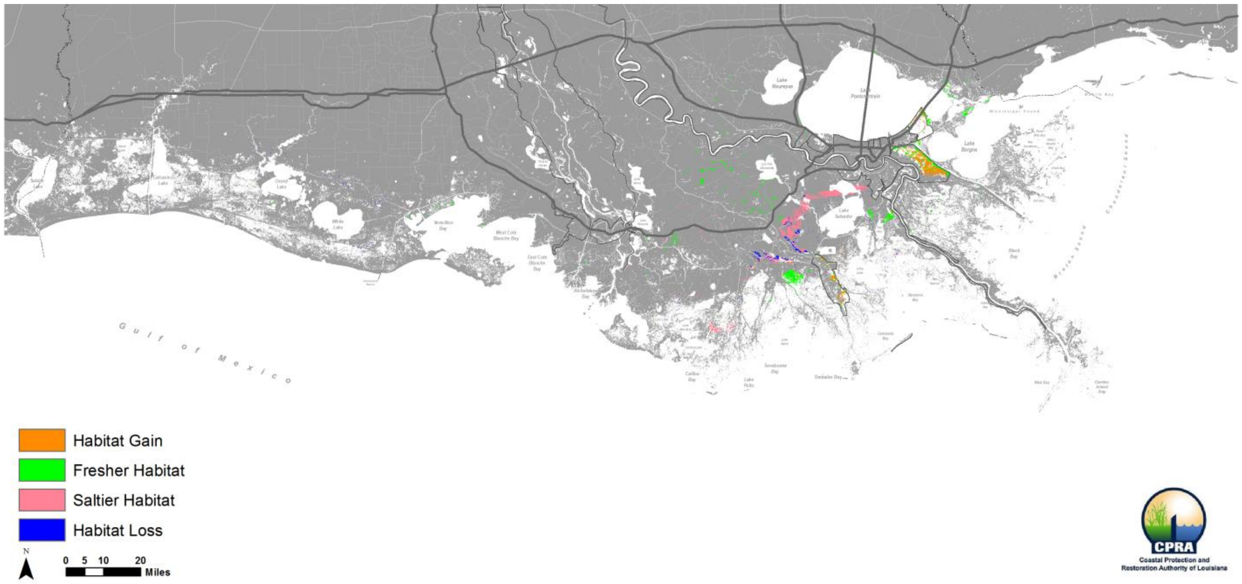
Figure 310: Land Change for G303 compared to FWOA (year 50; high scenario).

5.3.3.2 Vegetation

High Scenario

This alternative has no noticeable effect on habitat change compared to FWOA in the western and central regions of the coast both in years 25 and 50 (Figure 311). In the eastern region, the reduced tidal exchange between the upper and lower estuary due to the structural protection projects leads to preservation of forested wetlands and slightly more brackish marsh in the lower estuary especially in Barataria Basin. In year 25, the eastern region has an increase of 42 km^2 forested wetland, 52 km^2 brackish marsh, and 9 km^2 bare wetland and a reduction of 29 km^2 fresh marsh compared to the FWOA (Figure 312). The preservation of forested wetlands is primarily located in upper Barataria. In year 50, the eastern region has an increase of 985 km^2 fresh marsh, and 57 km^2 brackish marsh and a reduction of 29 km^2 intermediate marsh and 154 km^2 bare wetland compared to FWOA. Although forest still converts to fresh marsh the loss associated with salinity intrusion under the FWOA conditions is halted by the structural protection projects and covers both upper Pontchartrain Basin and upper Barataria Basin (Figure 65).

Year 25



Year 50

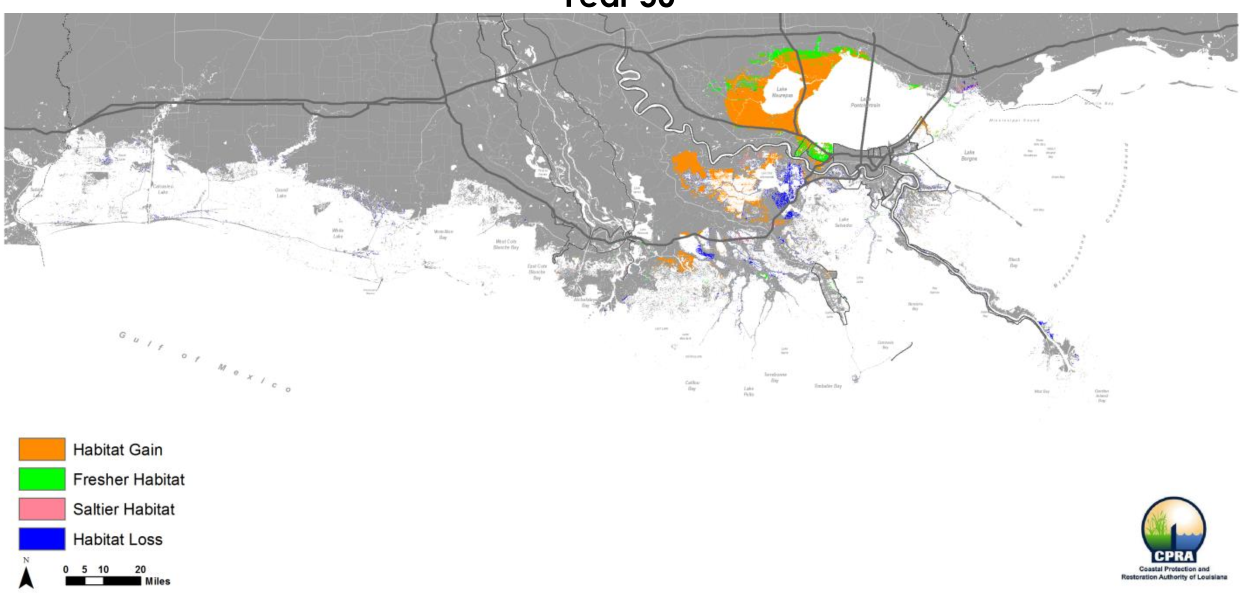


Figure 311: Vegetation Cover by Salinity under G303 compared to FWOA (year 25 [top]; year 50 [bottom]; high scenario).

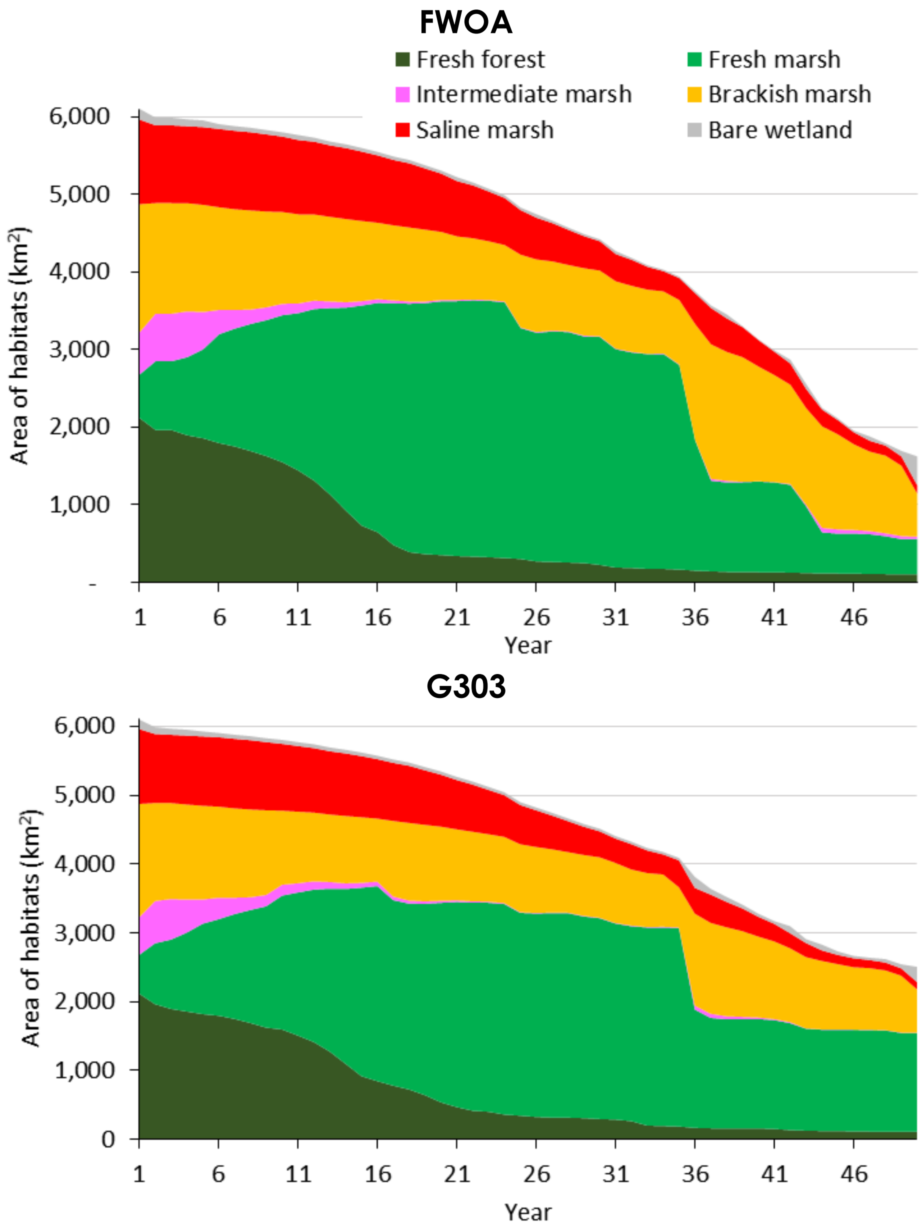
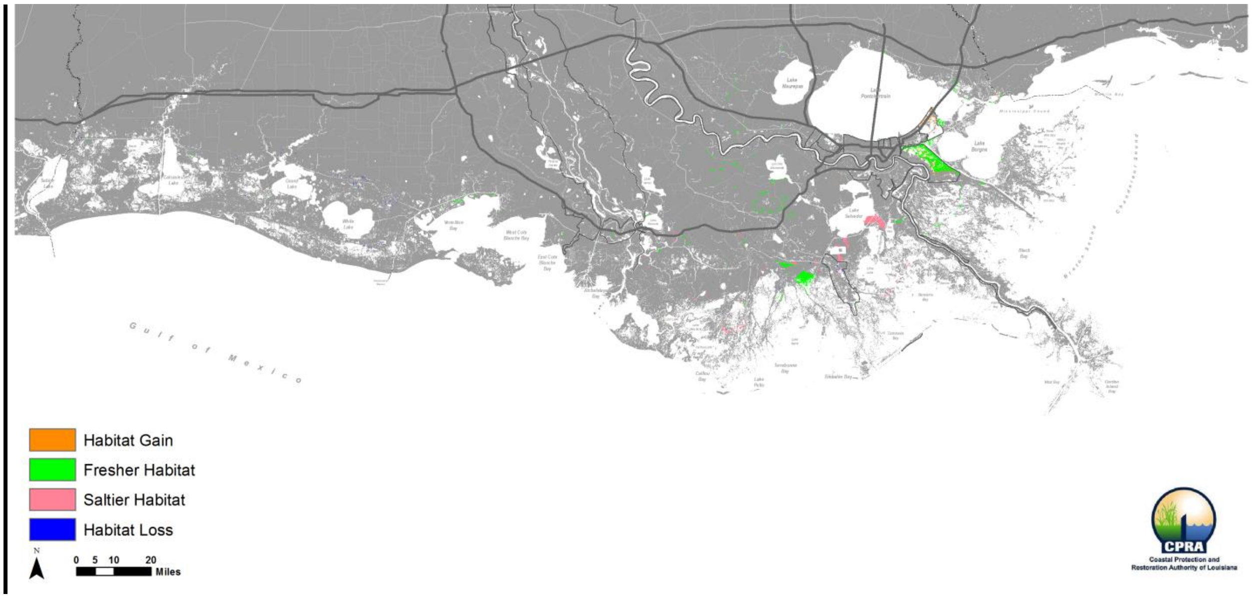


Figure 312: Changes in Marsh Type in the Eastern Coast (FWOA [top]; G303 [bottom]; high scenario).

Medium Scenario

There is no substantial effect on habitat change compared to FWOA in the western and central regions of the coast both in years 25 and 50 under the medium scenario (Figure 313). Effects on habitat change in the eastern region relative to the FWOA are relatively small, but similar to those observed under the high scenario. In year 25, there is an increase of 34 km^2 forested wetlands, 21 km^2 fresh marsh, and 7 km^2 bare wetland and a reduction of 43 km^2 brackish marsh compared to FWOA (Figure 314). In year 50, there is an increase of 16 km^2 forested wetlands, 79 km^2 fresh marsh, 97 km^2 intermediate marsh, and 71 km^2 salt marsh and a reduction of 74 km^2 brackish marsh and 68 km^2 bare wetland compared to FWOA (Figure 314).

Year 25



Year 50

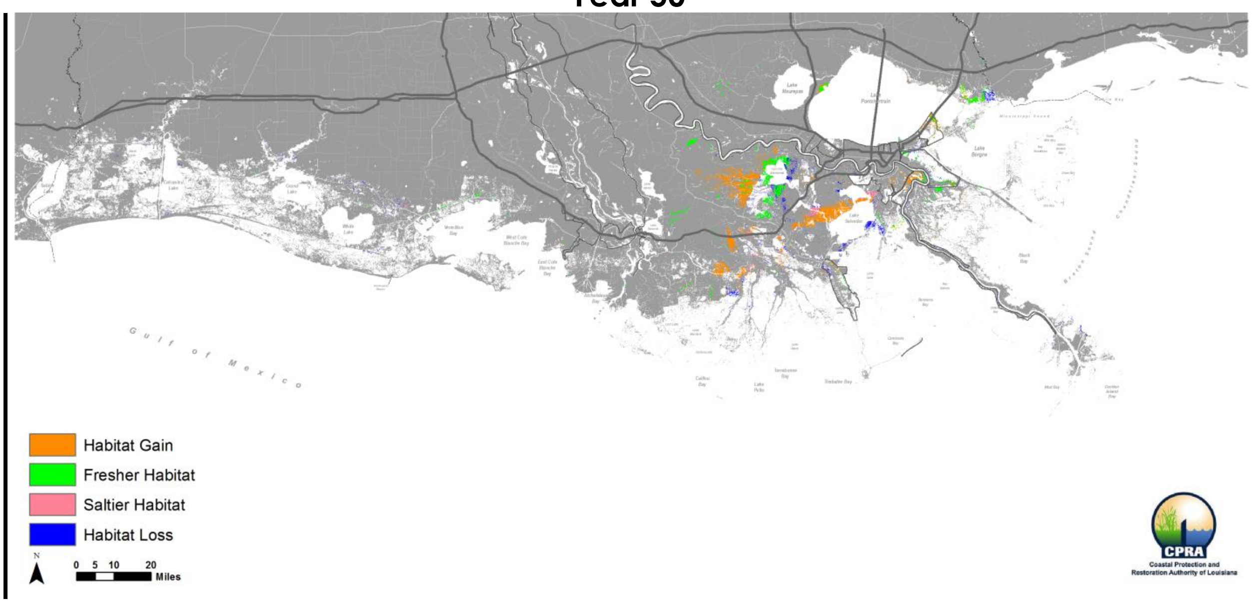


Figure 313: Vegetation Cover by Salinity under G303 compared to FWOA (year 25 [top]; year 50 [bottom]; medium scenario).

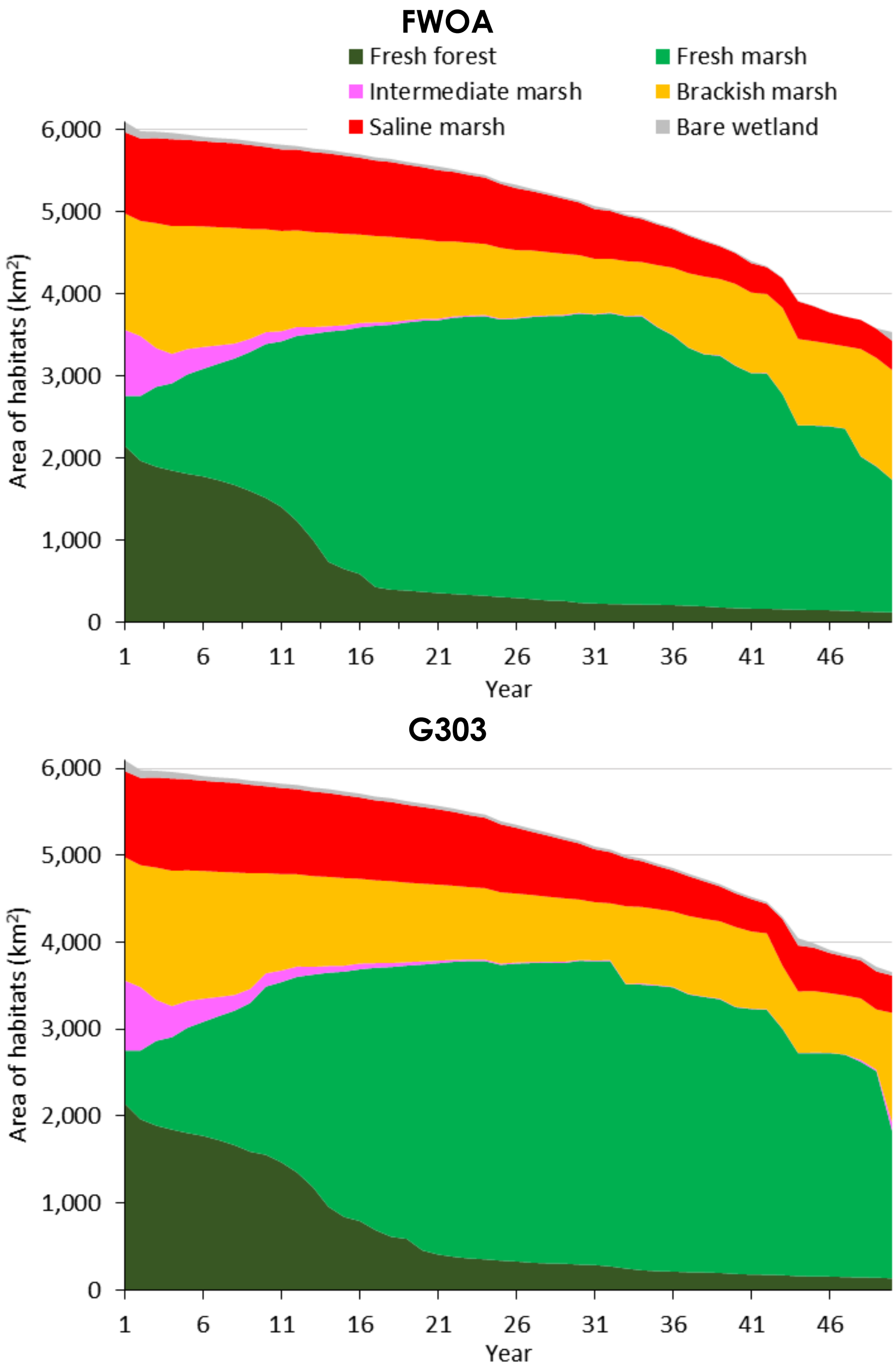


Figure 314: Changes in Marsh Type in the Eastern Coast (FWOA [top]; G303 [bottom]; medium scenario).

5.3.1 G304 compared to FWOA

Alternative G304 includes all of the restoration projects that were in G301 (discussed above) but the structural protection projects are not included. This section describes the difference the restoration projects make on land area and vegetation distribution for comparison with the other alternatives and FWOA.

5.3.1.1 Land Change

Medium Scenario

Under the medium scenario, G304 predicts approximately 1,980 km^2 of net land area benefit (floating marsh included) compared to FWOA at the end of the 50-year simulation (Table 14 and Figure 315). This figure includes both land sustained and new land built. While there is positive net land area benefit compared to FWOA, this G304 still forecasts an overall loss of total wetland area (-3,856 km^2) under this scenario during the 50-year simulation (Table 14). In the absence of any action (FWOA), the coast is projected to lose 5,837 km^2 under this scenario (Table 14). As the western region contains no protection features, G304 has an identical set of projects to that of G301. Consequently, net land area benefit for G304 under this scenario is identical to that of G301 at approximately 180 km^2 by year 25, increasing to 382 km^2 by year 50 compared to FWOA (Table 14, Figure 316, and Figure 317).

Similarly, in the central region of the coast, the only difference in G304 compared to G301 is the removal of some structural protection features which are, for the most part, located in inland areas which are not projected to undergo much coastal wetland change. As such, net land area benefit from project implementation is quite similar to that discussed in the G301 section, at approximately 49 km^2 by year 25, increasing to 187 km^2 by year 50 (Table 14). There is a difference of only 7 km^2 (G301: 194 km^2 at year 50; G304: 187 km^2 at year 50), which indicates that the structural protection projects, including Franklin and Vicinity (03b.HP.12) project (implemented in year 37), likely contributes to the additional land area benefit.

The eastern region has a net land area benefit of approximately 296 km^2 by year 25, increasing to 1,412 km^2 by year 50 compared to FWOA (Table 14). The increase in benefit of 3 km^2 at year 25 and decrease of 8 km^2 with G304 compared to G301 indicates the effects of the structural protection projects in G301 are negligible.

Table 14: Land Area for G304 and FWOA. Units are square kilometers.

Medium Scenario - Group 304									
	Year 0	**Year 25**	**Difference Year 25 vs. Year 0**	**FWOA Year 25**	**Difference with FWOA at Year 25**	**Year 50**	**Difference Year 50 vs. Year 0**	**FWOA Year 50**	**Difference with FWOA at Year 50**
East	8,927	8,071	-856	7,775	296	6,566	-2,361	5,155	1,412
Central	3,516	3,552	35	3,502	50	3,018	-499	2,830	187
West	3,853	3,978	124	3,798	180	2,856	-997	2,474	382
Total	16,297	15,601	-696	15,075	526	12,440	-3,857	10,460	1,980
High Scenario - Group 304									
	Year 0	**Year 25**	**Difference Year 25 vs. Year 0**	**FWOA Year 25**	**Difference with FWOA at Year 25**	**Year 50**	**Difference Year 50 vs. Year 0**	**FWOA Year 50**	**Difference with FWOA at Year 50**
East	8,927	7,589	-1,338	7,083	506	4,883	-4,044	3,076	1,806
Central	3,516	3,430	-86	3,358	73	2,074	-1,442	1,779	295
West	3,853	3,633	-221	3,363	269	912	-2,941	760	152
Total	16,297	14,652	-1,645	13,804	847	7,869	-8,428	5,615	2,253

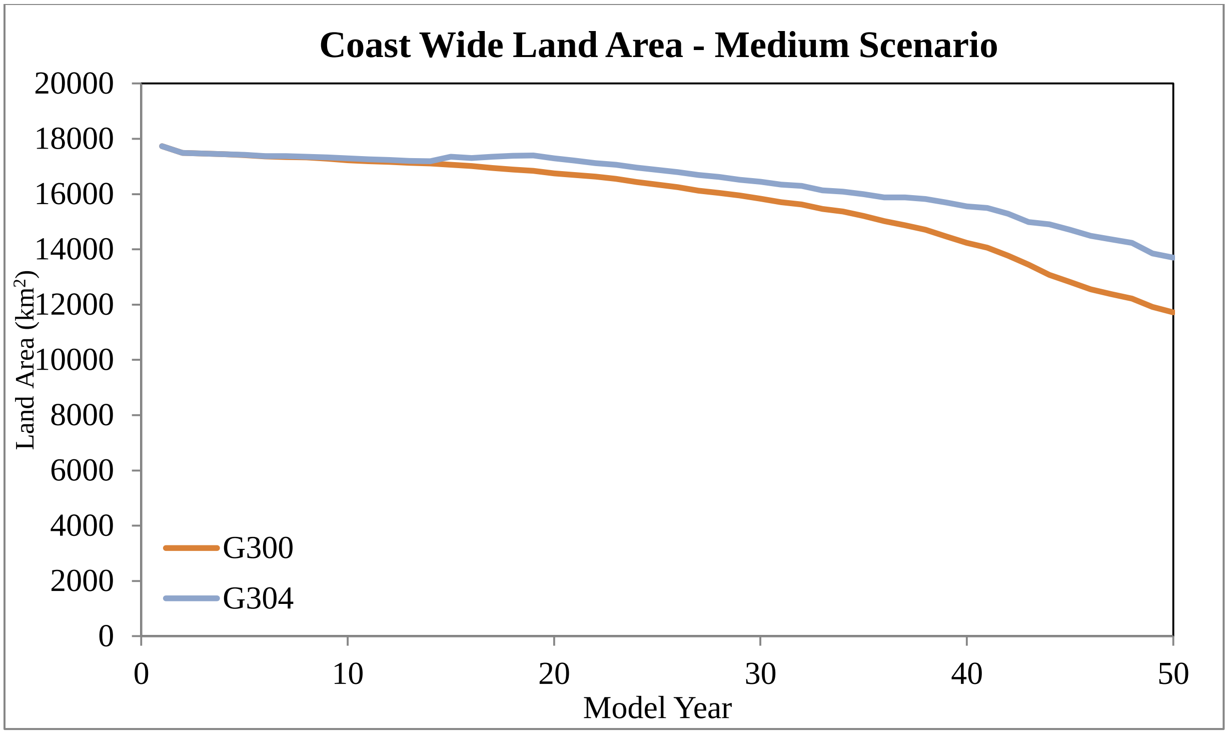


Figure 315: Land Change over Time for G304 and FWOA (medium scenario).

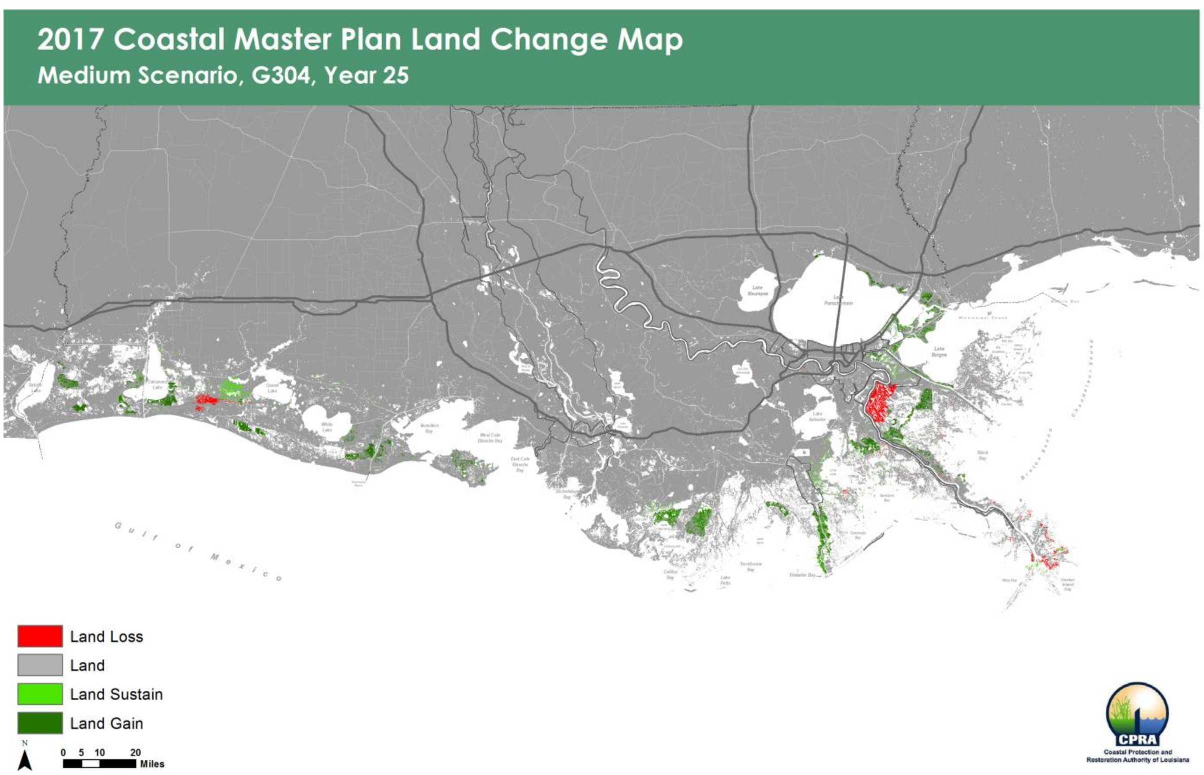


Figure 316: Land Change for G304 compared to FWOA (year 25; medium scenario).

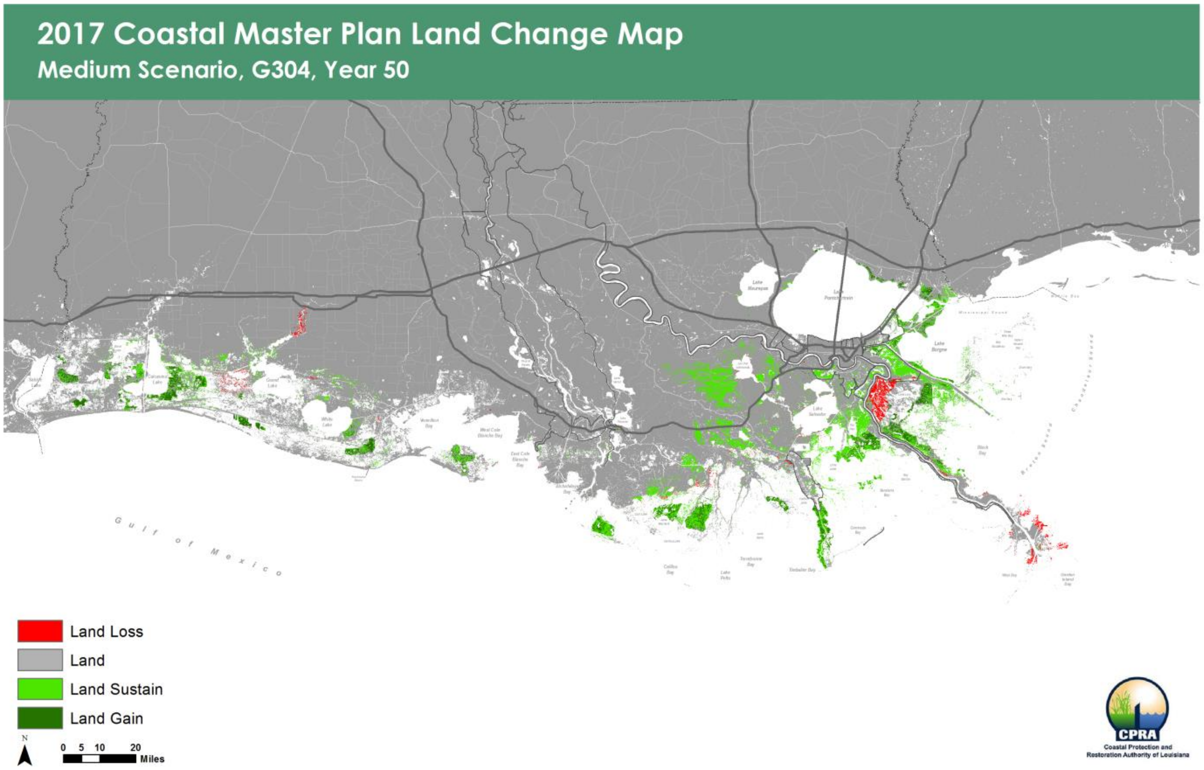


Figure 317: Land Change for G304 compared to FWOA (year 50; medium scenario).

High Scenario

Under the high scenario, G304 predicts approximately 2,253 km^2 of net land area benefit (floating marsh included) compared to FWOA at the end of the 50 year simulation (Table 14 and Figure 318). This figure includes both land sustained and new land built. At year 25, the land building effects of projects in this group are widespread (Figure 319), whereas by year 50, the land sustaining effects of projects in this group are more prevalent (Figure 320). Again, while the net land area benefit compared to FWOA is positive (2,253 km^2) at year 50, total land area over the modeling period is projected to decrease (-8,428 km^2; Table 14). It is important to note that this is far less loss than would be observed under FWOA (-10,682 km^2). There is more net land area benefit in this scenario compared to the medium scenario (high: 2,253 km^2 at year 50; medium: 1,980 km^2 at year 50), despite this scenario including higher rates of RSLR, which occurs for the reasons discussed in the G301 section.

None of the land area benefit in the western region can be attributable to structural protection projects since no protection projects are included in G304 in this region. As such, outcomes under this scenario are the same as that of G301 in this region, and net land area benefit with G304 in this scenario is the same as G301 at approximately 269 km^2 by year 25, decreasing to 152 km^2 by year 50 (Table 14).Removal of structural protection features in G304 (compared to G301) in the central region has a minimal effect on land change under the high scenario (G301: 72 km^2 at year 25; G304: 73 km^2 at year 50). There is, however, a difference by year 50 (G301: 335 km^2; G304: 295 km^2) which indicates that structural protection features contribute to additional land area benefit. The difference is scattered throughout the region, and as such, is likely attributable to slight difference in hydrology as a result of structural protection project implementation.

The net land area benefit in the eastern region is approximately 506 km^2 by year 25, increasing to 1,806 km^2 by year 50, as opposed to G301 which resulted in 498 km^2 by year 25, increasing to 2,176 km^2 by year 50 (Table 14). The increase in benefit of 8 km^2 at year 25 is negligible; however, the decrease of 370 km^2 by year 50 indicates the effects of the structural protection projects are eventually substantial. While the structural protection projects in this region are constructed prior to year 25, model output indicates a temporal lag between construction and land area benefit. As discussed previously, the benefit from structural protection project implementation is due largely to effects of the cross-basin barrier projects closing more frequently in later decades preventing incursion of saline waters into the Maurepas Swamp and parts of the Upper Barataria Basin.

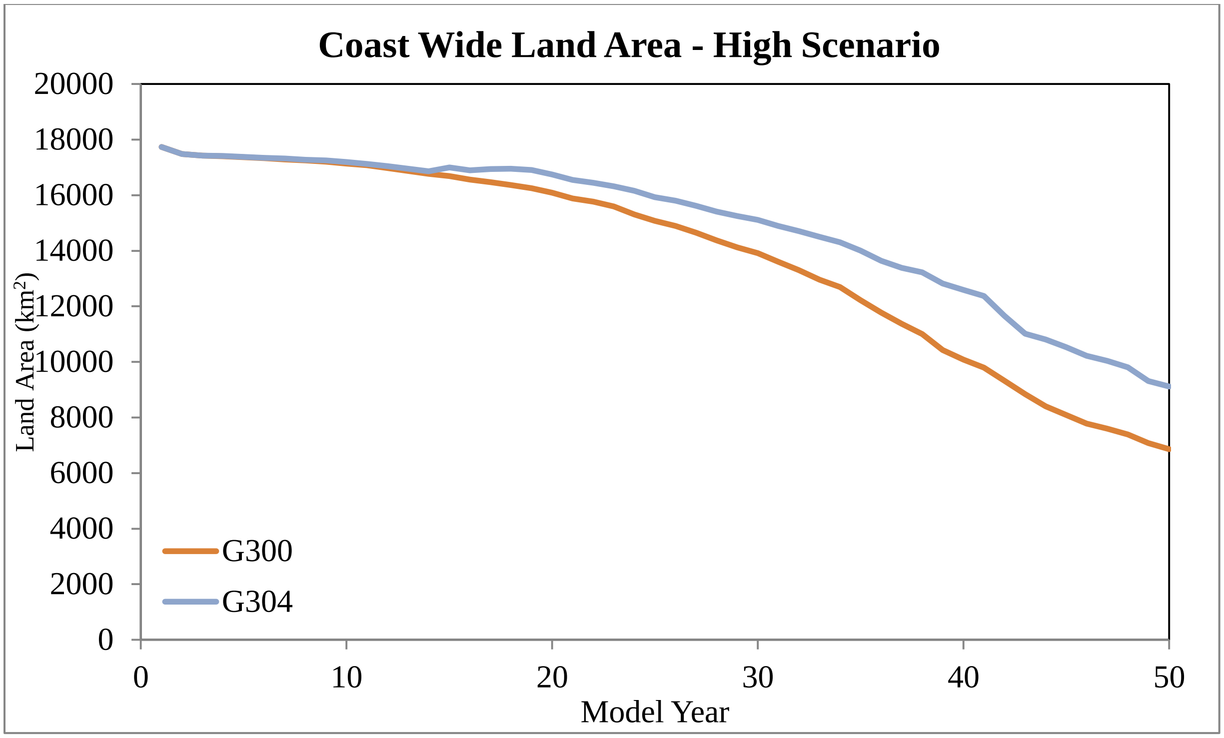


Figure 318: Land Change over Time for G304 and FWOA (high scenario).

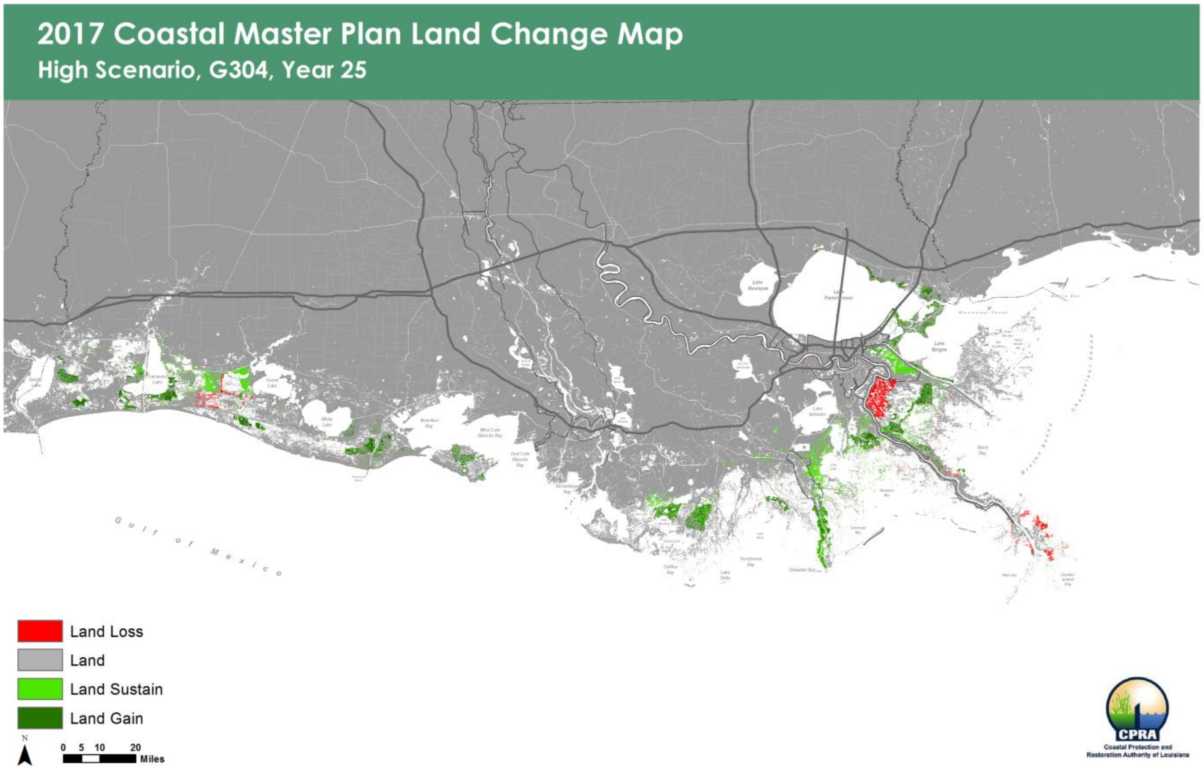


Figure 319: Land Change for G304 compared to FWOA (year 25; high scenario).

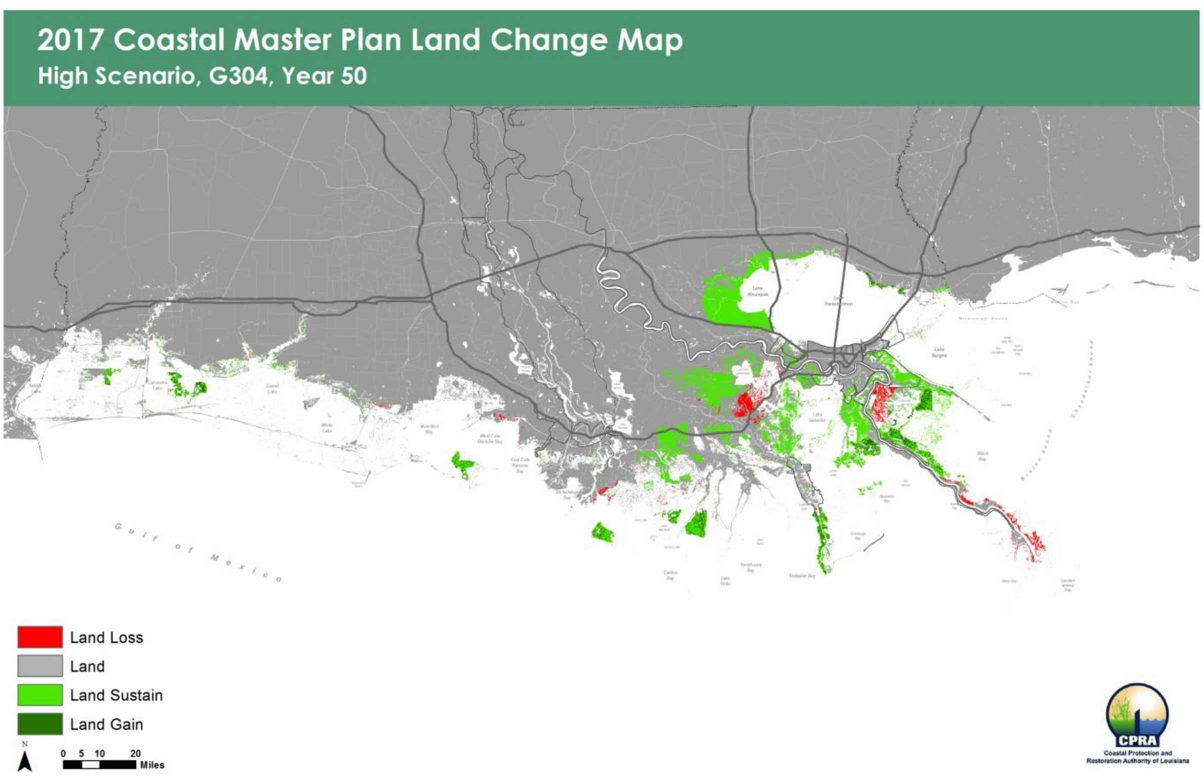


Figure 320: Land Change for G304 compared to FWOA (year 50; high scenario).

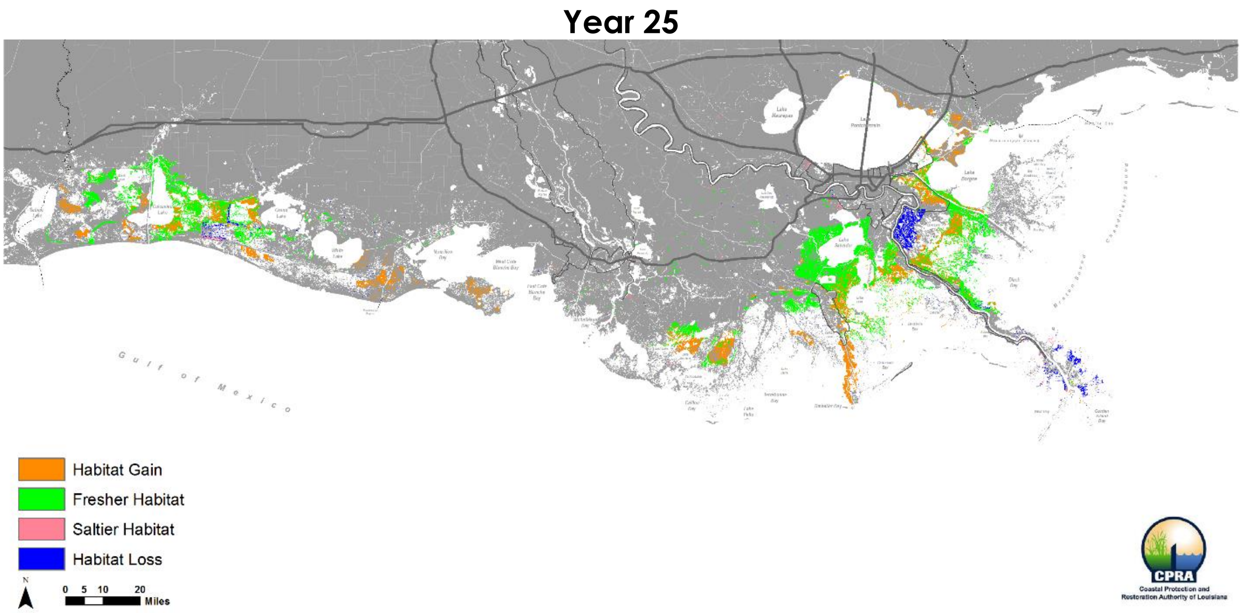
5.3.1.2 Vegetation

High Scenario

In the eastern region of the coast, the influence of the diversions is apparent at year 25 when compared to FWOA (Figure 321) and is very similar to the results of G301 (alternative with both restoration and protection projects). There is a general gain in fresher habitats (Figure 321). In year 25, the eastern region has gained in all habitat types compared to FWOA with an increase of 344 km^2 forested wetland, 3,977 km^2 fresh marsh, 13 km^2 intermediate marsh, 331 km^2 brackish marsh, 473 km^2 salt marsh, and 41 km^2 bare wetland (Figure 322). However, local increases in wetland loss occur either because of increased flooding associated with the diversions (e.g., upper Breton) or reduced sediment input for land building (e.g., Bird's foot delta). This local loss is offset by large areas of wetlands that are sustained (Figure 321). These trends continue through year 50 (Figure 321). By year 50, the eastern region has an increase of 150 km^2 forested wetland, 2,250 km^2 fresh marsh, 107 km^2 intermediate marsh, 602 km^2 brackish marsh, 64 km^2 salt marsh, and 32 km^2 bare wetland compared to the FWOA. These gains are significantly higher than those seen in G301 compared to FWOA, indicating that the interaction between restoration and protection projects (G301) is unfavorable for sustaining coastal wetlands compared to restoration projects alone (G304). The differences between G304 and G301 are diffuse throughout the landscape, but are noticeable along the north shore of Lake Pontchartrain. In G304 there is a wetland gain in this area, which does not occur in G301.

In the central region of the coast, all habitat types increase in area when compared to FWOA (Figure 323). By year 25, there is an increase of 565 km^2 forested wetland, 1,727 km^2 fresh marsh, 281 km^2 intermediate marsh, 611 km^2 brackish marsh, 964 km^2 salt marsh, and 17 km^2 bare wetland compared to FWOA. By year 50 these increases are: 287 km^2 forested wetland, 1,243 km^2 fresh marsh, 43 km^2 intermediate marsh, 122 km^2brackish marsh, 380 km^2 salt marsh, and 14 km^2 bare wetland compared to FWOA (Figure 323).

In the western region of the coast, habitat type changes are subtle in year 25 (Figure 324). These changes are identical to the changes observed under G301. In year 25, there is an increase of 6 km^2 forested wetland and 416 km^2 fresh marsh, and a decrease of 148 km^2 salt marsh and 9 km^2 intermediate marsh compared to FWOA. By year 50, the increases are smaller but occur in all habitats except for intermediate marsh (loss of 9 km^2). Year 50 shows an increase of 8 km^2 fresh marsh, 112 km^2 brackish marsh, 19 km^2 salt marsh, and 20 km^2 bare wetland compared to FWOA. These values are the same as those seen in G301.



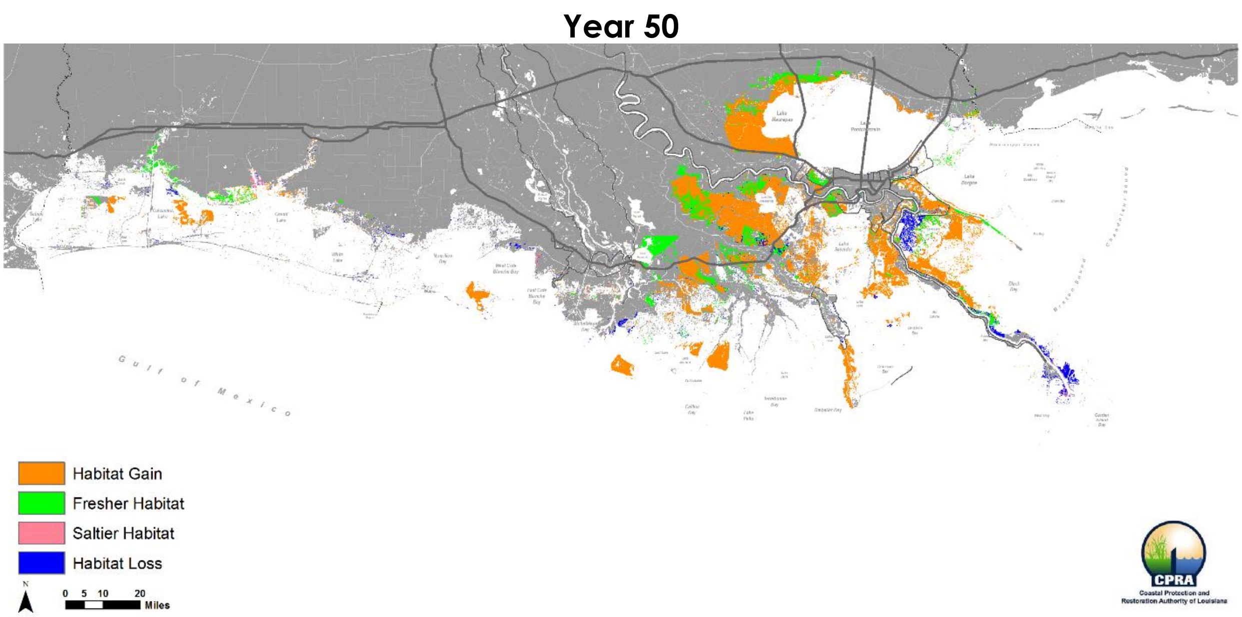


Figure 321: Vegetation cover by Salinity under G304 compared to FWOA (year 25 [top]; year 50 [bottom]; high scenario).

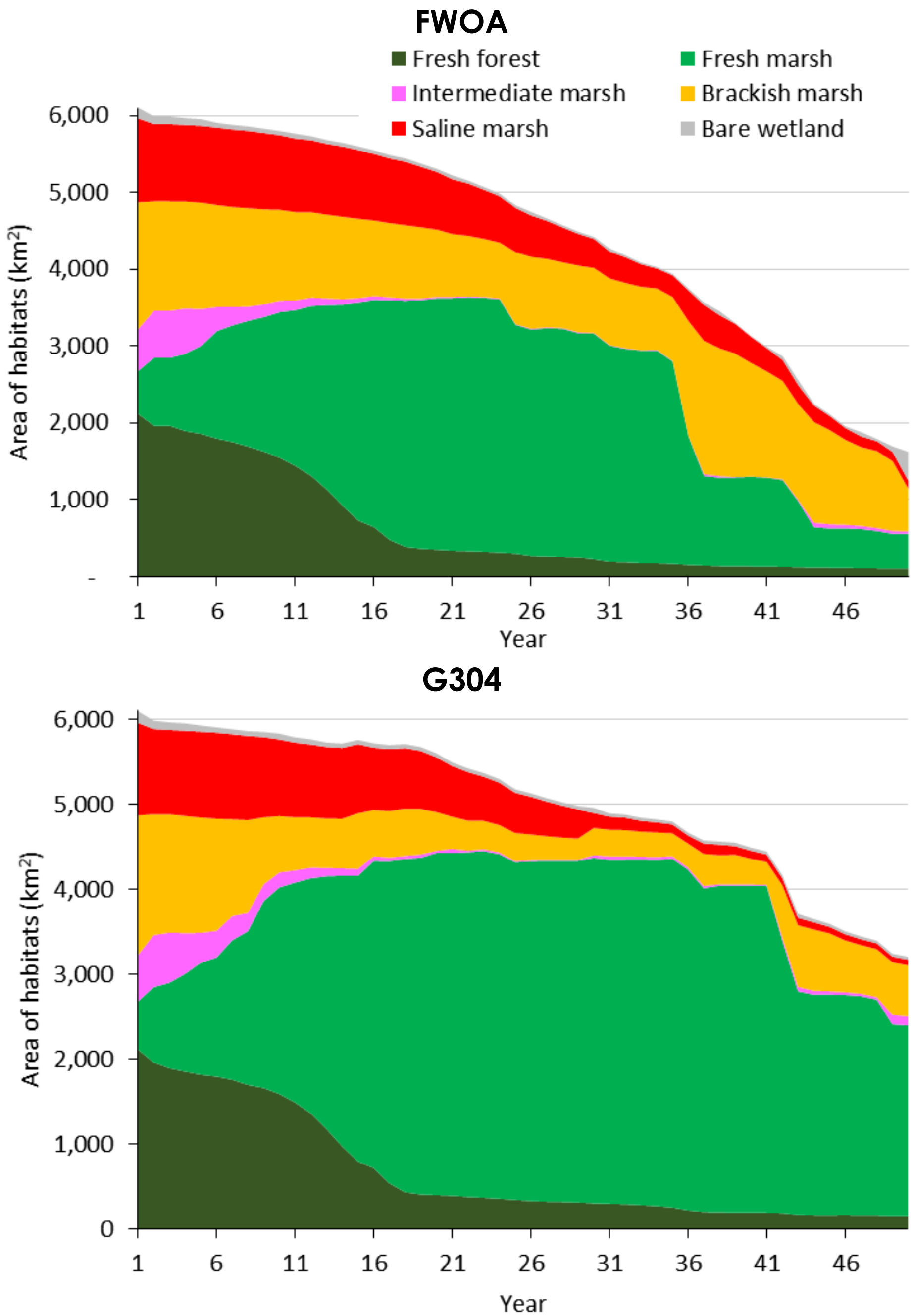


Figure 322: Changes in Marsh Type in the Eastern Coast (FWOA [top]; G304 [bottom]; high scenario).

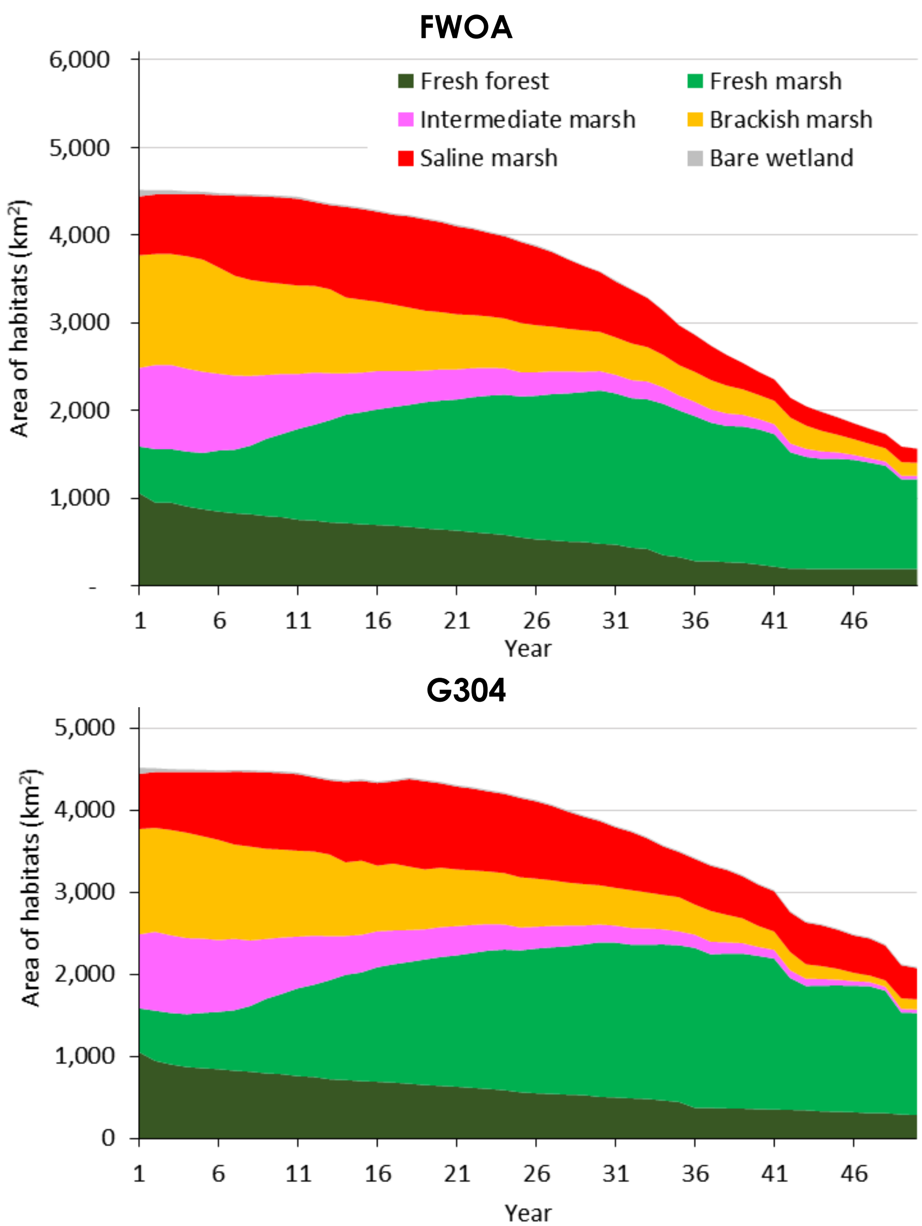


Figure 323: Changes in Marsh Type in the Central Coast (FWOA [top]; G304 [bottom]; high scenario).

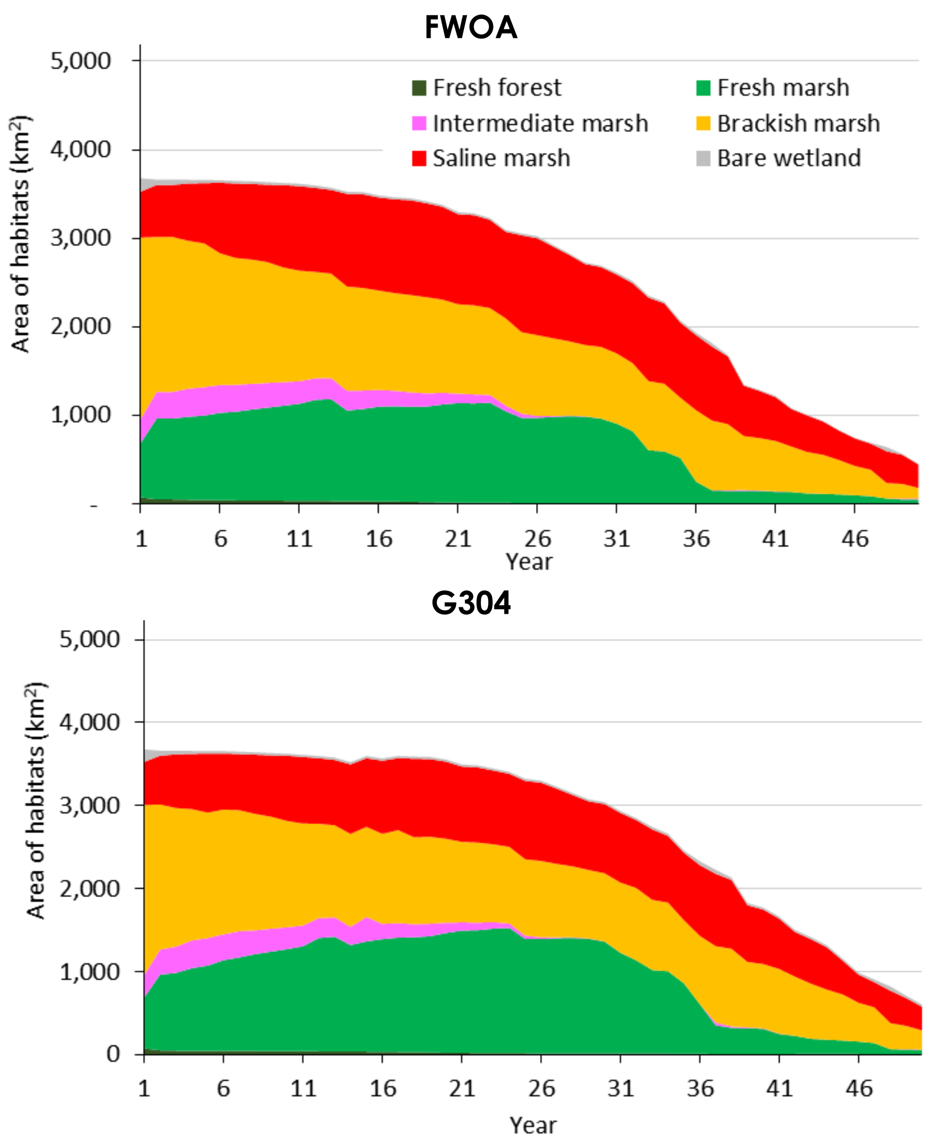


Figure 324: Changes in Marsh Type in the Western Coast (FWOA [top]; G304 [bottom]; high scenario).

Medium Scenario

At year 25, in the eastern region of the coast, the effects compared to FWOA (Figure 325) are very similar to the effects seen under the high scenario (Figure 321). However, the difference from the FWOA under the medium scenario is more subtle (Figure 326). By year 25, the eastern region has an increase of 76 km^2 forested wetland, 656 km^2 fresh marsh, 7 km^2 intermediate marsh and 6 km^2 bare wetland, and a decrease in 386 km^2 brackish marsh and 190 km^2 salt marsh compared to FWOA. However, locally increased wetland loss occurs either due to increased flooding associated with the diversions (e.g., upper Breton) or reduced sediment input for land building (i.e., Bird's Foot Delta). This localized loss is offset by large areas of wetlands that are sustained (Figure 325). These trends continue through year 50 (Figure 326). By year 50, the eastern region has an increase of 92 km^2 forested wetland, 2,133 km^2 fresh marsh, and 28 km^2 intermediate marsh, and a decrease of 818 km^2 brackish marsh, 269 km^2 salt marsh, and 82 km^2 bare wetland compared to FWOA.

In the central region of the coast, habitat changes are even more subtle under the medium scenario (Figure 327) than they are in the high scenario. However, by year 25, all habitat types have increased in size relative to FWOA: 6 km^2 forested wetland, 130 km^2 fresh marsh, 12 km^2 intermediate marsh, 12 km^2 brackish marsh, and 13 km^2 salt marsh. By year 50 there is 57 km^2 less brackish marsh and 7 km^2 of intermediate marsh than in FWOA, but all other habitat types increase in size: 129 km^2 forested wetland, 231 km^2 fresh marsh, 204 km^2 salt marsh, and 11 km^2 of bare wetland (Figure 327).

Under the medium scenario, there is only a very small effect in the western region of the coast (Figure 328) compared to FWOA. By year 25, there is 90 km^2 less brackish marsh, 119 km^2 less salt marsh than in FWOA, but there is 7 km^2 more forested wetland, 381 km^2 more fresh marsh, and 6 km^2 more bare wetland than in the FWOA. These values are virtually indistinguishable from the effects of G301, indicating that protection projects in this region do not affect the restoration project outcomes. By year 50, the effects are smaller, but all habitat types increase in area relative to FWOA: 2 km^2 forested wetland, 122 km^2 fresh marsh, 154 km^2 brackish marsh, 90 km^2 salt marsh, and 14 km^2 bare wetland (Figure 328).

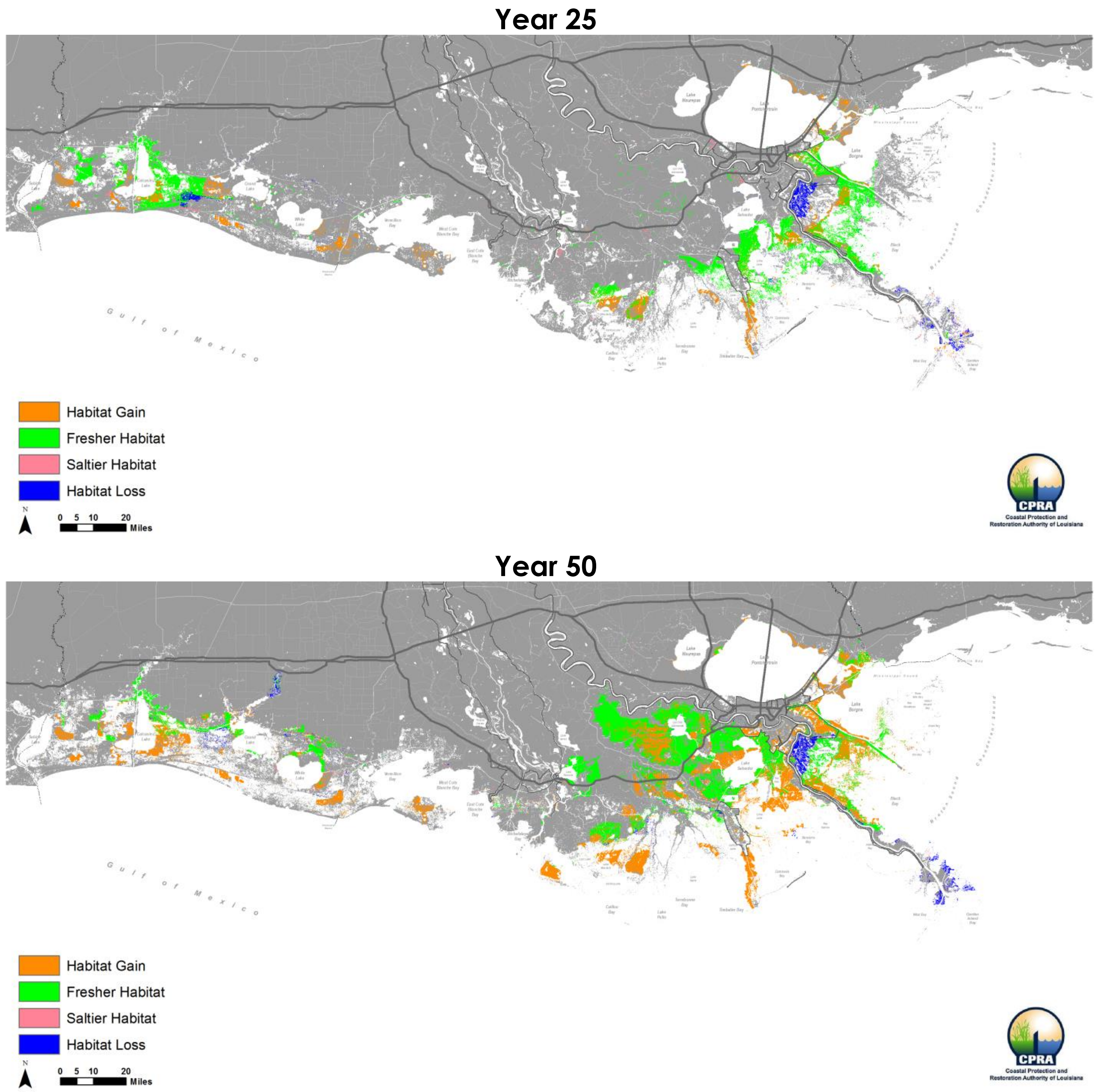


Figure 325: Vegetation Cover by Salinity under G304 compared to FWOA (year 25 [top]; year 50 [bottom]; medium scenario).

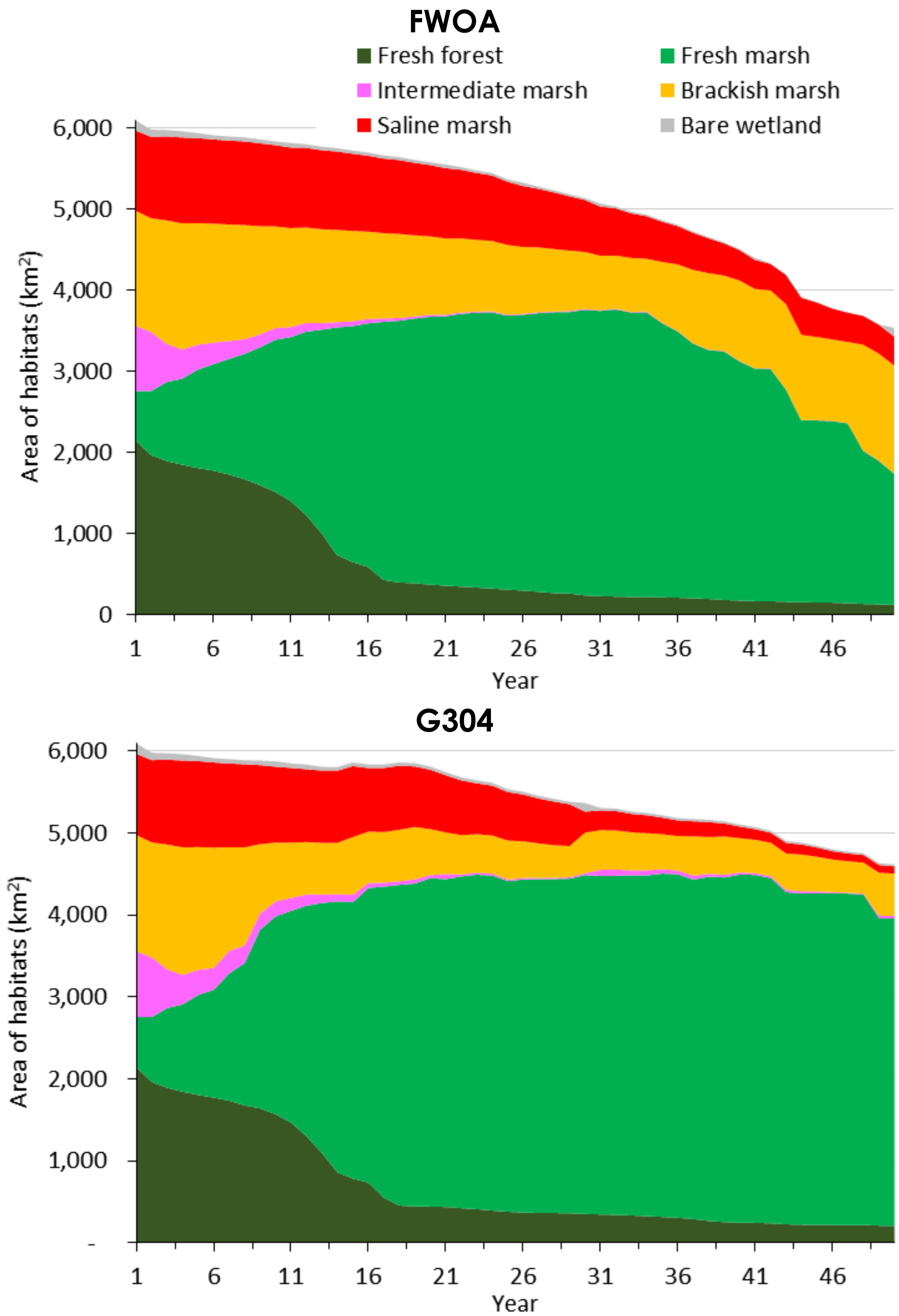


Figure 326: Changes in Marsh Type in the Eastern Coast (FWOA [top]; G304 [bottom]; medium scenario).

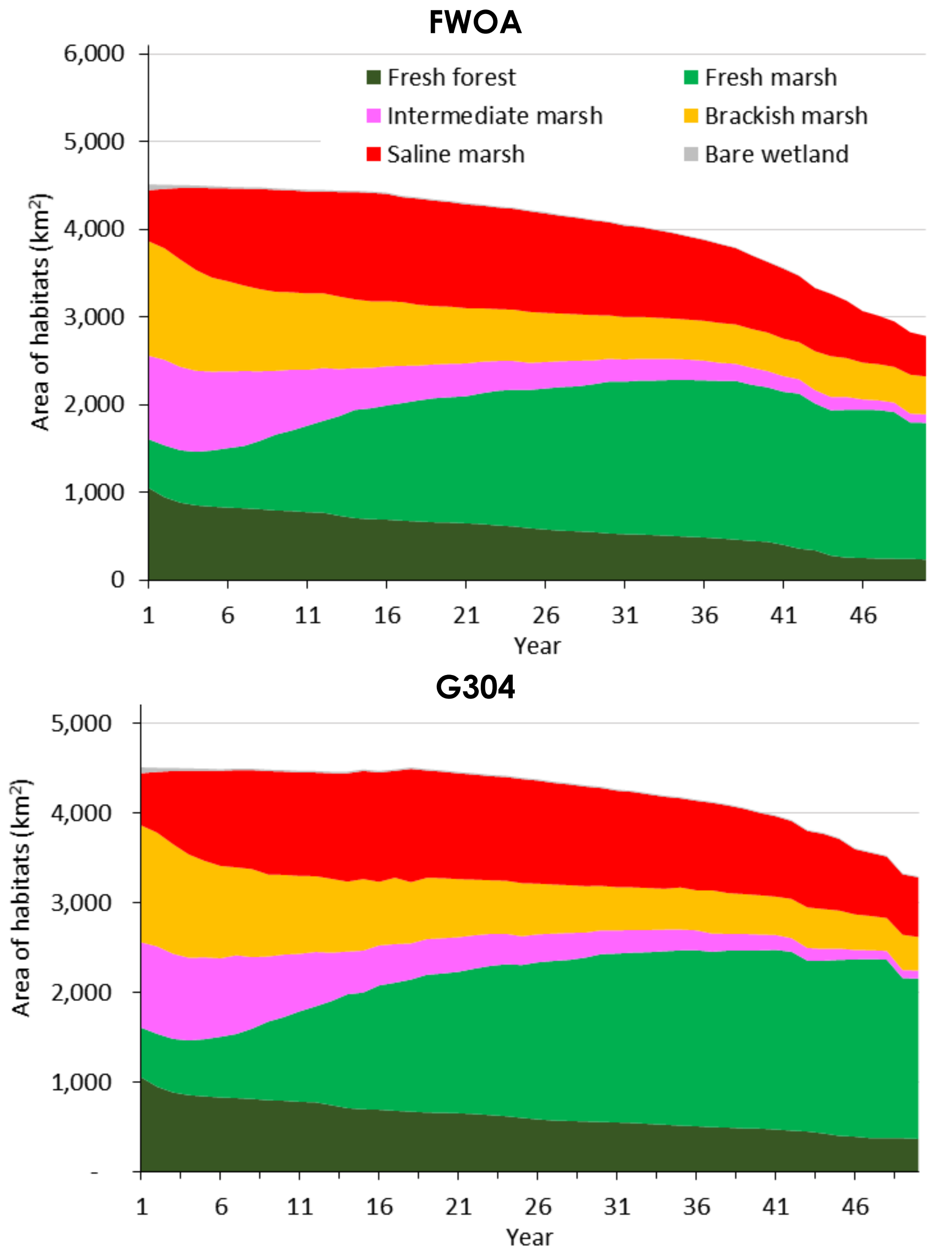


Figure 327: Changes in Marsh Type in the Central Coast (FWOA [top]; G304 [bottom]; medium scenario).

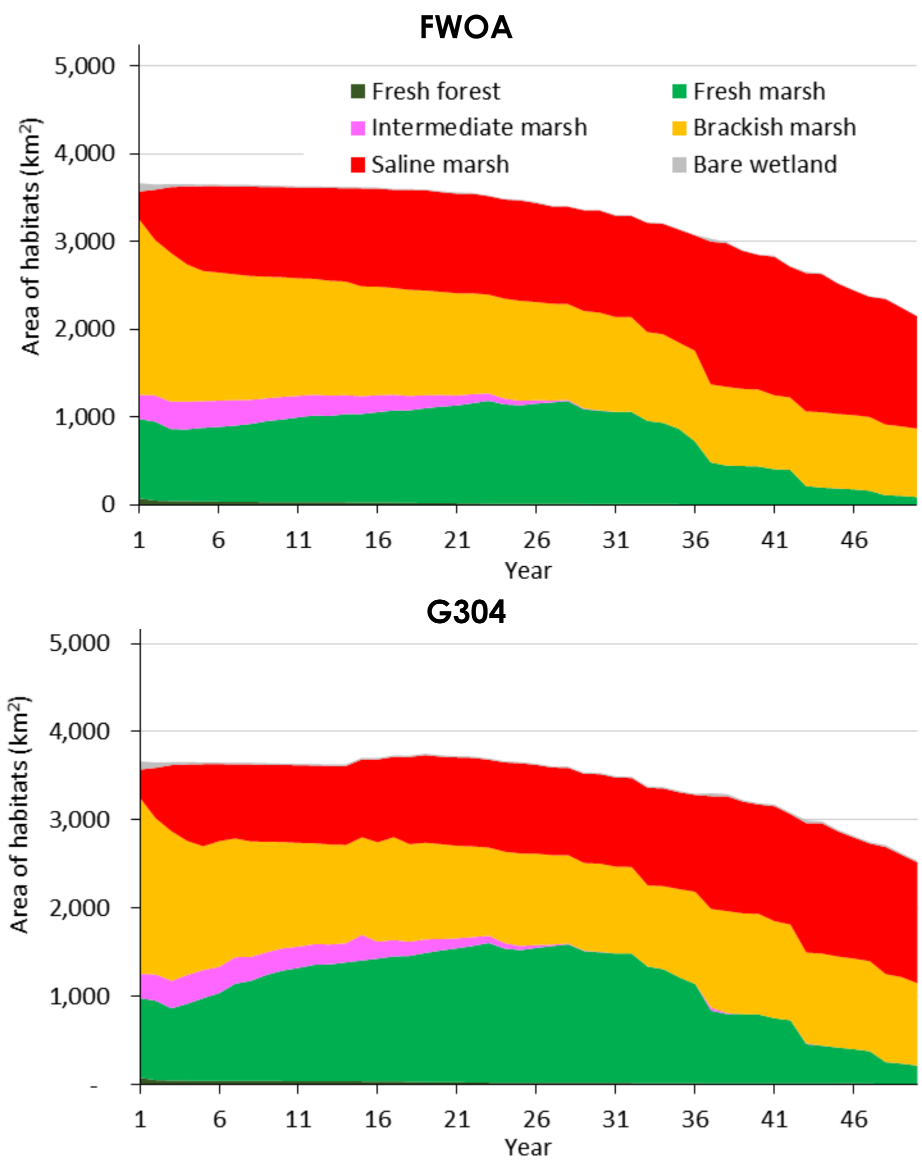


Figure 328: Changes in Marsh Type in the Western Coast (FWOA [top]; G304 [bottom]; medium scenario).

5.3.2 Summary Comparison of FWOA, G301, G303, and G304

During the original project-level analysis, no structural protection projects (e.g., levees) were analyzed with respect to impact upon the landscape. Once structural protection projects were included in alternatives, it was evident that these projects may interact with the restoration projects in either a synergistic manner or redundant manner. An interaction effect would be synergistic if the inclusion of a structural protection project resulted in more land being built or sustained at year 50 than when solely restoration projects were modeled. Conversely, redundant project interaction effects would occur if a structural protection project managed to sustain the same locations of land as a restoration project would have; two projects could be "saving" the same piece of land. In addition, structural protection projects, without additional restoration, may results in a change in the landscape dynamics relative to FWOA resulting in either additional loss or less loss of land.

In order to examine these potential interactive effects, the three aforementioned alternatives modeled - G301 (full alternative with both restoration and structural protection projects), G303 (alternative with only the structural protection projects from G301), and G304 (alternative with only the restoration projects from G301) – are considered together here.

Under the medium scenario, there is a slight increase in total coastal land area from FWOA when only the structural protection projects are modeled (green line in Figure 329). However, there is essentially no change to coastal land area under the medium scenario when comparing the alternative with both restoration and protection projects (G301, red line Figure 329) to the restoration project-only alternative (G304, blue line in Figure 329). This indicates that the slight increase in land area from the structural protection projects is due to maintaining the same land area that restoration projects also maintain.

Due to the substantially higher rates of relative sea level rise in the high scenario, the interactions among projects are different than under the medium scenario. First, building only structural protection projects prevents a rather large area of land in the Maurepas region from converting to open water under the high scenario (Figure 330). This is due to the Lake Pontchartrain Barrier (001.HP.08) project that is operated as a function of water levels in Lake Borgne. During the later years of the 50-year simulation (under the high scenario), the gates are frequently shut keeping highly salt water from entering Lake Pontchartrain. This serves to maintain lower salinities and lower water levels in the Maurepas/Pontchartrain Basin, resulting in prevention of land loss in later years. In the restoration only alternative (G304), this same area of land is maintained by several river diversion projects delivering water and sediment to the Maurepas Swamp and Manchac Landbridge. Under the high scenario, it appears that the combination of both of the restoration and protection projects results in a synergistic benefit which results in the most land being sustained when a full protection *and* restoration alternative is simulated (G301, red line in Figure 330).

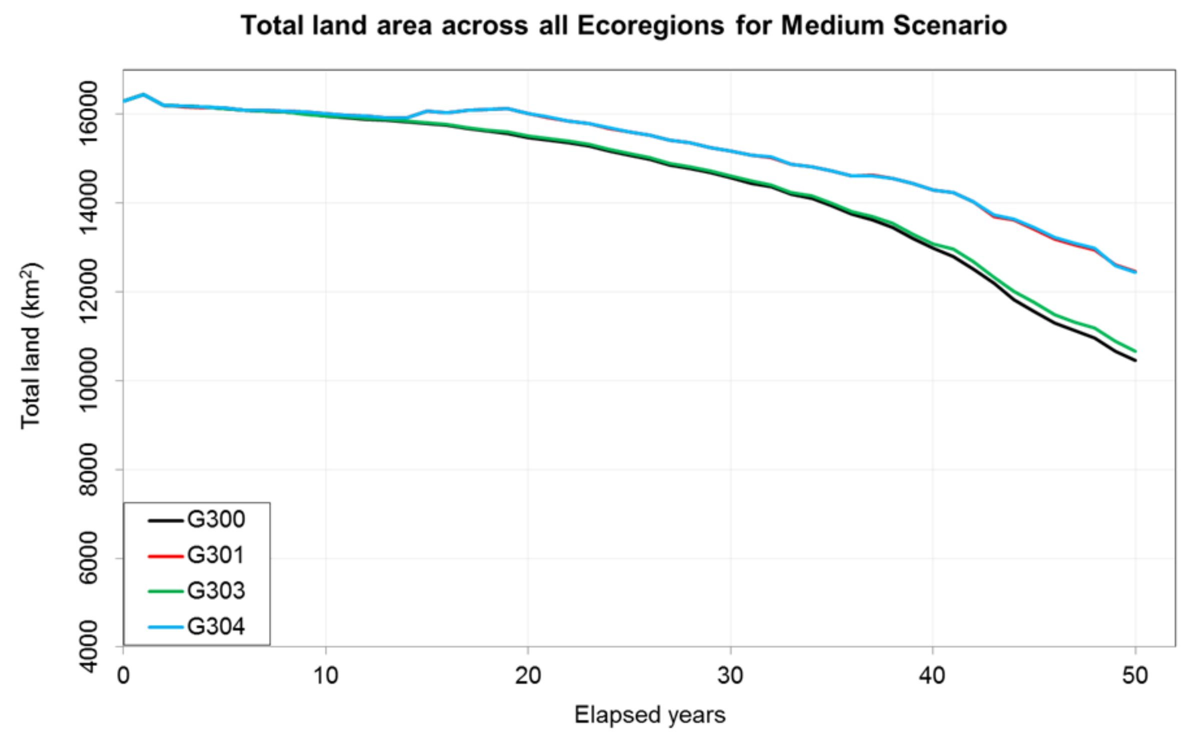


Figure 329: Project Interaction Effects on Coast Wide Land Area under the Medium Scenario.

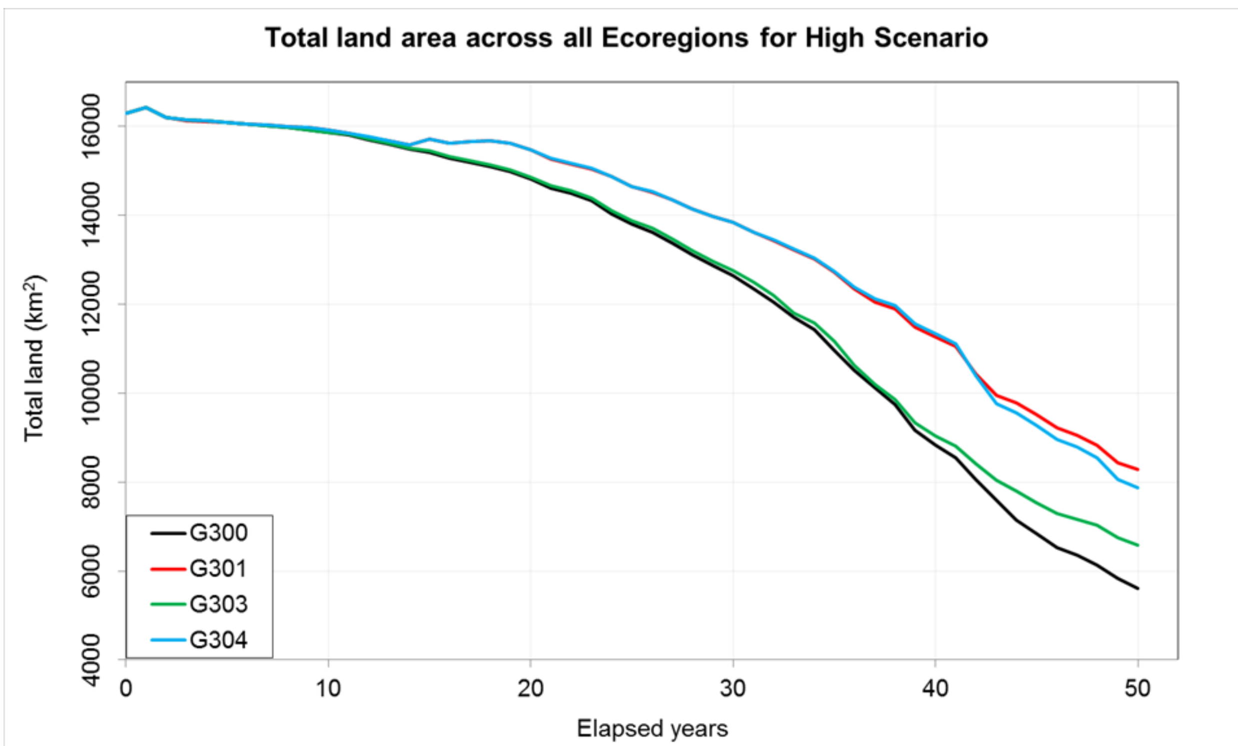


Figure 330: Project Interaction Effects on Coast Wide Land Area under the High Scenario.

5.4 Project Interactions - Storm Surge and Waves

Each of the alternatives has been simulated individually within a single ADCIRC and SWAN geometry to explore how the ensemble of projects performs. For instance, it is important to know if the risk reduction benefits provided by hurricane protection projects are enhanced or degraded by the presence of adjacent restoration projects or other protection projects. Because each project alters the flow of surge and waves during a storm event, the combined influence of multiple projects can be evaluated with simulations that include combinations of projects.

Alternative G301 includes both protection and restoration projects while G303 is a subset of G301, containing only the protection projects within G301. Comparing G301 and G303 provides an indication of the benefits associated with combining restoration projects with protection projects. Comparison of Figure 331 and Figure 332 shows the extensive restoration efforts that are not included in G303 though the protection projects are identical.

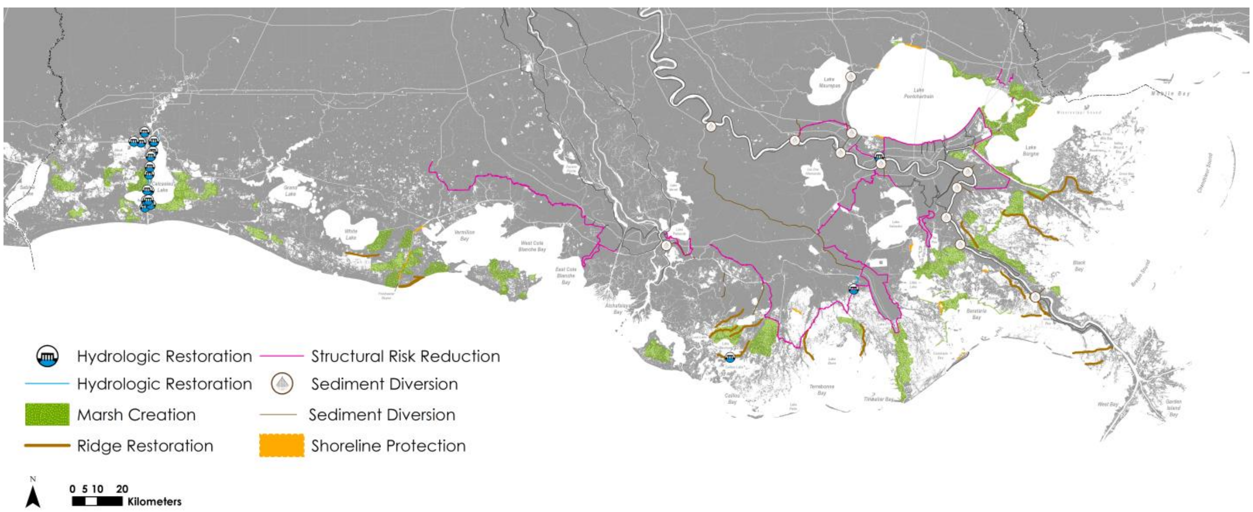


Figure 331: The Combination of Restoration and Protection Projects Implemented as Alternative G301. Note that the protection projects in G301 are identical to those in G303.

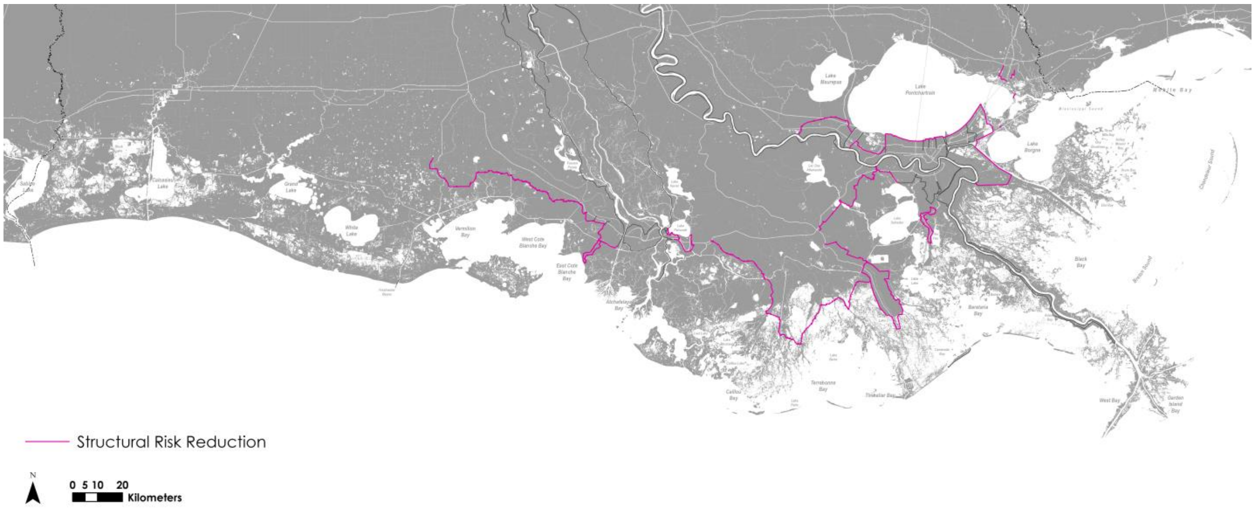


Figure 332: The Combination of Protection Projects Implemented in G303. Note that the only projects implemented in G303 are shown in this image.

5.4.1 Storm Impacts for Alternative G303

Alternative G303 includes structural protection projects only and is illustrated on Figure 332. Comparing the simulation results for G303 to those for FWOA indicates how the combination of protection projects implemented in G303 perform together. Simulations of G303 confirm that the combination of selected projects results in more extensive reduction of inundation than any of the projects individually. G303 includes multiple projects across the entire coast that result in water surface elevation reductions over a large area for all storm scenarios. The water surface elevation reductions reflect the spatial scale of the project combinations. For instance, the estimated impact on water surface elevation relative to FWOA during storm 014 for year 25 and year 50 is shown on Figure 333 and 334, respectively. Note that on both figures, large regions of water surface elevation reduction are visible throughout the upper Barataria Basin and in the western part of the Pontchartrain Basin. In the lower Barataria Basin and other regions south of the implemented project, a seaward increase of water surface elevation relative to FWOA can be seen resulting from the projects preventing surge from moving further inland.

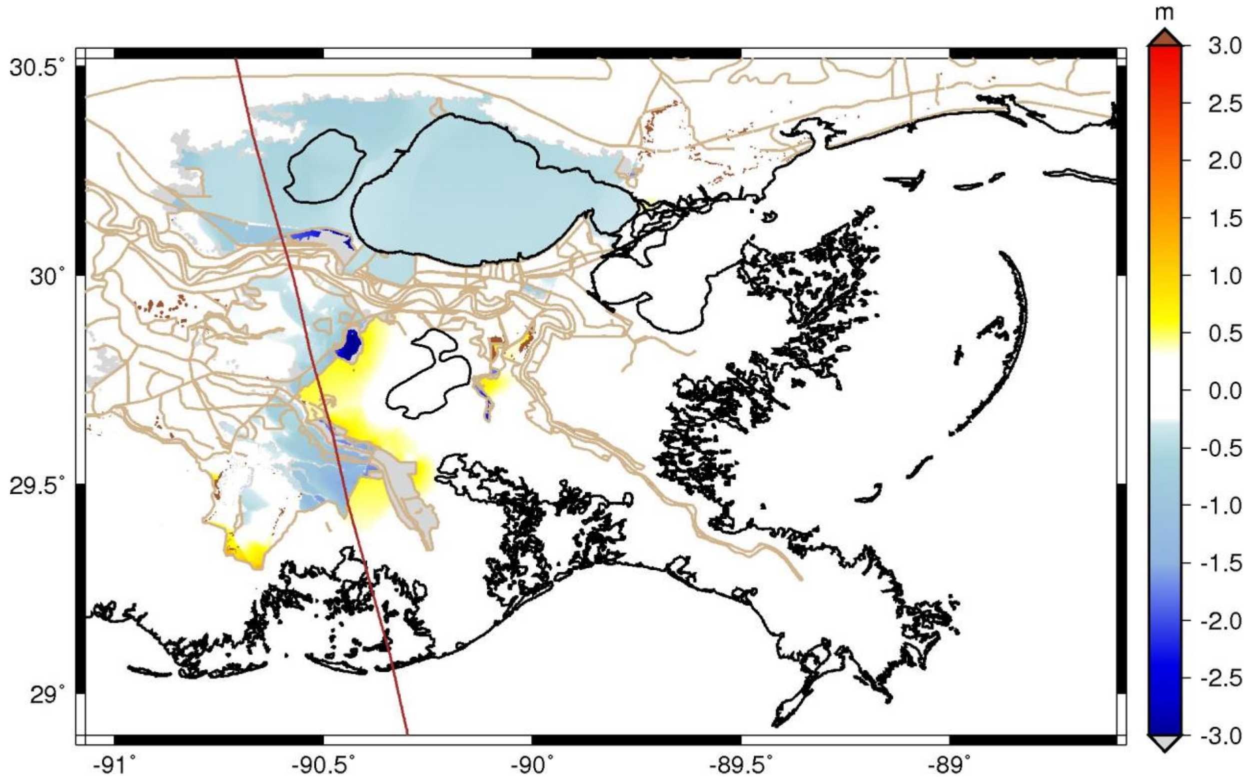


Figure 333: Differences in Maximum Water Surface Elevation (m) between G303 and FWOA for Storm 014 (year 25; high scenario). Positive values denote an increase with the projects in place.

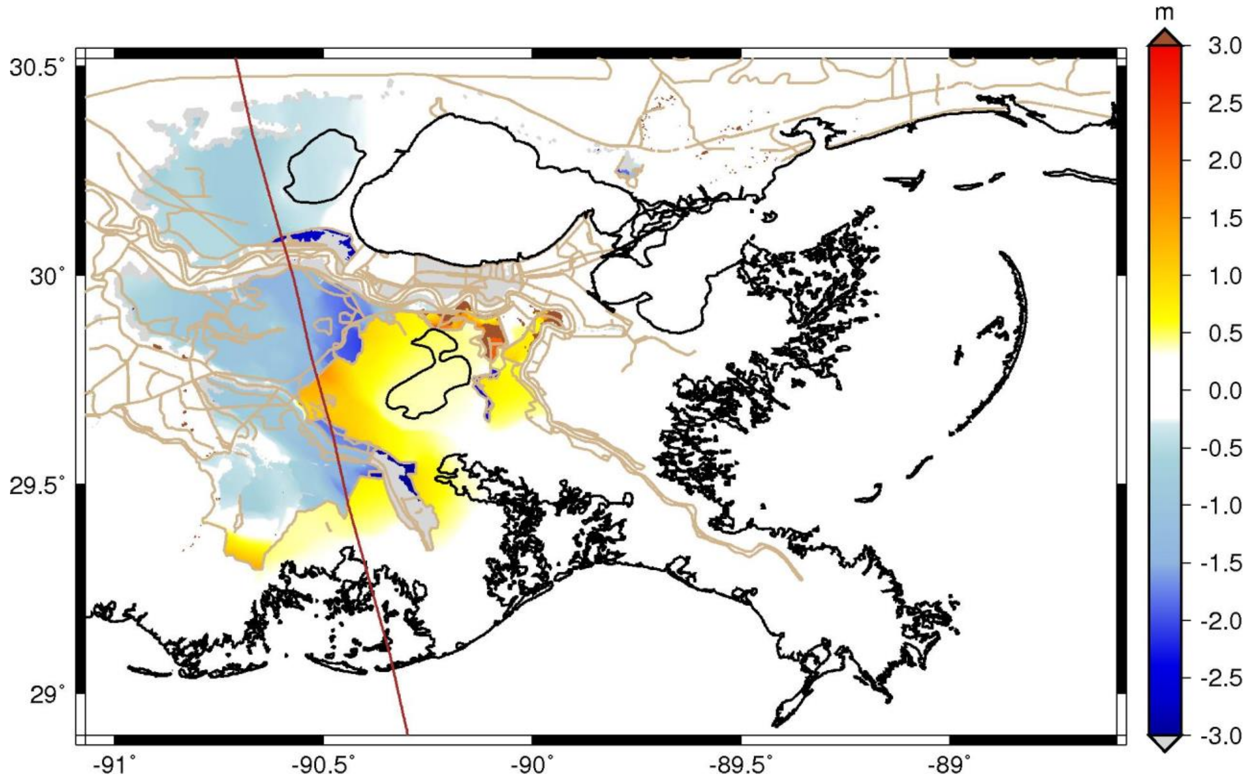


Figure 334: Differences in Maximum Water Surface Elevation (m) between G303 and FWOA for Storm 014 (year 50; high scenario). Positive values denote an increase with the projects in place.

Hurricane protection projects were evaluated individually to examine the benefits and impacts of each project in order to assist in the formulation of alternatives. However, the performance of alternatives cannot be estimated by simple addition of performance by individual projects because of the potential for interaction between adjacent projects. Accordingly, the performance of adjacent protection projects has been inspected to better understand their interaction. Depending on basin geometry and proximity to each other, protection projects have the potential to either increase or decrease the water surface elevation and wave conditions at neighboring projects.

As part of G303, the West Shore Lake Pontchartrain (WSLP; 001.HP.05) project is implemented in concert with the Lake Pontchartrain Barrier (001.HP.08) project with gates closed at Rigolets and Chef Menteur. During the project level analysis, the Lake Pontchartrain Barrier (001.HP.08) gates have been shown to consistently reduce water surface elevations up to 0.6 m, though the effectiveness is dependent on the water surface elevation on the exterior side of the gates which varies with sea level rise. The greater the exterior water surface elevation becomes, the less effective the gates are. With these two projects implemented together in the alternatives, water surface elevations for many of the storms (and thus exceedance probability for still water elevations) on the unprotected side of the WSLP project are lower with the Rigolets and Chef Menteur gates implemented than if the WSLP project is implemented without the gate closures. The reason for this is that the hydraulically isolated Lake Pontchartrain Barrier (001.HP.08) project reduces water surface elevations in Lake Pontchartrain by as much as 0.5 m (Figure 333). Conversely, when the Morganza to the Gulf project (03a.HP.02b) is combined with the Upper Barataria Risk Reduction (002.HP.06) project in G303, water surface elevations on the eastern portion of the Morganza alignment are higher than indicated in the individual project evaluation for storm 014. In this case, the peak water surface elevation in front of the eastern reach of the Morganza to the Gulf (03a.HP.02b) project is increased by 0.5 - 0.8 m due to the presence of the

Upper Barataria Risk Reduction (002.HP.06) project (Figure 334). The implication is that protection project interactions can induce higher or lower water surface elevations at adjacent structures, with significant impact on optimal crest elevations, implementation sequencing, and construction and maintenance cost. While the master plan process is not intended to optimize levee crest elevations, this interaction becomes an important consideration when projects are advanced to design level studies.

Note that Figure 333 and Figure 334 represent impacts under the high scenario. The sensitivity of benefits under different sea level rise scenarios depends upon the type and elevation of a specific project. For instance, if a flood protection structure is designed with a high crest that does not get overtopped (e.g., Morganza to the Gulf (03a.HP.02b) project), then the project maintains positive benefits under all sea level rise scenarios. For such a high-crested levee, the benefits are in proportion to the magnitude of flooding under each FWOA scenario. If flooding for FWOA during the high scenario is greater than flooding for FWOA during the medium scenario, then a sufficiently high-crested levee would provide more flood protection benefits within the project area under the high scenario because there is more flooding prevented behind the line of protection. In terms of interaction, as projects increase in size, particularly protection projects, the spatial footprint of surge inducement and reduction increase, leading to greater potential for project interaction. In contrast, low-crested protection features will be increasingly overtopped as sea level increases. This means the effectiveness of low-crested protection features such as the gates on the Rigolets and Chef Menteur Pass as part of the Lake Pontchartrain Flood Protection Project (001.HP.08) will decrease as sea levels rise and surge is able to directly pass into Lake Pontchartrain. Thus, as sea level rise diminishes the protection benefits of projects on the East Land Bridge such as Lake Pontchartrain Flood Protection Project, then the West Shore of Lake Pontchartrain (001.HP.05) and Slidell Ring Levee (001.HP.13) protection structures interior to the gates at Chef Menteur Pass and the Rigolets may require higher crest elevations. Consequently, the potential for beneficial interaction decreases. Note that the Greater New Orleans High Level (001.HP.04) is also implemented in G301 and has reaches that are interior to the gates. Though the risk of overtopping may be low, the gates may have additional resiliency benefits for these areas because of the potential for decreased water surface elevations.

5.4.2 Storm Impacts for Alternative G301

G301 contains the same protection projects as G303, as well as restoration projects (Figure 331). Comparison of simulation results for G303 and G301 provides an indication of how restoration projects such as diversions, marsh creation, and ridge restoration may influence the effectiveness of hurricane protection measures. Note on Figure 331 that there are many marsh and ridge restoration projects located near hurricane protection alignments. Several examples are the ridges and marshes to the west of Terrebonne Bay that lie on the unprotected side of Morganza to the Gulf (03a.HP.02b). There are also marsh creation projects in front of the Larose to Golden Meadow (03a.HP.20), throughout Barataria Bay and Caernarvon, around Lake Borgne, and on the New Orleans East Landbridge that are relatively close to hurricane protection structures. While the magnitude of water surface elevation reduction benefits from restoration projects is expected to be less than the benefits created by protection projects themselves, it is still expected that marshes and ridges will provide water surface elevation and wave reduction, thereby contributing to the total water surface elevation benefits of G301.

Figure 335 illustrates the differences between G301 and G303 for storm 012 in year 25. Positive values indicate higher water surface elevations with the restoration projects included in G301. The warm colors in lower Barataria and Breton marshes indicate that water surface increase due to the restoration project's obstruction to surge water. On the contrary, the cool color in the regions inland of the restoration projects indicate lower water surface elevation levels than when protection projects were implemented alone. For storms generating low to moderate surge levels, the presence of restoration projects can lower water surface elevation levels enough to potentially reduce levee overtopping further inland. Additionally, the negative values in Pontchartrain indicate water surface elevation reduction associated with marshes on the New Orleans East Landbridge Restoration (001.MC.05) project. Figure 336 shows the differences between G301 and G303, including those differences that can be seen in the region between Terrebonne and Vermilion Bays, for a storm making landfall farther to the west than the storm show in Figure 335. Alternative G301 (Figure 331) contains several marsh and ridge restorations in the region between the water surface elevation increases and decreases shown on Figure 336. It is the sequence of marsh and ridge restorations in that area that locally increases water surface elevation seaward of the projects and causes water surface elevation reduction landward of the projects. Similar behavior is induced by the presence of marshes around the southern part of Vermilion Bay. For all storm simulations, comparison of G301 to G303 demonstrates that restoration projects do contribute to the wave and water surface elevation reduction in locations throughout the coastal zone. For storms making landfall a large distance away from restoration project sites or storms making landfall to the east of the region of interest, the project impacts observed are less significant.

Similar to protection projects, the impact of restoration projects varies with sea level conditions. Figure 335 and Figure 336 represent the impacts under the high scenario. The benefits of restoration projects vary under different sea level rise scenarios, with the most significant benefits generally occurring for lower sea level rise scenarios; the impacts from restoration projects are greatest in shallow waters where storm surge can more easily be slowed and wave energy dissipated.

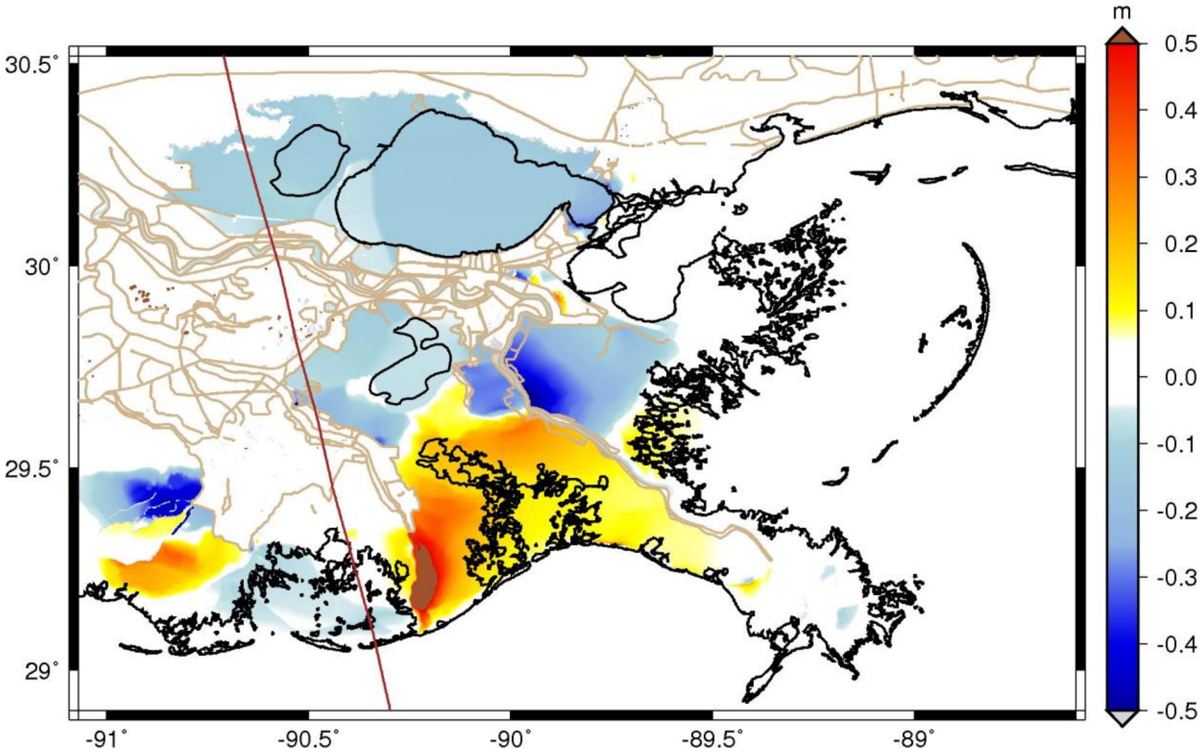


Figure 335: Differences in Maximum Water Surface Elevation (m) between G301and G303 for Storm 12 (year 25; high scenario). Positive values denote an increase with both restoration and protection projects in place.

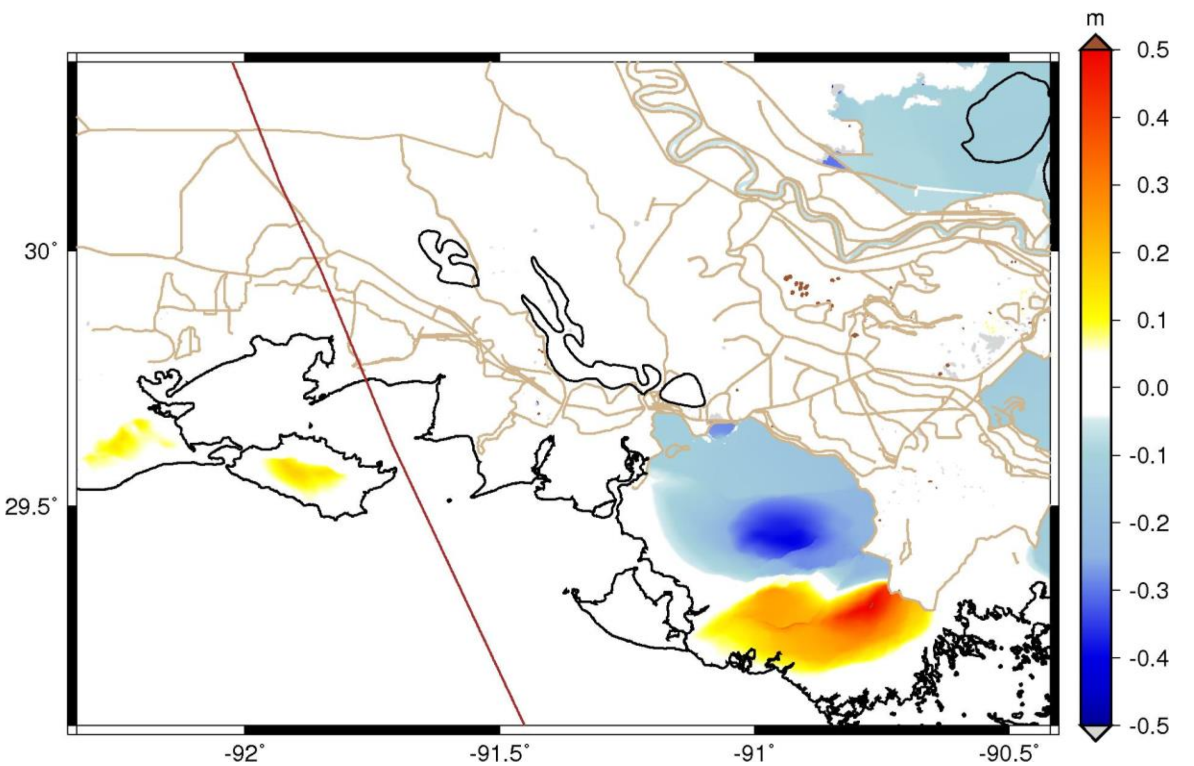


Figure 336: Differences in Maximum Water Surface Elevation (m) between G301and G303 for Storm 239 (year 25; high scenario). Positive values denote an increase with both restoration and protection projects in place.

While coast wide plots like those shown in Figure 335 and Figure 336 are useful to indicate spatial variations in risk reduction benefits, one-dimensional transects across various types of landscape features can reveal additional details for specific locations and projects. The following discussion makes use of model input parameters and model outputs extracted along the transects shown on Figure 337. The transects were placed to cut through restoration projects in front of the Morganza to the Gulf (03a.HP.02b) project, which are used as an example to explore the interaction of structural protection projects and restoration projects in more detail. All transect figures and discussion are based on analysis of the high scenario.

From year 25 to year 50, the topographic elevations and friction associated with restoration projects implemented in G301 are expected to be reduced in some areas and increased in other areas in accordance with attributes and implementation periods of restoration projects. Figure 338 and Figure 339 give two examples that show elevation and friction (represented by Manning's *n* roughness coefficient) for year 25 and year 50 along Transects ATT01 and ATT03, respectively. The transect ATT01 slices through Point Au Fer Island Marsh Creation (03b.MC.09) project. The effect of the project can be seen at the restoration site (near km 25) when comparing G301 and G303. Comparing the ATT01 values between years 25 and 50 demonstrates an increase in topographic elevation and friction when the project is implemented in year 35. Both G301 and G303 experience reduced friction inland of km 40. The transect ATT03 slices through South Terrebonne Marsh Creation (03a.MC.100) project. Comparing the ATT03 values demonstrates increased topographic elevation and friction inland of km 32, where the restoration project is planned. The differences are greatest in year 25, with the ICM predicting degraded elevations and friction for by year 50 due to marsh fragmentation and mortality.

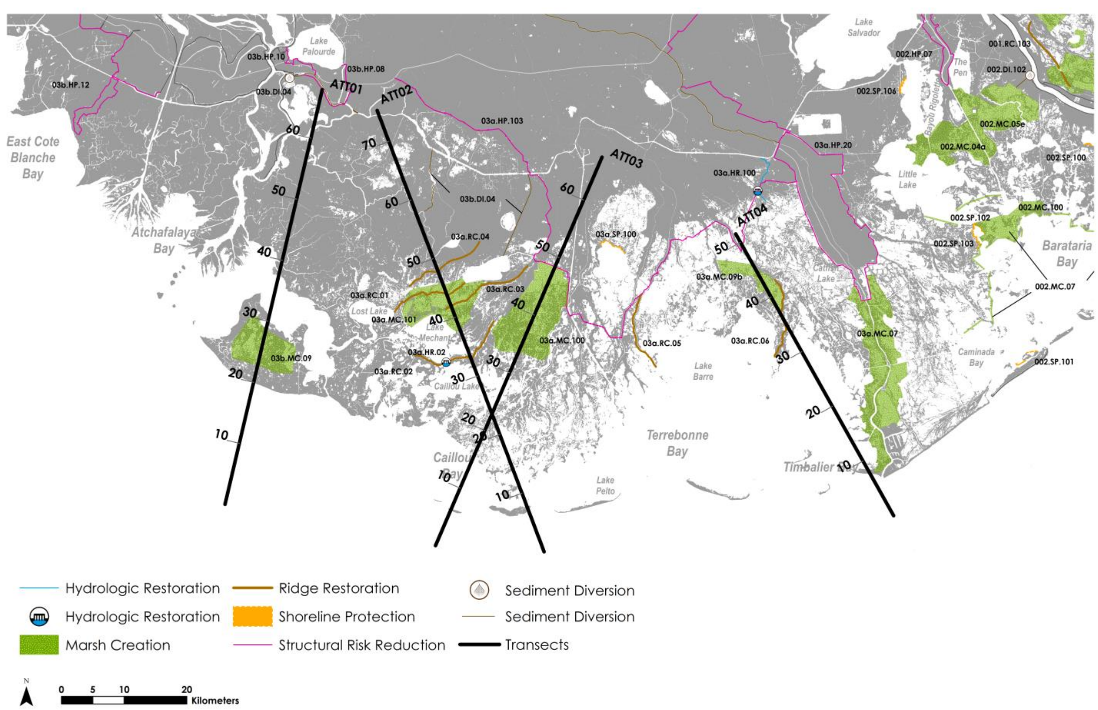


Figure 337: Transects Cut through Restoration Projects in Front of the Morganza to the Gulf Hurricane Protection Project.

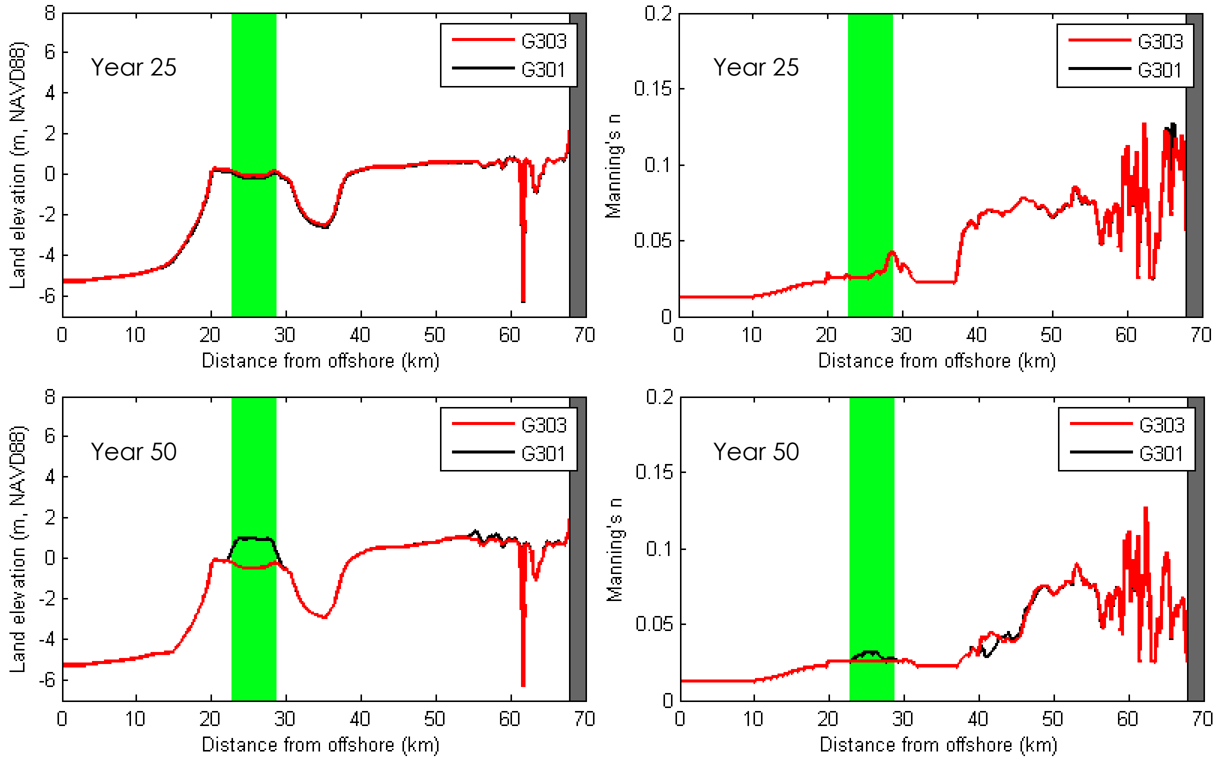


Figure 338: Topographic Elevations (left) and Friction Parameters (right) along Transect ATT01 for Year 25 and Year 50 (high scenario). The green shading indicates the location of the restoration project, the black line indicates G301 (hurricane protection plus restoration), and the red line indicates G303 (hurricane protection only).

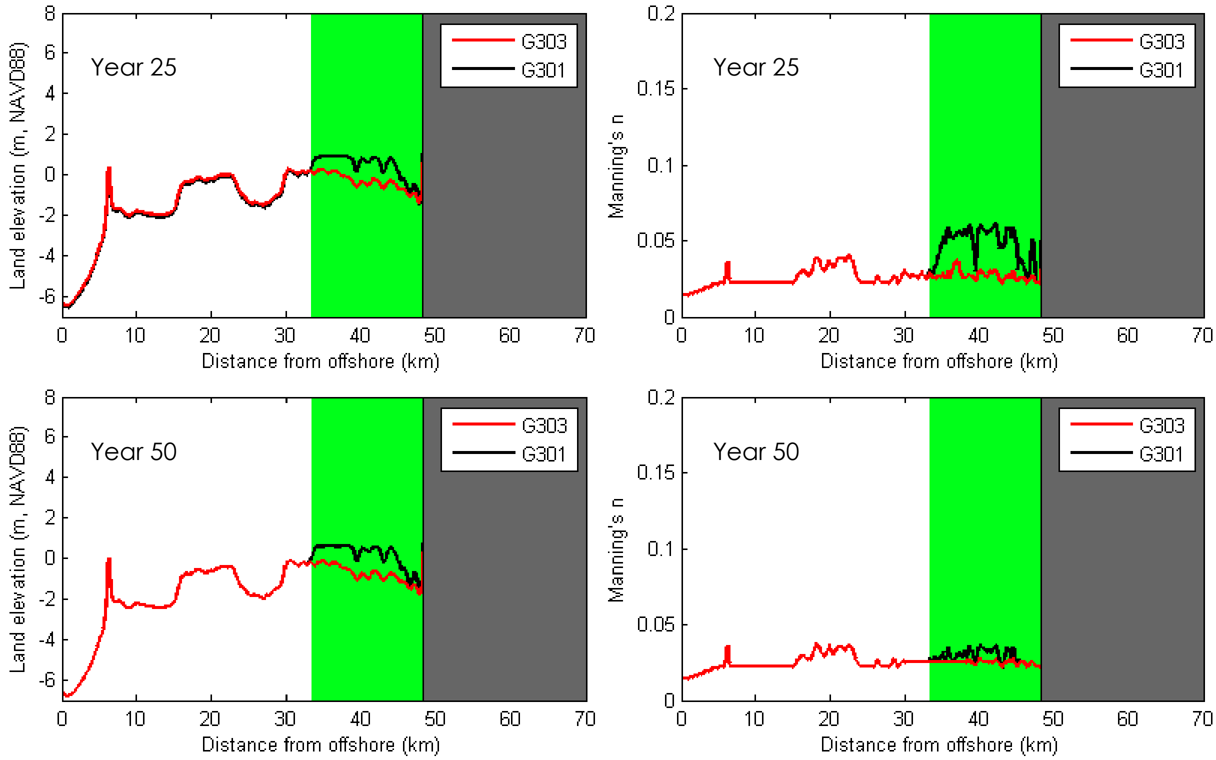


Figure 339: Topographic Elevations (left) and Friction Parameters (right) along Transect ATT03 for Year 25 and Year 50 (high scenario). The green shading indicates the location of the restoration project, the black line indicates G301 (hurricane protection plus restoration), and the red line Indicates G303 (hurricane protection only).

An example of the impact of restoration projects on maximum water surface elevation and wave heights is shown for transect ATT03 on Figure 340. For year 25, the effect of the restoration projects is to slow the propagation of water inland along the transect, resulting in an increase in water surface elevation in front of the restoration projects by as much as 0.5 m near km 33 and a decrease in water surface elevation at the levee face by approximately 0.3 m. This 0.3 m decrease on a water surface elevation of 3.3 m represents nearly a 10 percent reduction in water surface elevation at this levee location. Wave heights are similarly damped within the region of the restoration projects by as much as 0.5 m. For year 50, the impact of the restoration projects is diminished for storm surge due to the diminished differences in the G301 and G303 landscapes. However, waves remain impacted with similar damping between year 25 and year 50.

Inspection of water surface elevation and wave results for the other transects and for many different storm scenarios shows that the effects of the restoration projects are sensitive to the storm track because the surge and wave propagation direction determines where the water surface elevation and wave increases/decreases are located. Thus, depending upon the relative location of the restoration project and protection project to each other and to the storm direction, some parts of the protection project may experience increased water surface elevation and wave conditions or decreased water surface elevation and wave conditions. For instance, on Figure 336, which shows the spatial difference in water surface elevation for storm 239, while some reaches of the Morganza to the Gulf (03a.HP.02b) project experience lower water surface elevations due to the restoration project, there are also reaches of the hurricane protection project further south that experience increases in water surface elevation.

The extent and location of these changes depends upon the storm track and the proximity of the restoration project to the levee. These effects have implications on project performance and residual risk. Because the impact of restoration projects on hurricane protection project performance is sensitive to storm track and landfall location, it is important to consider restoration projects in the analysis of protection alternatives (e.g., evaluation of exceedance probabilities and expected damages). For projects that advance to implementation, design elevations, for instance, can be appropriately optimized along the entire protection project alignment to account for restoration effects. If design is based upon stand-alone protection project runs, the design will likely have regions of under- and overestimation.

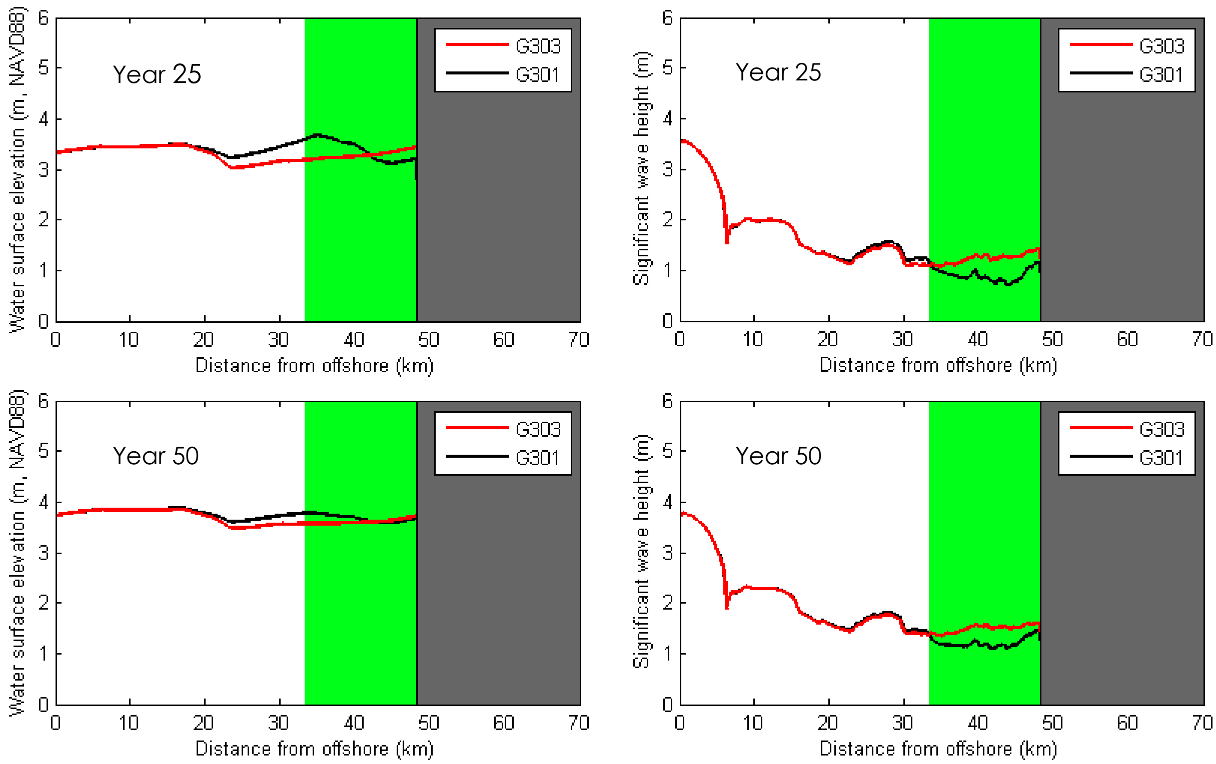


Figure 340: Maximum Water Surface Elevation (left) and Waves (right) for Storm 239 along Transect ATT03 for Year 25 and Year 50. The green shading indicates the location of the restoration project, the black line indicates G301 (hurricane protection plus restoration), and the red line indicates G303 (hurricane protection only).

5.4.3 Storm Impacts for G304 and G306

To investigate the impact of restoration projects on storm surge and waves, two alternatives were evaluated. G304 includes only the restoration projects included in G301. G306 was created from G304 by including additional restoration projects listed in Table 1. In G306, with the exception of the Biloxi Marsh Creation (001.MC.09) project, all other additional restoration projects are in the western region of coastal Louisiana and are shown on Figure 341. Neither G304 nor G306 include any protection projects, which allows for an evaluation of the extent to which restoration projects alone can mitigate surge and waves.

Based on ICM simulations of individual projects, the additional restoration projects in G306 are predicted to alter both vegetation and topography. Combined with the G304 model setup, ICM outputs for additional individual projects (Table 15) in year 25 and year 50 under the high scenario were used to modify the surge and wave model inputs to create G306. G306 and G304 are identical except for the locations of the additional restoration projects. Note that because the additional projects were added independent of the ICM simulation, the resulting landscape used as input to G306 does not, in contrast to G301 and G304, fully represent interactions among the included restoration projects. Similarly, shoreline protection, bank stabilization, and ridge restoration projects were implemented directly into ADCIRC by adding raised topographic elevations at design heights. These features are assumed to be maintained at those elevations over the course of the periods simulated. Topographic differences between G306 and FWOA applied for the simulations are shown in Figure 342.

The ICM predicts vegetation in most areas will be similar to FWOA by year 50 for both G304 and this is assumed to also be the case for G306. This similarity implies that Manning's *n* friction coefficients, which are largely a function of vegetation, will also be like the friction coefficients in FWOA year 50 surge and wave model.

Table 15: Restoration Projects Added to G304 to Create G306.

Project Type	Project ID	Project Name
Bank Stabilization	004.BS.01	Grand Lake Bank Stabilization
	004.BS.02	West Cove Bank Stabilization
	004.BS.05	Sabine Lake Bank Stabilization
Marsh Creation	001.MC.09	Biloxi Marsh
	004.MC.105	West Brown Lake
	004.MC.106	Cameron Meadows and Vicinity
	004.MC.25	West Brown Lake
Ridge Restoration	004.RC.01	Grand Chenier Ridge Restoration
	004.RC.05	Front Ridge Restoration
Shoreline Protection	004.SP.05a	Gulf SP (Calcasieu River to Rockefeller)
	004.SP.08	Calcasieu-Sabine Shoreline Protection - Component A
	004.SP.102	Sabine Pass Shoreline Protection

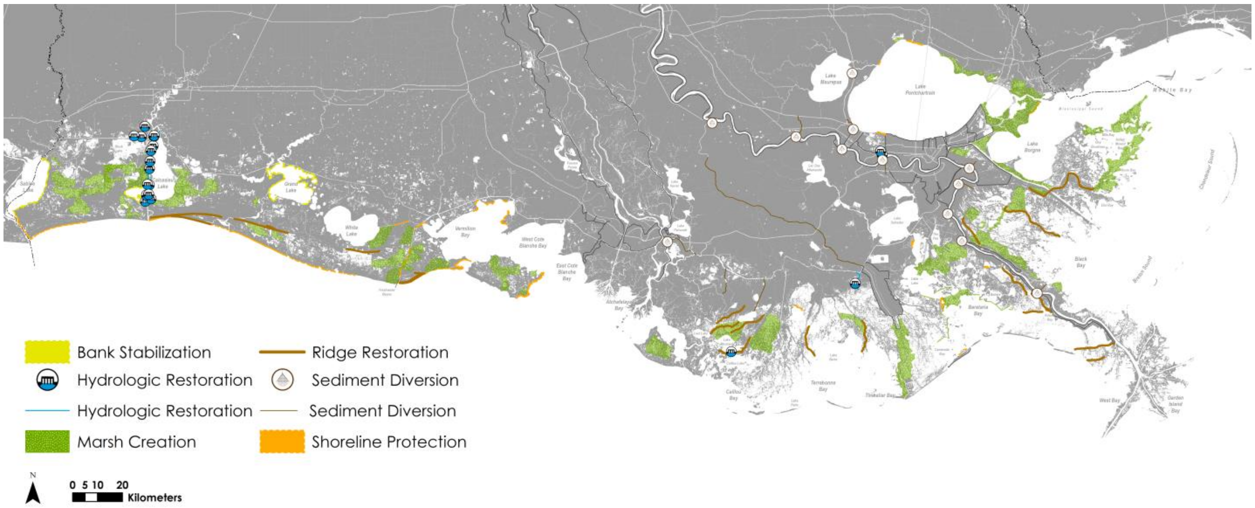


Figure 341: Additional Restoration Projects Combined as Alternative G306.

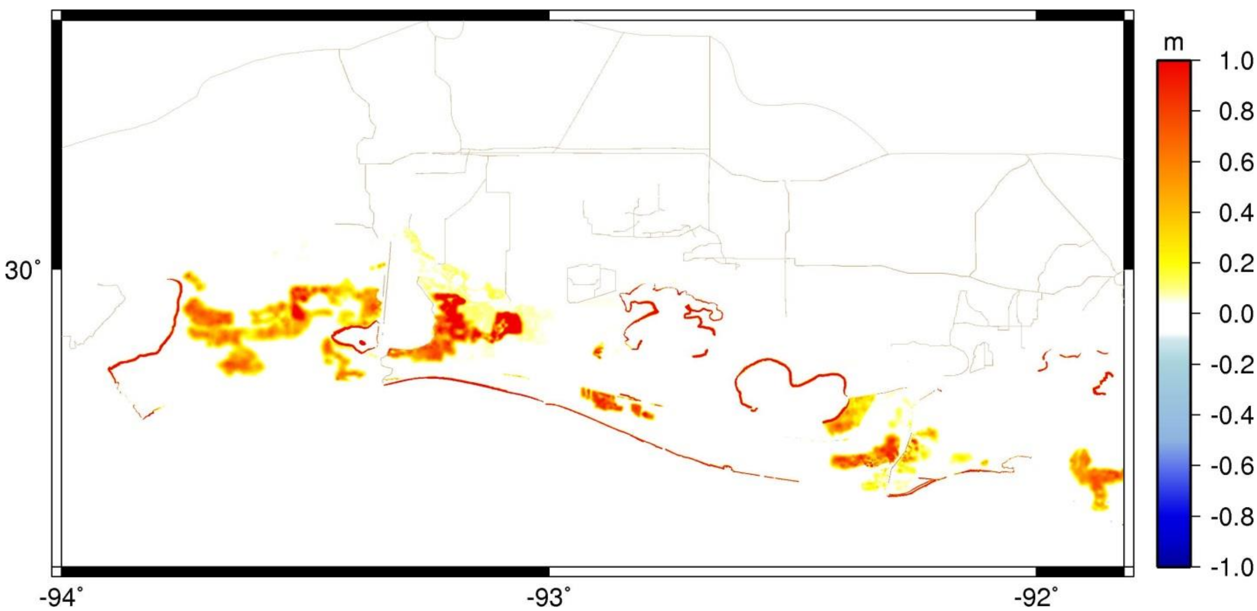


Figure 342: Topographic Change of Additional Restoration Projects in G306 compared to FWOA for the High Scenario, Year 50. Warm colors indicate topographic increases.

Simulations for both alternatives were performed for year 25 and year 50 under the high scenario. Results for both G304 and G306 show that restoration projects can induce changes in water level due to storm surge and waves by as much as 1 meter in some locations. However, the impacts are highly variable due to size and elevation differences in the individual projects and due to storm track and landfall location. Elevated features, such as shoreline protection, bank stabilization, and ridge restoration projects, may partially block flow during storms which generate lower surge levels. For storms generating surge lower than the crown elevation of a protection project, elevated landscape features may redirect storm surge to adjacent areas, increase water levels on the storm side of a feature, or both. On the contrary, higher storm surge levels may overtop and submerge the landscape features, thus producing negligible impact on the water surface elevation for large surge events. The potential impacts of restoration projects can also vary with the storm size and landfall location. In general, the trend is that surge and wave reductions are typically observed on the lee side of the restoration projects, with a corresponding increase on the storm side. The magnitude of the effects gradually diminishes with distance from the landscape feature. Overall, restoration projects provide less protection benefits than hurricane protection projects do, yet their benefits in surge and wave reduction can be as much as 0.5 m for relatively large areas and in some cases even further reduction is possible (e.g., 1 m) for locations immediately adjacent to the projects themselves.

The additional restoration projects located in the Chenier Plain (CHP) can provide additional benefits in reducing storm surge and waves up to an additional 0.5 m in G306 compared to G304. This effect has a large spatial extent for storms that make landfall nearby. In contrast, the impact of the additional Biloxi Marsh Creation (001.MC.09) project has a very small footprint and under all storm conditions provides no benefit to the New Orleans and Mississippi areas. Because most benefits between G306 and G304 are observed in the western region of coastal Louisiana, storms 214 and 241 have been selected as examples to illustrate the impacts of restoration projects in southwestern Louisiana on storm surge and waves. The variations of maximum water surface elevation and waves are evaluated with 2D contour plots along the 1D transects shown on Figure 343 and according to the proximity of impacts to local communities.

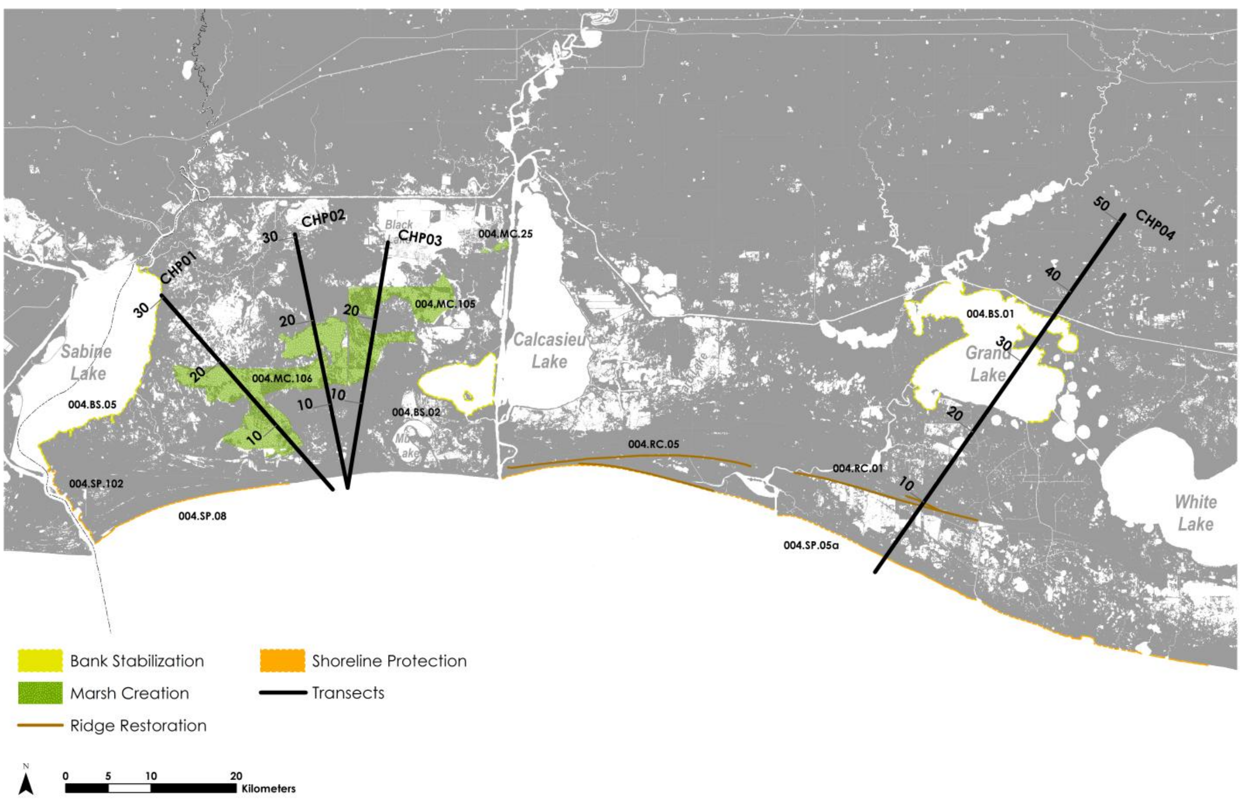


Figure 343: Transects Cut through the Extra Restoration Projects Included in G306 in Southwestern Louisiana.

Storm 214 is a high-intensity storm and makes landfall near the Texas and Louisiana border. Restoration projects composed of continuous raised features (e.g., shoreline protection, bank stabilization, and ridge creation) are easily overtopped by a storm generating storm surge higher than 1.0-1.5 m, therefore providing negligible impact (generally less than 5 cm) on surge as shown in Figure 345. In contrast, the marsh creation projects do result in surge reduction inland of their location and produce a corresponding increase of water levels on the shoreward side of the feature as shown on Figure 344. Note that surge levels build up on the south side of Calcasieu Lake, resulting in a large region further inland where surge in G306 is reduced by as much as 0.5 m compared to G304. Figure 345 shows the differences in surge along the southwestern Louisiana transects. Comparing G304 and G306 along these transects indicates there are surge reduction benefits from additional marsh creation projects along Transects CHP_01, CHP_02, and CHP_03, and there are negligible impacts due to the additional bank stabilization projects along Transect CHP_04.

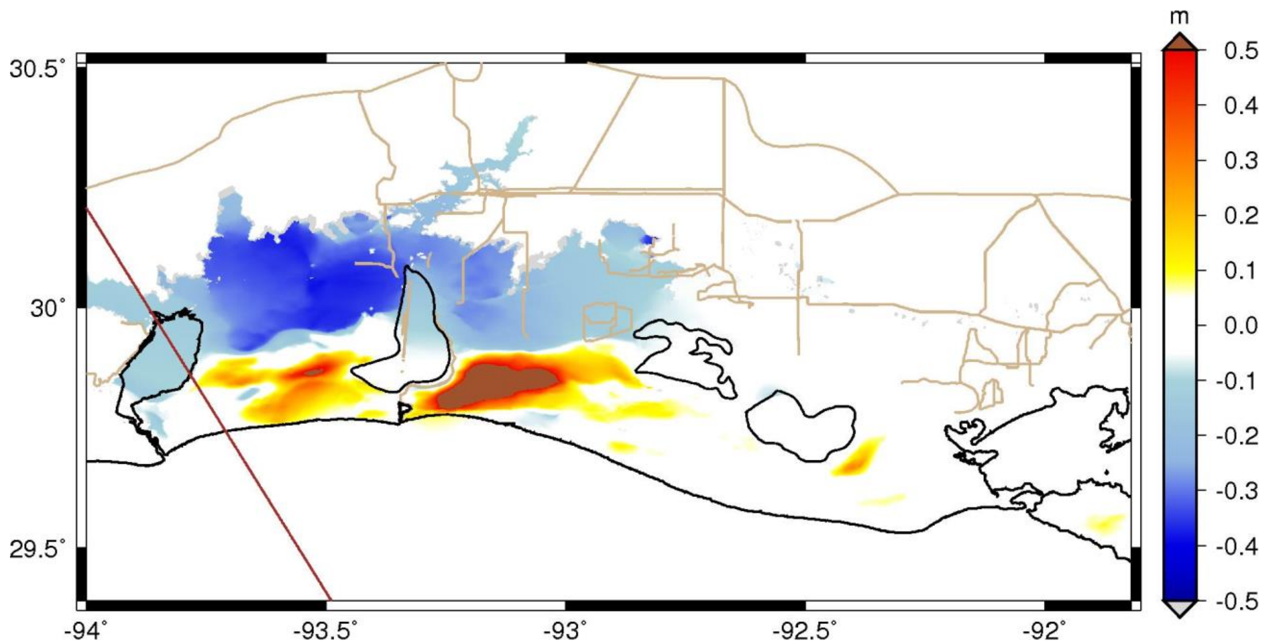


Figure 344: Differences in Maximum Water Surface Elevation (m) between G306 and FWOA for Storm 214 (year 25; high scenario). Positive values denote an increase with the projects in place.

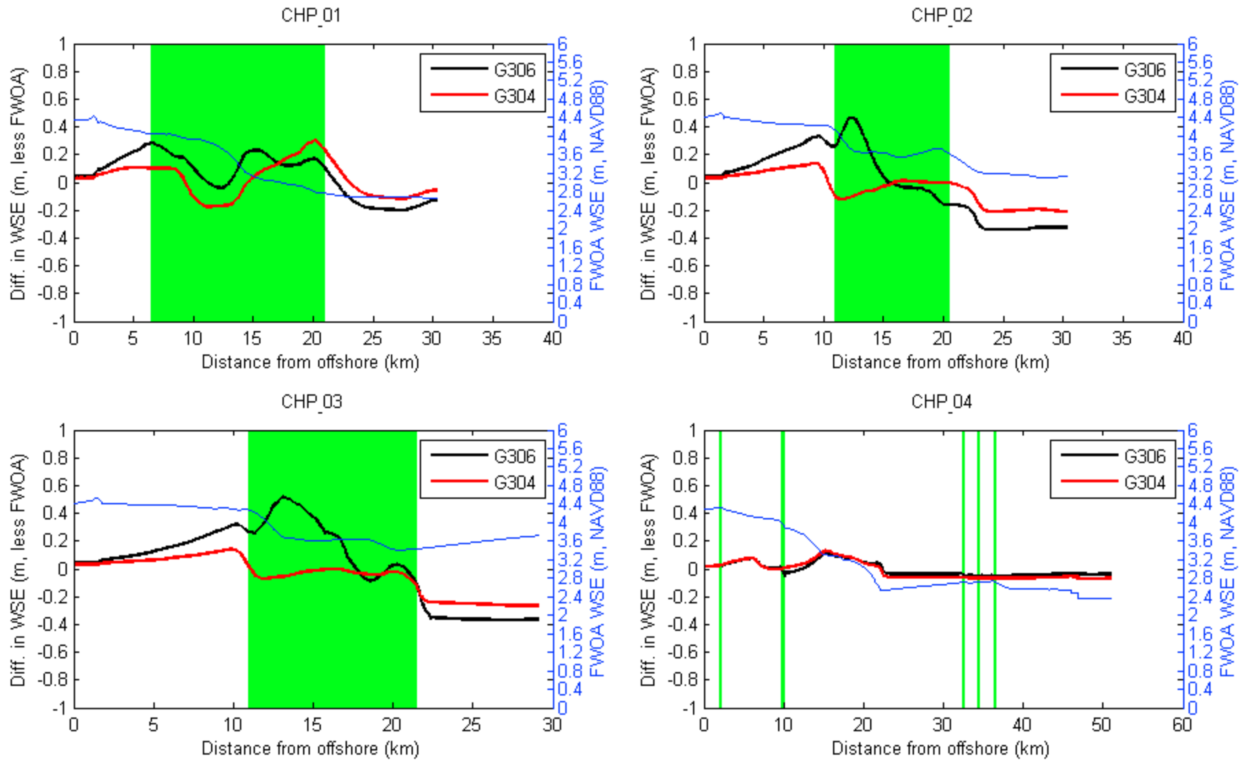


Figure 345: Transect View of Differences in Maximum Water Surface Elevation (m) due to G304 (red) and G306 (black) Relative to FWOA for Storm 214 (year 25; high scenario). The blue line is the FWOA water surface elevation. The green indicates the location of the additional restoration project.

For storms that make landfall further to the east, the additional restoration projects included in G306 generate a very different response. An example of this kind of storm is storm 241, which makes landfall in central Louisiana. Because the storm makes landfall to the east of the area of interest, relatively low levels of storm surge are experienced in southwest Louisiana, and for this storm, the peak surge height is generally lower than the crest of most shoreline restoration projects. Due to the relatively low surge level and due to the presence of winds from the north resulting from the counterclockwise circulation, the increases and decreases in surge are significantly different than seen for storm 214. The surge reduction due to restoration projects is primarily seen on the gulf side of the projects, as shown on Figure 346, while water builds up on the inland side due to projects obstructing water moving to the south. While similar impacts are observed in simulation results for G304, this phenomenon is enhanced in G306 due to implementation of additional restoration projects. Figure 347 illustrates the differences in surge between G304 and G306 along the southwestern Louisiana transects. It is apparent that increases in water surface elevation are observed on the inland side of projects, while decreases are limited to the seaward side of each project. Along Transect CHP_04, where five linear shoreline features are implemented, the greatest water surface reduction occurs between the Gulf Shoreline Protection (Freshwater Bayou to Southwest Pass; 004.SP.05a) project and the Grand Chenier Ridge Restoration (004.RC.01) project, while the Grand Lake Bank Stabilization (004.BS.01) project results only in a localized change indicated by a small increase in water surface elevation at the project site.

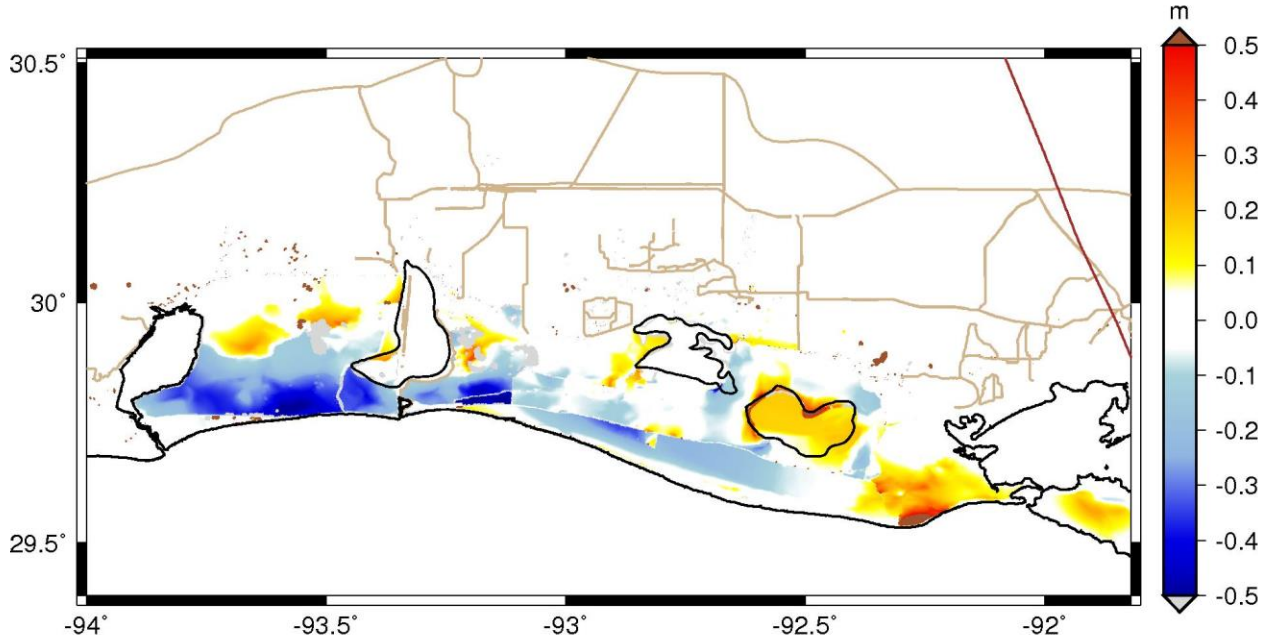


Figure 346: Differences in Maximum Water Surface Elevation (m) between G306 and FWOA for Storm 241 (year 25; high scenario). Positive values denote an increase with the projects in place.

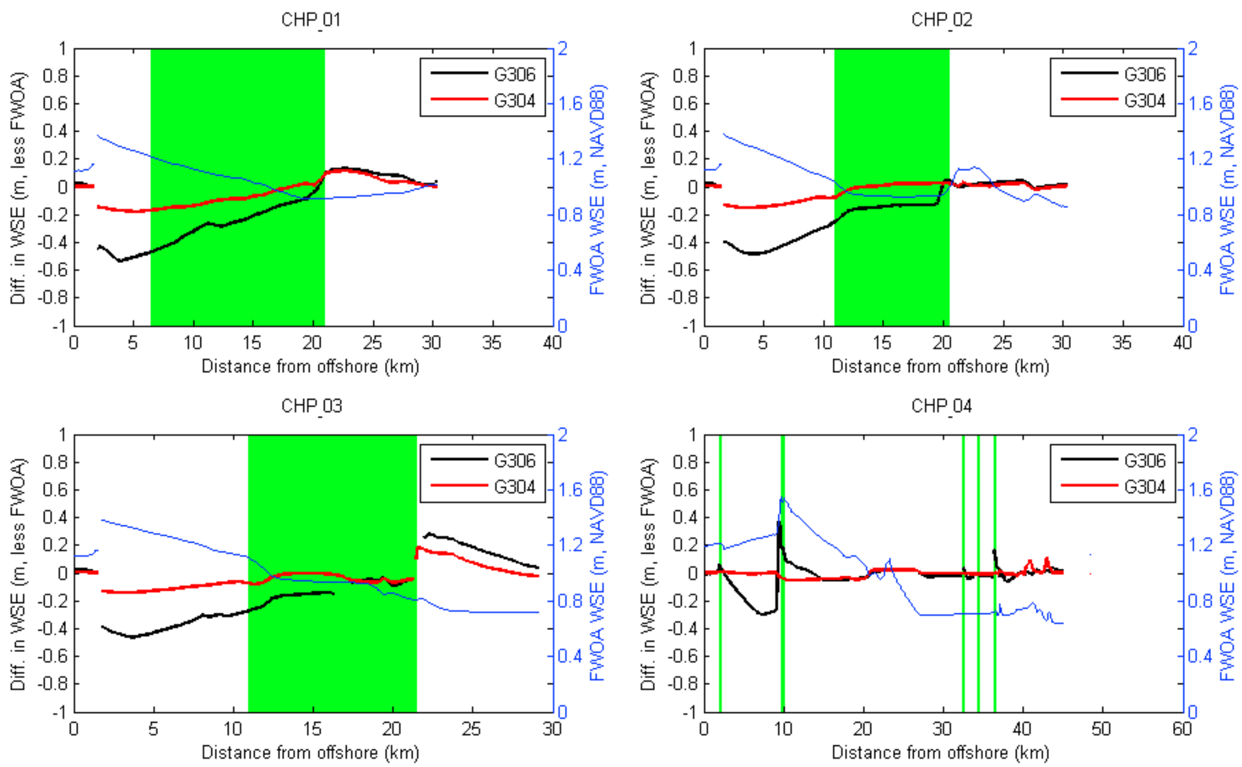


Figure 347: Transect View of Differences in Maximum Water Surface Elevation (m) due to G304 (red) and G306 (black) Relative to FWOA for Storm 241 (year 25; high scenario). The blue line is the FWOA water surface elevation. The green indicates the location of the additional restoration project. Discontinuities in the lines show areas where the model is dry.

In addition to the impacts on water surface elevation, restoration projects may also reduce significant wave heights. Figure 348 and Figure 349 present the spatial differences in wave heights for storm 214 and storm 241, respectively, for G306 relative to G304. With implementation of additional restoration projects, the overall wave height reduction is greater due to additional dissipation of wave energy.

While the magnitudes of wave height reduction are similar for these two storms, the spatial extent of the impact is much greater for storm 214 than for storm 241. However, storm 241generated smaller waves than storm 214. Thus, the decrease in wave height relative to FWOA wave height is much more significant for storm 241 than storm 214. The change relative to FWOA wave conditions can be seen in the transect plots provided on Figure 350 and Figure 351. By comparing the changes in wave height due to G304 (red line) and G306 (black line), additional wave dissipation is observed due to the additional restoration projects included in G306.

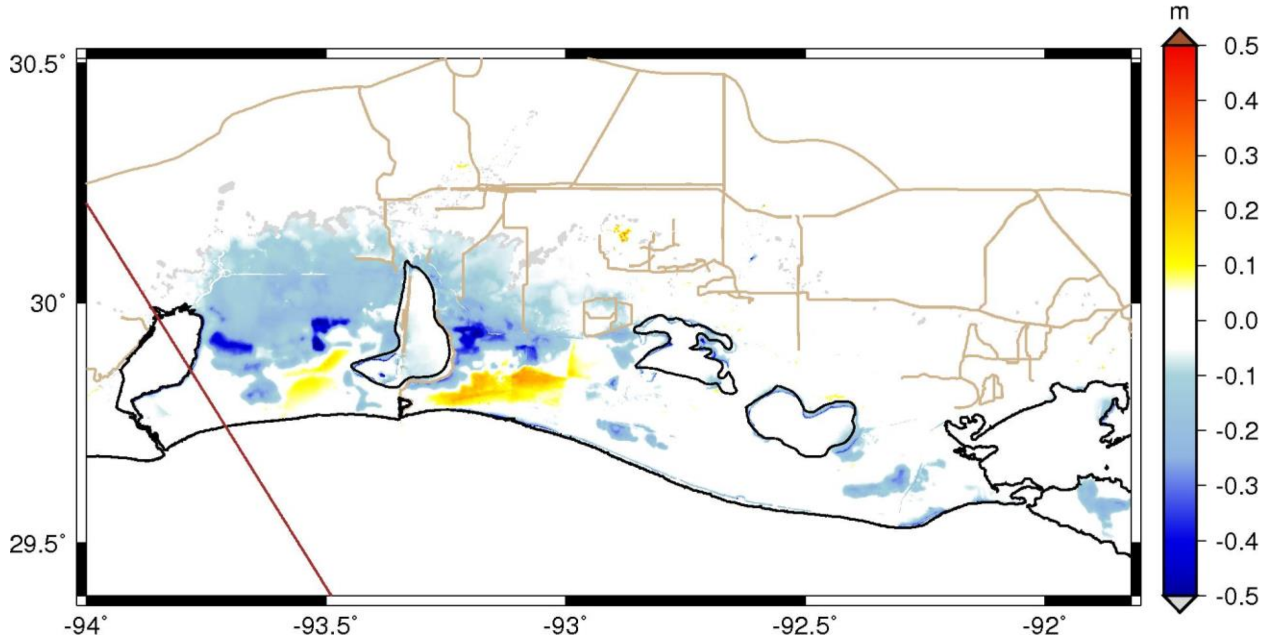


Figure 348: Differences in Maximum Wave Height (m) between G306 and FWOA for Storm 214 (year 25; high scenario). Positive values denote an increase with the projects in place.

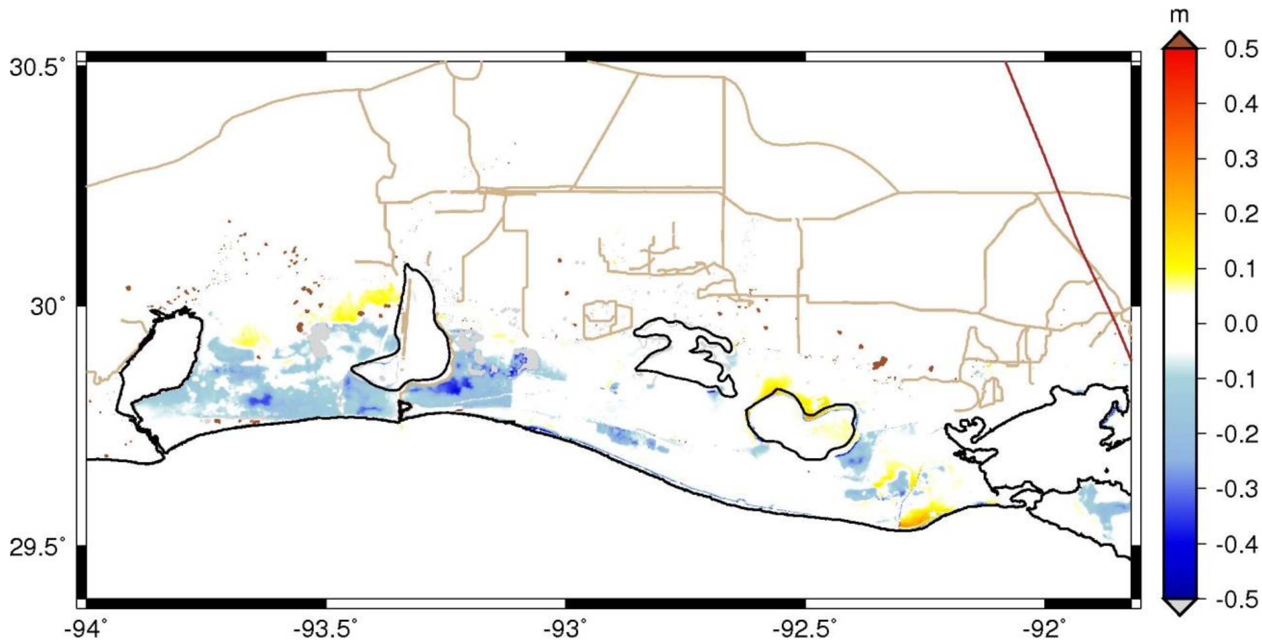


Figure 349: Differences in Maximum Wave Height (m) between G306 and FWOA for Storm 214 (year 25; high scenario). Positive values denote an increase with the projects in place.

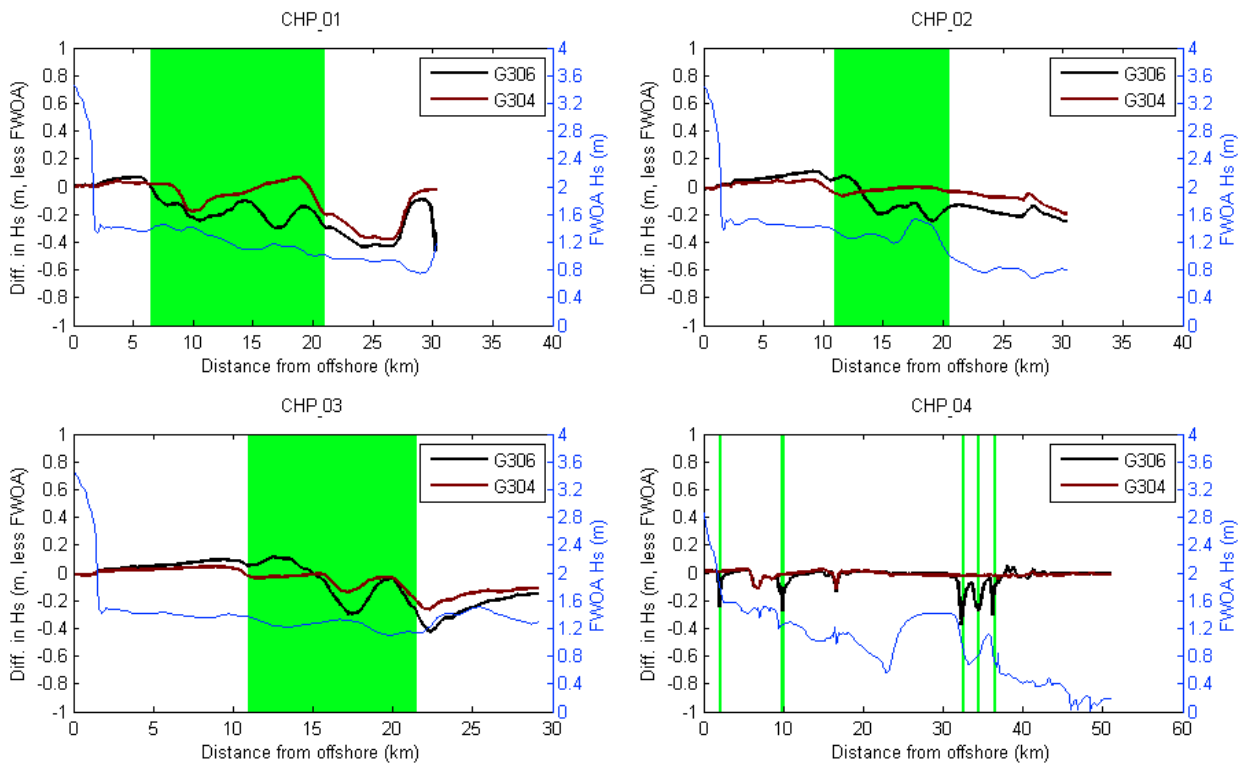


Figure 350: Transect View of Differences in Maximum Wave Height (m) due to G304 (red) and G306 (black) Relative to FWOA for Storm 214 (year 25; high scenario). The blue line is FWOA wave height. The green indicates the location of the additional restoration project.

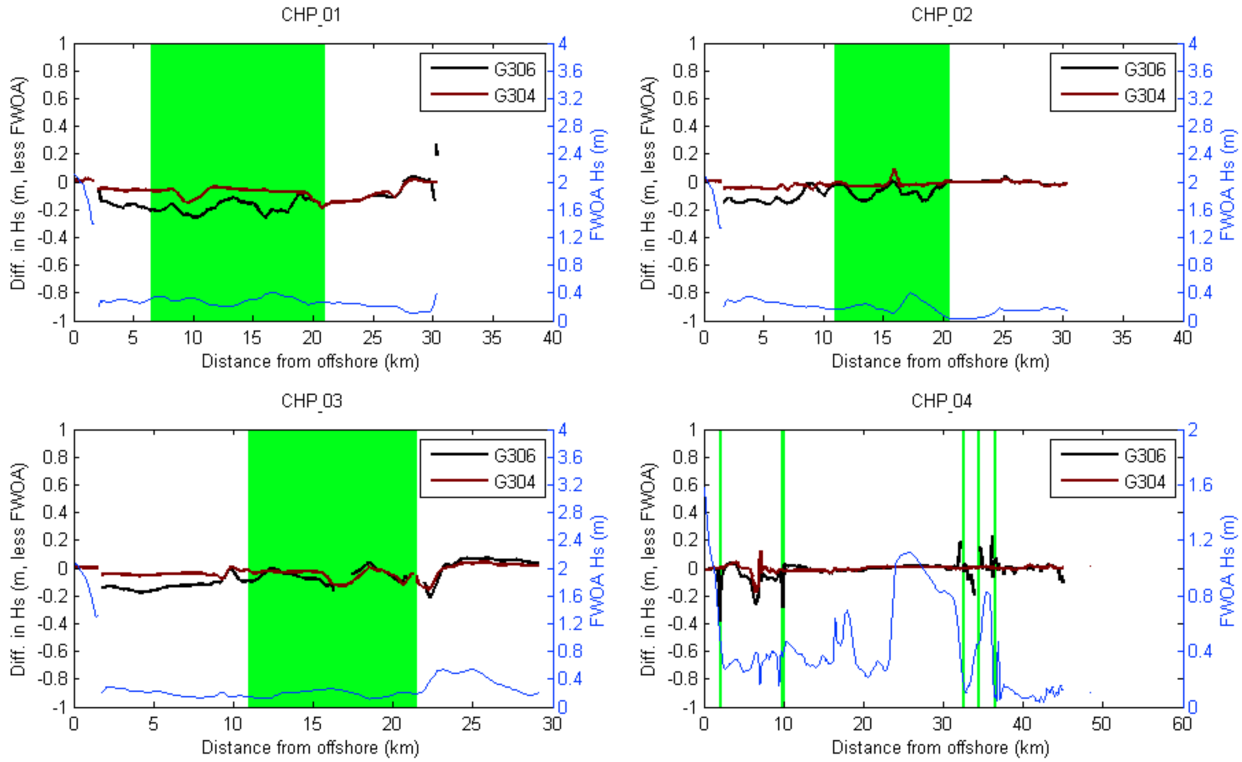


Figure 351: Transect View of Differences in Maximum Wave Height (m) due to G304 (red) and G306 (black) Relative to FWOA for Storm 241 (year 25; high scenario). The blue line is FWOA wave height. The green indicates the location of the additional restoration project.

In the above discussion of G306, the examples provided are for year 25. The observed surge and wave reduction benefits decrease over time due to sea level rise and landscape degradation until year 50, at which time the impact is largely negated. For instance, Figure 352 presents the reduction in water surface elevation due to G306 in comparison to FWOA for storm 241 in year 50. Comparing Figure 352 with Figure 346, it is apparent that the magnitude of both surge reduction and surge increase by year 50 is significantly less than that of year 25. However, the spatial extent of the surge increase has expanded to the north shore of White Lake between year 25 and year 50. This is because as sea level increases and land loss occurs over time, additional water can move inland under the same storm conditions, thus sea level rise may suppress the protective potential of restoration projects. In addition, the additional shoreline protection projects in G306 continue to obstruct shoreward-moving water during a storm like storm 241 that makes landfall to the east of the area of interest.

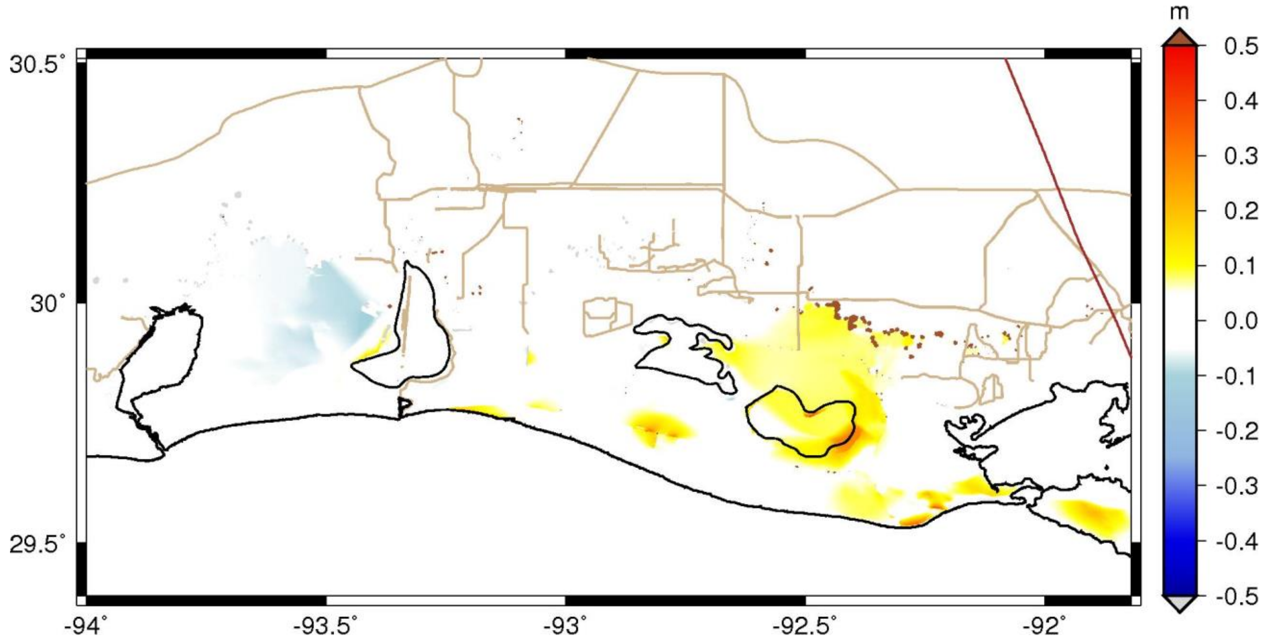


Figure 352: Differences in Maximum Water Surface Elevation (m) between G306 and FWOA for Storm 241 (year 50; high scenario). Positive values denote an increase with the projects in place.

To further examine the potential benefit of restoration projects in reducing surge and waves, it is of interest to understand where the benefits occur relative to the locations of populated communities. The additional surge reduction for G306 relative to G304 is shown along with community boundaries on Figure 353 for storm 214 and on Figure 354 for storm 241. These two figures show that the surge reduction impacts rarely intersect the location of populated communities. The exception is along the east shore of Sabine Lake. Even though the additional restoration projects may alter flood depths locally near the project site, the effects diminish with distance from the projects and the magnitude of changes is limited such that the overall extent of flooding commonly remains unchanged over the region. Thus, the additional restoration projects for G306 do not prevent flooding nor provide substantial protection benefits to any of the communities in the western region of coastal Louisiana. If other restoration projects were designed closer to populated areas, there may be some minor benefit. Restoration projects in general are not effective at preventing catastrophic flooding to communities, however, when combined with protection projects designed to prevent catastrophic flooding, the structures can be made more resilient.

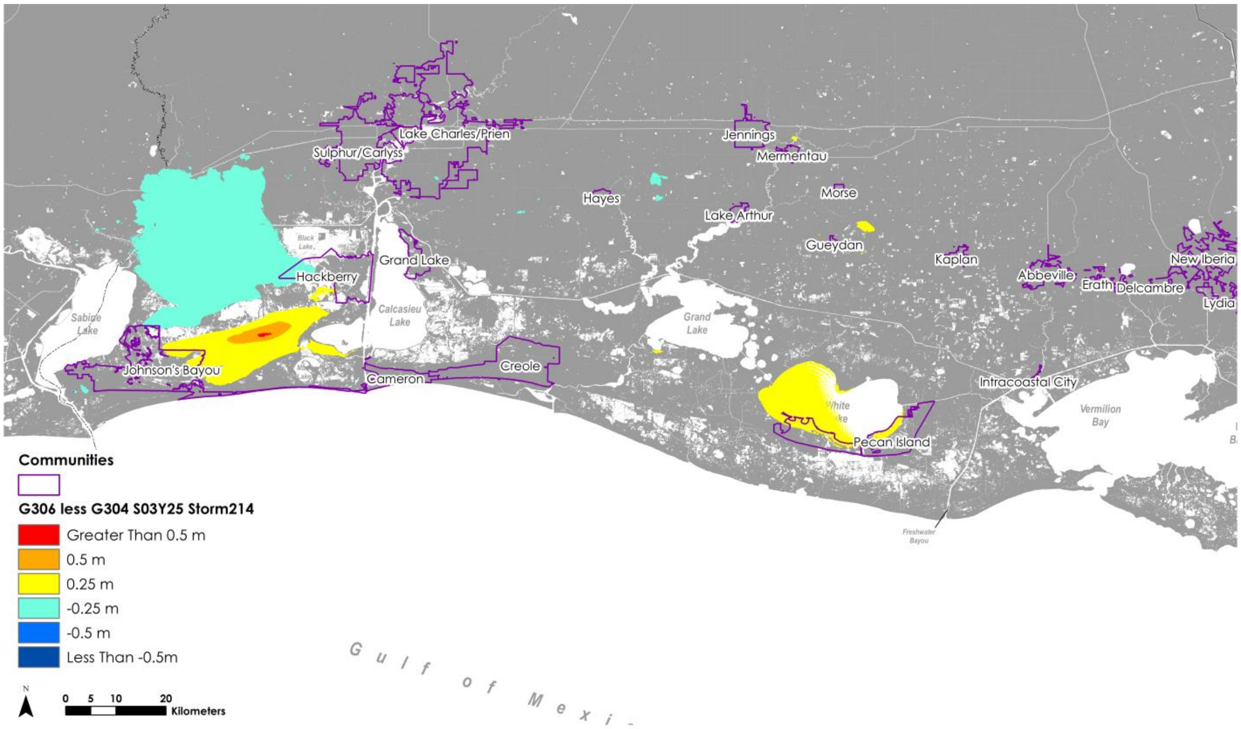


Figure 353: Differences in Maximum Surge between G304 and G306 for Storm 214 in Relation to Populated Communities (year 25; high scenario).

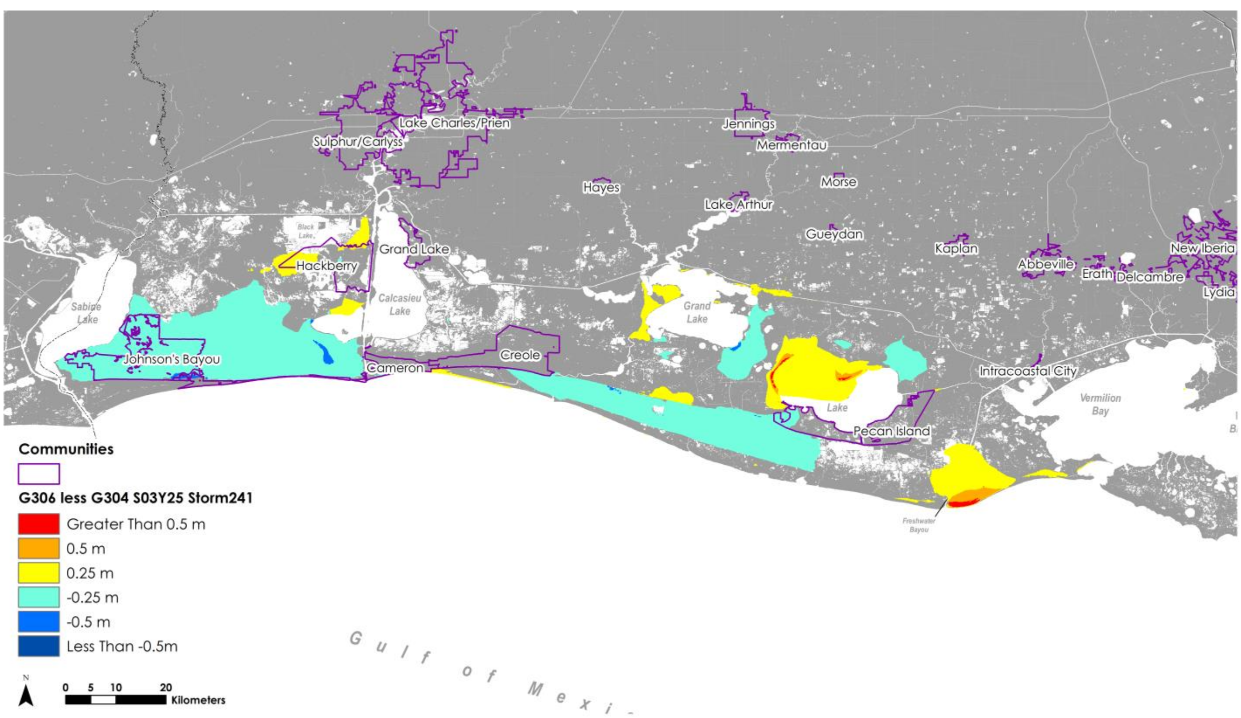


Figure 354: Differences in Maximum Surge between G304 and G306 for Storm 241 in Relation to Populated Communities (year 25; high scenario).

5.5 Project Interactions – Risk

5.5.1 Interaction of Protection Projects G303

5.5.1.1 Flood Depths

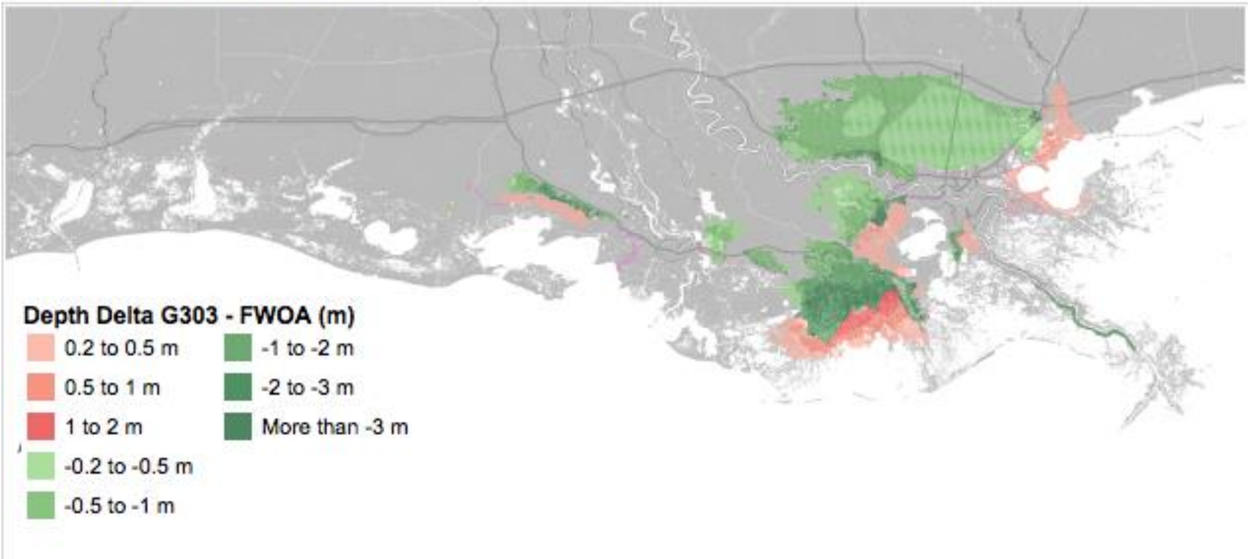
G303 includes a series of structural protection projects located in the eastern and central regions of coastal Louisiana. These projects combine to produce substantial coastal flood depth reduction for coastal communities, while also producing induced (increased) flood depths for areas on the unprotected side of the project alignments.

For example, Figure 355 shows the change in median 100-year flood depths in the medium scenario in year 25 (top) and year 50 (bottom). These figures show the IPET fragility scenario for enclosed protected areas. Nearly all structural projects are implemented by year 25 with the exception of the Morgan City Back Levee (03b.HP.10), Franklin and Vicinity (03b.HP.12), and Abbeville and Vicinity (004.HP.15), which are implemented before year 50. As a result, the spatial pattern of depth reduction is similar between year 25 and 50. However, FWOA flood depths in year 50 are generally much higher than in year 25, and as a result G303 yields a greater magnitude of depth reduction compared to FWOA year 50.

Areas with depth reduction of 1-2 m or greater at the 100-year recurrence interval by year 50 include the West Shore of Lake Pontchartrain (particularly Laplace), Jean Lafitte (enclosed ring levee), the upper Barataria Basin and Lafourche Parish region, Houma and surrounding areas of Terrebonne Parish, and portions of Iberia and Vermilion Parish in the central coastal region. The Lake Pontchartrain Barrier (001.HP.08) project also yields 0.5-1 m of depth reduction at this recurrence level for a wide area of the Pontchartrain Basin. In parts of the St. Tammany – Slidell region protected by the Slidell Ring Levees (001.HP.13) project, flood depths are reduced by over 3 m, with some points experiencing a greater reduction than what is produced by either the Slidell Ring Levees (001.HP.13) project or the Lake Pontchartrain Barrier (001.HP.08) project implemented alone. In general, the combination of G303 projects yields depth reduction for a significant portion of the more densely populated regions of the eastern and central portion of the Louisiana coast.

Induced flooding also occurs in front of these proposed projects (red colors). Of particular note are the increases in depth in front of the Morganza to the Gulf (03a.HP.02b) project with upgrades to the Larose to Golden Meadow (03a.HP.103) and Upper Barataria Risk Reduction (002.HP.06) projects. Together with the Larose to Golden Meadow (03a.HP.20) project and the West Bank of the New Orleans HSDRRS system, these form a long and unbroken line of protection that can increase flood depths on the unprotected east- or south-facing sides. In the medium scenario, year 50, depth increase of more than 1 m is estimated for areas in front of the Slidell Ring Levees (001.HP.13) project and Upper Barataria Risk Reduction (002.HP.06) project, for instance, while other projects or areas further from the projects show increases of 0.2-1 m.

Medium Scenario Year 25



Medium Scenario Year 50

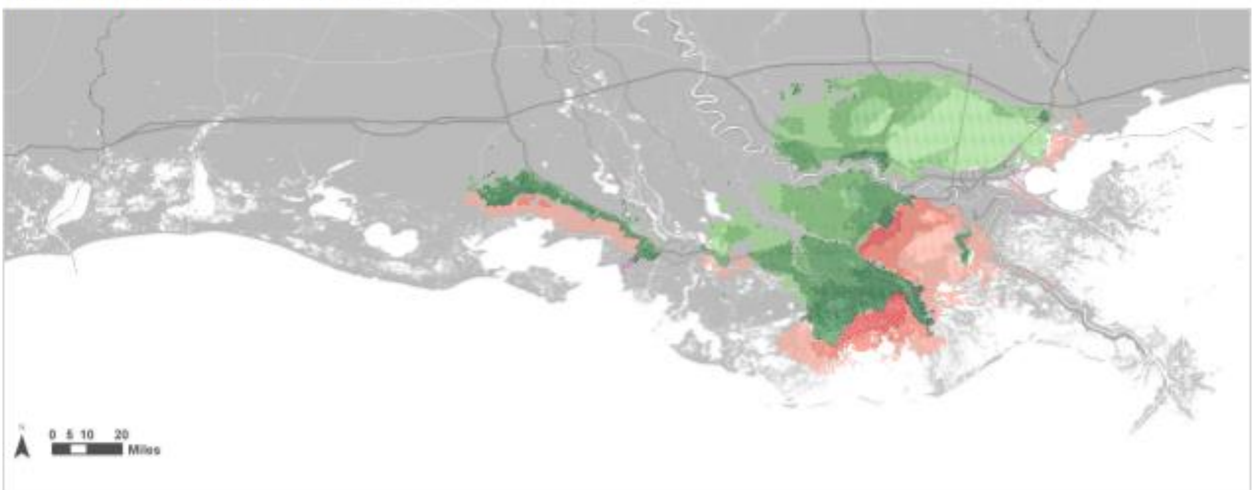
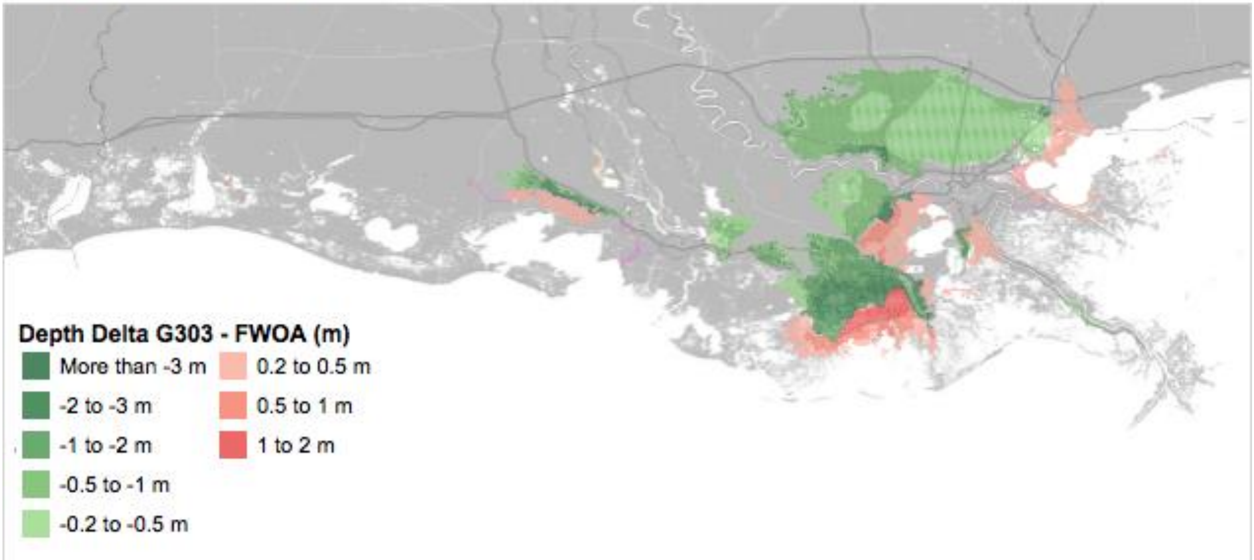


Figure 355: Difference in Median 100-Year Flood Depths due to Implementation of G303 (year 25 and 50; medium scenario). IPET fragility scenario shown in enclosed areas.

G303 depth reduction in the high scenario is summarized in Figure 356. Patterns of depth reduction and increase are similar to the medium scenario, but with generally greater magnitudes and a greater geographic area of effect due to the higher flood depths that occur in this scenario. Note that these projects most often reduce rather than eliminate 100-year flooding in protected areas. Many communities behind the alignments would still experience flooding at the 100-year recurrence interval (not shown in Figure).

High Scenario Year 25



High Scenario Year 50

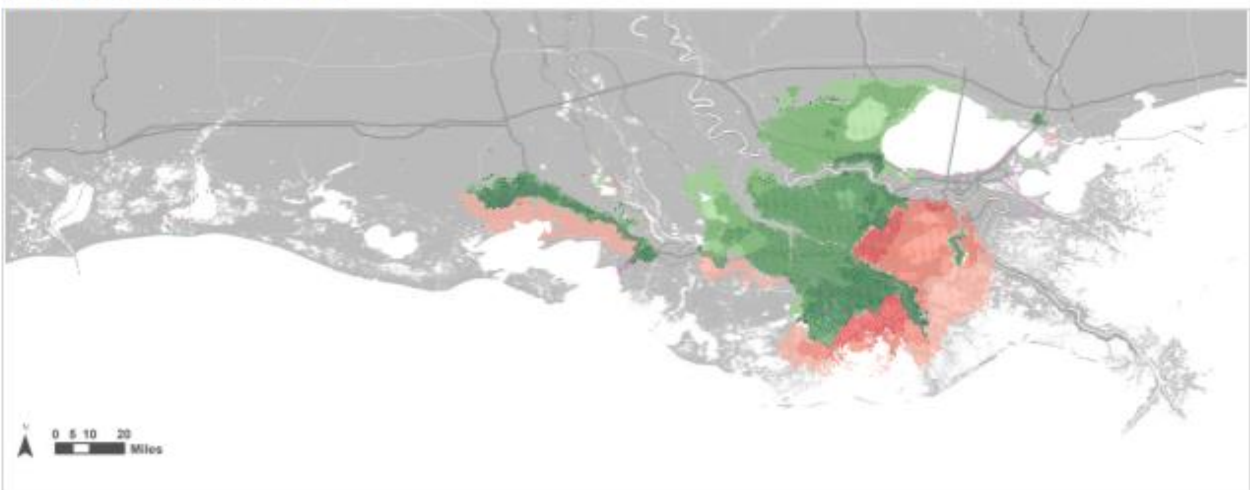
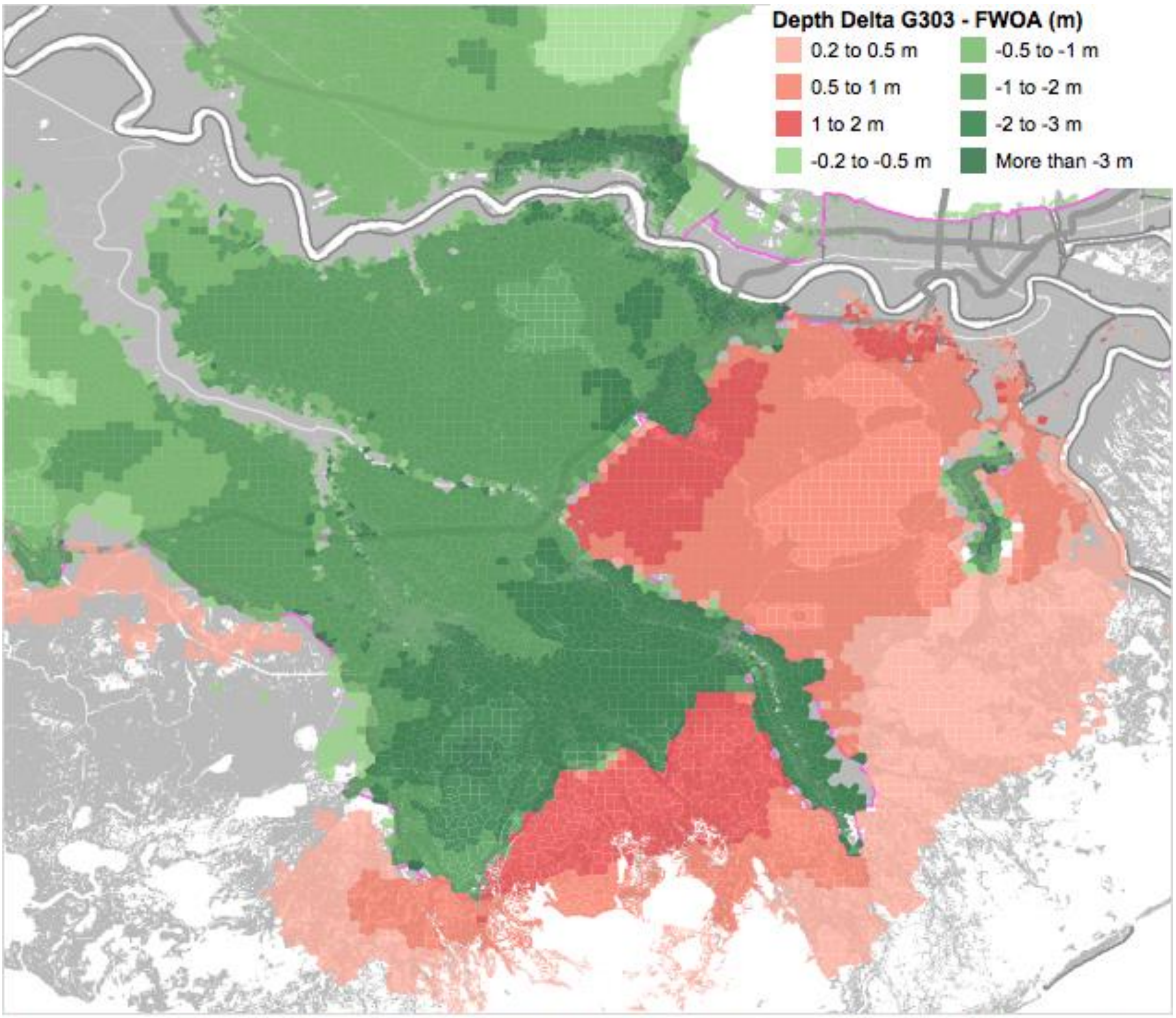


Figure 356: Difference in Median 100-Year Flood Depths due to Implementation of G303 (year 25 and 50; high scenario). IPET fragility scenario shown in enclosed areas.

Figure 355 and Figure 356 also illustrate the areas in which project interactions can yield increased depth reduction. Notable positive project interactions include the Upper Barataria Risk Reduction (002.HP.06) and Morganza to the Gulf (03a.HP.02b) projects. The Morganza to the Gulf (03a.HP.02b) project acts to cut off surge approaching from west of the Larose to Golden Meadow system, reducing surge penetration further inland to the St. Charles (Hahnville/Luling) and Lafourche (Raceland) regions protected by the Upper Barataria Risk Reduction project. As a result, in cities like Des Allemands risk is further reduced by the implementation of both projects than by either alone. Similarly, the Lake Pontchartrain Barrier (001.HP.08) project provides additional risk reduction in areas such as Laplace protected by the West Shore Lake Pontchartrain (001.HP.05) project.

Figure 357 zooms in to illustrate changes in 100-year flood depths, covering a region from the New Orleans area west to areas impacted by the Morganza to the Gulf project. When zoomed in, potential increases in flood depths on the West Bank of HSDRRS are readily apparent due to interactions between the Upper Barataria Risk Reduction (002.HP.06), Lafitte Ring Levees (002.HP.07), and Larose to Golden Meadow (03a.HP.20) projects. These alignments can act to redirect surge towards the HSDRRS West Bank subsystem for storms along certain tracks moving through that region, producing greater statistical flood depths at the 100-year return period in parts of Jefferson Parish.



Note: Change in 50th percentile 100-year flood depths with G303. Only grid points with flood depth deltas greater than 0.2 m shown.

Figure 357: Difference in Median 100-Year Flood Depths due to Implementation of G303 in Barataria, Terrebonne, and Laplace (year 50; high scenario). IPET fragility scenario shown in enclosed areas.

In G303, combinations of projects can also yield higher flood depths in some enclosed areas. For example, the combination of Upper Barataria Risk Reduction (002.HP.06) and Lafitte Ring Levee (002.HP.07) can increase surge and wave heights along the HSDRRS West Bank alignment, producing greater flood depths at the 100-year and/or 500-year recurrence intervals on the enclosed side due to increasing overtopping rates and a higher likelihood of levee failure. Figure 358 illustrates this with 500-year depths in the high scenario, showing the change in flood depth within HSDRRS for year 25 and 50 across all three fragility scenarios. While East Bank HSDRRS shows depth reduction from the Greater New Orleans High Level (001.HP.04) project and the Lake Pontchartrain Barrier (001.HP.08) project, the West Bank shows inducement from 0.2 to 2 m in many locations, depending on scenario. A lower level of induced flooding at the 500-year interval is also observed in the enclosed St. Bernard Parish, including New Orleans' Lower Ninth Ward neighborhood, in the IPET or MTTG fragility scenarios.

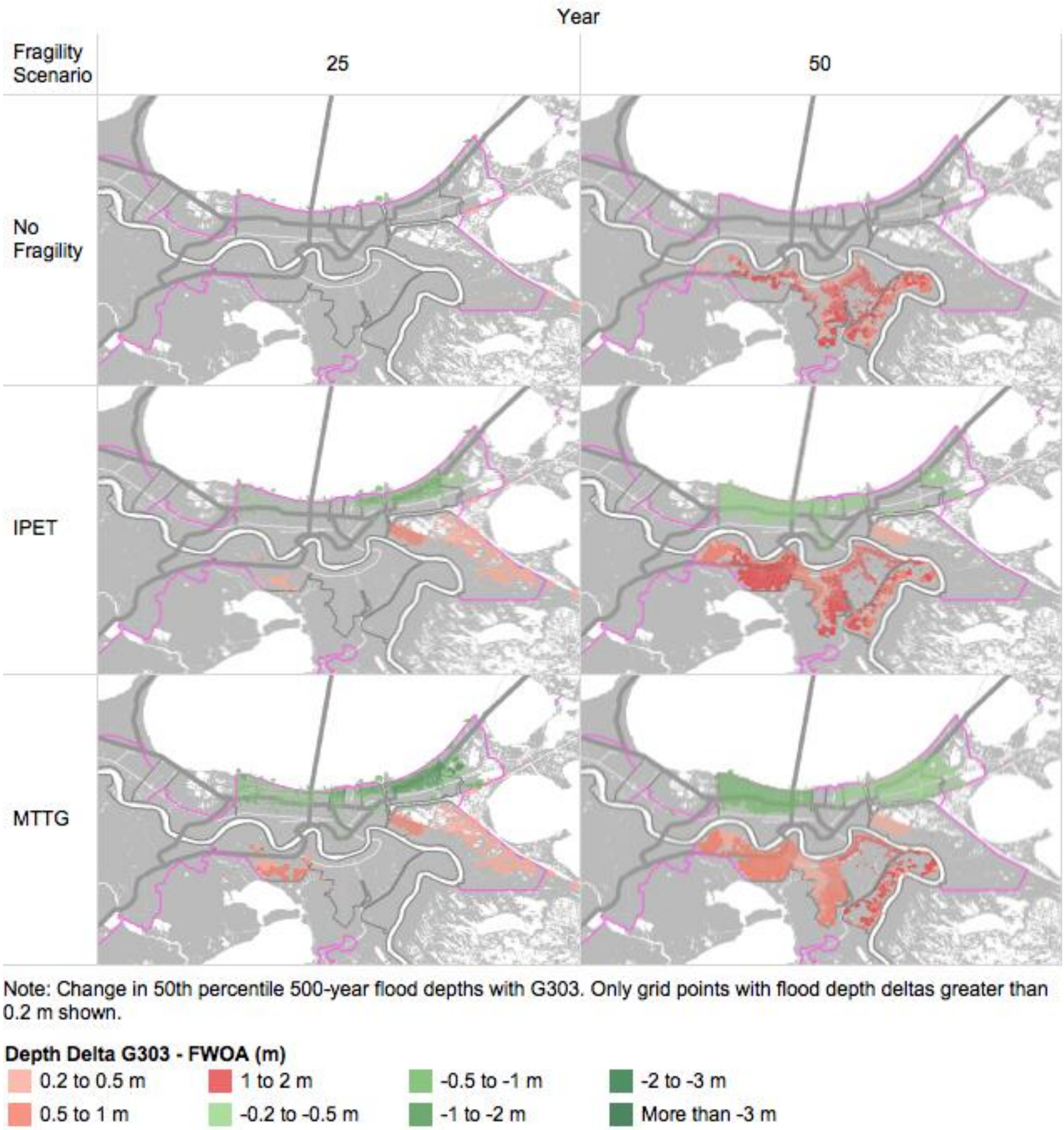


Figure 358: Difference in Median 500-Year Flood Depths due to Implementation of G303 Greater New Orleans HSDRRS Only (year 25 and 50; high scenario; all fragility scenarios).

5.5.1.2 Damage

Project interactions are also observed in the CLARA flood damage simulation results. For example, Figure 359 shows remaining EAD (top pane) and EAD reduction (G303 - FWOA, in percent) for G303 in one set of scenario assumptions for year 50. These damage results reflect proposed investment in a series of nonstructural risk reduction projects for many coastal communities (see Attachment E3 for a list of nonstructural projects selected for the draft alternatives) as well as the structural protection projects described above.

Damage reduction generally tracks the spatial pattern of depth reduction noted previously, with 50 percent or greater damage reduction compared with FWOA in Houma, Laplace/Reserve, Raceland, Morgan City, Larose to Golden Meadow, Slidell, and Hahnville/Luling. The combination of protection projects leads to greater damage reduction than individual project effects for some regions. For example, the Morganza to the Gulf (03a.HP.02b) project combined with the Upper Barataria Risk Reduction (002.HP.06) project in G303 yields $2.9 billion in damage reduction for Houma and vicinity in this scenario versus $2.7 billion with the Morganza to the Gulf (03a.HP.02b) project alone (note: some of this additional benefit is also attributable to implementation of nonstructural protection measures in the Houma region). Similarly, G303 yields $748 million in EAD reduction for Hahnville/Luling versus $676 million with the Upper Barataria Risk Reduction (002.HP.06) project alone. This is attributable to the Morganza to the Gulf (03a.HP.02b) project providing a first barrier of defense to the area protected by the Upper Barataria Risk Reduction (002.HP.06) project for certain storm tracks.

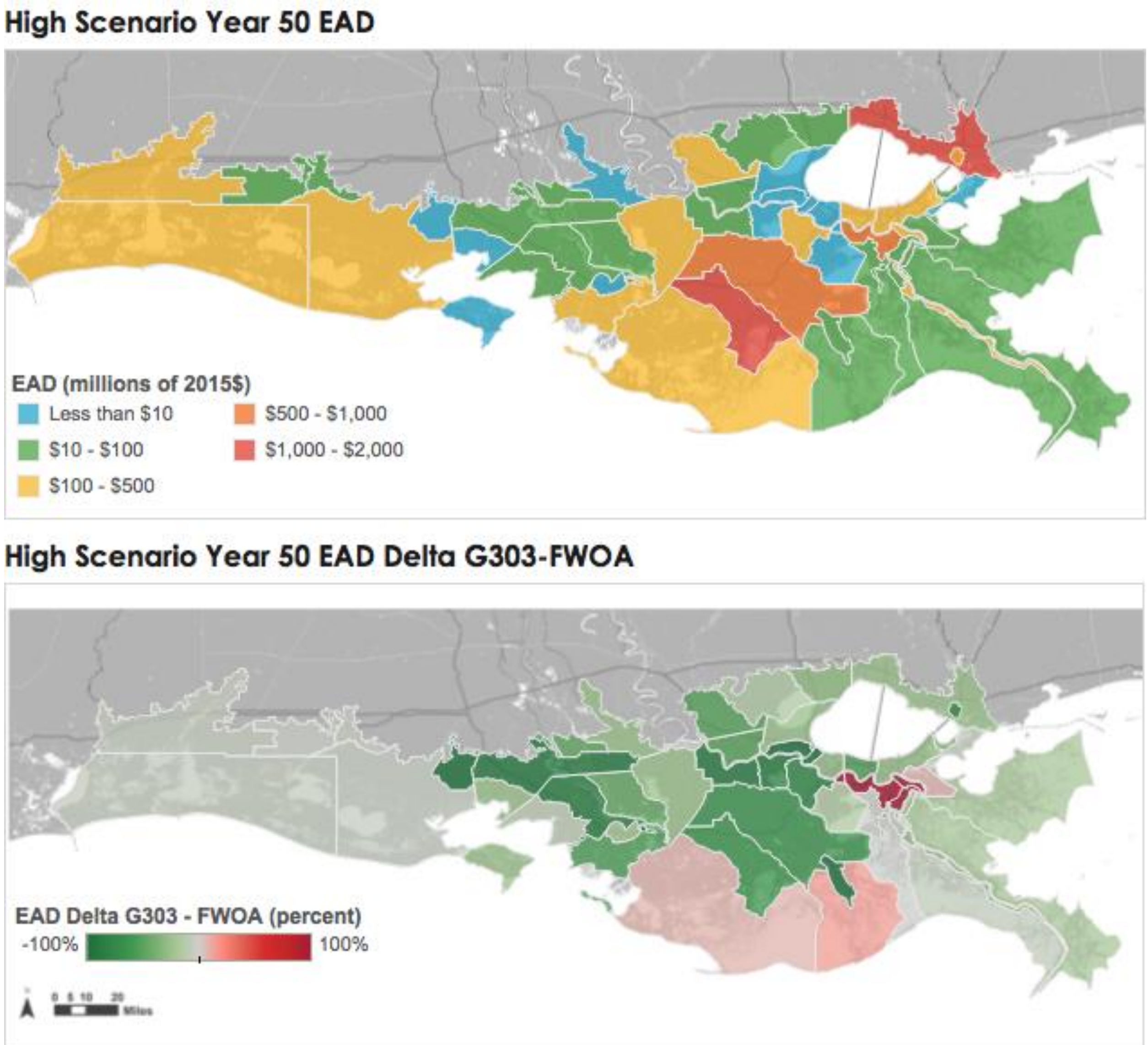


Figure 359: G303 Remaining EAD (top pane) and EAD Reduction (bottom pane); Year 50, High Scenario, Historical Growth and IPET Fragility Scenarios, Mean Estimate.

Lower Terrebonne and Lafourche Parishes, conversely, show modest damage increases (8 - 14 percent; $7 - 9 million increase compared with FWOA). West Bank HSDRRS (enclosed areas of Jefferson Parish) is the only region that shows a significant increase in flood damage with G303 projects and project interactions. Compared with FWOA, EAD in this region increases by $900 million with these scenario assumptions, going from $86 million in FWOA to $986 million with the alternative in place. By contrast, induced damage in this region is $237 million with the Upper Barataria Risk Reduction (002.HP.06) project alone, while the Lafitte Ring Levee (002.HP.07) project in isolation yields only a minor damage increase ($11 million).

EAD reduction benefits from G303 are summarized in Figure 360 for the medium and high scenarios in years 25 and 50 (historical growth, IPET fragility scenarios). This chart includes the combined effects from all proposed structural and nonstructural projects, but without coastal restoration projects implemented. G303 yields substantial damage reduction in all year and scenario combinations, generally producing over 50 percent damage reduction when compared to a FWOA. Remaining damage in the high scenario, year 50 still exceeds $9 billion, but compared to an $18.9 billion FWOA baseline.

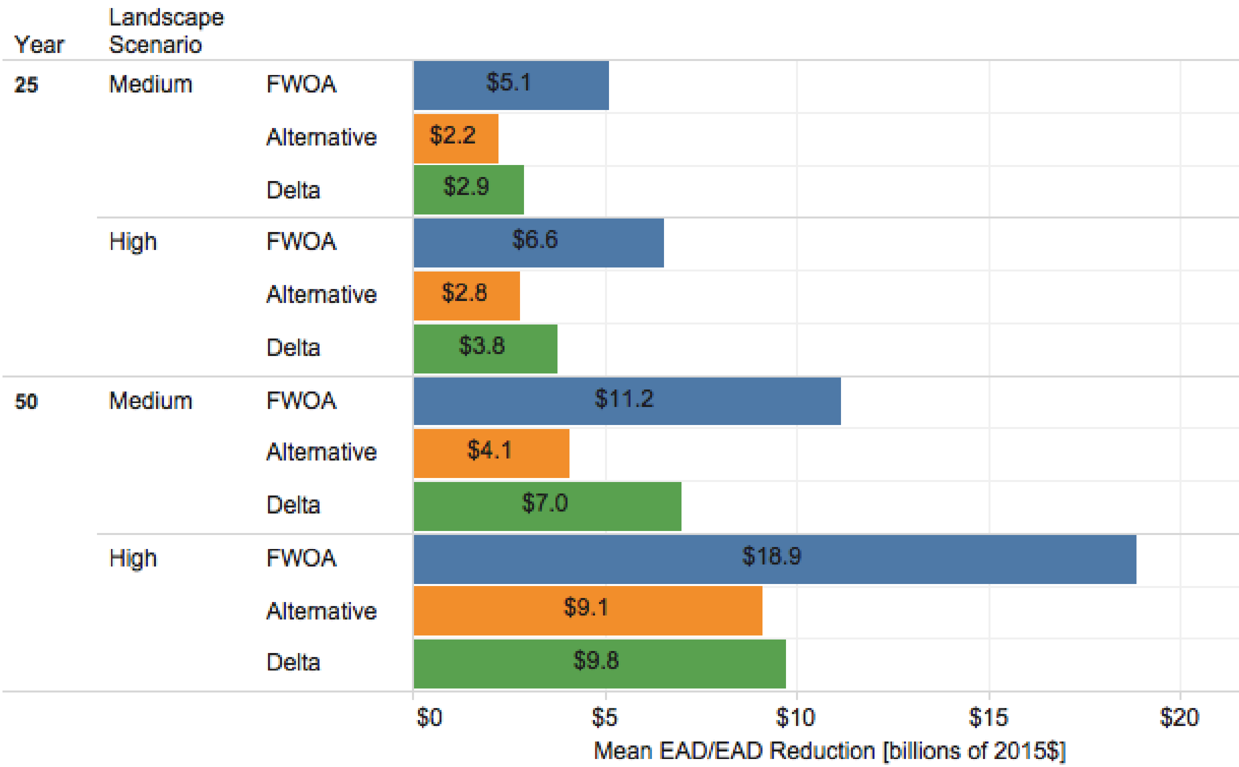


Figure 360: EAD and EAD Reduction in the High Scenario, Year 50, from G303 (historical growth, IPET fragility scenarios). Colored bars and labels show mean EAD in the FWOA (blue), with G303 (orange), and the results mean EAD reduction (green).

5.5.2 Interaction of Protection and Restoration Projects - G301 and G303

5.5.2.1 Flood Depths

Differences in flood depths at the 100-year return period between G301 and G303 are shown for the medium scenario (Figure 30) and high scenario (Figure 362) below. Green shades show locations where depth reduction is greater in G301, while red shades highlight areas in which depths increase with G301 restoration projects in place.

In general, additional depth reduction can be observed on the actual restoration sites selected for some locations, such as the series of marsh creation projects selected for the southwest coastal region. In other areas, a combination of restoration projects can yield more systematic changes over a wider region. For instance, the combination of ridge restoration and marsh creation projects in Terrebonne Parish southwest of the Morganza to the Gulf alignment yields 100-year depth reduction of 0.5-2 m across a broad area in front of the levee in years 25 and 50. Similarly, the combined effects from a combination of restoration projects in year 50 yield depth reduction in areas around Lake Pontchartrain as well as Breton Sound/portions of Plaquemines Parish (East Bank). By year 50, restoration yields depth reduction across a large portion of Barataria Basin coastward of the Upper Barataria Risk Reduction (002.HP.06) project. Restoration can yield beneficial effects of 1-2 m or greater at the 100-year return period, but note that the remaining flood depths with G301 in place can still be 4-5 m or higher for many of these sites.

Restoration projects can also yield slight depth increases, as shown in the figures below, for some locations. These effects are generally modest, less than 0.5-1 m for areas that can be exposed to 4-5 m or more of flooding. Patterns of depth reduction and increase comparing G301 and G303 are similar in the medium and high scenarios, with magnitudes generally greater in the high scenario.

Figure 363 provides a closer look at the southeastern part of the coast. This region provides a clear example of restoration projects having an impact on storm surge risk. The red band of induced surge east of the Larose to Golden Meadow ring levee coincides with marsh creation projects, such as Lower Barataria Marsh Creation - Component A (002.MC.04a) and Large-Scale Barataria Marsh Creation - Component E (002.MC.05e), which generate up to 2 m of additional land elevation by year 50 of the high scenario. This has the effect of significantly reducing 100-year flood depths inland around Lafitte and Lake Salvador. These projects, in combination with the Belle Pass-Golden Meadow Marsh Creation (03a.MC.07), also result in some induced flooding within the Larose system. Because of the impact of the marsh creation projects, the Maintain Larose to Golden Meadow (03a.HP.20) project is no longer able to provide the same level of protection as it does in G303.

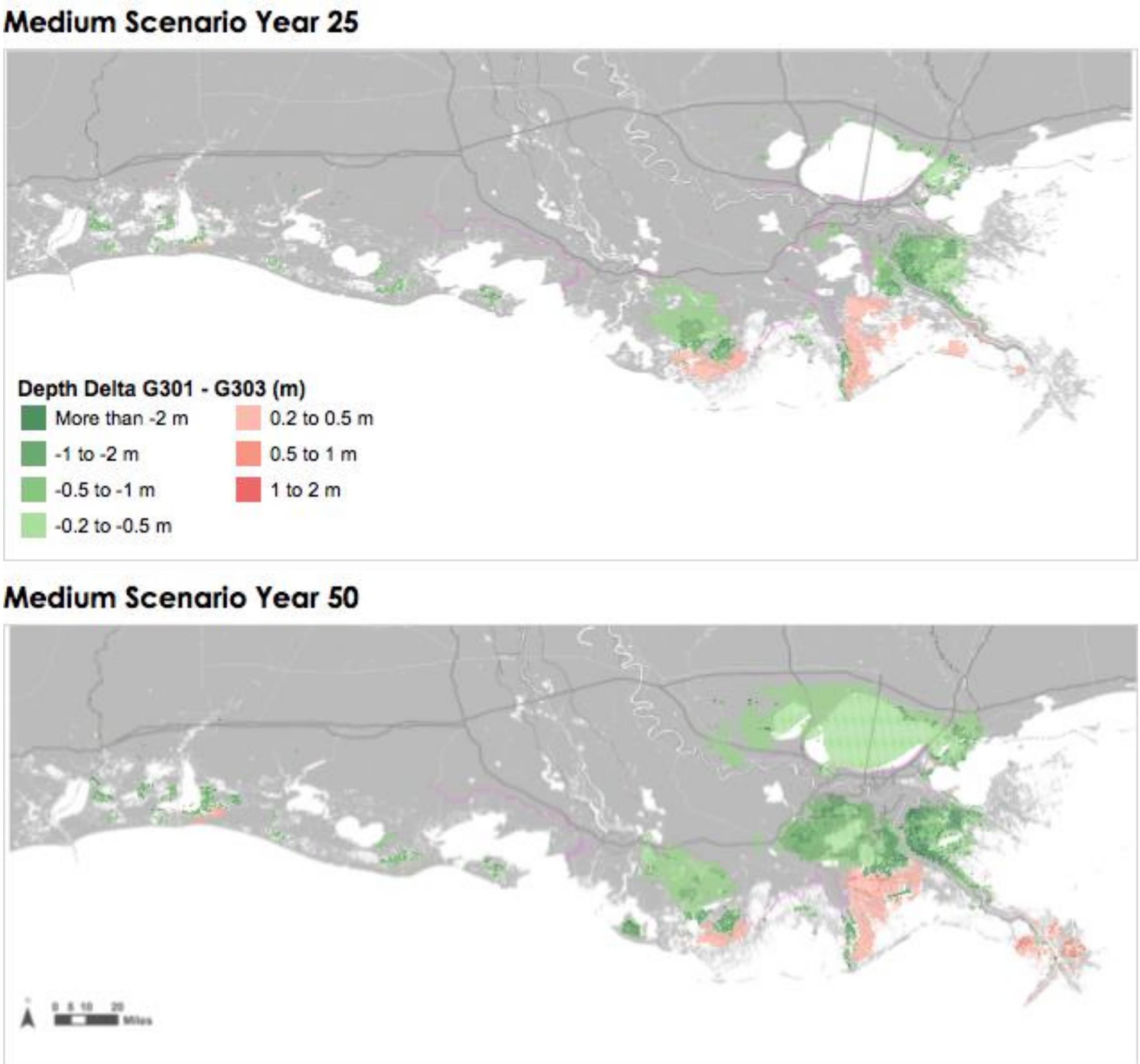
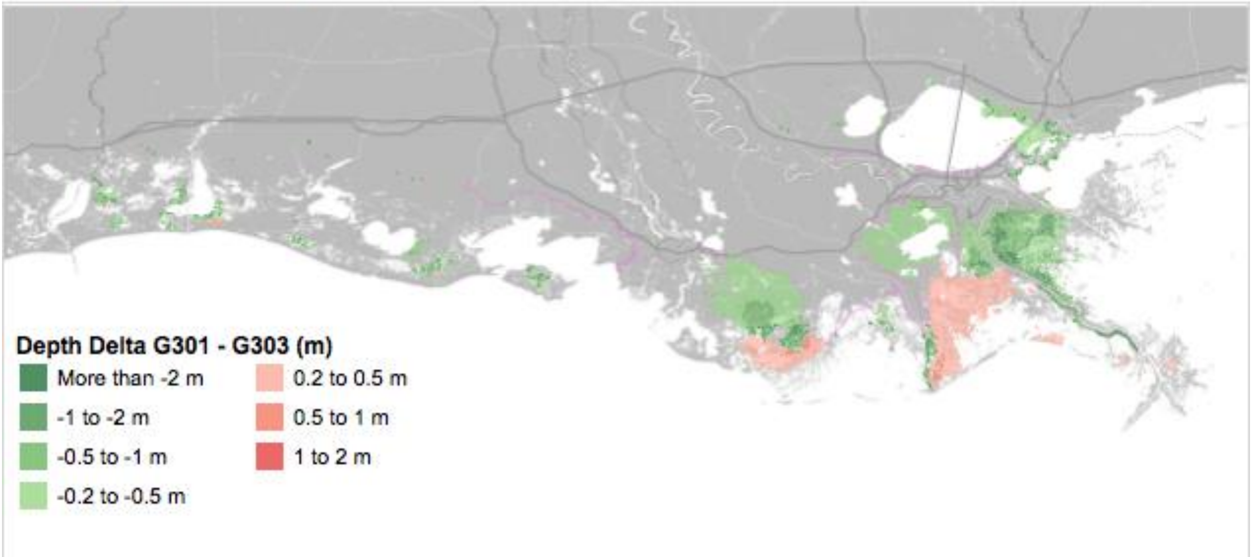
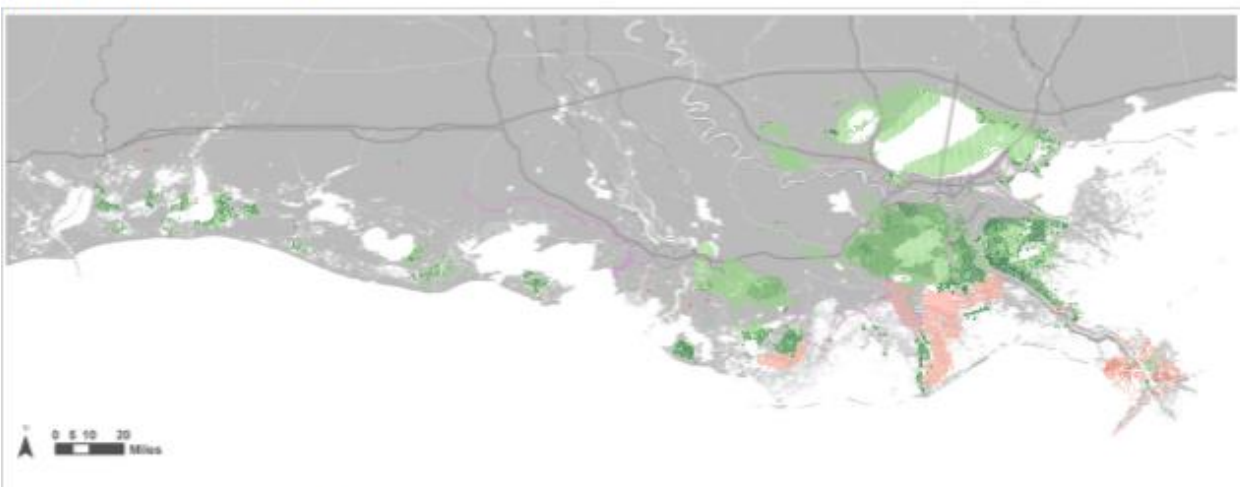


Figure 361: Difference in Median 100-Year Flood Depths due to Implementation of G301 compared with G303 (year 25 and 50; medium scenario). IPET fragility scenario shown in enclosed areas.

High Scenario Year 25

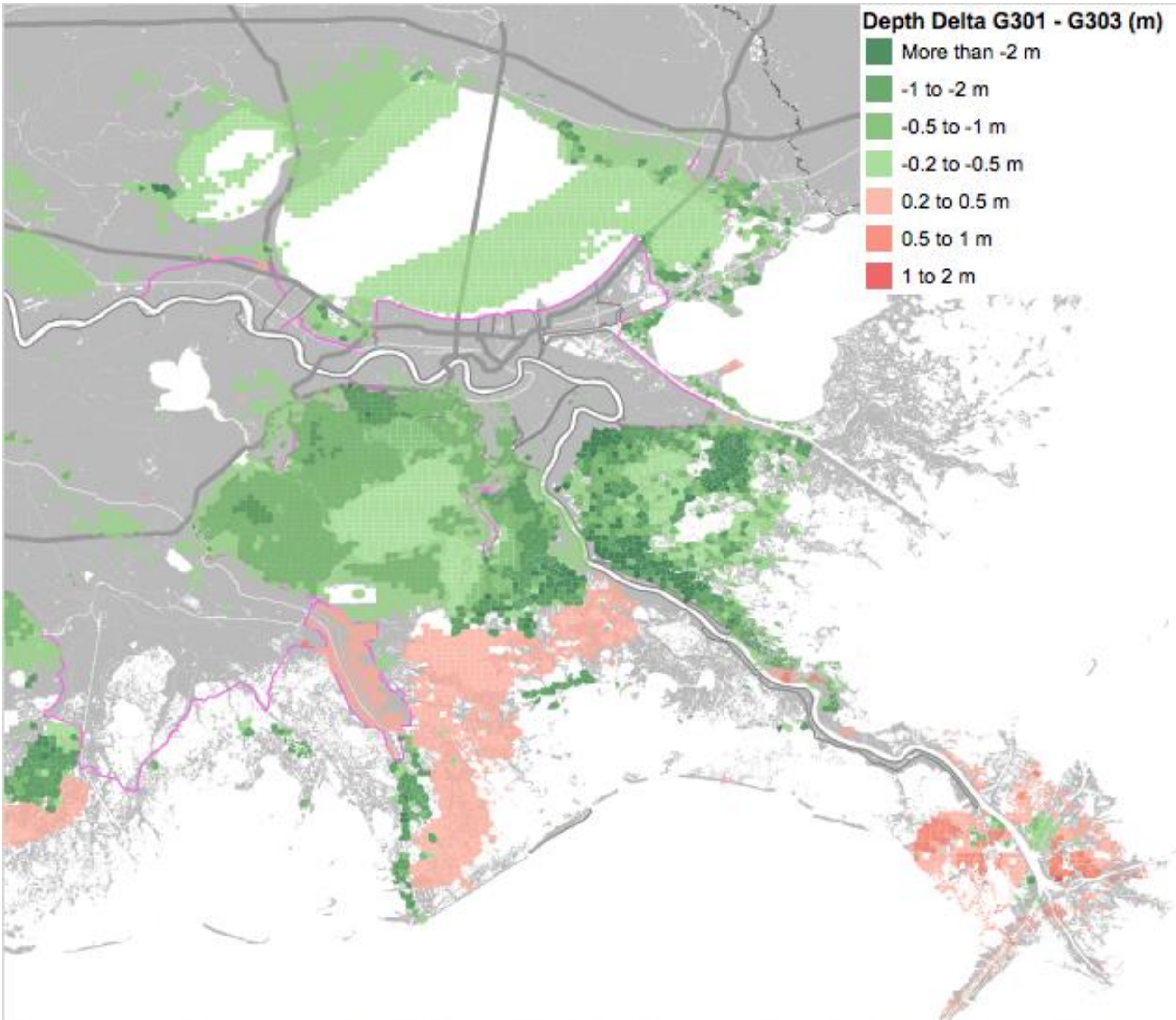


High Scenario Year 50



Note: Change in 50th percentile 100-year flood depths with G301 compared to G303. Only grid points with flood depth deltas greater than 0.2 m shown.

Figure 362: Difference in Median 100-Year Flood Depths due to Implementation of G301 compared with G303 (year 25 and 50; high scenario). IPET fragility scenario shown in enclosed areas.

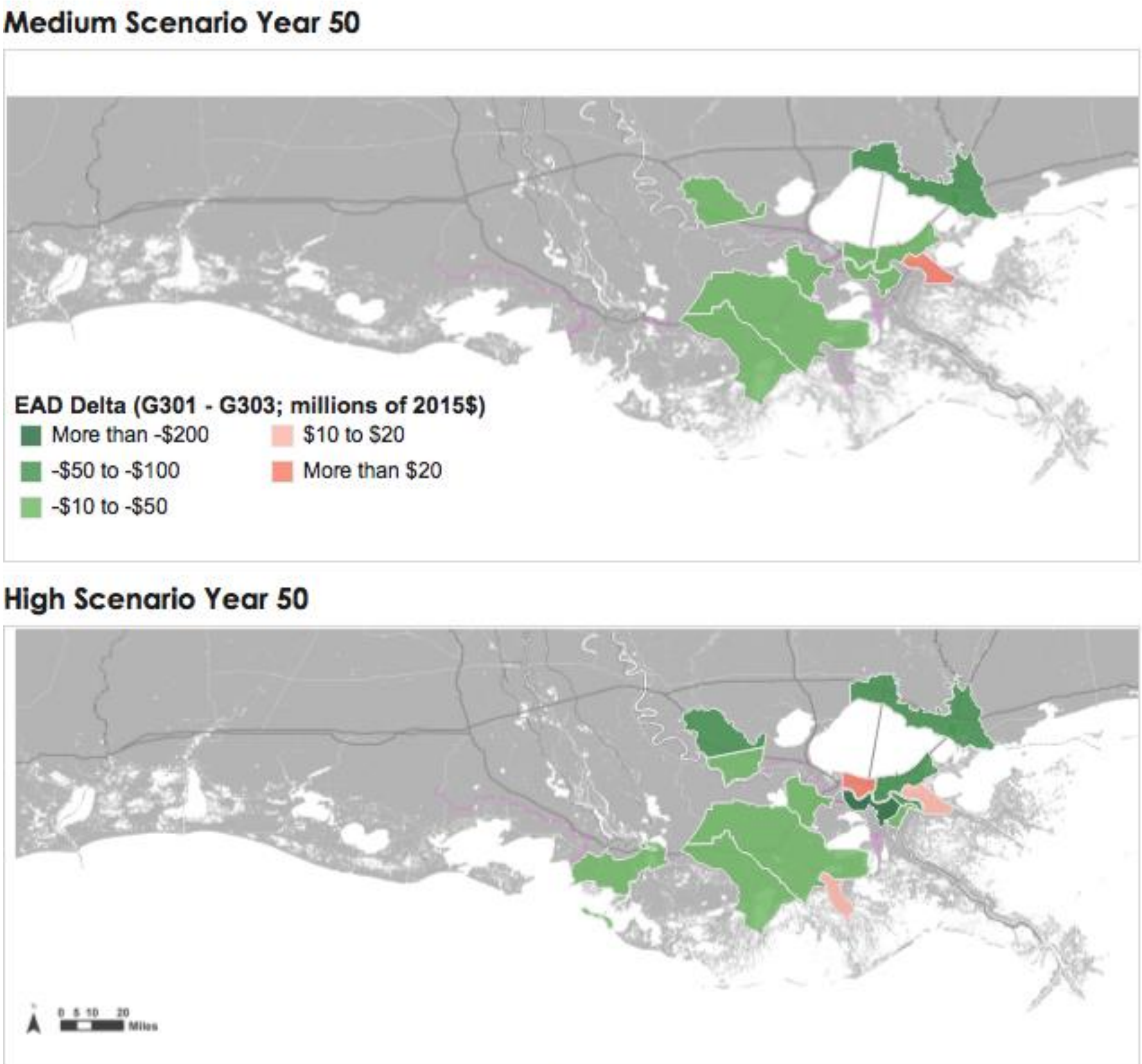


Note: Change in 50th percentile 100-year flood depths with G301 compared to G303. Only grid points with flood depth deltas greater than 0.2 m shown.

Figure 363: Difference in Median 100-Year Flood Depths due to Implementation of G301 compared with G303 in the Eastern Region of Coastal Louisiana (year 50; high scenario). IPET fragility scenario shown in enclosed areas.

5.5.2.2 Damage

The inclusion of restoration projects together with risk reduction projects in G301 also yields damage changes when compared to risk reduction projects alone (G303). These changes are most often beneficial, with a net reduction in damage for G301 compared to G303. Figure 364 summarizes these differences coast wide in the medium and high scenarios (year 50, historical growth, IPET fragility), mapping the change in EAD between the alternatives. Green shades show locations where damage reduction is greater with G301, while red shades indicate where the inclusion of restoration projects might yield induced damage. Results show that in most cases, restoration projects work synergistically with structural risk reduction projects or alignments to yield additional damage reduction. For instance, restoration projects in Lake Pontchartrain yield an additional $90-92 million in damage reduction for St. Tammany Parish when compared with risk reduction from the Lake Pontchartrain Barrier (001.HP.08) and Slidell Ring Levees (001.HP.13) projects alone. Similar effects are observed for Houma and areas behind the Morganza to the Gulf alignment, areas west of Lake Maurepas, and much of the East and West Bank HSDRRS system. However, some portions of HSDRRS, particularly St. Bernard Parish, show damage increase rather than reduction with restoration included. Increases are generally modest, however ($10-20 million).



Note: Change in mean EAD with G301 compared to G303 (IPET fragility scenario, Historical Growth population scenario). Only risk regions with EAD deltas greater than $5 million are shown for clarity.

Figure 364: Change in EAD between G301 and G303 (year 50; medium and high scenario; historical growth and IPET fragility scenarios; mean estimate).

Particularly notable is the change in damage in G301 for Jefferson Parish (West Bank HSDRRS). Here, the inclusion of restoration reduces the induced damage from protection alignments highlighted in the previous section, going from $986 million (G303) to $518 million (G301) in the high scenario, year 50 (historical growth, IPET fragility). Restoration in the Barataria Basin appears to work together with protection alignments to yield improved damage reduction for most neighboring regions, including St. Charles (Hahnville/Luling).

Total EAD reduction from both G301 and G303 is compared below for the medium and high scenarios in years 25 and 50 (Figure 365). Total effect sizes are modest in year 25, with approximately $100 million in additional damage reduction from G301 compared to G303 in both scenarios. These effects increase by year 50, however, with $400 million in additional damage reduction in the medium scenario and nearly $1 billion in the high scenario. The damage reduction in Jefferson Parish (West Bank HSDRRS) accounts for approximately half of the additional benefit noted in the high scenario.

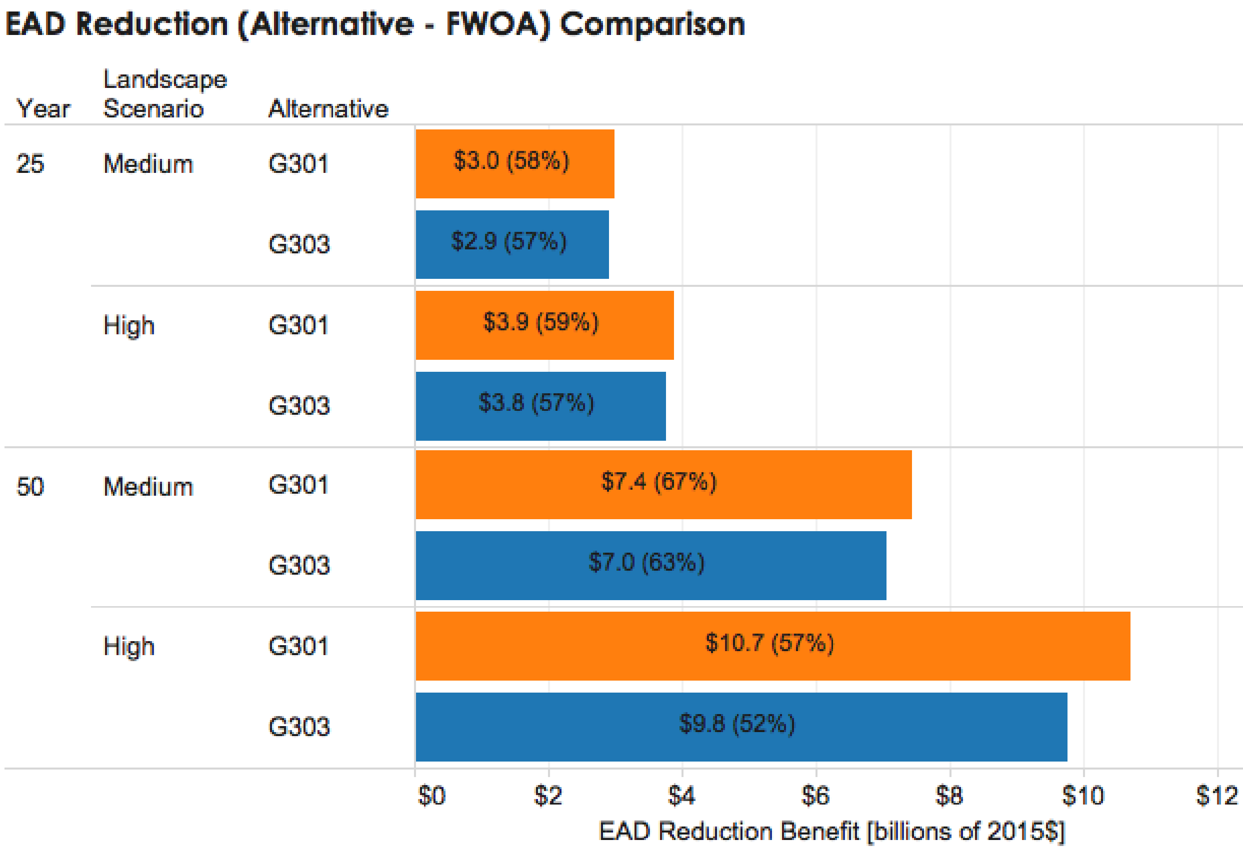


Figure 365: EAD Reduction for G301 and G303 (historical growth, IPET fragility scenarios; percent reduction in parentheses).

6.0 2017 Coastal Master Plan (G400)

This section contains outcomes and interpretations from the 50 year simulations of the draft master plan (G400) - Figure 366 compared to FWOA (G300). Example outputs are provided for stage, salinity, land, vegetation, fish and shellfish, storm surge and waves, and risk reduction. For a full set of decadal outputs for the landscape and ecological parameters, refer to Attachment C4-10. Because the final Coastal Master Plan did not change substantively from the draft version, model outcomes from the draft plan also serve as those for the final version of the plan.

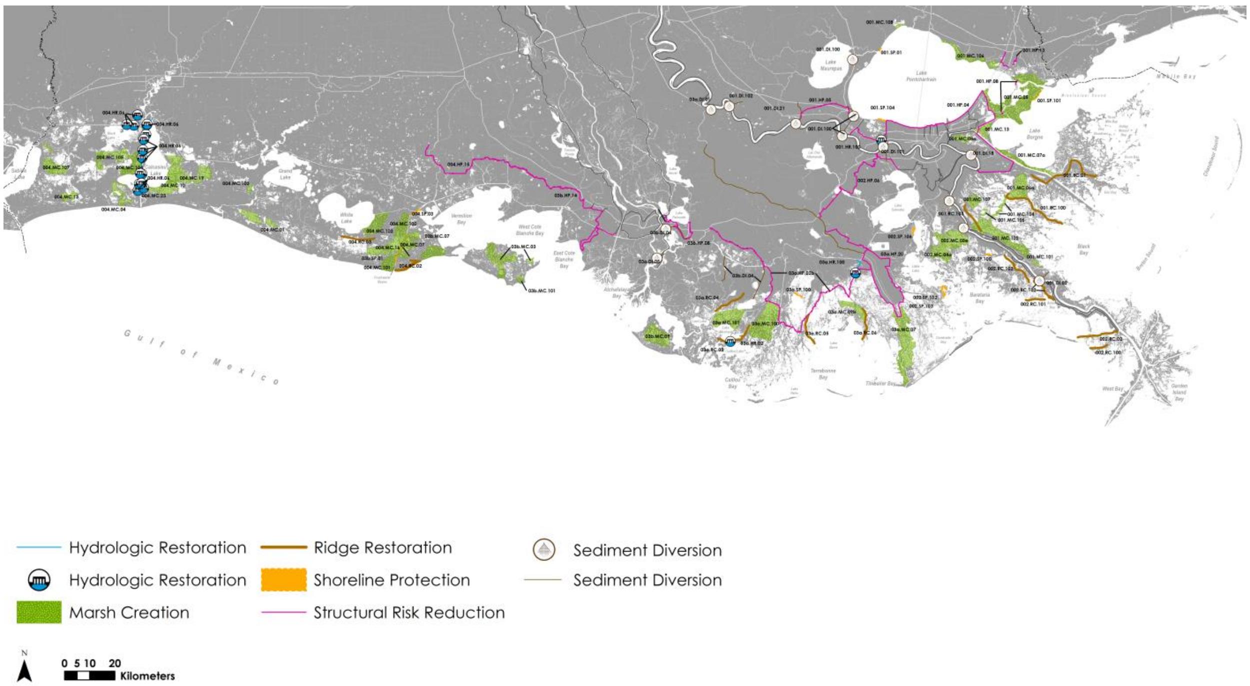


Figure 366: 2017 Draft Coastal Master Plan (G400).

6.1 Landscape and Ecosystem

6.1.1 Stage

High Scenario

The changes in mean water levels at year 10 are intuitive and show impacts on water level as a result of the many diversions that are implemented in the first decade (Figure 367). These patterns are also evident in the low scenario and medium scenario. However, the magnitude of difference is generally smaller under the high scenario, as compared to low. The large effects seen in Breton Sound and lower Bayou Lafourche due to diversions are slightly muted under the high scenario when compared to the low and medium scenarios. This is likely due to the higher rates of RSLR, which would cause a dampening of stage increases due to diversion inflows. In years 20 and 30, there is a general increase in water level in the Breton, Barataria, Maurepas, and Terrebonne areas in the high scenario, which also is evident in the low and medium scenarios. However, the magnitude of change from FWOA under the high scenario is not as substantial as the magnitude of change seen in the medium scenario. This holds with the assessment made for the medium scenario (below), that the magnitude of these changes in water level decrease with increased rates of sea level rise. There are a few regions in year 30, under the high scenario, where the water level is reduced compared to FWOA. This appears to be the result of structural protection projects (Larose to Golden Meadow [03a.HP.20]) and from maintaining marsh areas east of New Orleans as a result of the New Orleans Landbridge East Restoration (001.MC.05) project. At year 50 (Figure 382), the spatial extent of impacted annual mean water level remains relatively consistent with the patterns seen in earlier decades. The water level is still most impacted in areas immediately adjacent to diversion outfall locations. Upper Barataria Basin has slightly higher water levels than FWOA due to the control structures on the Upper Barataria Risk Reduction (002.HP.06) project.

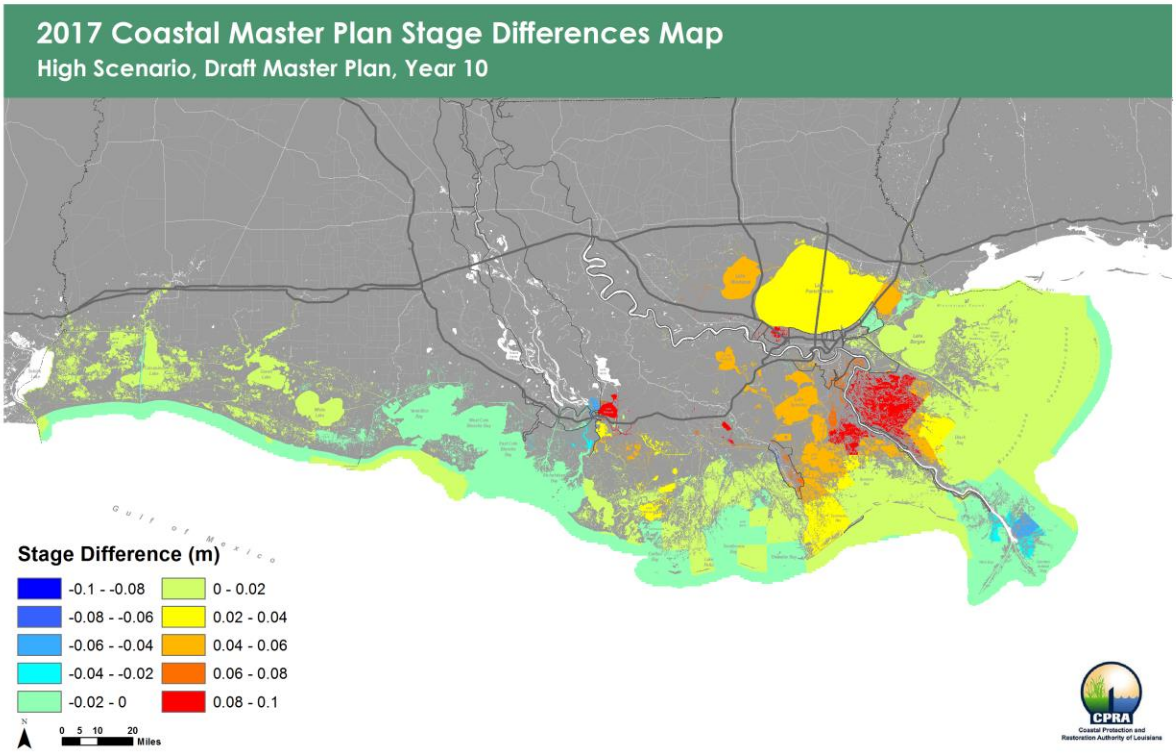


Figure 367: Difference in Annual Mean Water Level for the Draft Master Plan compared to FWOA (year 10; high scenario). Warm colors indicate higher water level for draft master plan.

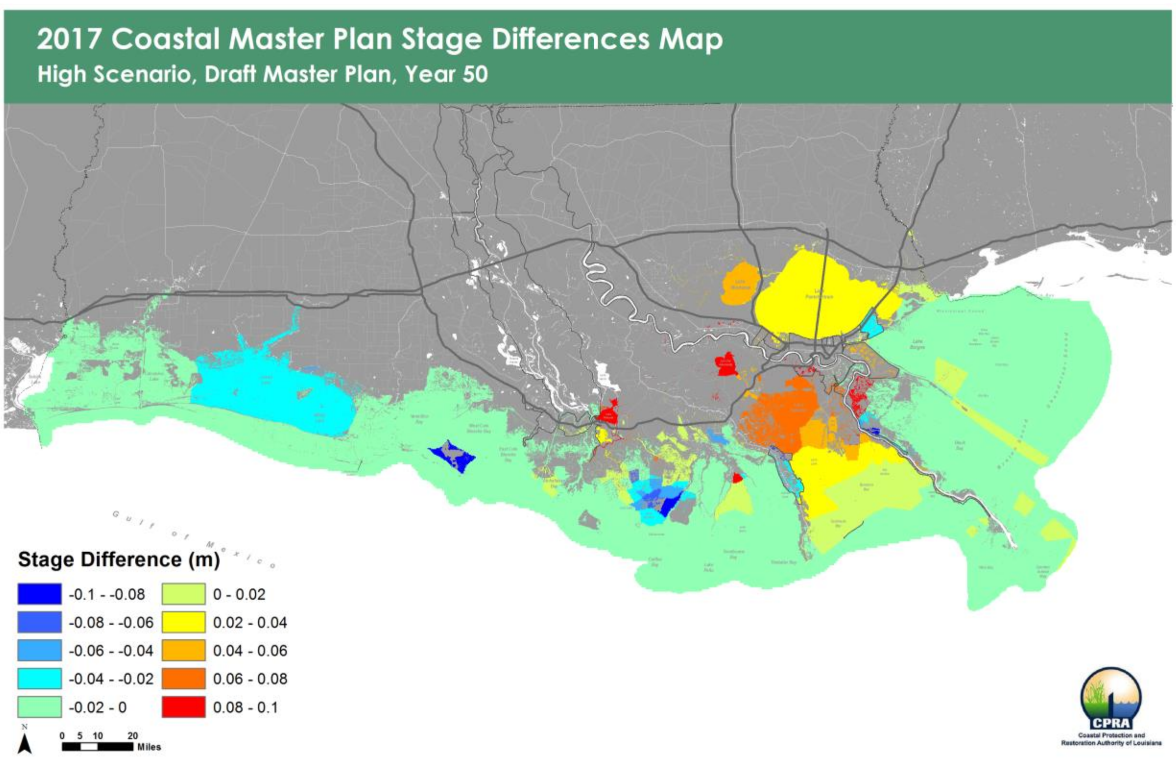


Figure 368: Difference in Annual Mean Water Level for the Draft Master Plan compared to FWOA (year 50; high scenario). Warm colors indicate higher water level for draft master plan.

Medium Scenario

The changes in mean water level at year 10 (Figure 369)are intuitive and show impacts on water level as a result of the many diversions that are implemented in the first decade. Water level is substantially higher, compared to FWOA, in Breton Sound due to the Mid-Breton Sound Diversion (001.DI.23). The water level in Barataria is higher near the Mid-Barataria Diversion (002.DI.03) outfall, with smaller increases further away. The water level is higher in the Maurepas region due to the Union Freshwater Diversion (001.DI.102), and similar increases can be seen due to the Labranche Hydrologic Restoration (001.HR.100) project. Water levels are higher in central Terrebonne, while slightly lower in the Atchafalaya area due to the Increase Atchafalaya Flow to Terrebonne (03b.DI.04) project. The magnitudes of the changes in water level in Terrebonne are slightly dampened in the medium scenario compared to the low scenario, likely due to the higher rates of RSLR. A large water level increase is also evident at the downstream regions of Bayou Lafourche, due to the Bayou Lafourche Diversion (03a.DI.01) that is implemented in year seven.

At year 25 of the simulation (Figure 370), the water levels in the Barataria, Breton, and central Terrebonne areas remain elevated due to the many diversion projects, relative to FWOA. The Maurepas region, particularly in the immediate receiving bodies of the freshwater diversion, also has elevated mean water level compared to FWOA, as it did in earlier decades. The upper Barataria region shows a marked increase from FWOA in the receiving region of the Ama Sediment Diversion (001.DI.101), implemented in year 19. The Upper Barataria Risk Reduction (002.HP.06) project (implemented in year 11), also appears to produce a slight increase in water level in the uppermost reaches of Barataria. There is no significant impact on water levels in the Bird’s Foot Delta under the medium scenario. Also, while the spatial extent of increased water level is approximately the same under both medium and low scenarios, the magnitude of the increase (relative to FWOA), is smaller under the medium scenario than it is under the low. This is an intuitive response due to the higher rates of sea level rise under the medium scenario compared to the low scenario

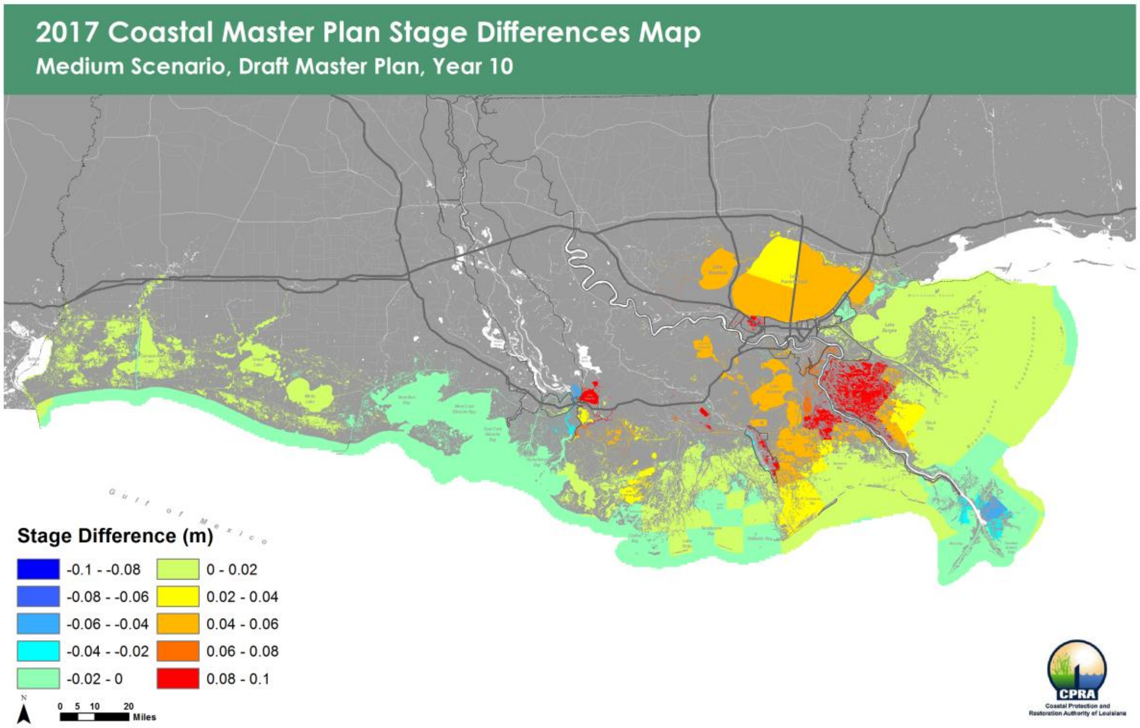


Figure 369: Difference in Annual Mean Water Level for the Draft Master Plan compared to FWOA (year 10; medium scenario). Warm colors indicate higher water level for draft master plan.

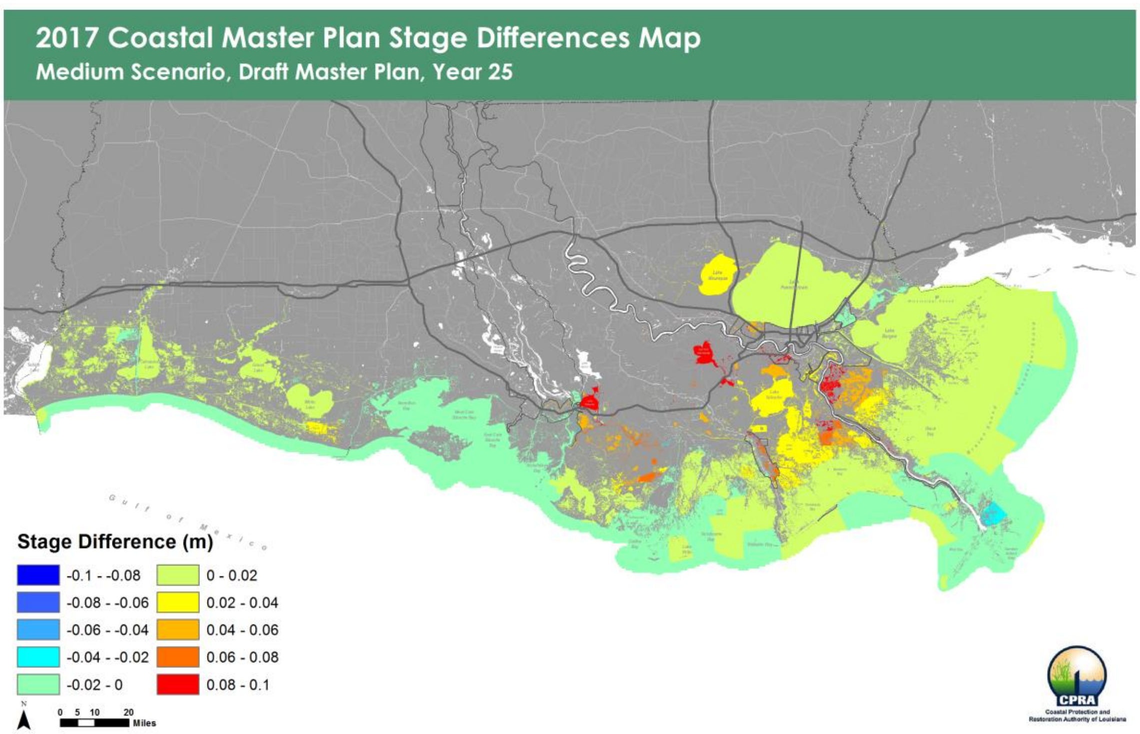


Figure 370: Difference in Annual Mean Water Level for the Draft Master Plan compared to FWOA (year 25; medium scenario). Warm colors indicate higher water level for draft master plan.

During later years of the simulation, under the medium scenario, the only region of the model domain showing any meaningful changes in mean water level are the regions directly impacted by diversions. Eastern Terrebonne has a significant extent of increased water level compared to FWOA, which is likely a combined effect of the Bayou Lafourche Diversion (03a.DI.01) and Increase Atchafalaya Flow to Terrebonne (03b.DI.04) project. Barataria and Breton both show large extents of increases in water level due to the multiple diversions located there; as does the southwestern portion of Maurepas swamp and Labranche wetland, which are locations of freshwater diversions. By year 50 (Figure 371), there is a decrease in mean water level in the Larose to Golden Meadow region, likely the result of the Larose to Golden Meadow (03a.HP.20) project implemented in year nine preventing water that would have entered the region during later years of FWOA.

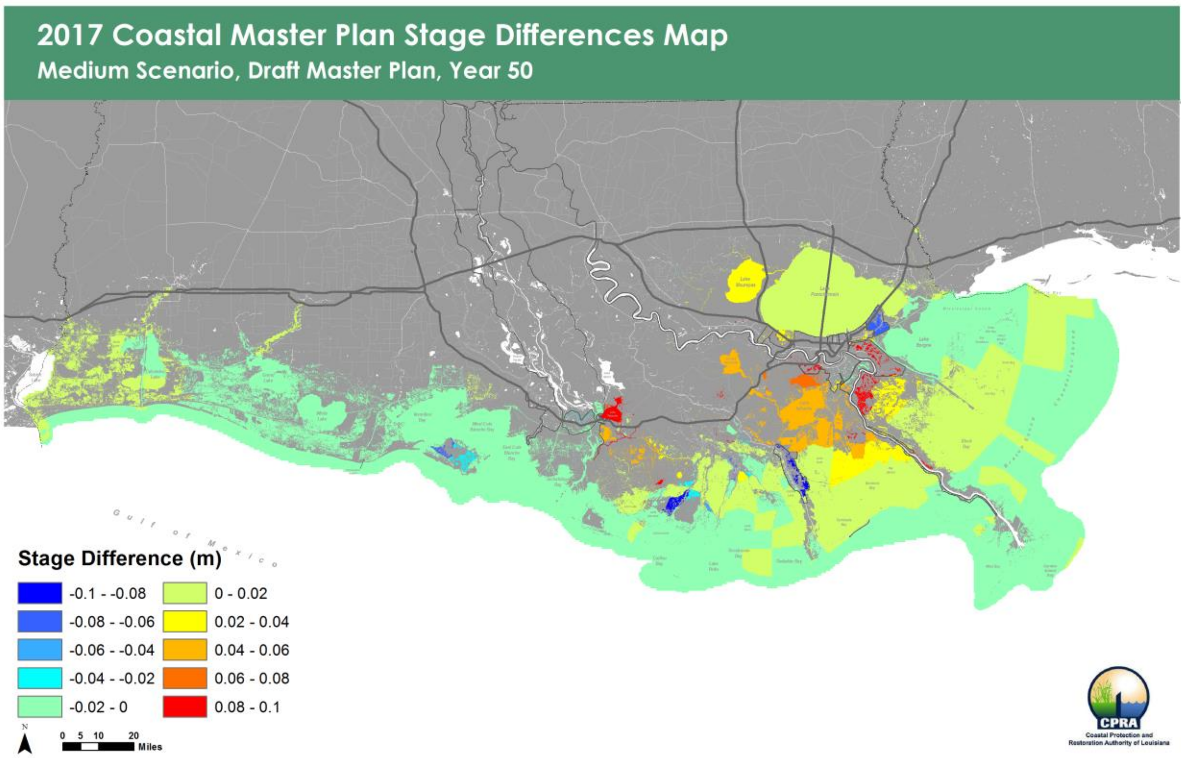


Figure 371: Difference in Annual Mean Water Level for the Draft Master Plan compared to FWOA (year 50; medium scenario). Warm colors indicate higher water level for draft master plan.

6.1.2 Salinity

High Scenario

At year five (Figure 372), the impacts on salinity under the high, medium, and low scenarios are essentially the same. They are intuitive and show a significant freshening effect in Calcasieu Lake (including West Cove) and the surrounding wetland areas due to the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project coming online at year four. There is a small area of increased salinity in upper Breton Sound due to the construction of the Bayou Terre aux Boeufs Ridge Restoration (001.RC.100) project during year five. The area between the ridge and the Mississippi River Gulf Outlet is slightly more saline with the draft master plan compared to FWOA, likely due to a reduction in flow capacity, resulting in less fresh water from the Caernarvon diversion reaching this region post-implementation. There is also an impact on salinities due to the Bayou Eau Noire Ridge Restoration project (002.RC.102). This ridge appears to "trap" fresh flow in between the ridge and the Mississippi River, resulting in fresher water post-implementation on the eastern side of the ridge and slightly higher salinities on the western side. The other area of salinity impact at year five is to the east of the Bayou Pointe au Chene Ridge Restoration (03a.RC.06) project, due to a reduction in flow, which prevents water from the Bayou Lafourche drainage areas from flowing westward into eastern Terrebonne.

In year 10 (Figure 373), the salinity patterns in Calcasieu Lake and surrounding areas continue to show significant freshening. However, compared to the medium scenario, the impact on salinity in West Cove seems to be dampened, with only slight freshening from FWOA under the high scenario. The multiple diversions that are implemented in Barataria, Breton, and Terrebonne basins (including the Increase Atchafalaya Flow to Terrebonne (03b.DI.04) project and Bayou Lafourche Diversion (03a.DI.01)), result in wide-spread freshening, with the largest magnitude of freshening in lower Barataria Basin. The Union Freshwater Diversion (001.DI.102), which is implemented in year nine, does not show any impact on annual mean salinities, likely due to the generally low salinities in the receiving areas at year 10.

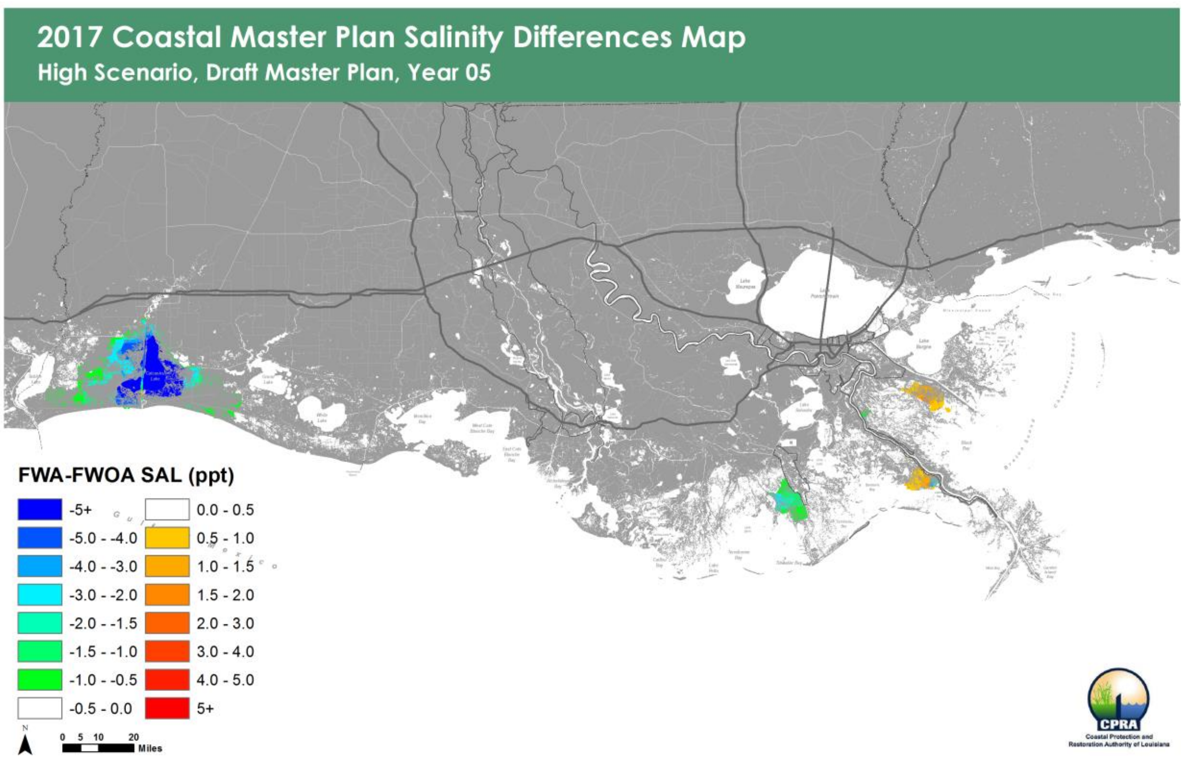


Figure 372: Difference in Annual Mean Salinity for the Draft Master Plan compared to FWOA (year 5; high scenario). Warm colors indicate more saline conditions for the draft master plan.

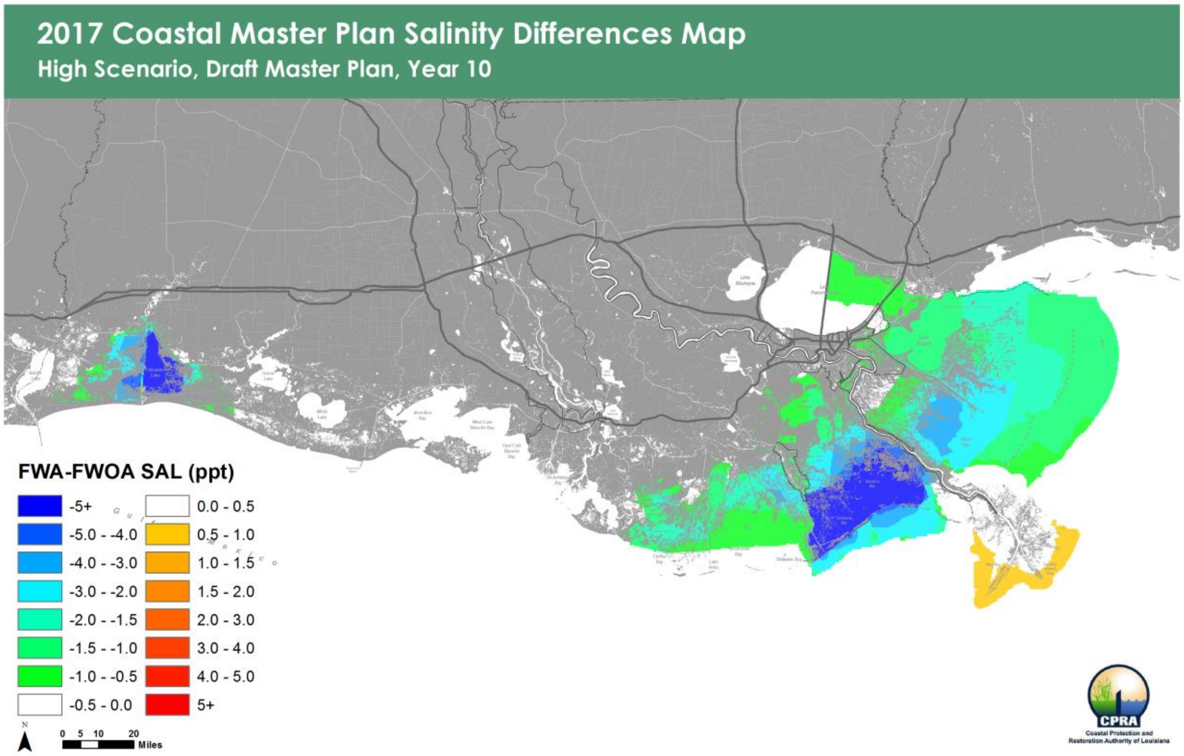


Figure 373: Difference in Annual Mean Salinity for the Draft Master Plan compared to FWOA (year 10; high scenario). Warm colors indicate more saline conditions for the draft master plan.

The salinity patterns seen at year 10 generally remain at year 20 and 30. Significant freshening can be seen in and around Calcasieu Lake and in Breton Sound, Barataria, and eastern Terrebonne basins. The magnitude of the freshening (compared to FWOA) is greater in Barataria in year 30 than in year 20. This is evidence of the diversions keeping salinities from increasing as high as they do in FWOA during later years of the simulation. Slight increases in salinity at the Bird's Foot Delta, compared to FWOA, can be seen both at year 20 and year 30 (Figure 374) due to the large diversions upstream. Compared to the medium scenario, the magnitude and spatial extent of salinity reduction (compared to FWOA) under the high scenario is noticeably higher at year 30. This is an intuitive response since these diversions keep areas fresh, whereas under the high scenario for FWOA they become more saline than under the medium scenario for FWOA. Similar to the medium scenario (although to a slightly lesser extent), there is a region of increased salinity (compared to FWOA) southeast of White Lake. This is likely due to the implementation of numerous marsh creation projects near Freshwater Bayou that reduce the hydrologic connectivity of this area and at the same time reduce the volume of water bodies and therefore their buffering capacity when receiving intermittent flow from saline sources (e.g., during high water events in the Gulf).

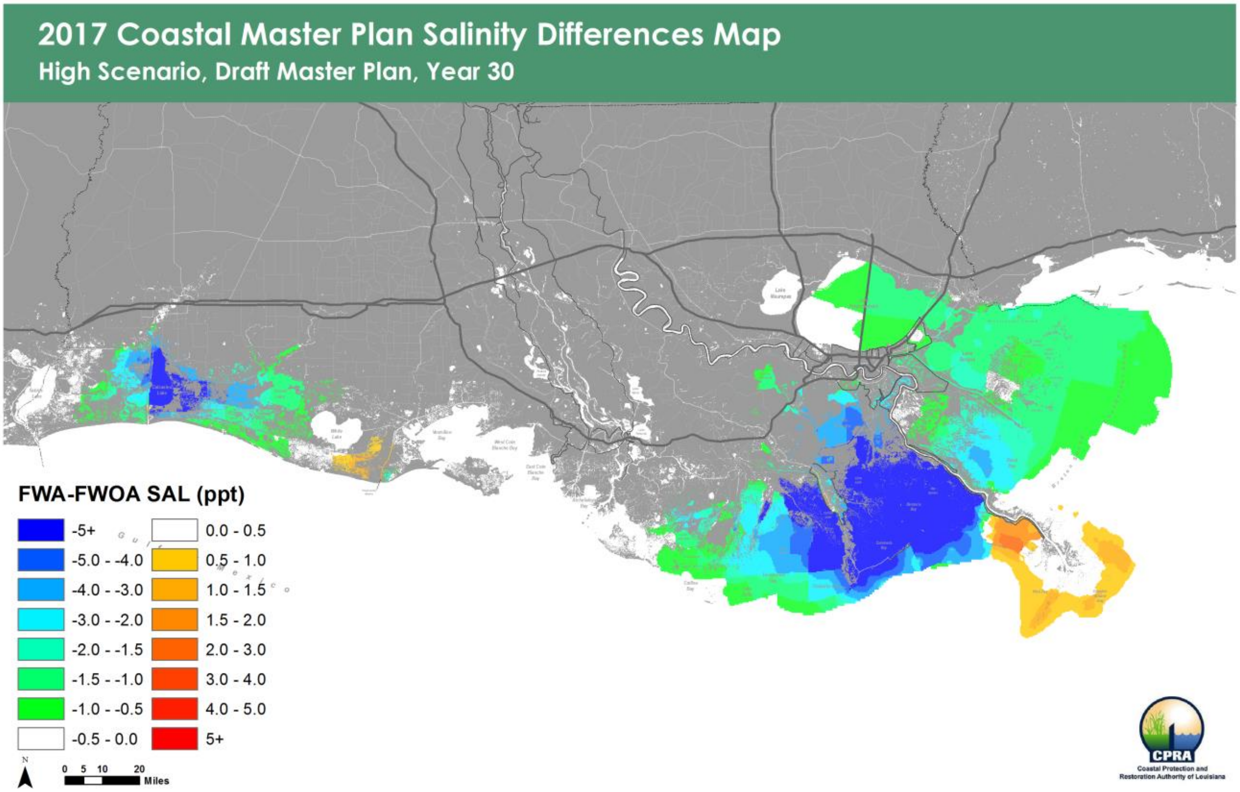


Figure 374: Difference in Annual Mean Salinity for the Draft Master Plan compared to FWOA (year 30; high scenario). Warm colors indicate more saline conditions for the draft master plan.

Additional differences under the high scenario are seen in the eastern portion of Lake Pontchartrain during year 30 (Figure 374), where freshening (compared to FWOA) occurs. This is likely due to the Lake Pontchartrain Barrier (001.HP.08) project. The flood gates are activated more often in later years of the simulation under the high scenario due to the higher rates of sea level rise triggering the stage controls more frequently. Closing of the flood gates, in conjunction with increased freshwater flows into the Pontchartrain Basin, results in freshening in the region. At year 50 (Figure 375), there is evidence of substantial freshening, compared to FWOA. The entire Barataria Basin, from the Gulf of Mexico to Donaldsonville, is the largest impacted region, with salinity more than 5 ppt lower than in FWOA. This is likely the result of the various diversions into Barataria Basin (e.g., Ama Sediment Diversion (001.DI.101) and Mid-Barataria Diversion [002.DI.03]) as well as the Upper Barataria Risk Reduction (002.HP.06) project, which results in the maintenance of land areas in the upper Barataria area, and also keeps salt water from intruding. There is also significant freshening at year 50 in both central and eastern Terrebonne, compared to FWOA. This is likely the result of the Increase Atchafalaya Flow to Terrebonne (03b.DI.04) project and Bayou Lafourche Diversion (03a.DI.01). Upper Pontchartrain Basin, in the Maurepas region, is also less saline than in FWOA. This results from a combined effect of the Lake Pontchartrain Barrier (001.HP.08) project as well as the river diversions into the Maurepas swamp. In year 50, under the high scenario, the Lake Pontchartrain Barrier (001.HP.08) project control gates remain closed for much of the time; not only is Lake Pontchartrain less saline than in FWOA, but there is a slight increase in salinity in Lake Borgne and Chandeleur Sound. This is due to the "trapping" of fresh water in Lake Pontchartrain when the flood control gates are closed. A similar increase in salinity is also seen in Breton Sound southwest of the Mississippi River Gulf Outlet, which is likely a combined effect of the Lake Pontchartrain Barrier (001.HP.08) project and less residual river flow reaching the Bird's Foot Delta due to the numerous diversions further upstream. An increase in salinity is also seen near the Bird's Foot Delta on the Breton side of the River. The Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project, results in salinity reduction in the western region of the coast; however, the magnitude is less in later years of the simulation. In the western/central region of the coast (near Grand and White Lakes) there are areas of both slightly more saline and fresher areas compared to FWOA. The Freshwater Bayou Marsh Creation (004.MC.100) project appears to slightly freshen areas directly adjacent to Freshwater Bayou. This localized freshening seems to cause the slightly higher salinities further away from the project, indicating reduced hydrologic connectivity between the interior marsh areas and the bayou.

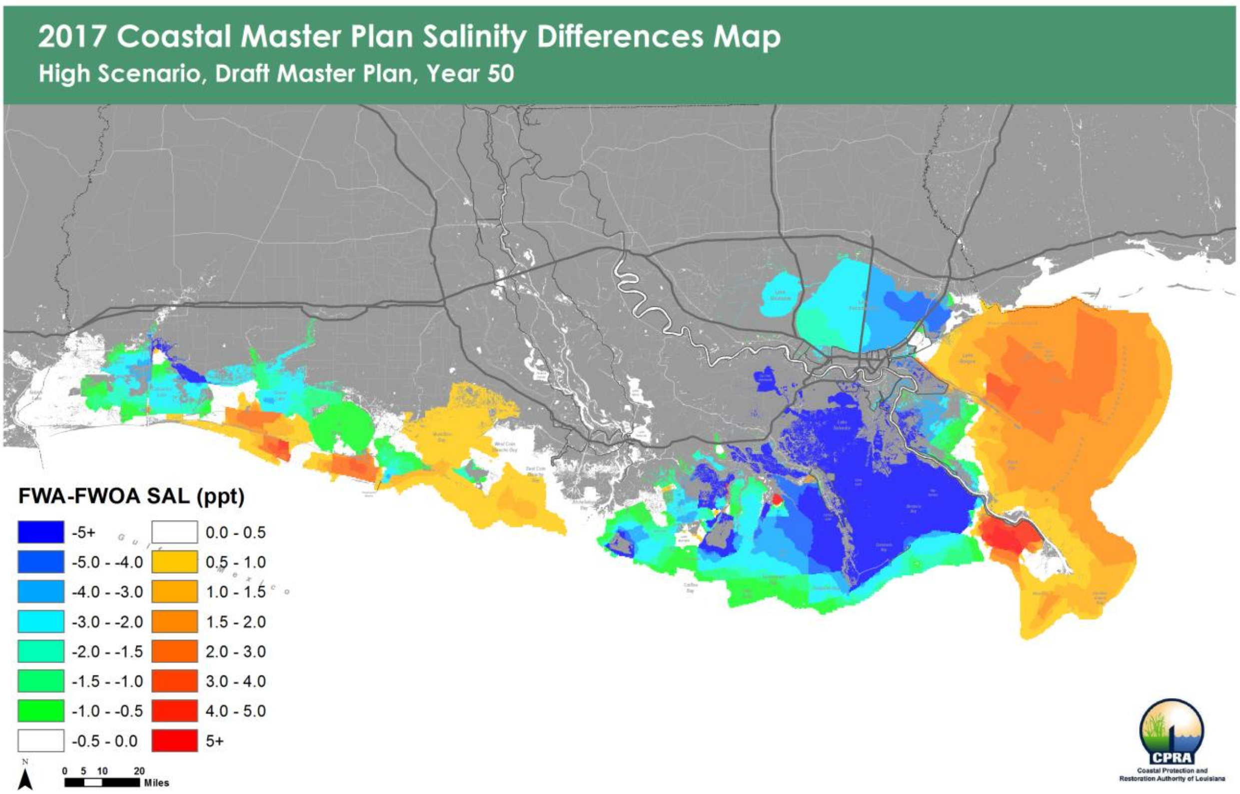


Figure 375: Difference in Annual Mean Salinity for the Draft Master Plan compared to FWOA (year 50; high scenario). Warm colors indicate more saline conditions for the draft master plan.

Medium Scenario

For the first five years, the impacts on salinity under the medium scenario are essentially the same as those seen under the high scenario. They are intuitive and show a significant freshening effect in Calcasieu Lake (including West Cove) and the surrounding wetland areas due to the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project (implemented at year four). There is a small area of increased salinity in upper Breton, due to the construction of the Bayou Terre aux Boeufs Ridge Restoration (001.RC.100) project during year 5. The area between the ridge and the Mississippi River Gulf Outlet is slightly more saline with the draft master plan projects in place when compared to FWOA. This is likely due to reduced flow capacity resulting in less fresh water from the Caernarvon diversion reaching this region post-implementation. There is also an impact on salinity due to the Bayou Eau Noire Ridge Restoration (002.RC.102) project. This ridge appears to "trap" fresh water between the ridge and the Mississippi River, resulting in fresher water post-implementation on the eastern side of the ridge, and slightly higher salinities on the western side. The other area of salinity impact at year 5 is to the east of the Bayou Pointe au Chene Ridge Restoration (03a.RC.06) project, due to a reduction in flow, which prevents water from the Bayou Lafourche drainage areas from flowing westward into eastern Terrebonne. In year 10, the patterns in Calcasieu Lake and surrounding areas continue to show substantial freshening due to the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project.

The multiple diversions that are implemented in Barataria, Breton, and Terrebonne (including Increase Atchafalaya Flow to Terrebonne (03b.DI.04) project and Bayou Lafourche Diversion (03a.DI.01)) result in widespread freshening, with the largest magnitude freshening in lower Barataria. The Union Freshwater Diversion (001.DI.102) does not show an impact on annual mean salinities, likely due to the generally low salinities in the receiving areas of the model at year 10. The salinity patterns observed at year 10 generally remain at year 20 and 30. Substantial freshening is seen in and around Calcasieu Lake and in Breton Sound, Barataria, and eastern Terrebonne basins. The magnitude of the freshening (compared to FWOA) is greater in Barataria Bay in year 30 than in year 20. This is evidence of the diversions keeping salinities from increasing as high as they do in FWOA during later years of the simulation. Slight increase in salinity at the Bird's Foot Delta, compared to FWOA, is seen both at year 20 and year 30 due to the large flow diversions upstream. There appears to be a region of increased salinity (compared to FWOA) southeast of White Lake. This is likely due to the implementation of several marsh creation projects near Freshwater Bayou that likely reduce the hydrologic connectivity of this area while also reducing the volume of water bodies and therefore their buffering capacity when receiving intermittent flow from saline sources (e.g., during high water events in the Gulf). During later years of the simulation under the medium scenario, the salinity reduction compared to FWOA is greater than that under the high scenario (Figure 376). The Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project appears to have quite a bit more freshening impact under the medium scenario than under the high scenario. Lake Pontchartrain also has some freshening as it does under the high scenario; however, the Lake Pontchartrain Barrier (001.HP.08) project gates do not seem to be closed as often, and therefore, there is no increase in salinity in Lake Borgne/Chandeleur Sound under the medium scenario, as there is under the high scenario. Under the medium scenario, Barataria again appears to be the most impacted region in the model domain, showing substantial freshening (compared to FWOA) as a result of the combined effects of the multiple diversions and the Upper Barataria Risk Reduction (002.HP.06) project.

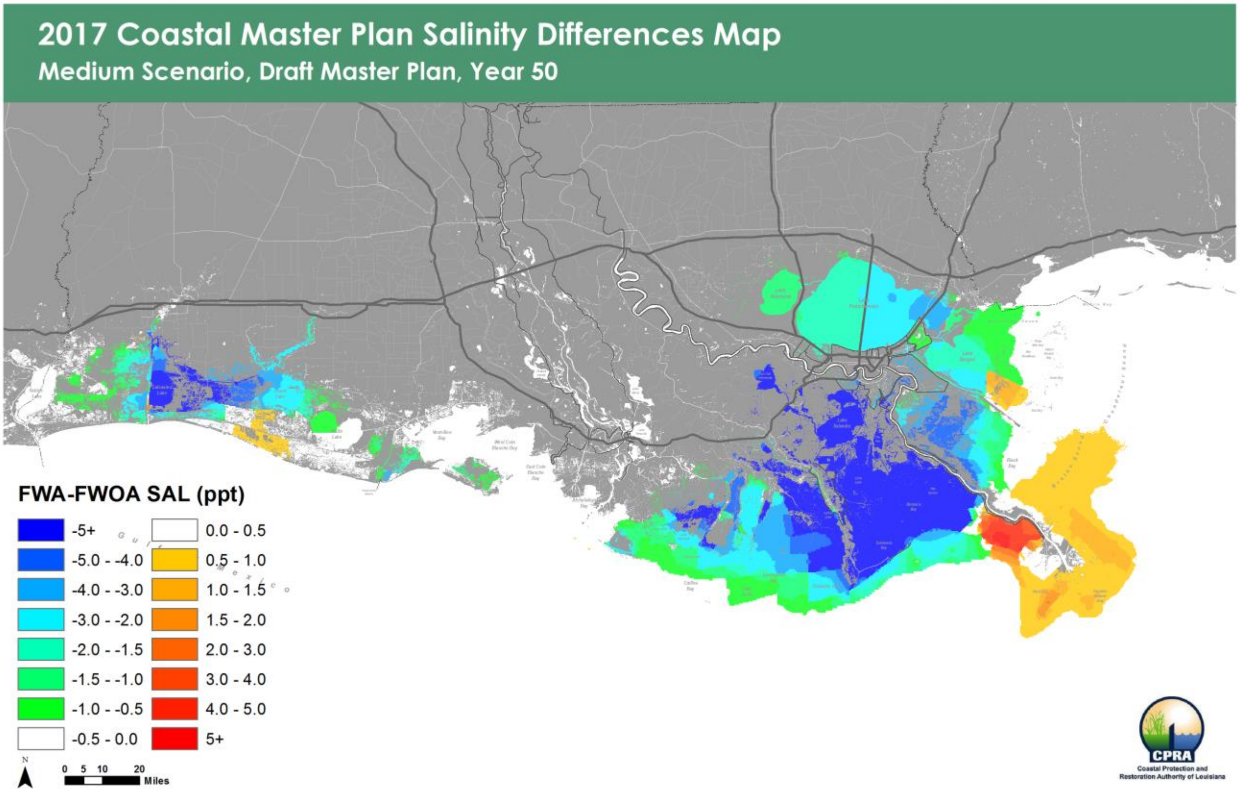


Figure 376: Difference in Annual Mean Salinity for the Draft Master Plan compared to FWOA (year 50; medium scenario). Warm colors indicate more saline conditions for the draft master plan.

6.1.3 Land Change

High Scenario

Land change over time under the high scenario, similar to the medium scenario, is intuitive considering the parameters being modeled. Overall, the draft plan results in approximately 3,000 km^2 of net land area benefit under the high scenario, compared to FWOA at the end of the 50-year simulation. This figure includes both land sustained and new land built (Figure 377).

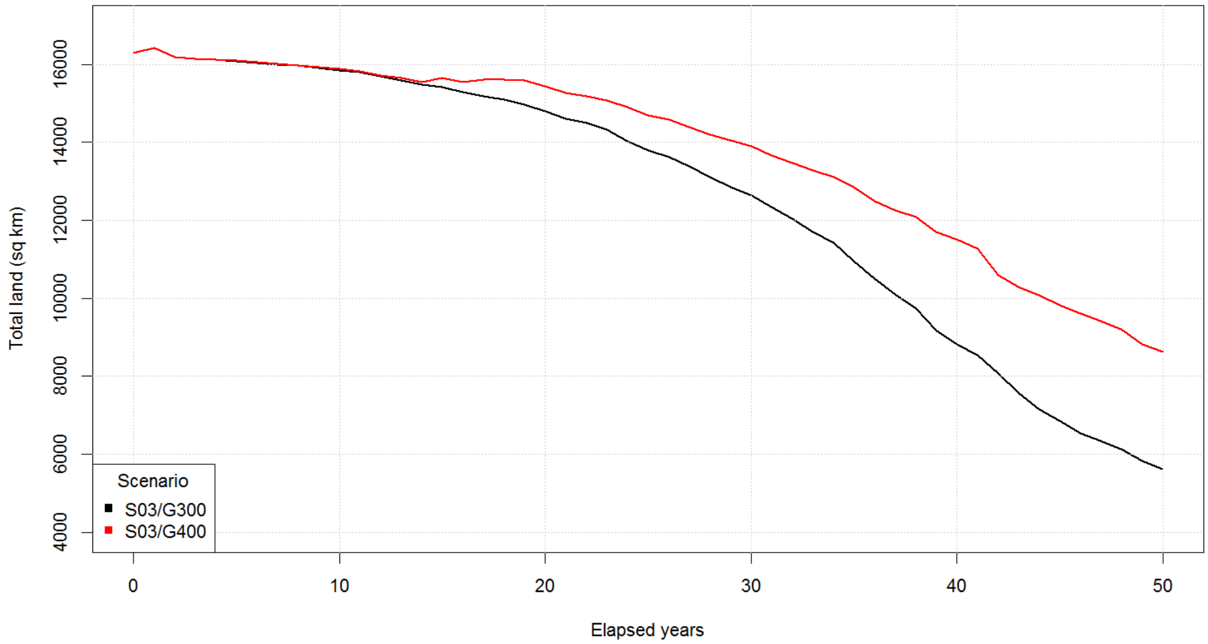


Figure 377: Coast Wide Land Area over Time for the Draft Master Plan (G400) and FWOA (G300); high scenario.

The land change benefits in the western region are almost exclusively due to marsh creation projects implemented in the draft plan. Marsh creation projects are observed to generally have a positive impact on net land area, at least for a period of time. In several instances, the benefits are short-lived due to the overwhelming impacts of the sea level rise and subsidence modeled in the high scenario.

In year 20 (Figure 378), there is a large area of negative effect in the area north of Creole and Grand Chenier southeast of the East Calcasieu Lake Marsh Creation (004.MC.19) project; its impact disappears by year 30 as the loss also occurs in FWOA. By year 40, there is net land area benefit in the vicinity of the GIWW due to a lowering of salinity with the draft plan. By year 50 (Figure 379), many of the land benefits are lost, with only East Calcasieu Lake (004.MC.19), Calcasieu Lake West Bank (004.MC.104), West Brown Lake (004.MC.105), and West Sabine Refuge (004.MC.107) Marsh Creation projects remaining largely intact. This is likely a result of their late implementation date.

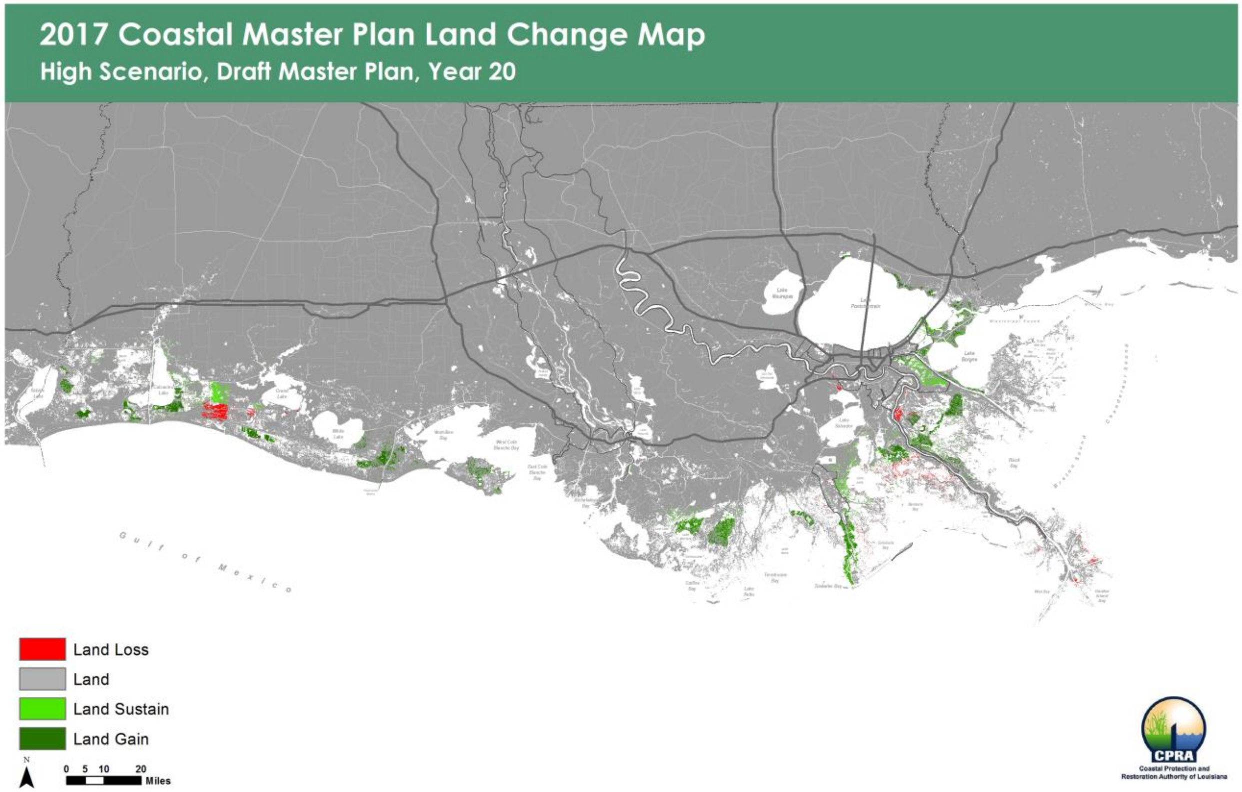


Figure 378: Land Change with the Draft Master Plan compared to FWOA (year 20; high scenario).

Marsh creation and diversion projects in the central region of the coast generally have a positive impact on net land area, in most cases, for a majority of the modeling period under the high scenario.

Similar to the medium scenario, benefits from the Increase Atchafalaya Flow to Terrebonne (03b.DI.04) project are seen beginning at year 20 (south of the Lake Palourde) and continue to expand through year 50. The benefit is localized and areas of land change benefits are generally confined to shallow areas along the shoreline in the vicinity of the diversion outfall. There is substantial land area benefit southwest and northwest of Houma at year 50. This was also observed in previously modeled alternatives. It is the result of hydrological and salinity changes due to the implementation of multiple projects that cause a vegetation transition and different marsh collapse criteria between a future with these projects and FWOA.

In the eastern region of the coast, there is a combination of land gain and land loss areas. Negative land area impacts occur in the Bird's Foot Delta, which is a result of diversions, which pull water and sediment out of the Mississippi River further upstream, thereby leading to a negative impact on deposition/accretion in the delta region. There is also some local negative impact around Mid-Breton Sound Diversion (001.DI.23) outfall due primarily to the increase in stage produced by the operation of the diversion.

Positive impacts on land area are observed as a result of the many diversions included in the draft master plan; additional positive impacts are realized from marsh creation, ridge creation, and shoreline protection projects. Some marsh creation associated benefits begin to be lost in later years of the simulation, particularly in lower parts of the basins as would be expected due to the higher sea level rise and subsidence rates modeled in this (high) scenario. Positive impacts are observed in upper Barataria Basin by year 50 due to the freshening of that area (Figure 379), even more so than are observed under the medium scenario. There is benefit observed in the Maurepas region that likely results from the East Maurepas Diversion (001.DI.21), West Maurepas Diversion (001.DI.29), and the Manchac Landbridge Shoreline Protection (001.SP.01) project, in concert with the New Orleans East Landbridge Restoration (001.MC.05) project, to reduce salinity and thereby prevent the marsh collapse seen in FWOA. The presence of the Lake Pontchartrain Barrier (001.HP.08) project also impacts water level and salinity levels in the Maurepas region, further improving the land benefit in this region under the high scenario.

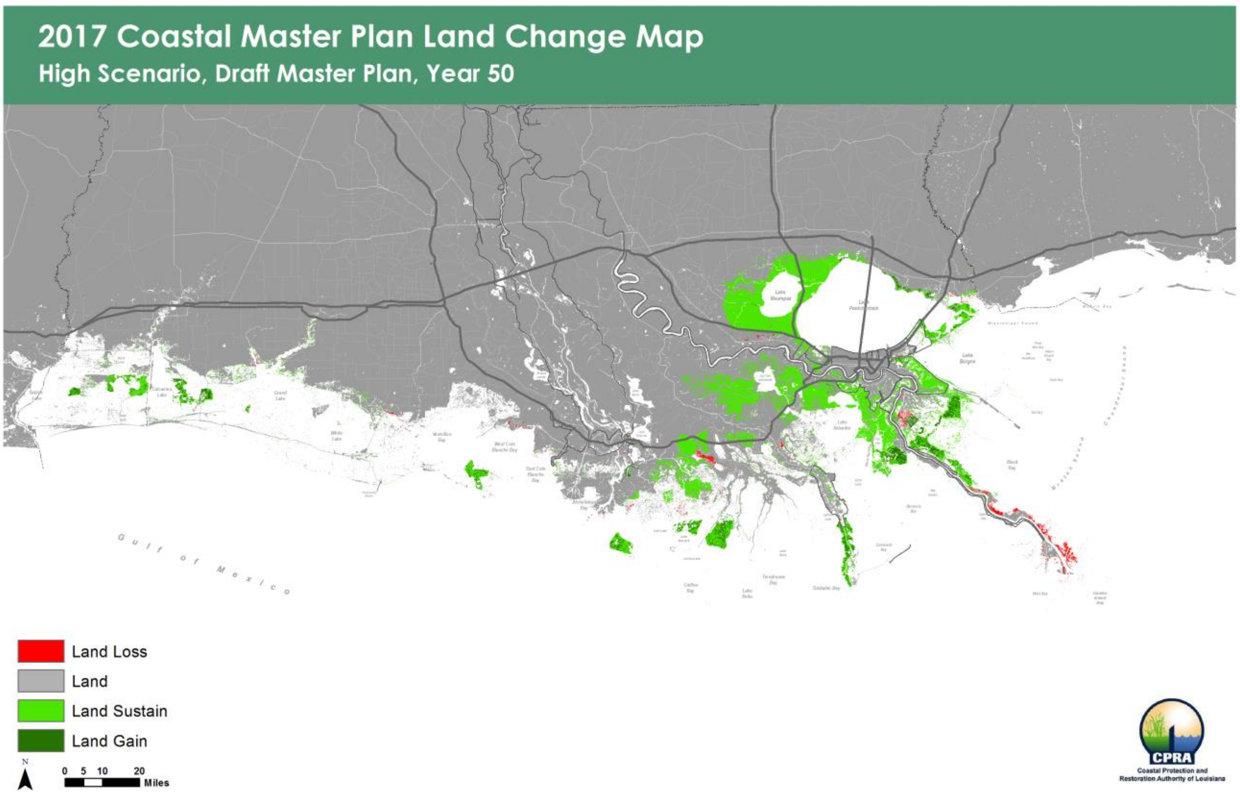


Figure 379: Land Change with the Draft Master Plan compared to FWOA (year 50; high scenario).

Medium Scenario

The pattern of land change under the medium scenario for the draft plan is intuitive considering the parameters being modeled. Overall, approximately 2,077 km^2 of net land area benefit is realized compared to FWOA at the end of the 50-year simulation. This figure includes both land sustained and new land built (Figure 380).

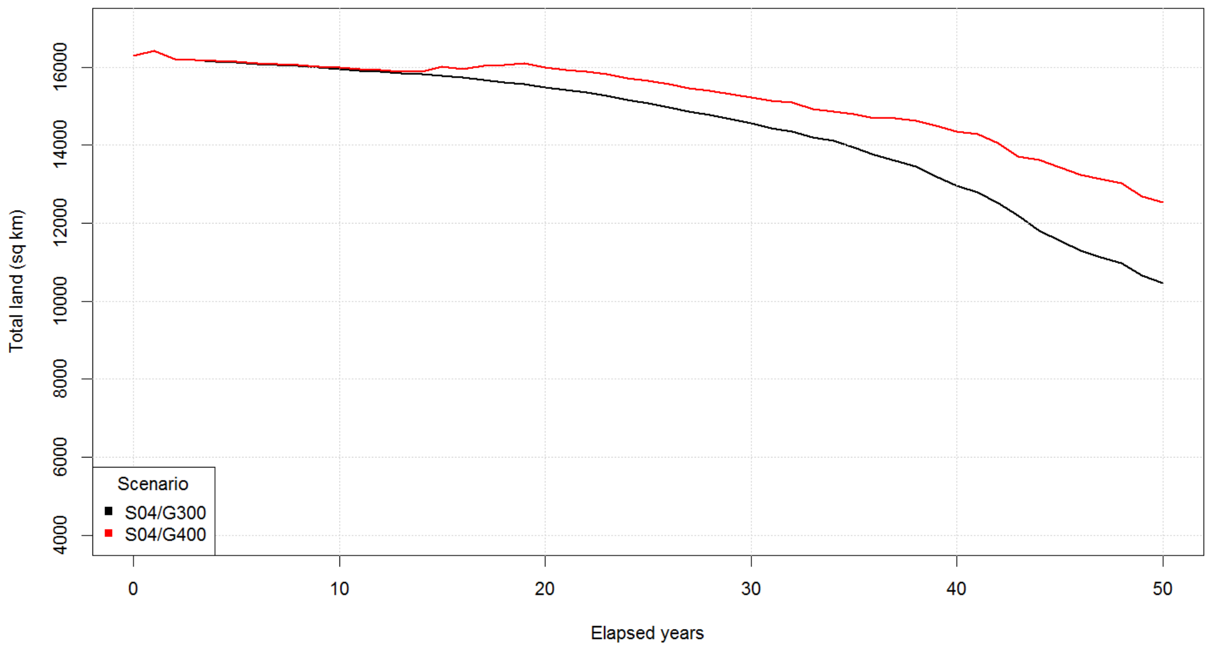


Figure 380: Coast Wide Land Area over Time for the Draft Master Plan (G400) and FWOA (G300); Medium Scenario.

Net land area benefit from project implementation is observed in the western region of the coast. The benefits in the region are almost exclusively due to marsh creation projects. Marsh creation projects generally have a positive impact on net land area with benefits persisting longer than that observed under the high scenario.

From years 20-40, there is an area of negative impact southwest of Lake Misere. There is little observable difference in stage compared to FWOA in the comparison years but some lowering in salinity. Most of this negative impact disappears by year 50, implying project implementation hastened losses in this area that would eventually occur in FWOA.

Marsh creation and diversion projects are observed to generally have a positive impact on net land area, in most cases, for a majority of the simulation period. Benefit from the Increase Atchafalaya Flow to Terrebonne (03b.DI.04) project is observed beginning at year 20 and continues to expand through year 50 (Figure 381).

The eastern region of the coast has a mixture of positive and negative impacts on land change, with a total net gain in land area compared to FWOA. Marsh creation, ridge creation, and shoreline protection projects generally have a positive impact on net land area. Diversion projects produce both positive impacts along with some negative. Positive impacts are observed due to sustaining initial land built by the Lower Barataria Marsh Creation - Component A (002.MC.04a) and Large-Scale Barataria Marsh Creation - Component E (002.MC.05e) projects. Additional benefit from the Mid-Barataria diversion (002.DI.03) is also seen in the vicinity of The Pen, resulting from lowered salinities. Large positive impacts are observed in upper Barataria by year 50 due to the freshening and increased sediment deposition in that area. The negative impacts on land area are consistent with the high scenario; namely, a reduction in land area in the Bird’s Foot Delta due to upstream diversion of sediment laden water and a negative impact around Mid-Breton Sound Diversion (001.DI.23) due primarily to the increase in stage produced by the operation of the diversion.

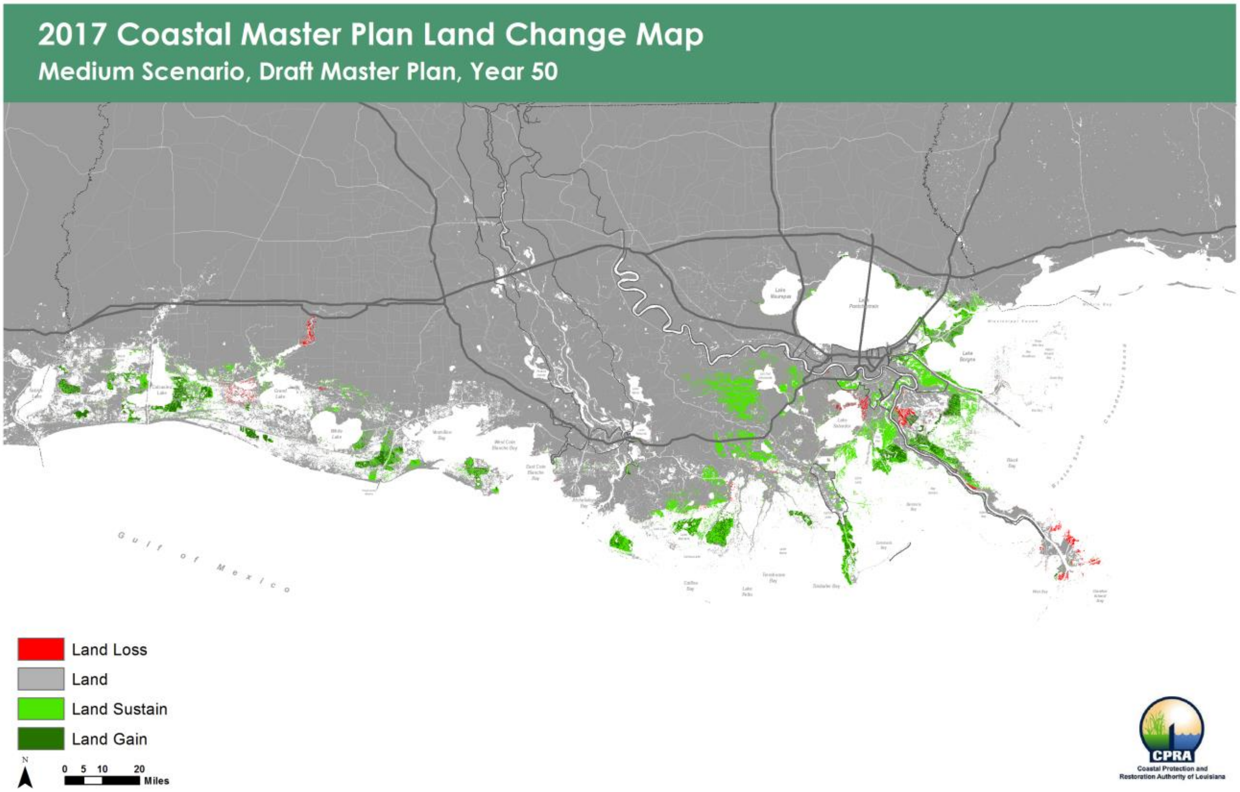


Figure 381: Land Change with the Draft Master Plan compared to FWOA (year 50; medium scenario).

6.1.4 Vegetation

High Scenario

In the eastern region of the coast, the draft master plan dramatically increases the area of fresh marsh and forested wetland compared to FWOA (Figure 382). The diversion projects in this region start preserving forested wetlands around year 10 and slowly lose some of this forest over the remaining 40 years (Figure 382). The preserved forested wetlands are primarily located south of I-10 in the upper Pontchartrain basin (Figure 383) a region primarily influenced by the East Maurepas Diversion (001.DI.21) and the Union Freshwater diversion (001.DI.102). The diversions in the draft master plan also increase the area of fresh marsh over FWOA (Figure 382). In FWOA, areas around Lake Salvador convert from intermediate marsh at year 0 to brackish marsh at year 25; while, with the Mid-Barataria diversion (002.DI.102)this area converts to fresh marsh (Figure 383). In the Breton Sound Basin, substantial expansion of fresh marsh is predicted under FWOA, but is more substantial with the Mid-Breton Sound Diversion (001.DI.104). Most of the area in Breton Sound that is intermediate and brackish marsh in year 0 becomes fresh marsh by year 25 under the draft master plan (Figure 383). In the Pontchartrain Basin, areas that are brackish around Lake Pontchartrain and Lake Borgne in year 0 become fresh in year 25 primarily due to the Lake Pontchartrain Barrier (001.HP.08) project, but augmented by additional fresh water input from the multiple small diversions into the upper Pontchartrain Basin. Therefore, there is substantially less brackish marsh under the draft master plan than in FWOA (Figure 382). In year 50, FWOA shows a tremendous loss of coastal wetlands with only fringes remaining along the upland margins (Figure 383). The draft master plan saves substantial areas with most of the area occupied by fresh marsh.

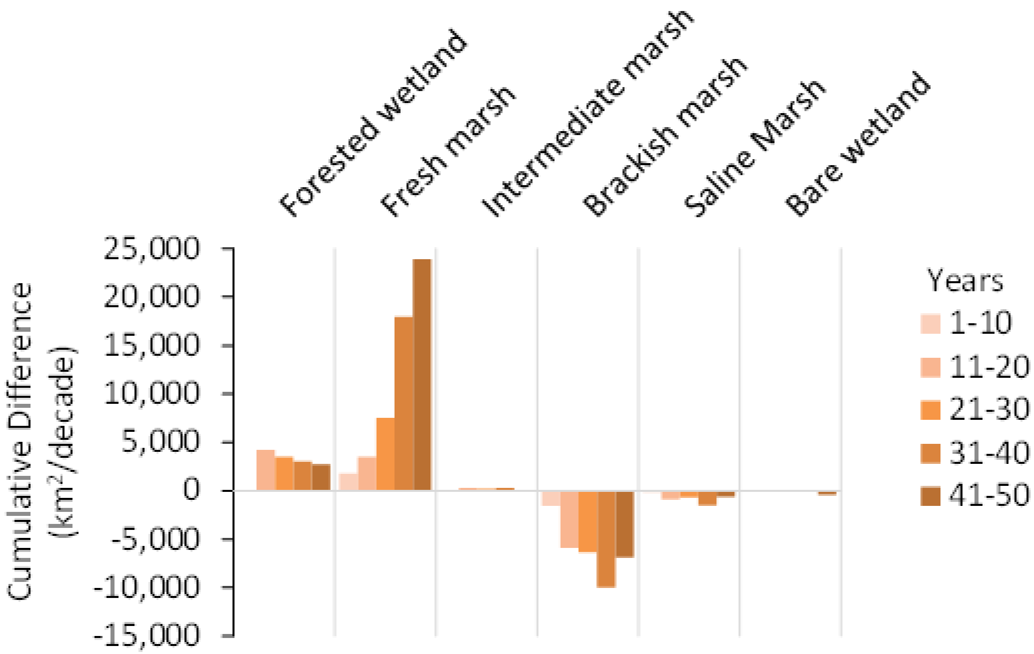


Figure 382: Cumulative Change (Difference between Draft Master Plan and FWOA) in Vegetation Distribution in the Eastern Region of the Coast (high scenario).

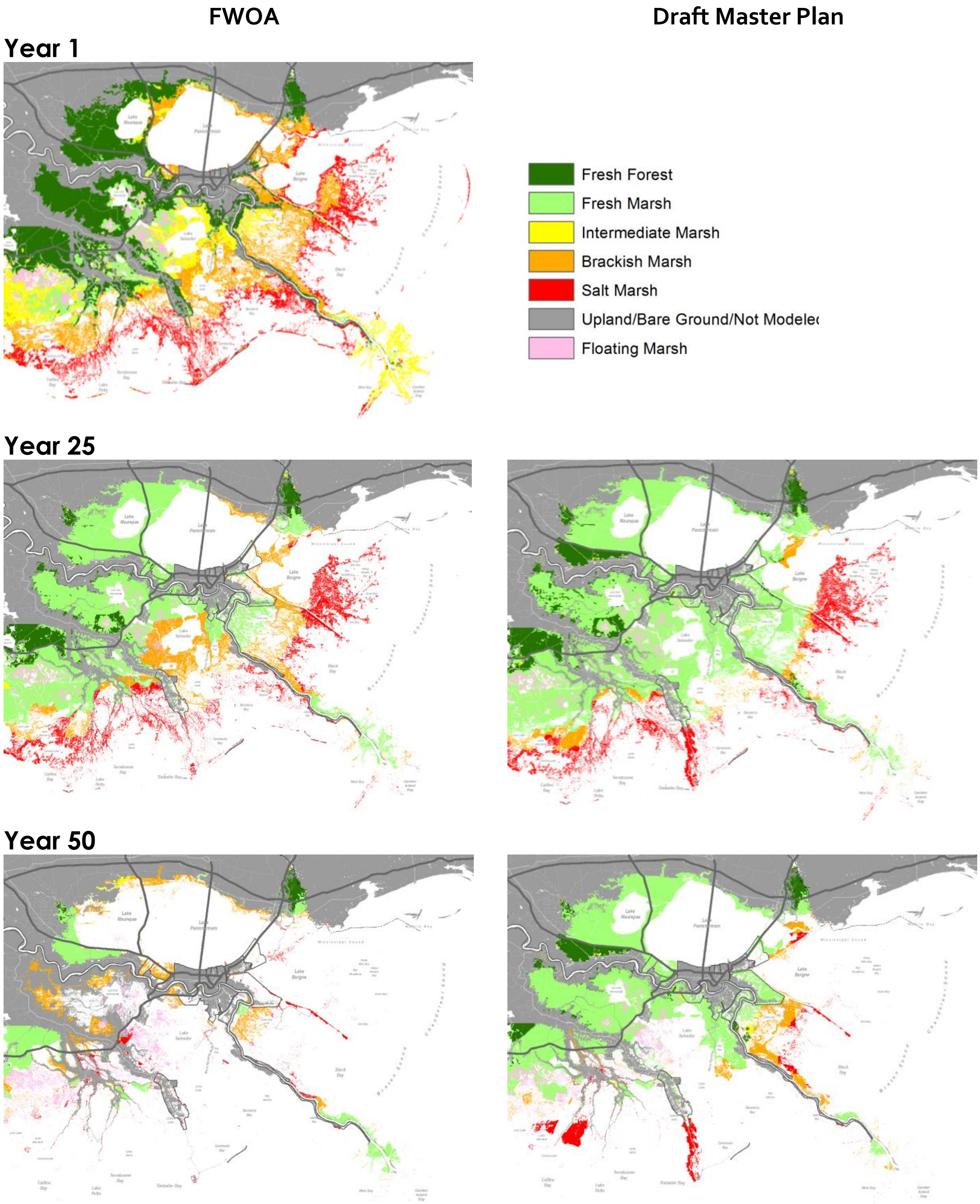


Figure 383: Changes in Vegetation Distribution in the Eastern Region of the Coast with the Draft Master Plan and for FWOA (high scenario).

In the central region of the coast the effects of the draft master plan are more subtle than those in the eastern region. However, there is generally an increase in all habitat types (Figure 384) over all years. In year 25, the most noticeable differences between FWOA and the draft master plan is the saline marsh created by the Belle Pass-Golden Meadow Marsh Creation (03a.MC.07), the brackish marsh created by the South Terrebonne Marsh Creation (03a.MC.07) and the North Lake Mechant Marsh Creation (03a.MC.101) and the conversion of brackish marsh to fresh marsh around Lake Decade (Figure 385) as a result of the Central Terrebonne Hydrologic Restoration (03a.HR.02) and the Bayou DuLarge Ridge Restoration (03a.RC.02). In year 50, the draft master plan preserves more fresh marsh north of Lake Decade, and most of the created marshes become saline marshes including South Terrebonne Marsh Creation (03a.MC.07, North Lake Mechant Marsh Creation (03a.MC.101), Point Au Fer Island Marsh Creation (03b.MC.09), and Marsh Island Marsh Creation (03b.MC.03).

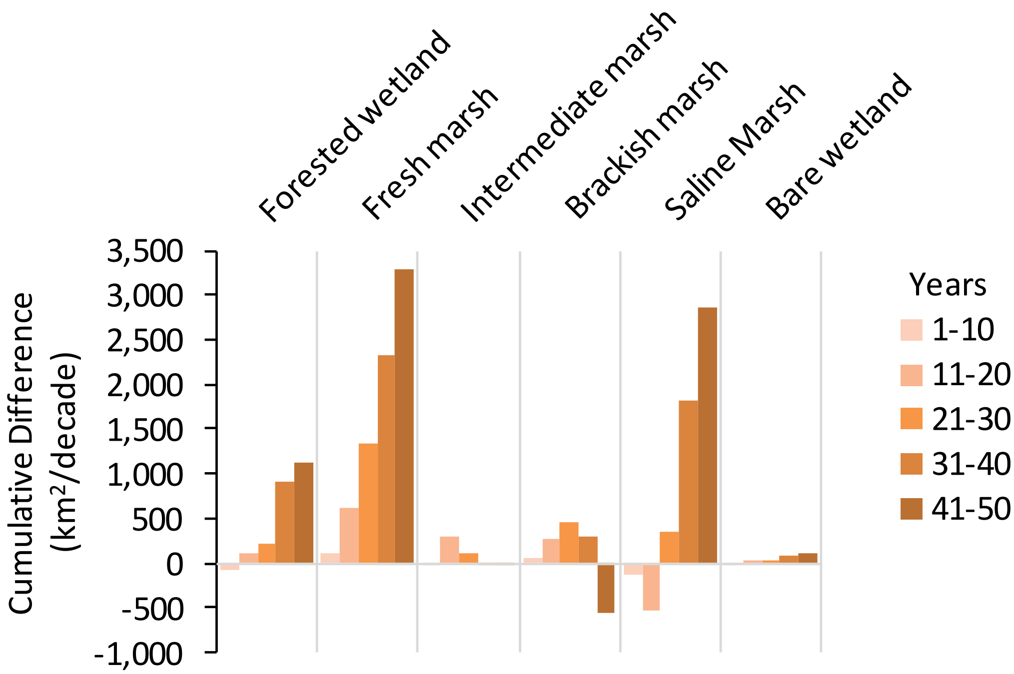


Figure 384: Cumulative Change (Difference between Draft Master Plan and FWOA) in Vegetation Distribution in the Central Region of the Coast (high scenario).

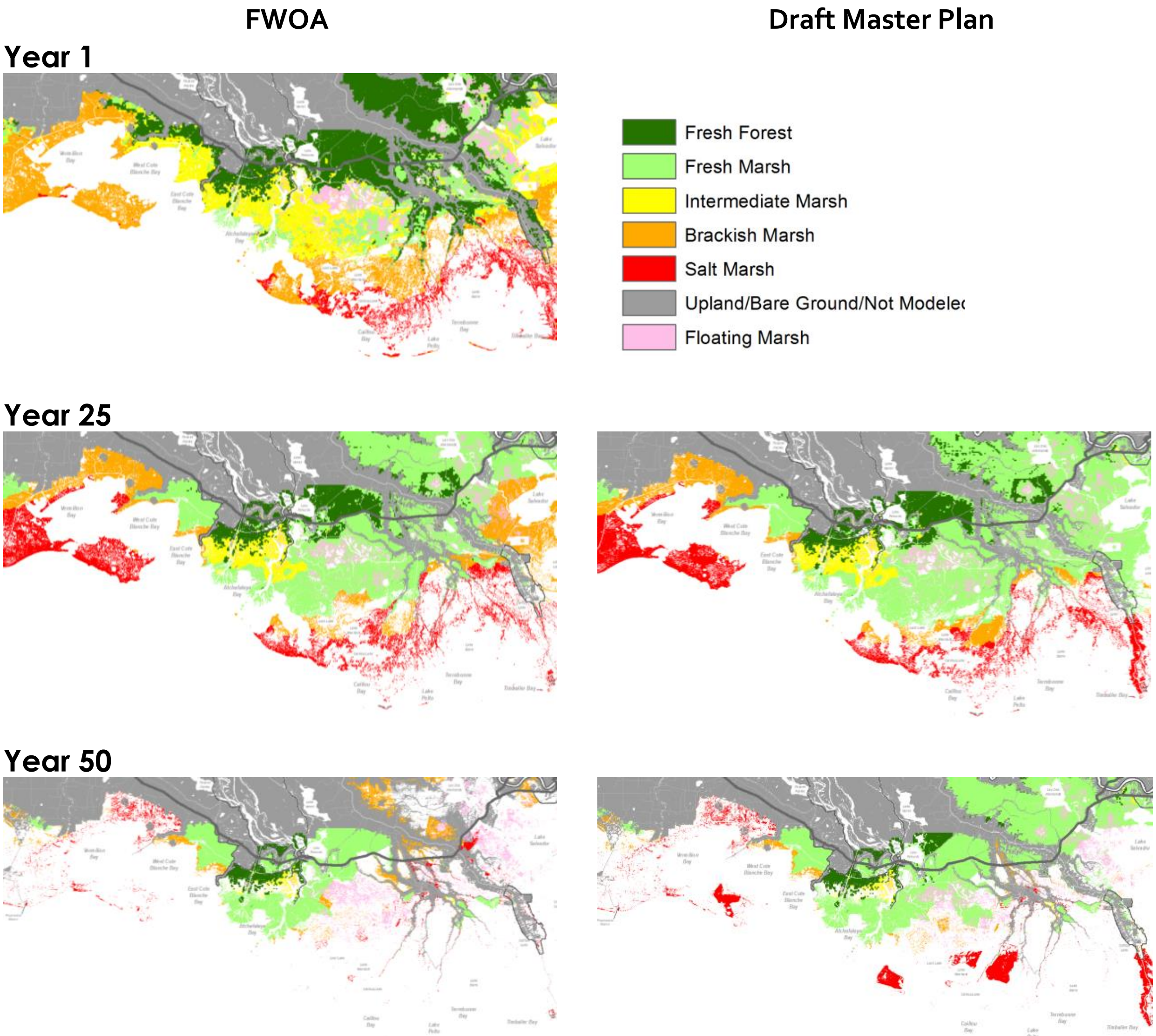


Figure 385: Changes in Vegetation Distribution in the Central Region of the Coast with the Draft Master Plan and for FWOA (high scenario).

In the western region of the coast, the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project preserves some areas of fresh marsh (Figure 386) and converts some brackish and saline marsh to fresh marsh in the first 30 years. This conversion occurs primarily between Calcasieu Lake and Grand Lake (Figure 387). By year 50, FWOA shows very little marsh remaining and most of it is saline marsh (Figure 387). The draft master plan preserves some more marsh and most of it is brackish marsh, while in addition, East Calcasieu Lake Marsh Creation (004.MC.19), Calcasieu Lake West Bank Marsh Creation (004.MC.104), West Brown Lake Marsh Creation (004.MC.105), and West Sabine Refuge Marsh Creation (004.MC.107) survive and they are mostly saline marsh. Most of these marsh creation projects are implemented after year 34 and explain the increase in brackish and saline marshes in the last twenty years of the simulation (Figure 386).

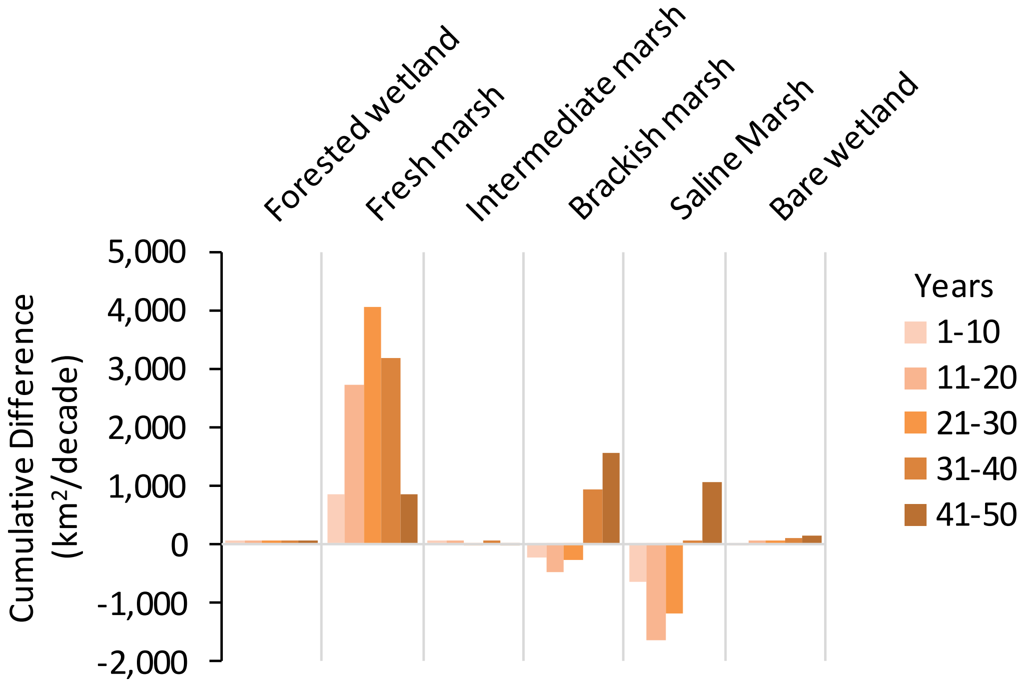


Figure 386: Cumulative Change (Difference between Draft master Plan and FWOA) in Vegetation Distribution in the Western Region of the Coast (high scenario).

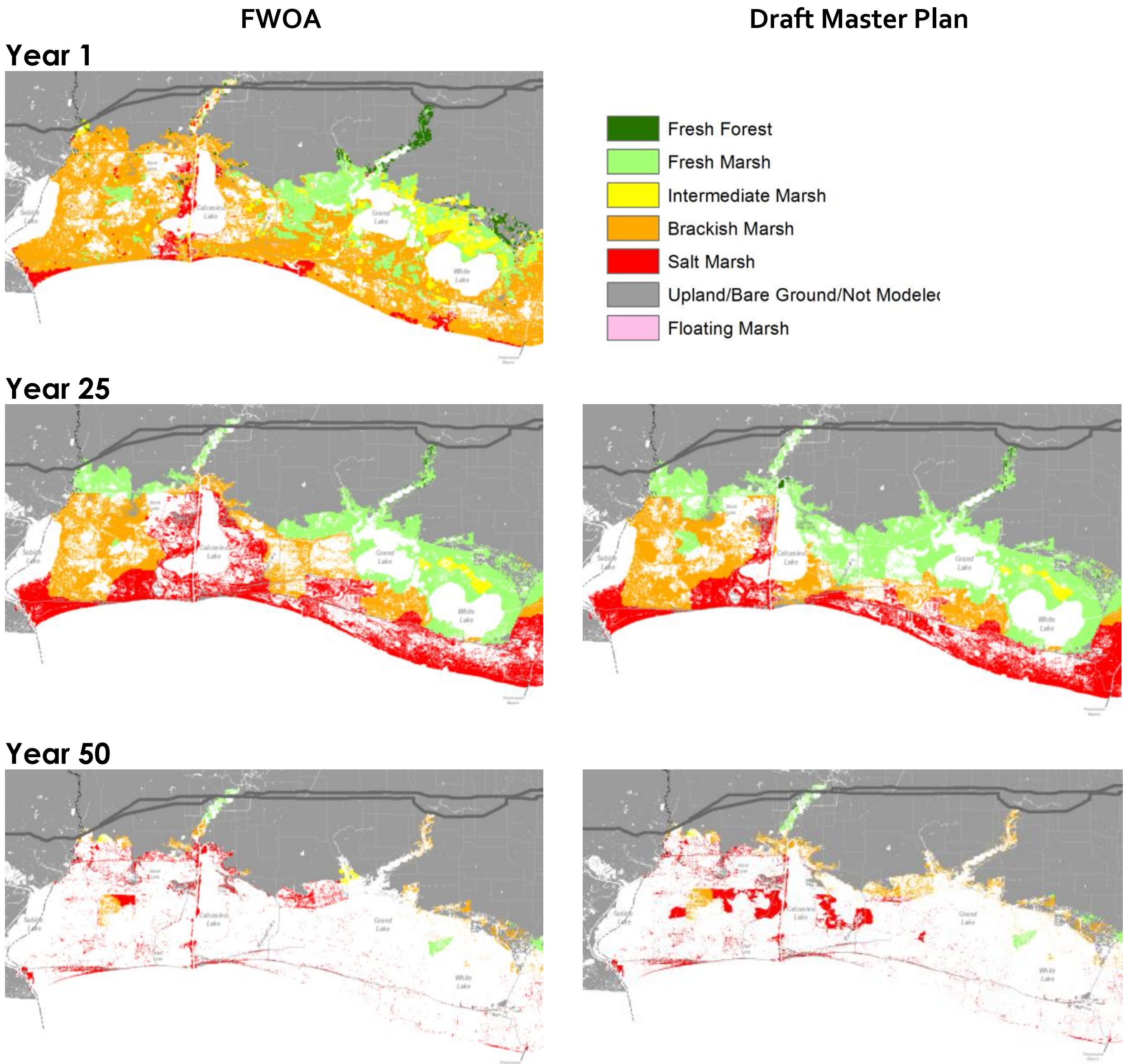


Figure 387: Changes in Vegetation Distribution in the Central Region of the Coast with the Draft Master Plan and for FWOA (high scenario).

Medium Scenario

Under the medium scenario, the effects of the draft master plan are less pronounced than those observed under the high scenario, but generally follow the same patterns. In the eastern region, the diversions into the upper Pontchartrain Basin prevent the conversion of swamp forest to fresh marsh primarily south of I-10 in the upper Pontchartrain basin in the first 10 years (Figure 388 and Figure 389). This forest then slowly converts to fresh marsh and the extent of forested area preserved by the draft master plan declines over time (Figure 388). The draft master plan also converts large areas of brackish marsh to fresh marsh in the eastern coast in the first 30 years (Figure 388 and Figure 389). The loss of saline marsh due to the draft master plan, when compared to FWOA in the first 30 years (Figure 388), is primarily due to conversion of saline marsh to brackish marsh in upper Barataria Basin (Figure 389) resulting from the Mid-Barataria Basin Diversion (002.DI.102). In FWOA, under the medium scenario, upper Barataria Basin slowly converts from fresh to brackish marsh, while implementation of the Mid-Barataria Basin Diversion (002.DI.102) allows this area to remain fresh (Figure 389). The inland migration of brackish and saline marshes is also dampened by the draft master plan in the Pontchartrain and Breton Sound basins (Figure 389).

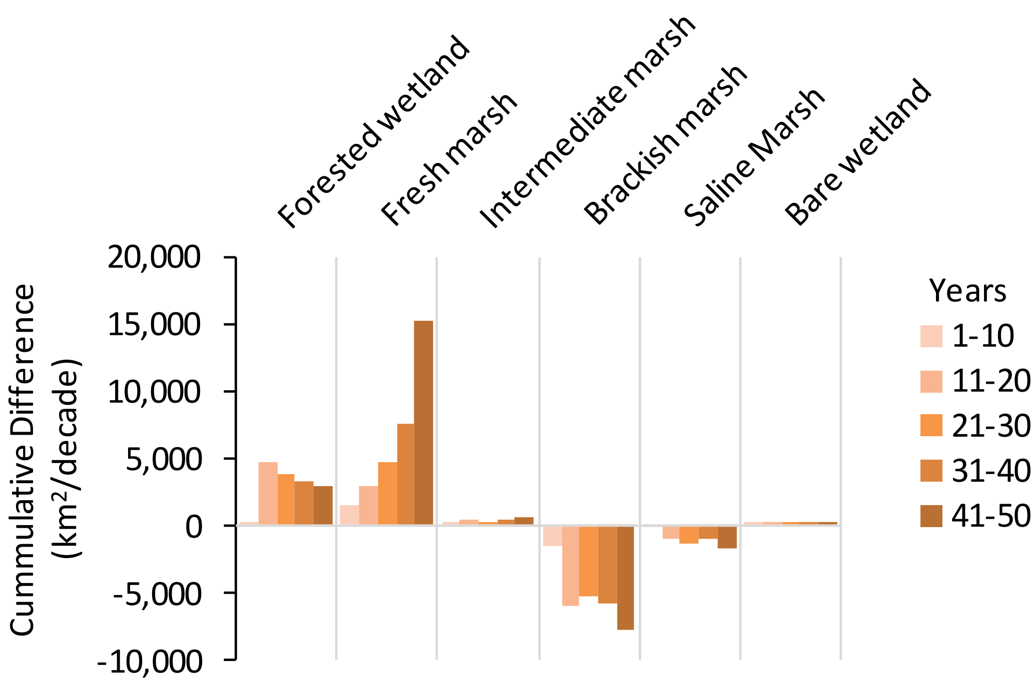


Figure 388: Cumulative Change (Difference between Draft Master Plan and FWOA) in Vegetation Distribution in the Eastern Region of the Coast (medium scenario).

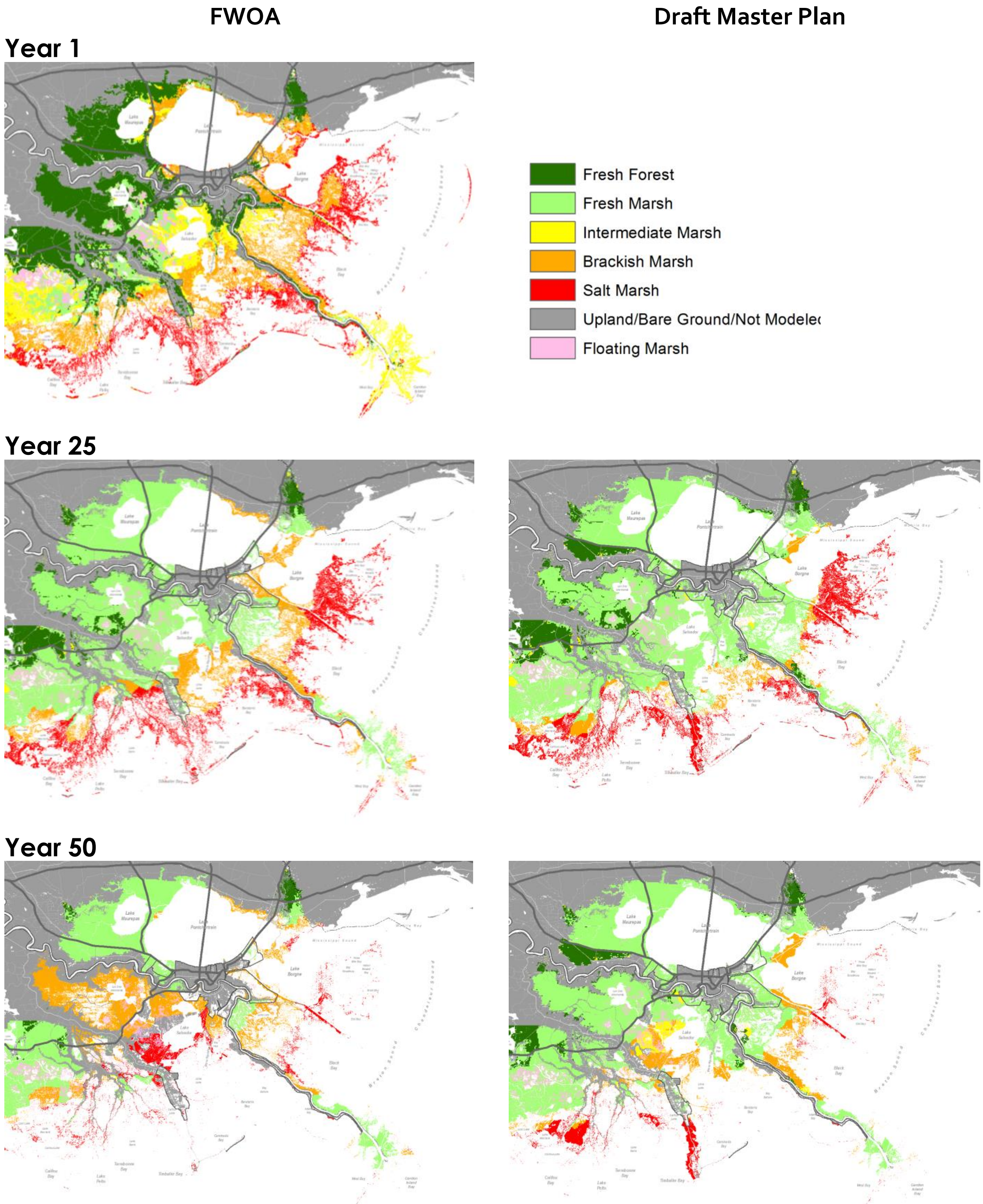


Figure 389: Changes in Vegetation Distribution in the Eastern Region of the Coast with the Draft Master Plan and for FWOA (medium scenario).

The effect of the draft master plan in the central region of the coast under the medium scenario (Figure 390) follows similar patterns to those observed under the high scenario (Figure 384). However, under the medium scenario, there is a loss of brackish marsh. This loss of brackish marsh comes primarily from the conversion of brackish marsh to fresh marsh in the area north of Caillou Lake which is affected by the Central Terrebonne Hydrologic Restoration (03a.HR.02) and the Bayou DuLarge Ridge Restoration (03a.RC.02). Under the medium scenario, South Terrebonne Marsh Creation (03a.MC.07) and the North Lake Mechant Marsh Creation (03a.MC.101) still consist primarily of saline marsh by year 50, but are components of more intact landscape. Under the medium scenario, the marsh creation sites still consist primarily of saline marsh by year 50, but are components of more intact landscape (Figure 391) instead of the created islands observed under the high scenario (Figure 385). Under the medium scenario, there is also more forested wetland preserved through year 50 (Figure 390) and most of this is located east of Lake Palourde (Figure 391) the area affected by the Amelia Levee Improvements (03b.HP.08)..

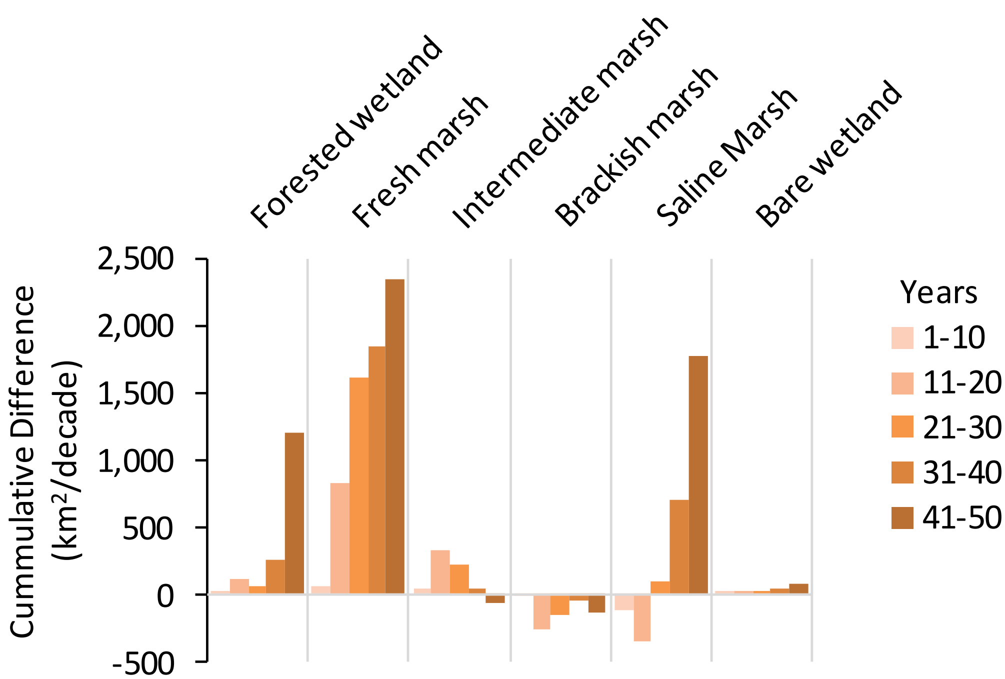


Figure 390: Cumulative Change (Difference between Draft Master Plan and FWOA) in Vegetation Distribution in the Central Region of the Coast (medium scenario).

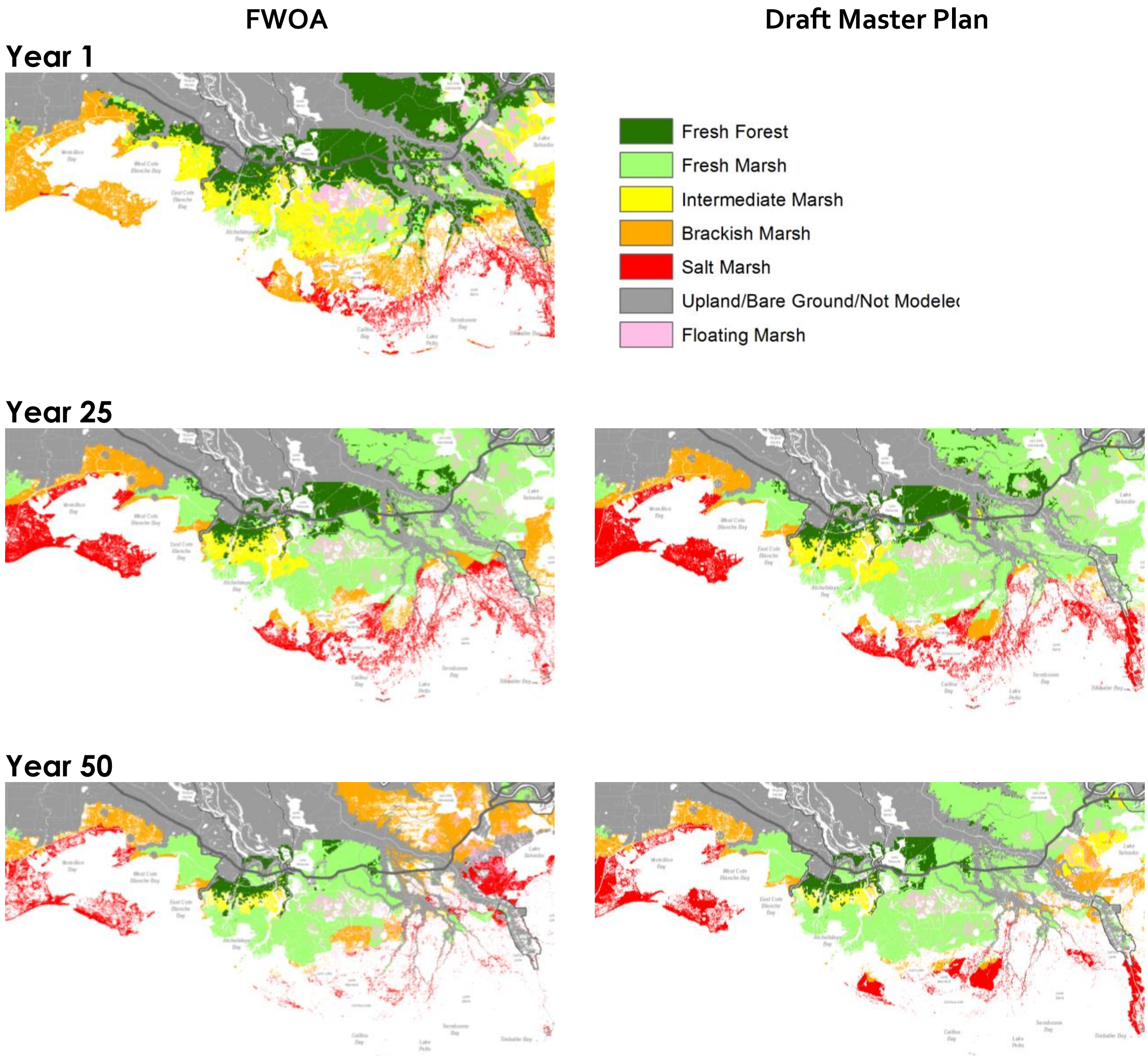


Figure 391: Changes in Vegetation Distribution in the Central Region of the Coast with the Draft Master Plan and for FWOA (medium scenario).

In the western region of the coast, the draft master plan under the medium scenario leads to gains in fresh marsh, losses in saline marsh, and loss of brackish marsh in the first 30 years followed by gains in brackish marsh in the last 20 years compared to FWOA (Figure 392). Most of these effects can be attributed to Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project. In year 25, the largest difference between FWOA and the draft master plan is the significant reduction in the conversion of brackish marsh to saline marsh around Calcasieu Lake as well as the expansion of fresh marsh in the Calcasieu Basin (Figure 393). By year 50, very little fresh marsh remains in both FWOA and the draft master plan (Figure 393). There is more brackish marsh between Calcasieu Lake and Grand Lake and although there are similar areas of saline marsh, the saline marsh under the draft master plan forms a less fragmented landscape than in FWOA (Figure 393).

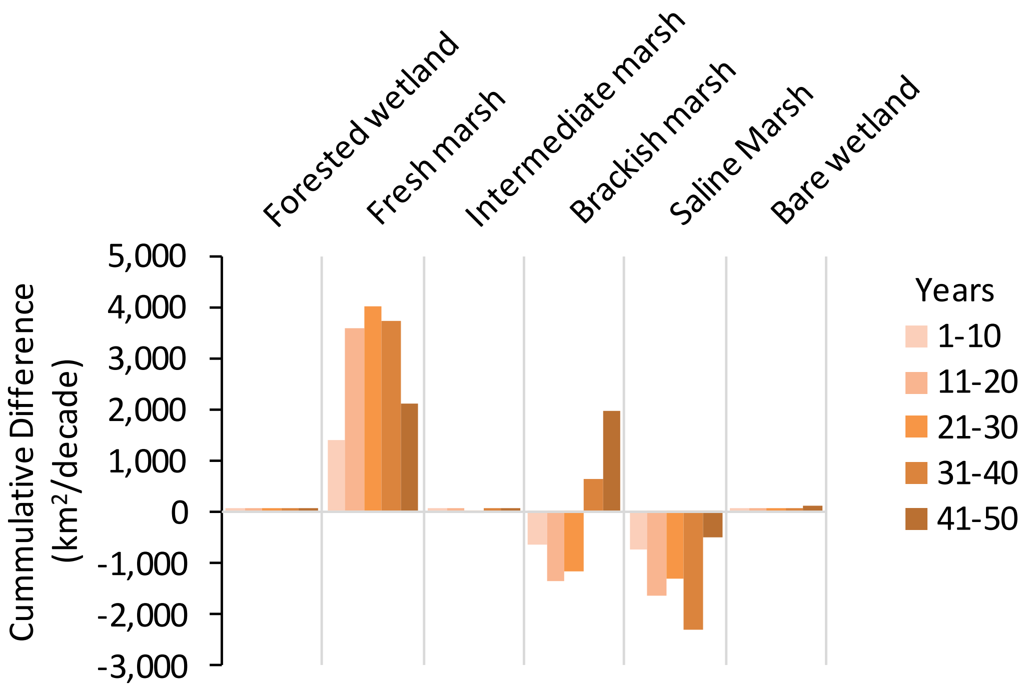


Figure 392: Cumulative Change (Difference between Draft Master Plan and FWOA) in Vegetation Distribution in the Western Region of the Coast (medium scenario).

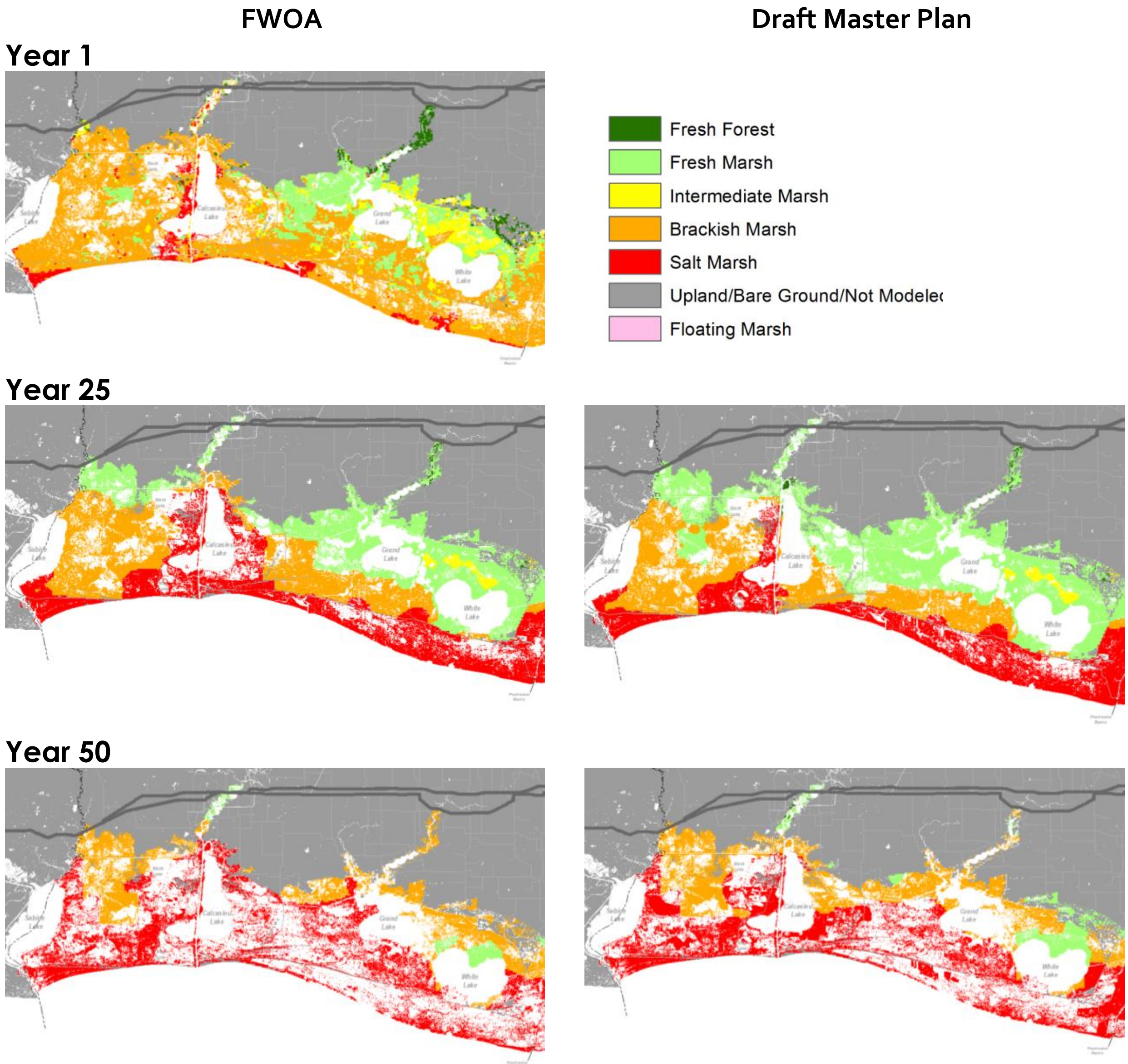


Figure 393: Changes in Vegetation Distribution in the Western Region of the Coast with the Draft Master Plan and for FWOA (medium scenario).

6.1.5 HSIs and EwE

The draft master plan generally has negative effects on habitat suitability for the higher-salinity species: small juvenile brown shrimp, adult spotted seatrout, and oyster in each environmental scenario (e.g., small juvenile brown shrimp; Figure 394 and Figure 395). Much of this is due to the plan's effect on the salinity regime. Hydrologic restoration projects, such as the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) project, reduce saltwater intrusion into interior wetlands, decreasing the suitability of these areas relative to FWOA. Meanwhile, sediment diversion projects, such as the Mid-Barataria Diversion (002.DI.03), introduce large volumes of freshwater that reduce salinities and thus habitat suitability across much of the eastern region (Figure 394 and Figure 395). However, the salinity reduction also increases the suitability, relative to the FWOA, of parts of lower Barataria and lower Terrebonne basins for small juvenile brown shrimp and oyster, because salinities in these areas were higher than optimal for these species in the FWOA. This effect is most extensive when saltwater intrusion is greatest during the FWOA, i.e., during the latter part of the environmental scenarios and particularly in the high scenario.

Landscape changes contribute to the decreased habitat suitability for small juvenile brown shrimp and adult spotted seatrout. Marsh creation projects replace highly-suitable fragmented marsh with less suitable solid marsh, resulting in areas of greatly-decreased suitability (>0.5 decrease in HSI relative to the FWOA; Figure 394 and Figure 395). The draft master plan also maintains large areas of solid marsh in upper Terrebonne, upper Barataria, and around Lake Maurepas (in the high scenario), which similarly results in decreased habitat suitability as these areas are open water or fragmented marsh in the FWOA. The draft master plan similarly prevents some fragmented marsh from being lost, but these habitats typically occur in areas of unsuitable salinities for these species. However, during the latter part of the high scenario, some of this fragmented marsh, such as in lower Breton Sound, becomes more suitable as a result of saltwater intrusion (Figure 395). In the G301 simulation, the marsh in lower Breton Sound is kept unsuitable by the high freshwater discharge from the Upper Breton Diversion (001.DI.17), a project which is not included in the draft master plan.

The overall, coast wide effect of the draft master plan on habitat suitability for low-salinity species: largemouth bass, green-winged teal, and American alligator, is more varied than for the higher-salinity species. Salinity reduction increases habitat suitability for the low-salinity species across large areas of Calcasieu/Sabine, Terrebonne, Barataria, and Breton Sound basins, with this effect increasing in extent during the latter part of each environmental scenario (e.g. largemouth bass (Figure 396 and Figure 397). However, suitability also decreases in many other areas due to the creation and maintenance of less-suitable solid marsh areas (Figure 396 and Figure 397). In addition, habitat suitability for alligator and green-winged teal decreases in parts of upper Breton Sound and upper Barataria Basin as a result of increased water levels from diversion discharges.

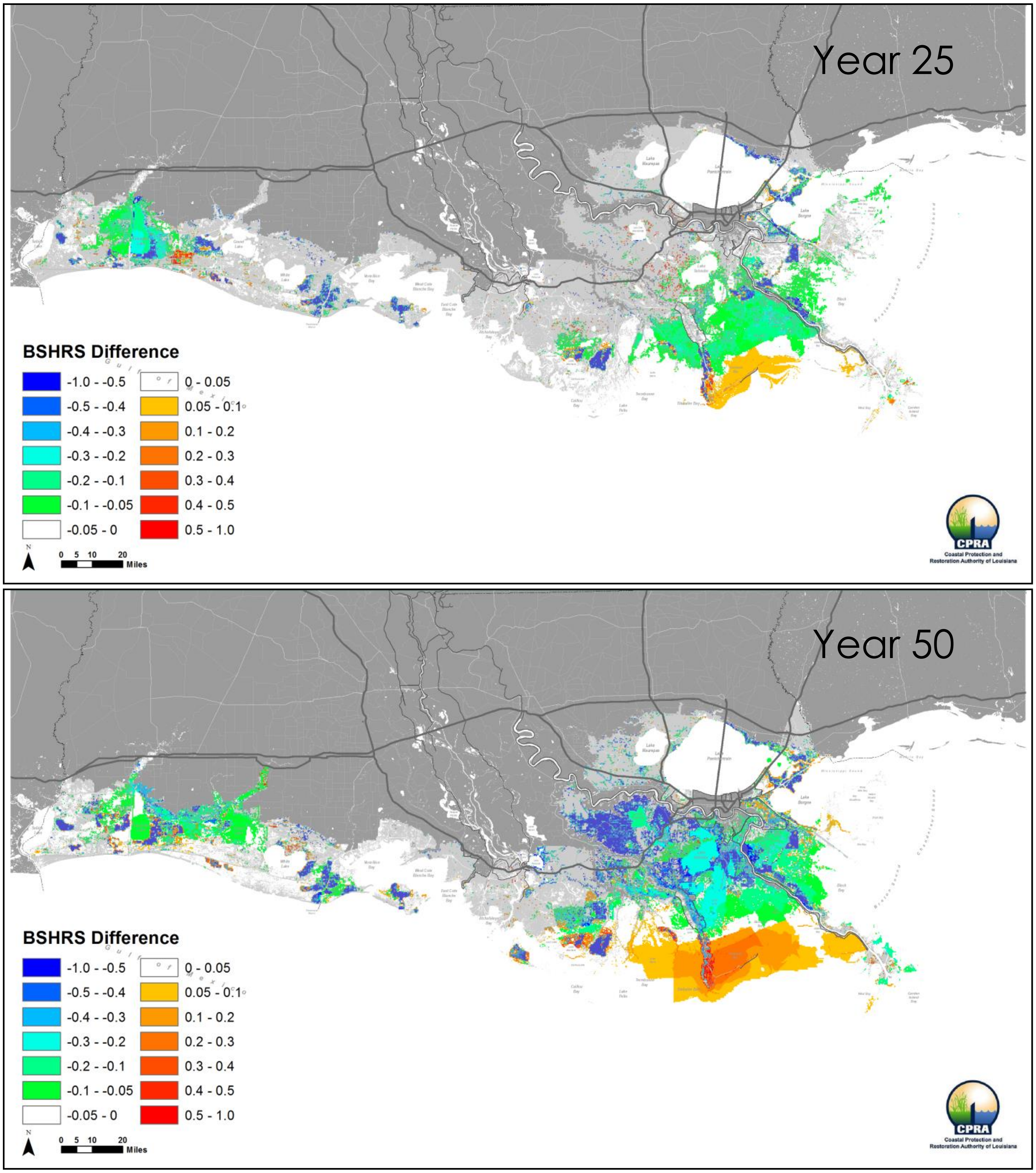
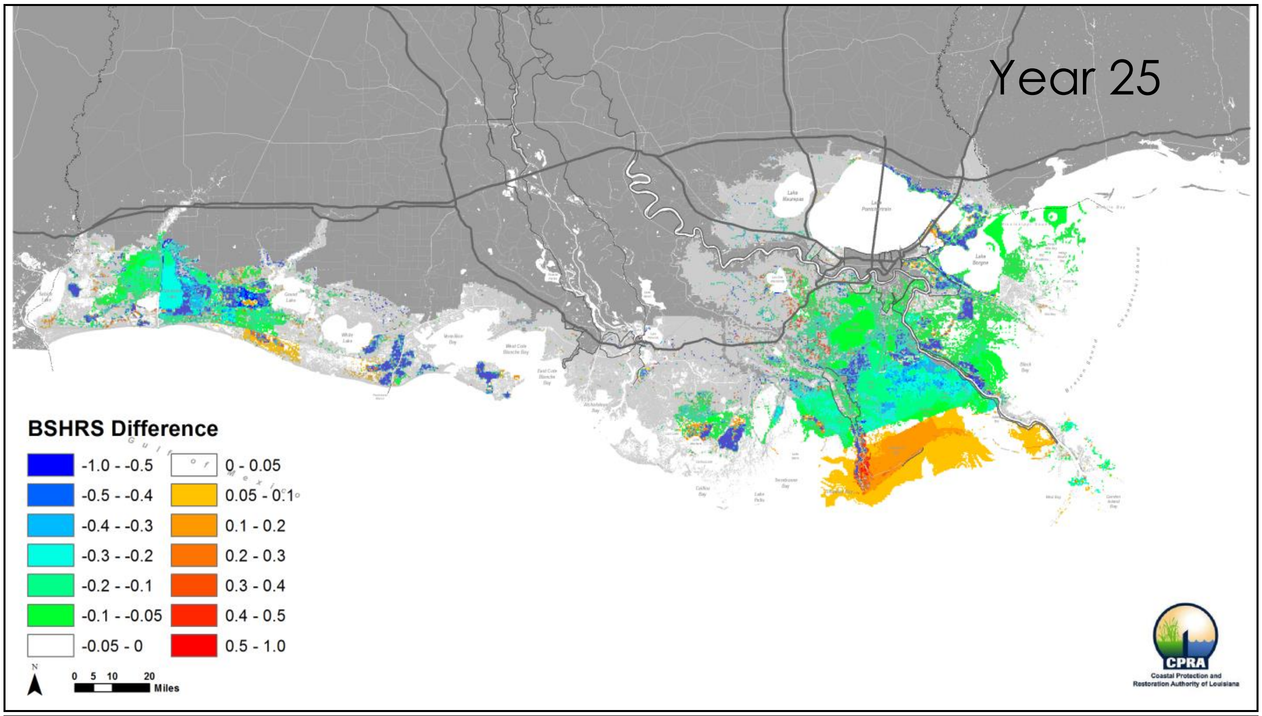


Figure 394: Difference in Small Juvenile Brown Shrimp Habitat Suitability between the Draft Master Plan and FWOA (year 25 [top], year 50 [bottom]; medium scenario). Warmer colors indicate an increase in suitability with the draft master plan.



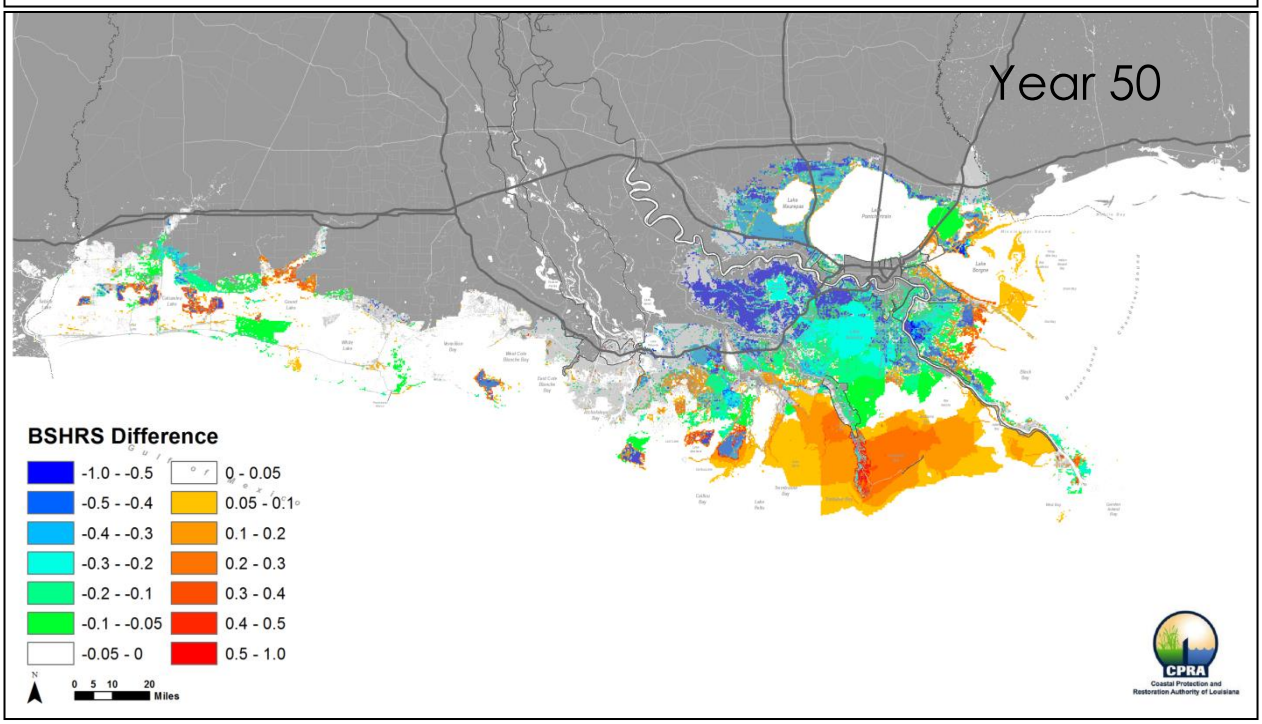


Figure 395: Difference in Small Juvenile Brown Shrimp Habitat Suitability between the Draft Master Plan and FWOA (year 25 [top], year 50 [bottom]; high scenario). Warmer colors indicate an increase in suitability with the draft master plan.

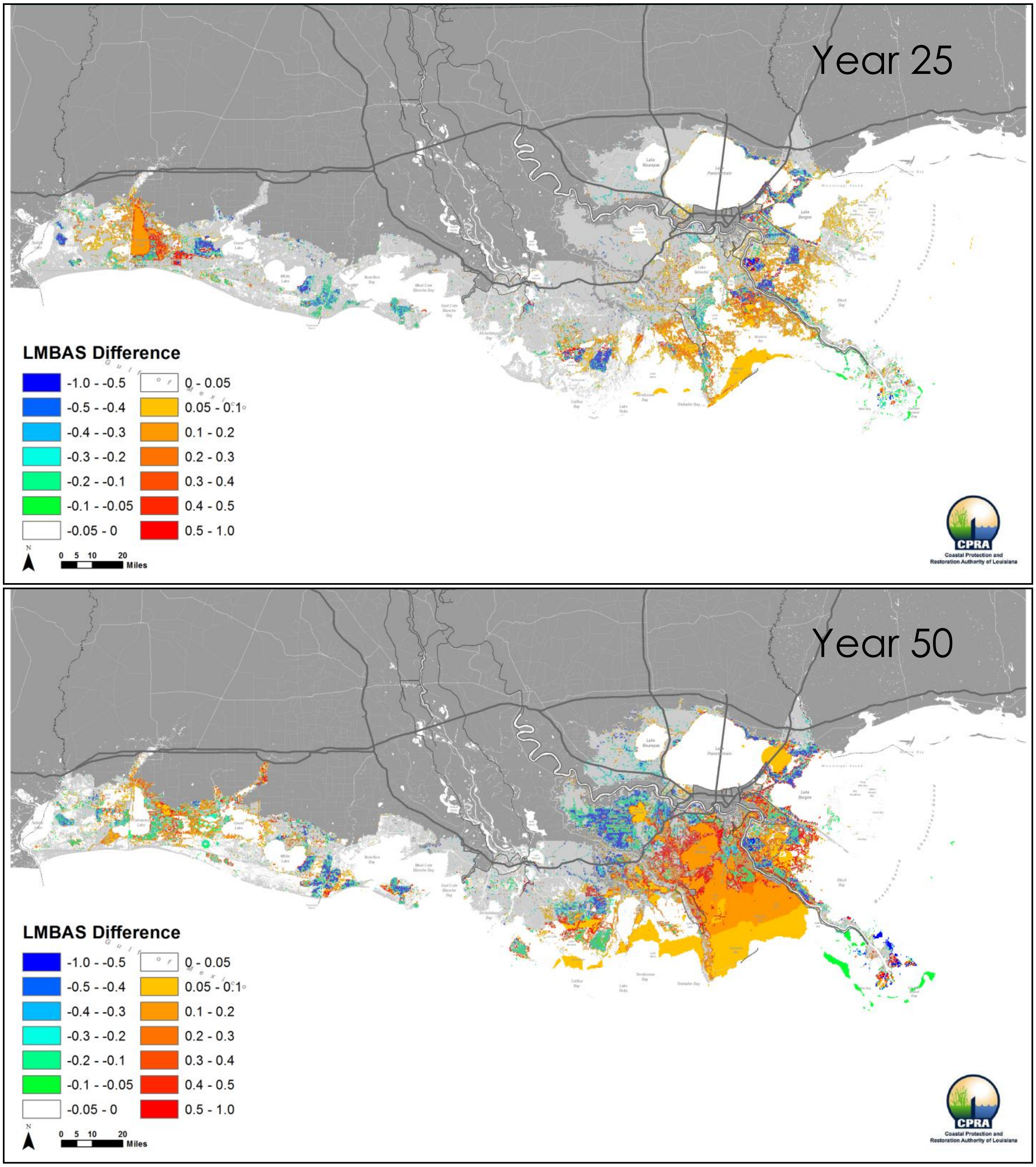


Figure 396: Difference in Largemouth Bass Habitat Suitability between the Draft Master Plan and FWOA (year 25 [top], year 50 [bottom]; medium scenario). Warmer colors indicate an increase in suitability with the draft master plan.

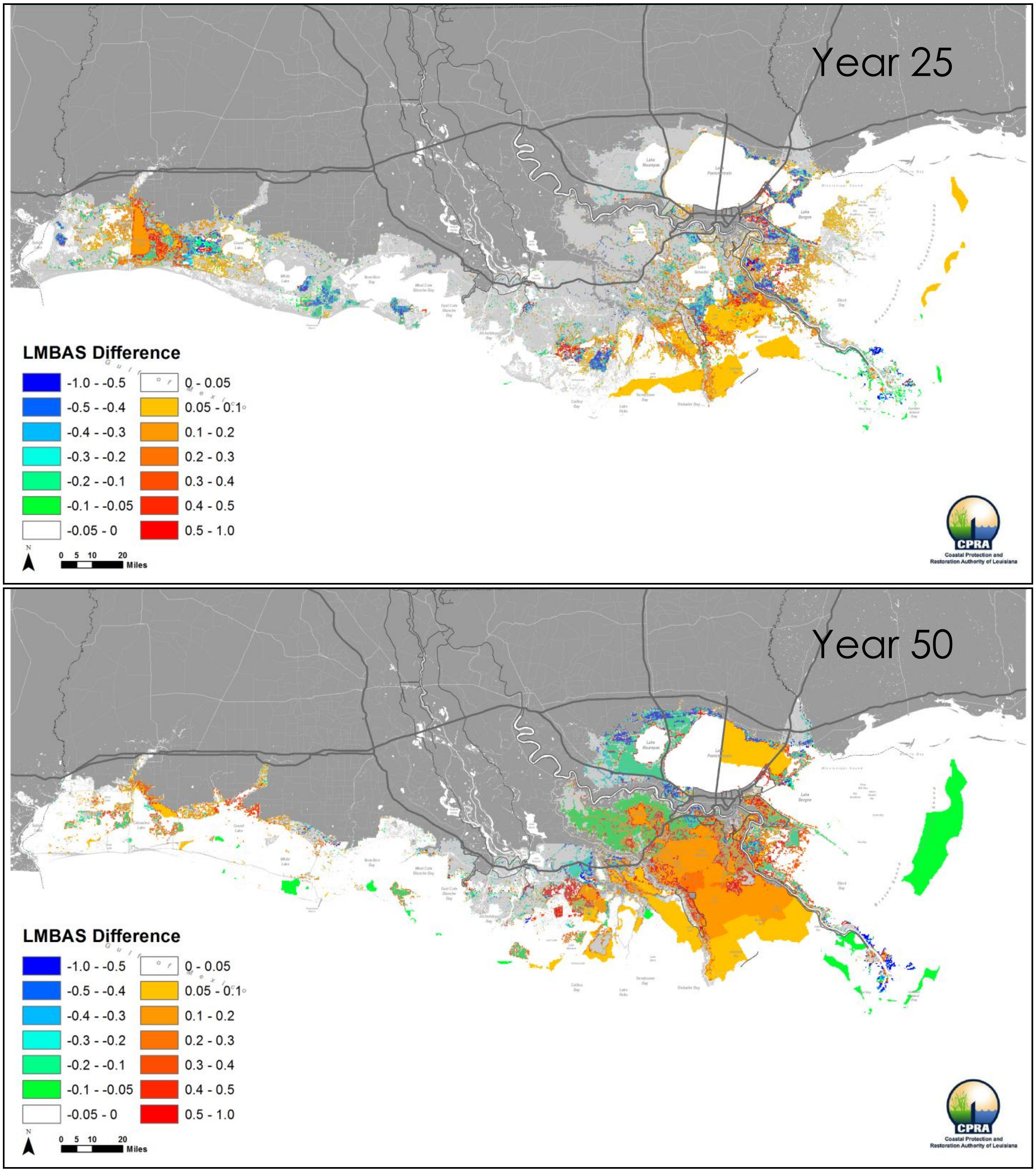


Figure 397: Difference in Largemouth Bass Habitat Suitability between the Draft Master Plan and FWOA (year 25 [top], year 50 [bottom]; high scenario). Warmer colors indicate an increase in suitability with the draft master plan.

The effects of the draft master plan on fish and shellfish biomasses are mostly positive for both the low-salinity and the higher-salinity species. The biomass of low-salinity species increases and expands in distribution because of salinity reduction and increased food production, which is stimulated by diversion-delivered inputs of TKN (e.g., juvenile largemouth bass; Figure 398 and Figure 399). For the higher-salinity species, there are some areas where biomass decreases relative to FWOA as a result of salinity reduction, but for the most part, these species also increase in biomass (e.g., juvenile brown shrimp; Figure 400 and Figure 401). This may be counter-intuitive considering the results of the habitat suitability analyses, but because the biomass of these species is concentrated in the lower basins it is less affected by low salinities from the diversion discharges. Furthermore, the biomass of the higher-salinity species in these areas benefits from the more suitable salinity conditions created by the draft master plan as well as the increased food production, which extends into parts of the lower basins.

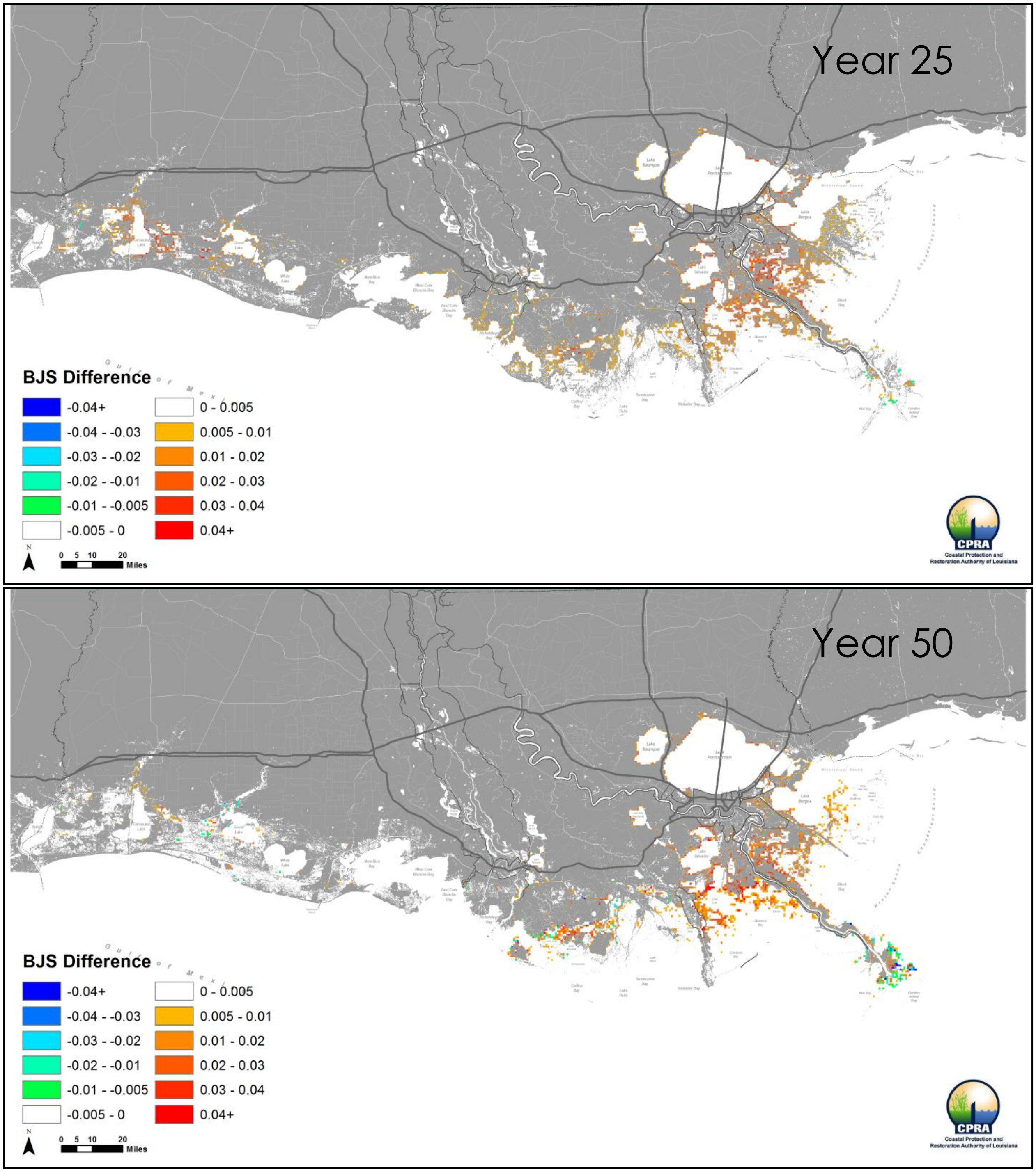


Figure 398: Difference in EwE Juvenile Largemouth Bass Biomass with the Draft Master Plan compared to FWOA for the Month of April (year 25 [top], year 50 [bottom]; medium scenario). Warmer colors indicate an increase in biomass (in tonnes per km^2) with the draft master plan.

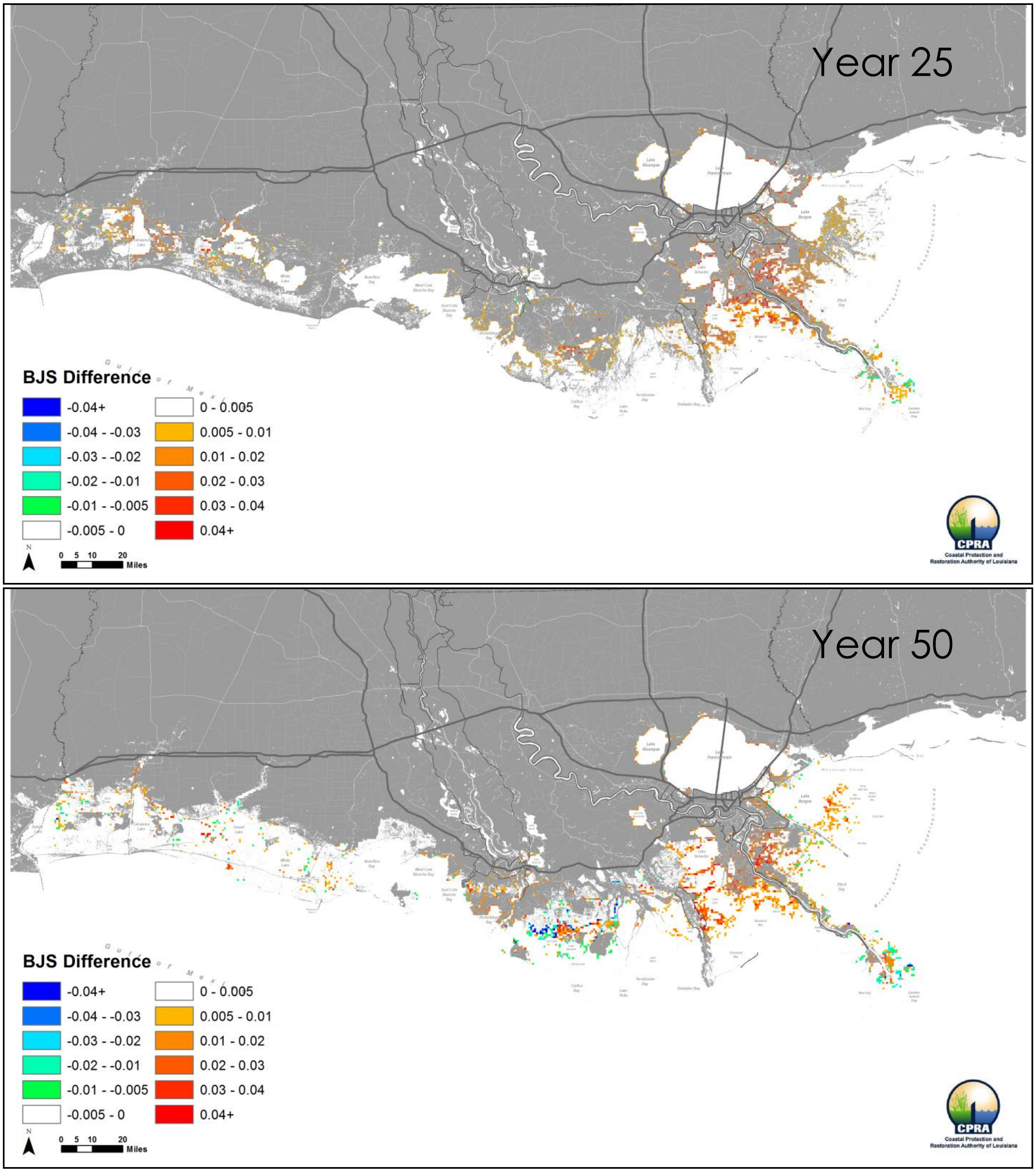


Figure 399: Difference in EwE Juvenile Largemouth Bass Biomass between the Draft Master Plan compared to FWOA for the Month of April (year 25 [top], year 50 [bottom]; high scenario). Warmer colors indicate an increase in biomass (in tonnes per km2) with the draft master plan.

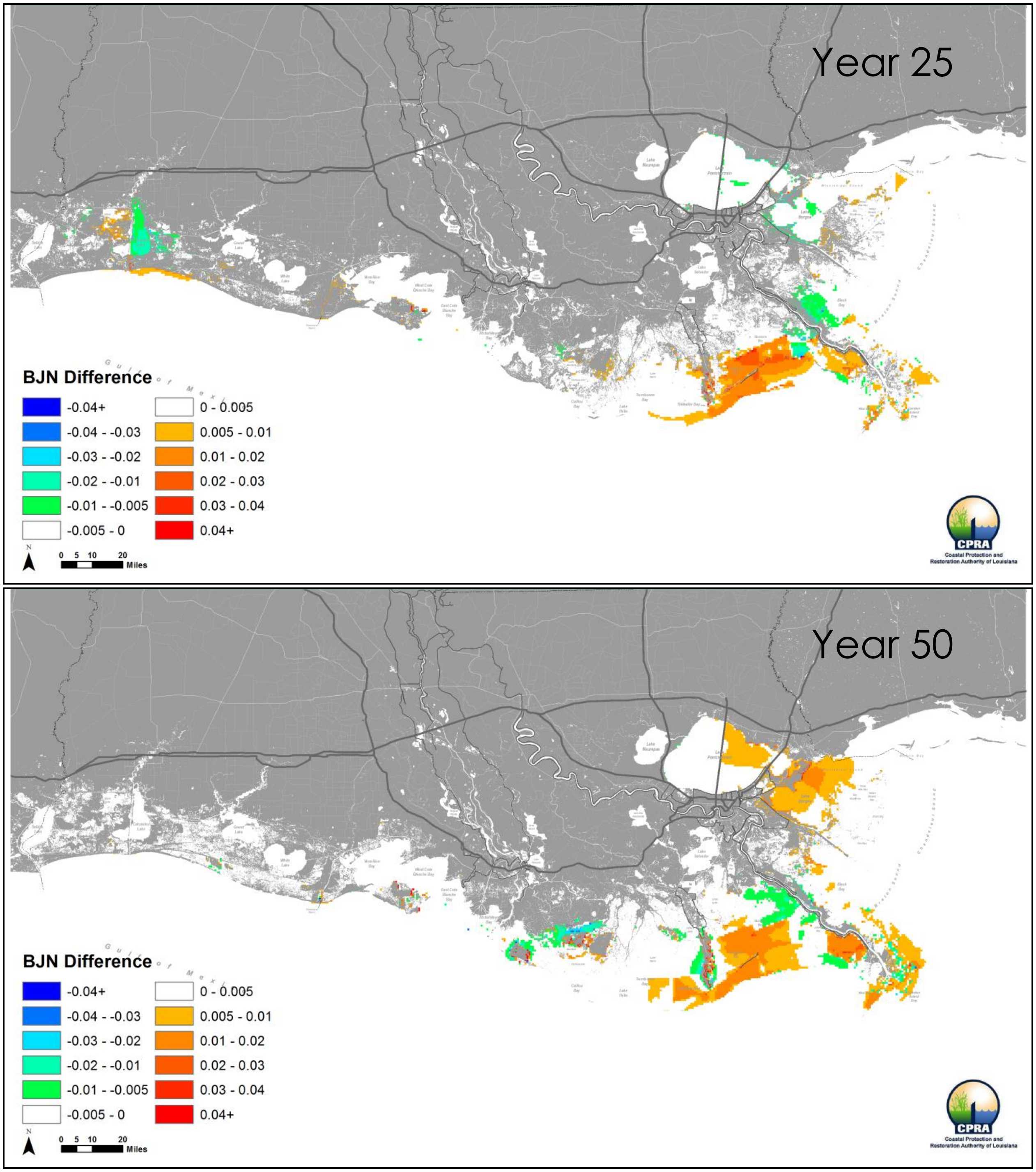


Figure 400: Difference in EwE Juvenile Brown Shrimp Biomass with the Draft master plan compared to FWOA for the month of April (year 25 [top], year 50 [bottom]; medium scenario). Warmer colors indicate an increase in biomass (in tonnes per km^2) with the draft master plan.

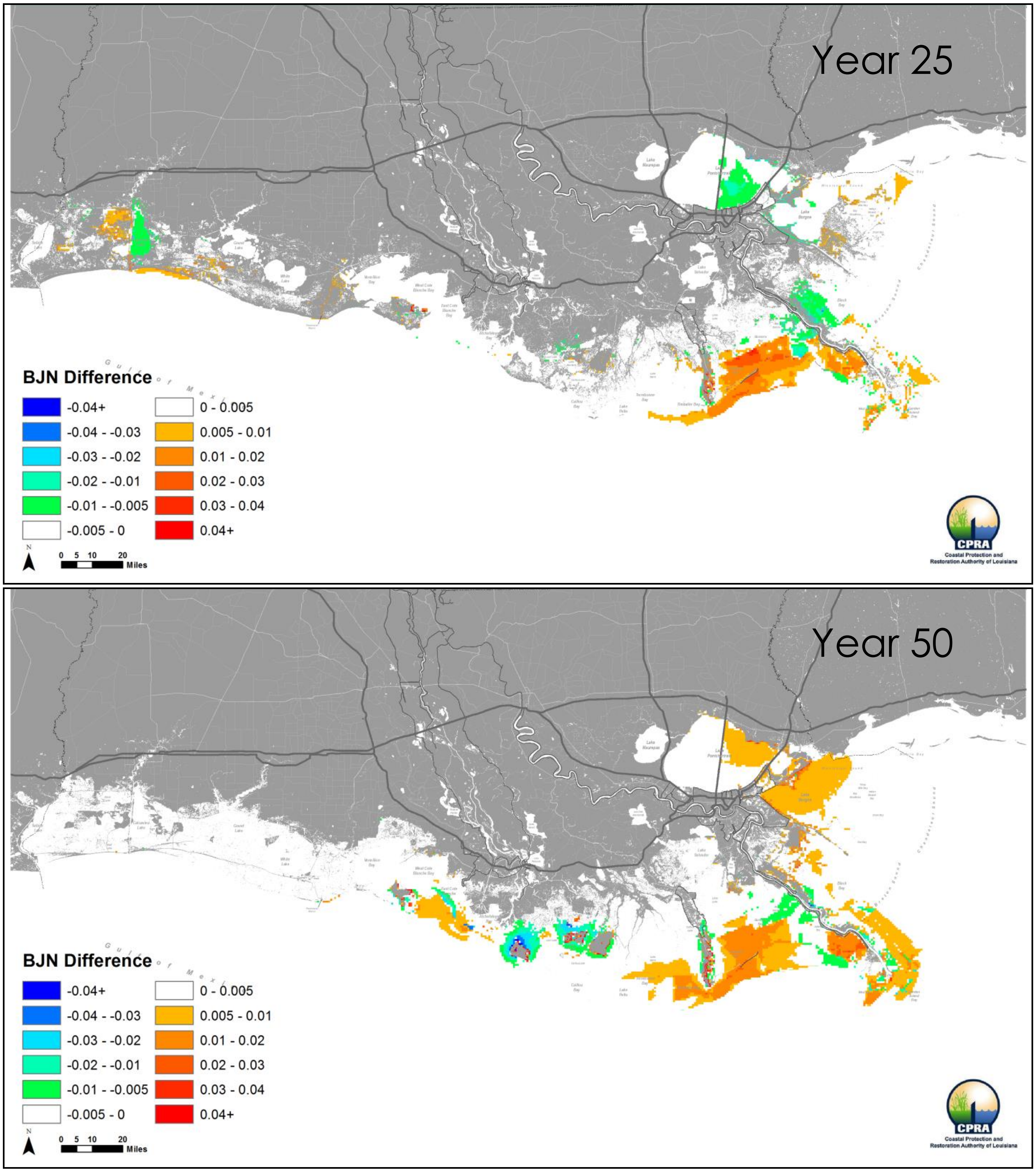


Figure 401: Difference in EwE Juvenile Brown Shrimp Biomass with the Draft Master Plan compared to FWOA for the Month of April (year 25 [top], year 50 [bottom]; high scenario). Warmer colors indicate an increase in biomass (in tonnes per km^2) with the draft master plan.

6.2 Storm Surge and Waves

The draft master plan has been simulated with ADCIRC+SWAN under both the high and medium future scenarios for year 10, year 25, and year 50. Simulations for the draft master plan (G400) are compared to FWOA (G300) to quantify risk reduction benefits provided by the draft plan.

6.2.1 Coast Wide Risk Reduction Benefits

Due to the diversity of restoration projects and hurricane protection projects across the coast, reductions of surge and waves are not uniform but reflect the spatial scale of the project combinations. In addition, the estimated risk reduction benefits vary in time because of the schedule of project implementation and because the impacts of restoration projects change over time as the landscape responds to restoration measures. The differences in maximum water surfaces and maximum wave heights between simulation results for the draft master plan and those for the FWOA are used as an indication of the benefits associated with the draft master plan.

6.2.1.1 Western Region

In the draft master plan, the western region of the coast (primarily the Chenier Plain) has many marsh restoration and hydraulic restoration projects and no hurricane protection projects. The impacts on water surface elevation relative to FWOA are generally less than 0.25 m for all storms simulated for all years. Differences at year 10 are minimal, mostly due to project implementation periods later than year 10. The most notable impacts are seen at the year 25 interval. The medium scenario and high scenario are shown to have similar impacts for individual storms. This is due to the Calcasieu Ship Channel Salinity Control Measures (004.HR.06) being modeled at a constant elevation for each time interval and environmental scenario. The project alters the way Calcasieu Lake and the surrounding areas inundate during early portions of storms, leading to the reductions shown for an example storm in Figure 402 and Figure 404 for the high scenario and Figure 403 and Figure 405 for the medium scenario. In year 25, the eastern reaches of Calcasieu Lake do not inundate as easily with the draft master plan as in FWOA, leading to decreases within the lake itself between the two simulations. At year 50, however, the increase in sea level allows the lake to fill much more easily and very little difference is observed between FWOA and the draft master plan within the lake itself. An area of water surface elevation decrease does form, however, due to the implementation of a number of marsh creation projects which increase the topographic elevations and frictional resistance to flow.

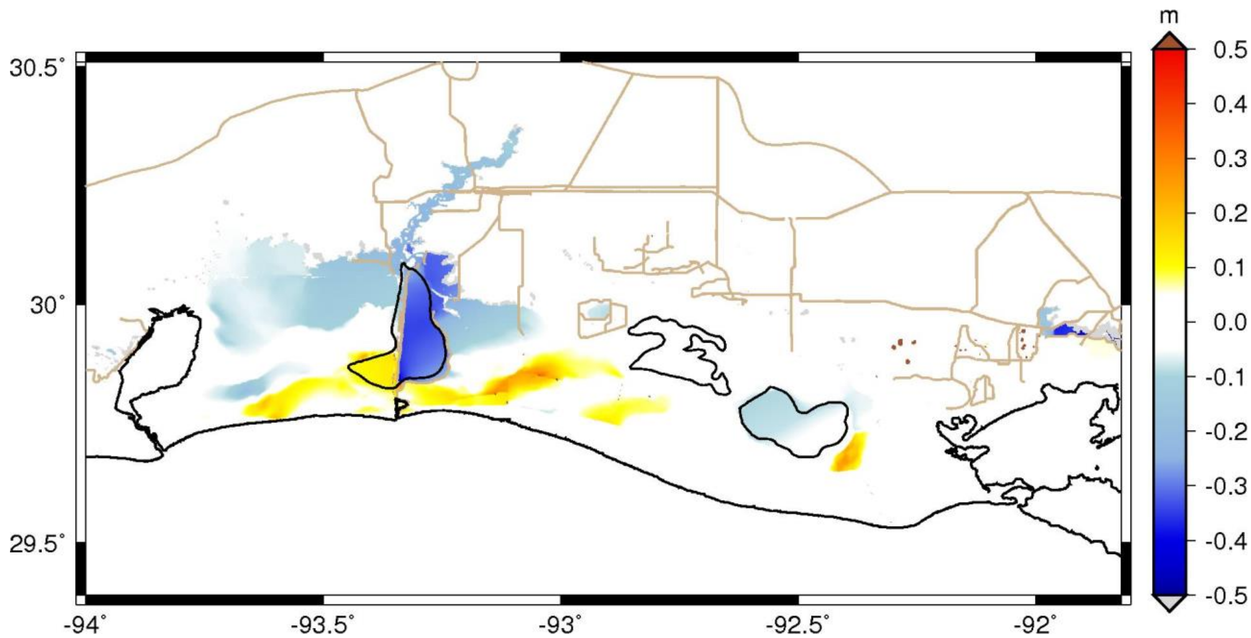


Figure 402: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 201 (year 25; high scenario). Positive values denote an increase with the projects in place.

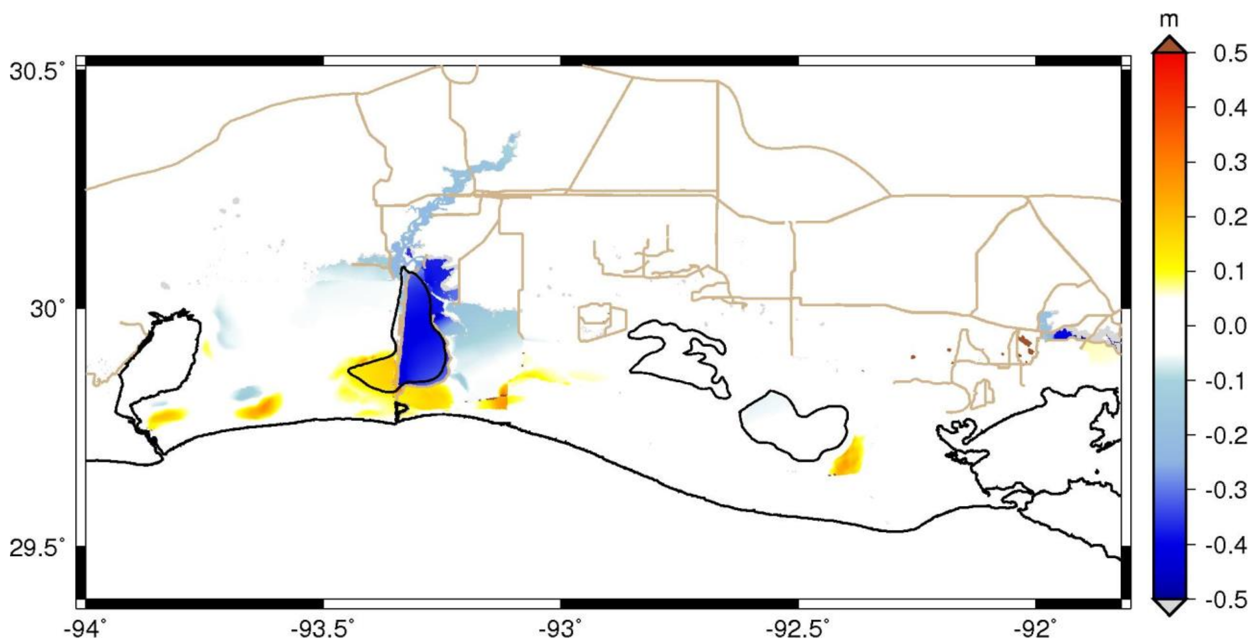


Figure 403: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 201 (year 25; medium scenario). Positive values denote an increase with the projects in place.

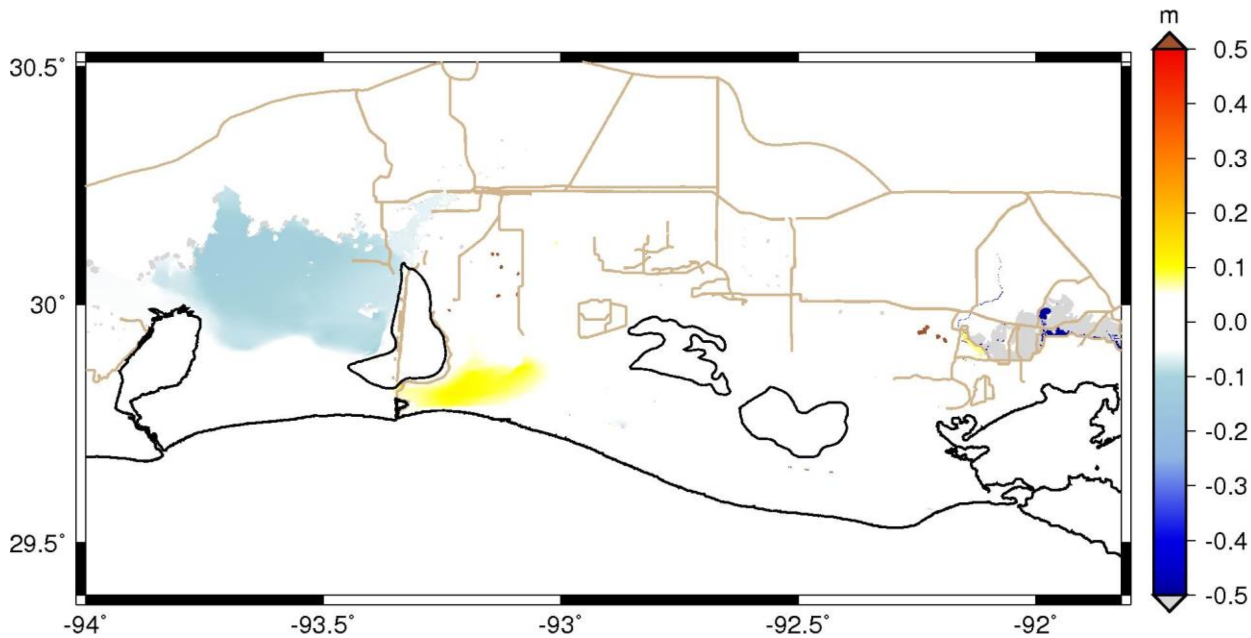


Figure 404: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 201 (year 50; high scenario). Positive values denote an increase with the projects in place.

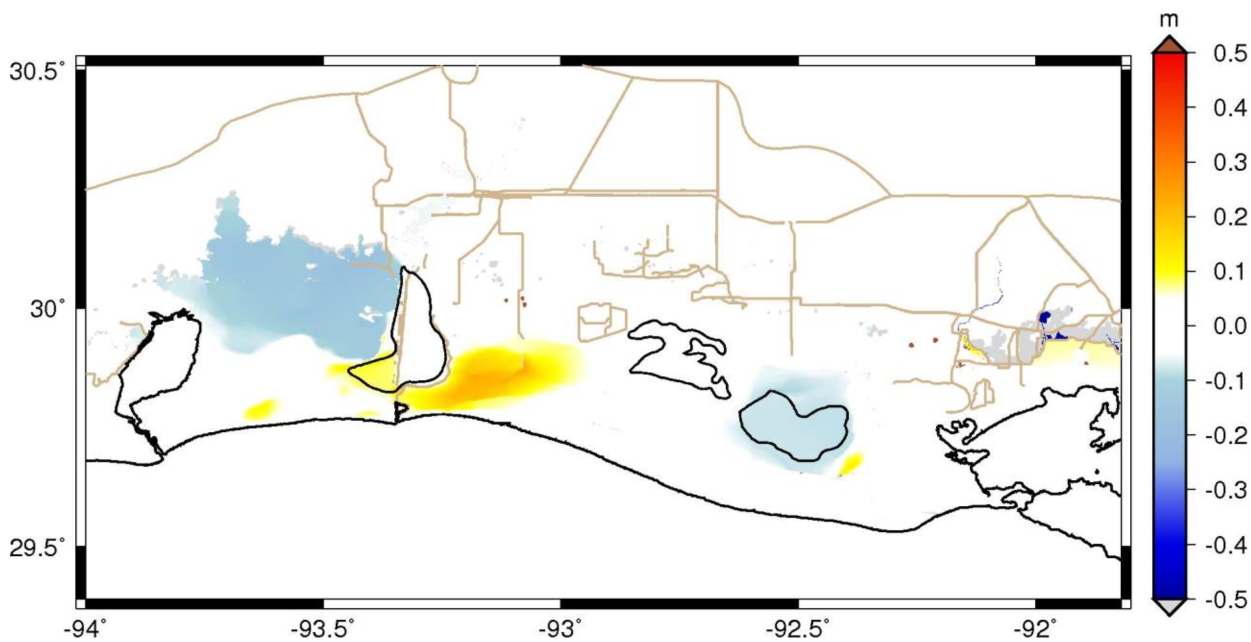


Figure 405: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 201 (year 50; medium scenario). Positive values denote an increase with the projects in place.

While water surface elevations exhibit reductions of generally 0.25 m or less due to the draft master plan, impacts on wave heights are typically 0.1 m or less. Maximum wave reduction benefits, both in terms of wave height reduction and the area impacted, are observed in year 50 under the medium scenario (Figure 406) and diminish under the high scenario.

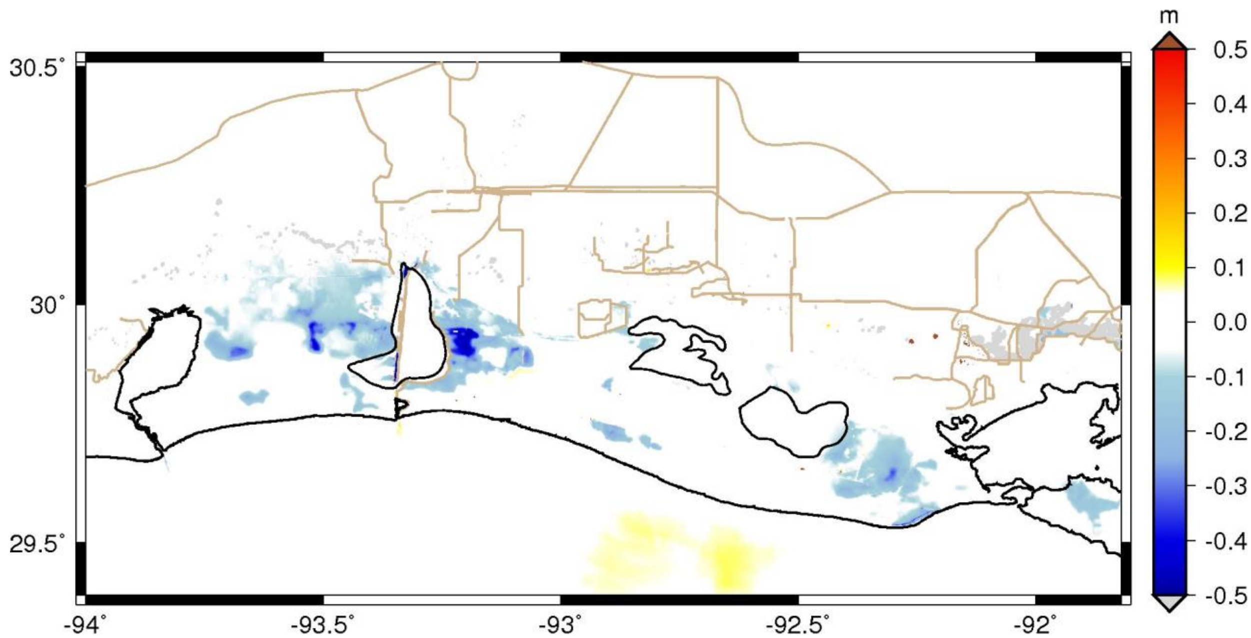


Figure 406: Differences in Maximum Wave Height (m) between the Draft Master Plan and FWOA for Storm 201 (year 50; medium scenario). Positive values denote an increase with the projects in place.

6.2.1.2 Central Region

In the central region of coastal Louisiana (from Vermilion Bay to the Atchafalaya-Terrebonne Basin), the draft master plan includes a variety of hurricane protection projects combined with a collection of marsh creation and ridge restoration projects. Impacts of the draft master plan in this area are due largely to hurricane protection projects with some minor changes to surge and waves due to the presence of the restoration projects. In year 10, the impacts on water surface elevations and wave heights are limited to Morgan City behind the Amelia Levee Improvements (03b.HP.08) project and within the Larose to Golden Meadow levee (03a.HP.20) project, as shown on Figure 407 and Figure 408, using storm 245 as an example.

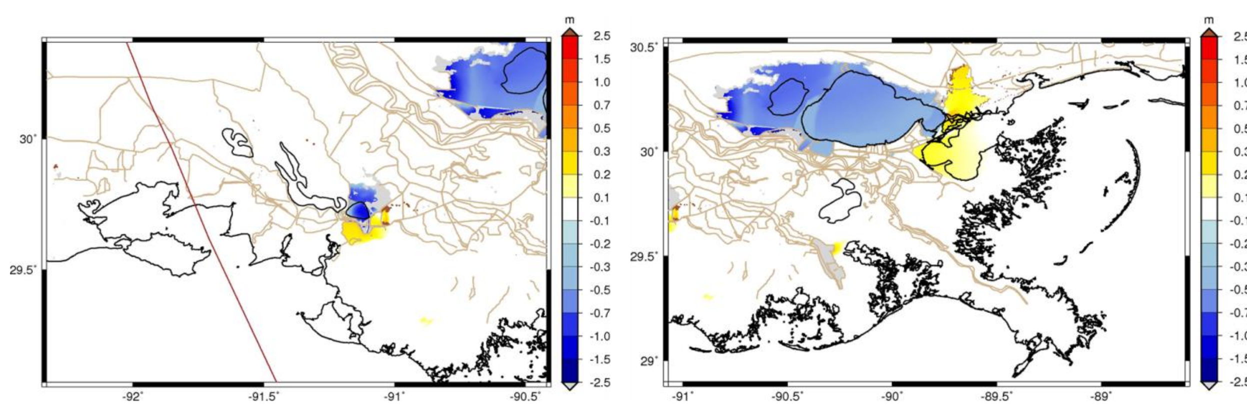


Figure 407: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 245 (year 10; high scenario). Positive values denote an increase with the projects in place.

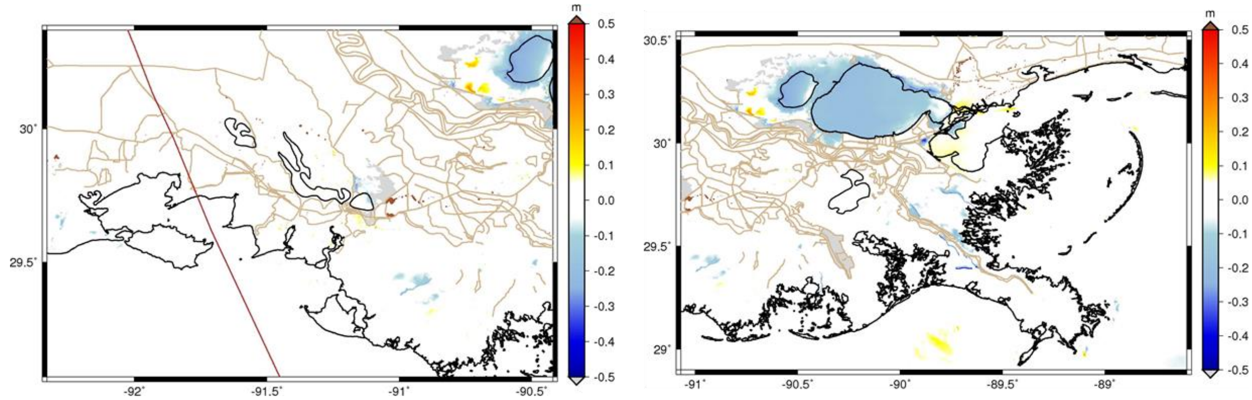


Figure 408: Differences in Maximum Wave Height (m) between the Draft Master Plan and FWOA for Storm 245 (year 10; high scenario). Positive values denote an increase with the projects in place.

The impacts are larger in magnitude and extent after implementation of several projects including South Terrebonne Marsh Creation (03a.MC.100), North Lake Mechant Marsh Creation (03a.MC.101), Bayou DuLarge Ridge Restoration (03a.RC.02), North Terrebonne Bay Marsh Creation (03a.MC.09b), Bayou Terrebonne Ridge Restoration (03a.RC.05), and most significantly, the Morganza to the Gulf (03a.HP.02b) project. As shown on Figure 409 for year 25, water surface elevation increases significantly in front of the Morganza to the Gulf (03a.HP.02b) project, while protecting communities inland. Changes to maximum water surface elevations due to draft master plan projects are more significant in year 50 than in year 25, as illustrated on Figure 410. Though Figure 409 illustrates the high scenario, similar patterns are observed for the medium scenario.

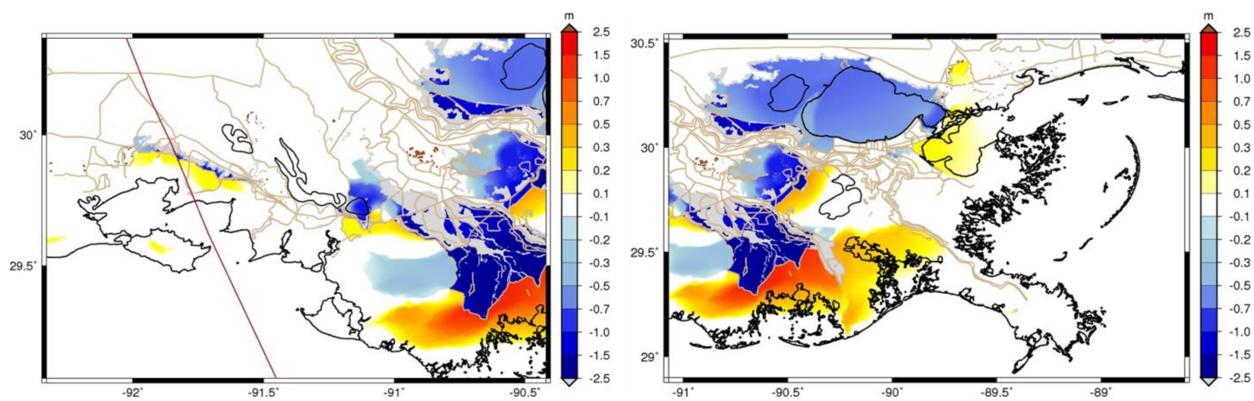


Figure 409: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 245 (year 25; high scenario). Positive values denote an increase with the projects in place.

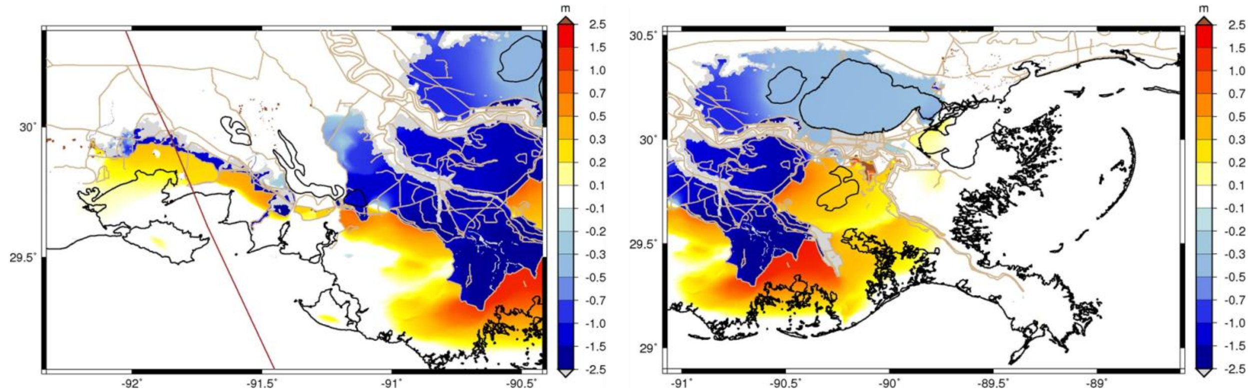


Figure 410: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 245 (year 50; high scenario). Positive values denote an increase with the projects in place.

6.2.1.3 Eastern Region

The eastern region of the coast contains a number of sediment diversion projects, other restoration projects, and hurricane protection projects with the draft master plan. Most projects are implemented after year 10; therefore, impacts on water surface elevations are primarily noticed in years 25 and 50. The exception is water surface reduction in Lake Pontchartrain and upper Breton Sound from Belle Chasse to Phoenix. The water surface elevation reduction in this area is approximately 0.5 to 1.0 m even in year 10 due to implementation of the Lake Pontchartrain Barrier (001.HP.08), Mid-Breton Sound Diversion (001.DI.23), and Carlisle Ridge Restoration (001.RC.103) projects. An example of the difference is shown for storm 025 in Figure 411 under the high scenario.

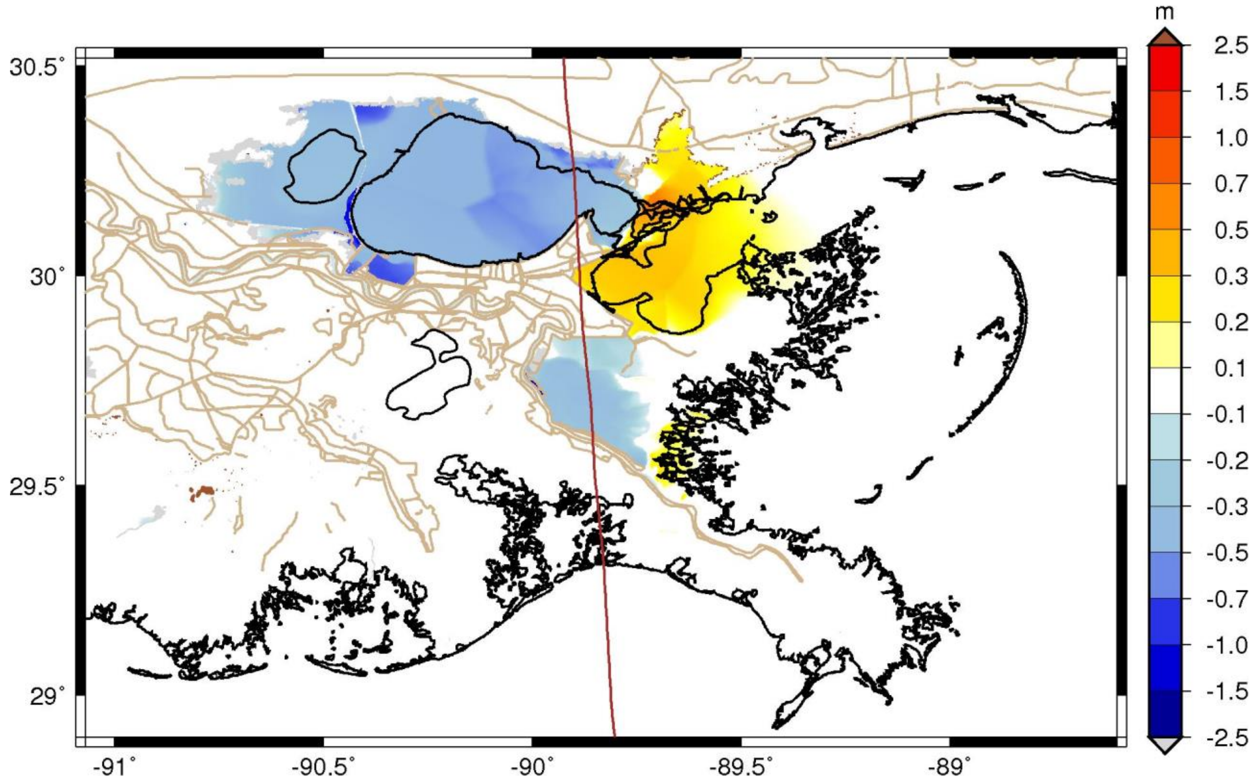


Figure 411: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA Storm 025 (year 10; high scenario). Positive values denote an increase with the projects in place.

Additional projects are implemented in the draft master plan for year 25 and year 50, especially further west toward Gonzales and the upper Barataria Basin. For instance, Figure 333 and Figure 413 show in year 25 and year 50, respectively, the differences in water surface elevations between the draft master plan and FWOA under the high scenario using storm 025 as an example. Similar patterns of impacts due to the draft master plan are also observed for individual storms under the medium scenario.

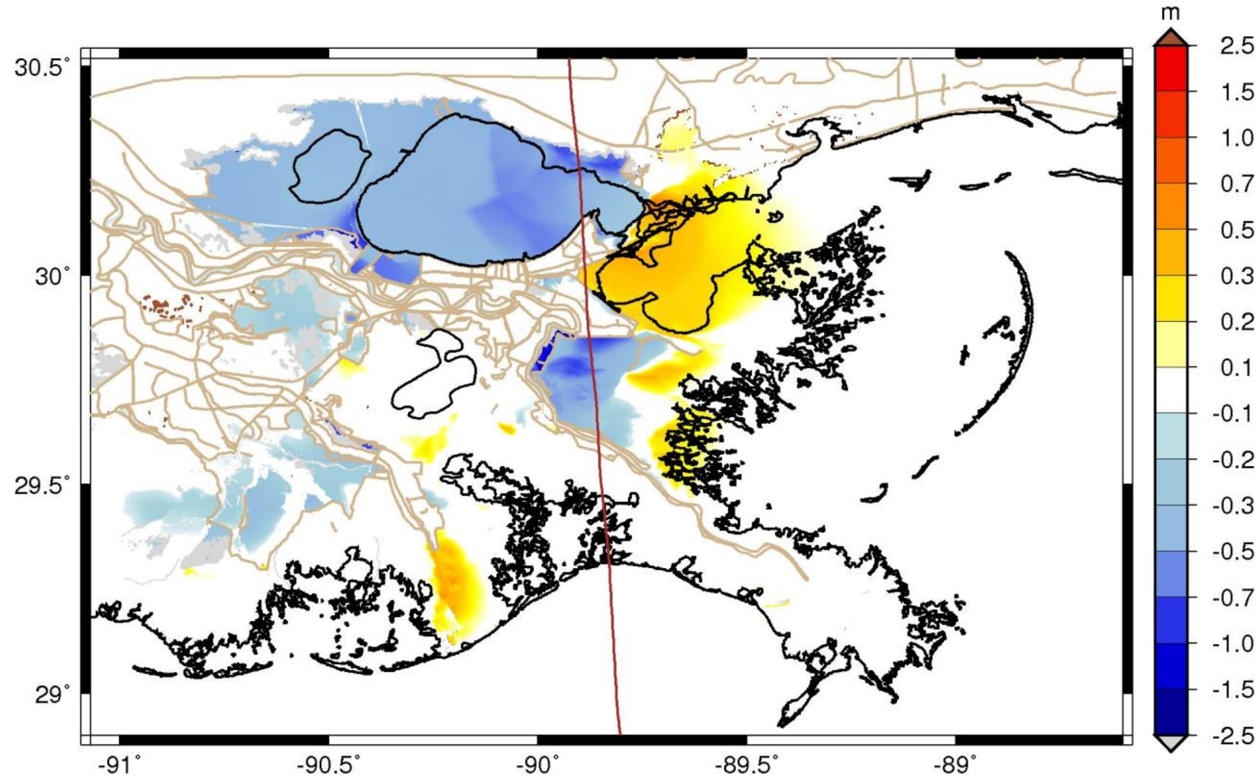


Figure 412: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 025 (year 25; high scenario). Positive values denote an increase with the projects in place.

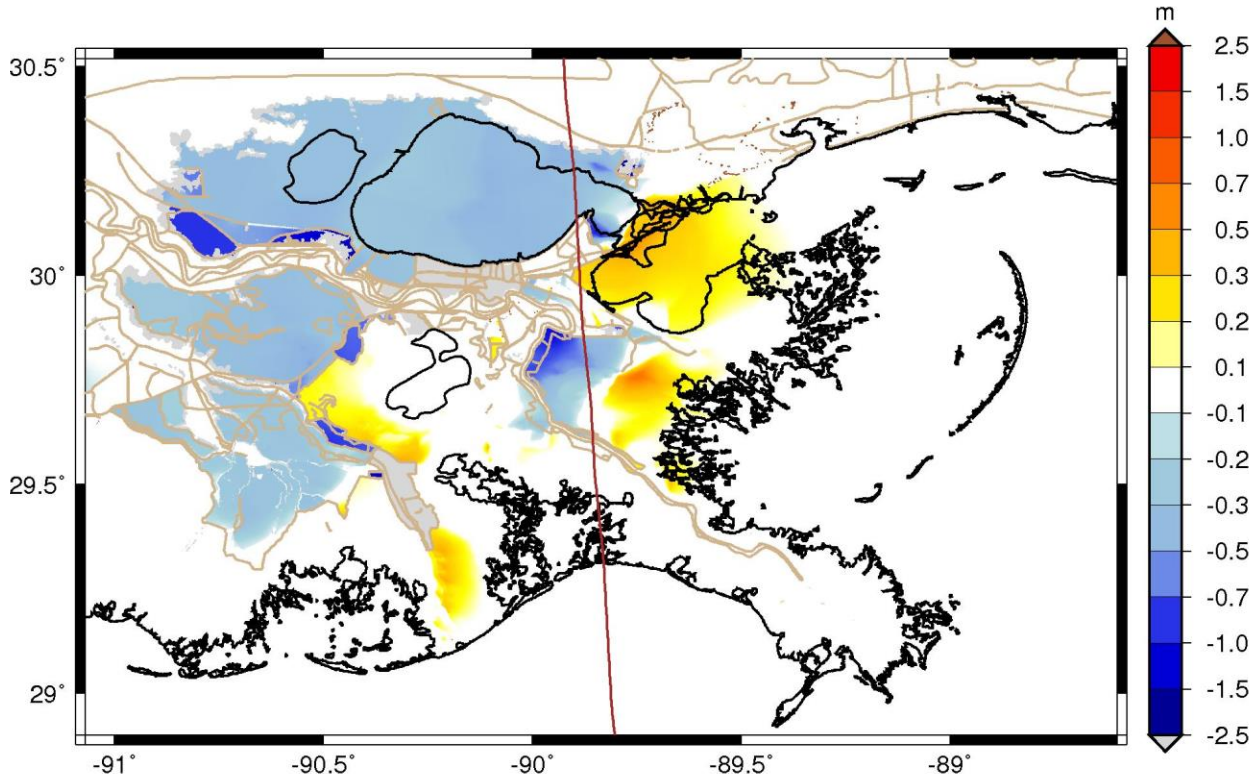


Figure 413: Differences in Maximum Water Surface Elevation (m) between the Draft Master Plan and FWOA for Storm 025 (year 50; high scenario). Positive values denote an increase with the projects in place.

6.2.2 Transect Analysis

While coast wide plots are useful to indicate spatial variations in risk reduction benefits of the draft master plan, one-dimensional transects across various types of landscape features can reveal additional details for specific locations and projects. The following discussion makes use of model input parameters and model outputs extracted along the transects shown in Figure 414. The transects were placed to cut through restoration projects in front of the Morganza to the Gulf protection project and are labeled ATT to identify their location in the Atchafalaya-Terrebonne basin.

In the central region, the draft master plan specifies implementation of the Larose to Golden Meadow (03a.HP.20) project in conjunction with several restoration projects. Figure 414 presents four transects through the central region, where storm surges and waves are altered by both hurricane protection and restoration projects. Figure 415 shows the variation in water surface elevation and wave height from offshore to onshore along each of the four transects. The response of surge and waves is not uniform along these transects. In general, water surface elevation is increased in front of the levee, but the location of the marsh creation projects influences the water surface elevation variation to some extent. In Figure 415, the vertical green bar indicates the location of the restoration project along the transect.

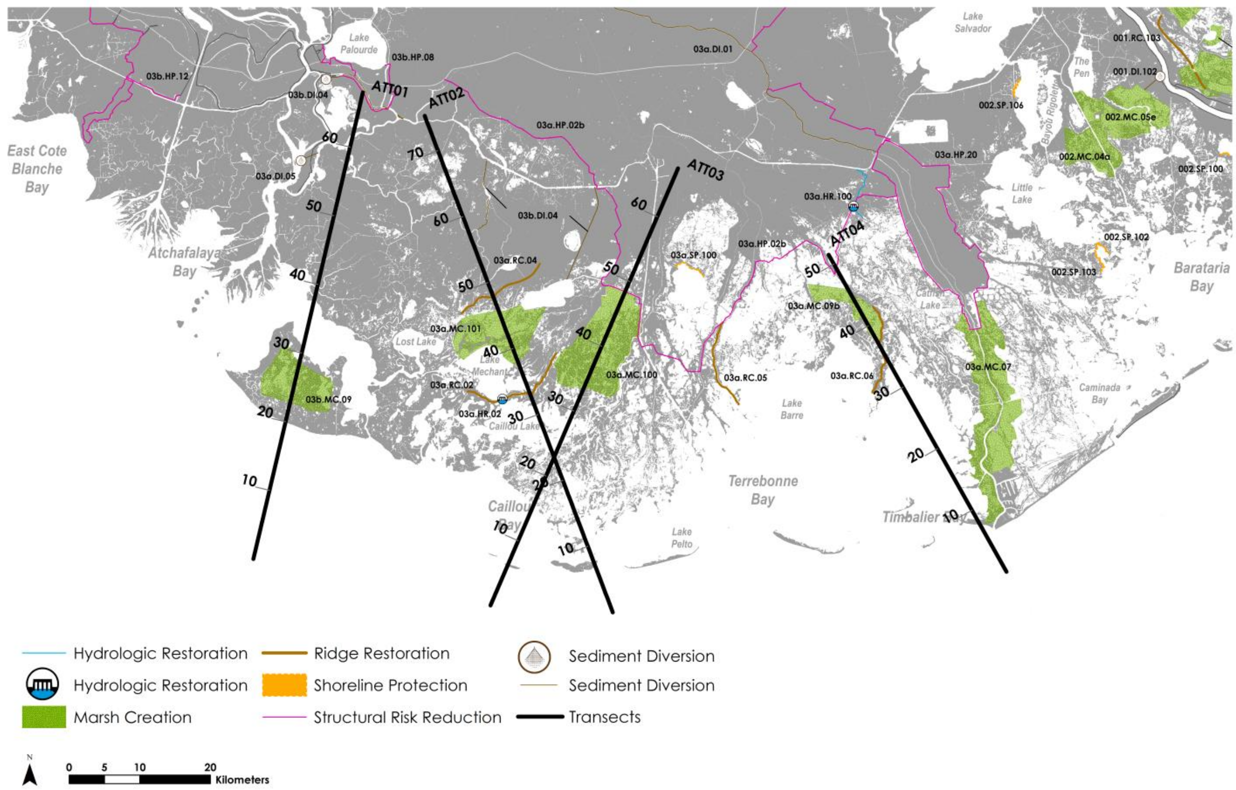


Figure 414: Transects in Atchafalaya-Terrebonne (ATT).

Transect ATT_01 passes through the Point Au Fer Island Marsh Creation project (03b.MC.09). Comparing the FWOA (red line) and the draft master plan (black line) Figure 415, water surface elevations indicates that the risk reduction potential provided by the Point Au Fer Island Marsh Creation project is negligible because the project is rather isolated, of small size, and relatively distant from the front of the levees near Morgan City. During a storm event, water is easily able to move around the project, resulting in overall water surface elevation along this transect remaining similar to FWOA. The protective benefits of Point Au Fer Island Marsh Creation are minor.

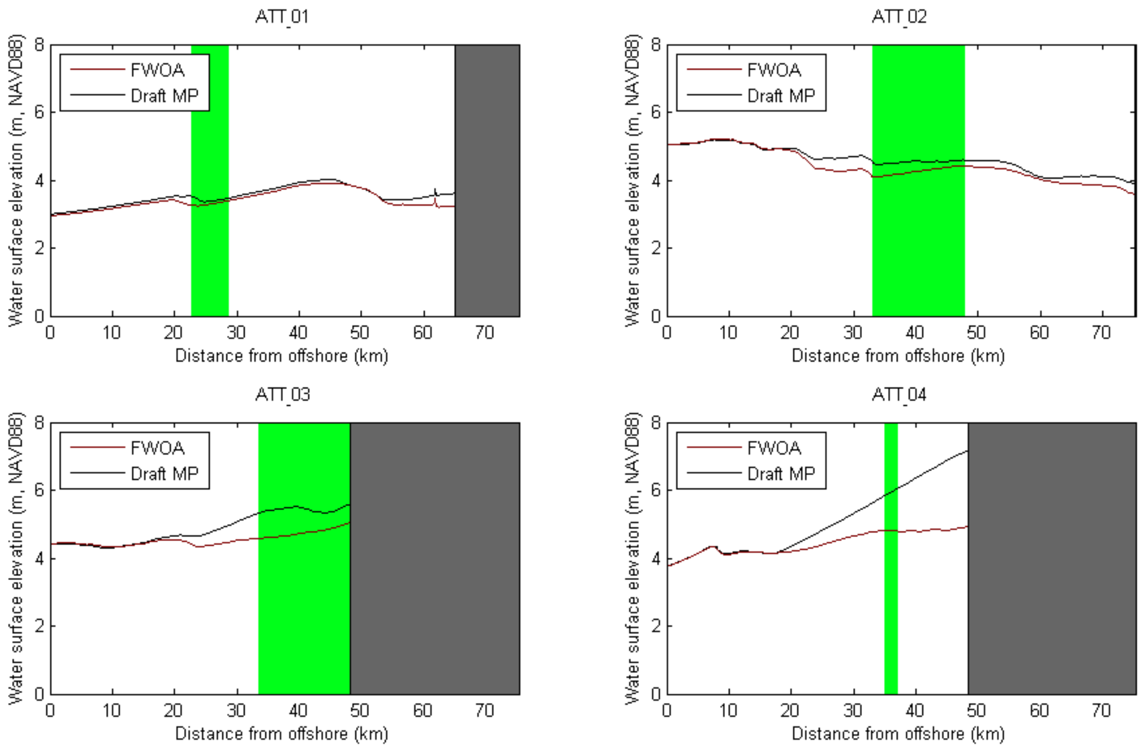


Figure 415: Variation in Maximum Water Surface Elevation (m) along Transects and Differences between the Draft Master Plan and FWOA for Storm 009 (year 50; high scenario).

Transect ATT_02 reveals a somewhat larger change from FWOA than transect ATT_01. Water surface elevation is increased over a distance of almost 10 km in front of the restored marsh due to the increased resistance of the modified landscape around (i.e., east of) the project implementation. Moving inland through the marsh, the water surface in the draft master plan becomes more like FWOA, demonstrating the risk reduction benefits of the marsh itself, but a slight increase in water surface elevation persists over the duration of the transect.

In contrast to ATT_01 and ATT_02, larger changes in water surface elevations are seen along Transects ATT_03 and ATT_04 between the draft master plan and FWOA. Along ATT_03, a pattern of increasing and then decreasing water levels is observed due to the existence of a series of marsh restoration and ridge restoration projects. The difference is largest in front of the marsh and slowly diminishes inland through the restoration site. However, the restoration projects along this transect extend all the way to the Morganza to the Gulf (03a.HP.02b) project. The influence of the levee can be seen at the upward increase in water surface elevation at the inland portion of the marsh (approximately km 43 to 48). Along ATT_04, impacts of restoration projects are negligible due to project size and orientation. Instead, water surface elevations gradually increase inland along the transect because of the presence of the Morganza to the Gulf levee, which obstructs flow from moving further inland. The water surface response along ATT_04 is almost entirely a consequence of the Morganza to the Gulf (03a.HP.02b) project, while along the other transects, the presence of the restoration projects contributes to the efficacy of the total protection system. The impacts of the draft master plan on wave heights are relatively localized to where the landscape changes due to restoration projects, and water surface elevations are changed due to obstruction by the levee and/or marshes. Figure 416 presents an example of wave height variation along each of the four transects and the differences between the draft master plan and FWOA.

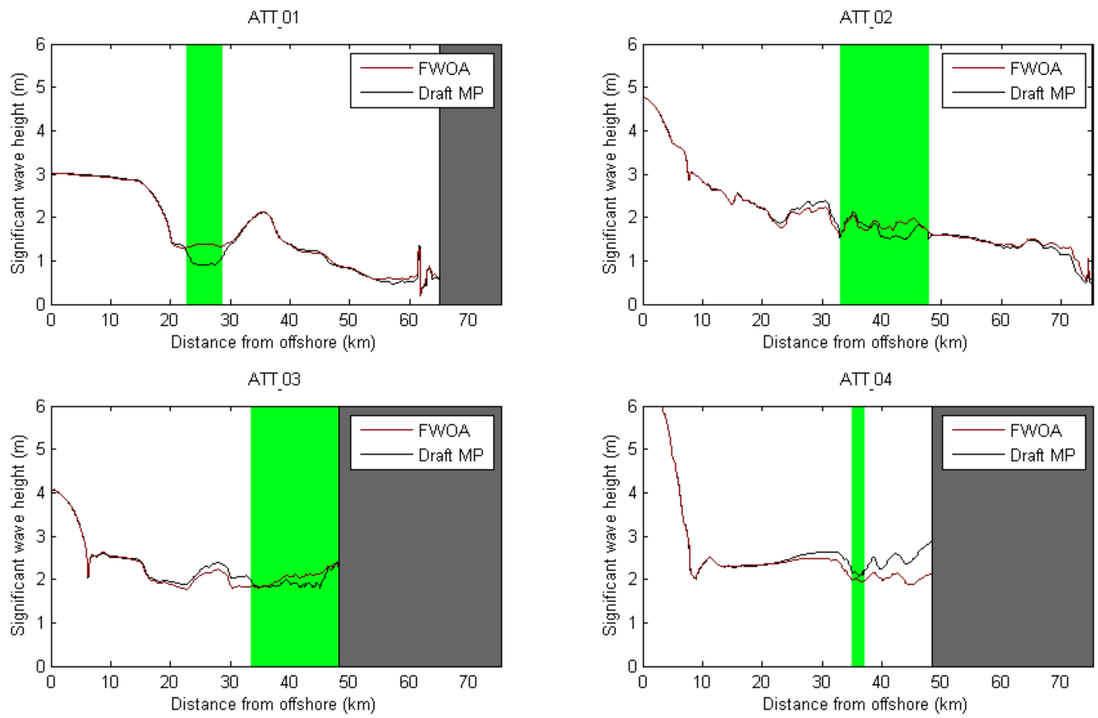


Figure 416: Variation in Maximum Wave Height (m) along Transects and Differences between the Draft Master Plan and FWOA for Storm 009 (year 50; high scenario).

6.3 Risk Reduction

6.3.1 Flood Depth Reduction

Following the storm surge and wave investigation, the CLARA model was used to estimate future flood depths and damage for the draft master plan (G400). Results from this analysis are summarized below, beginning with the results showing combined structural and nonstructural risk reduction projects. Flood depth reduction, comparing G400 with FWOA, is first summarized for each region of the coast (western, central, and eastern). Next, coast wide damage reduction is summarized, and nonstructural risk reduction benefits are highlighted for several communities.

6.3.1.1 Western Region

The change in median 100-year flood depths in the medium scenario in years 10 (top), 25 (middle), and 50 (bottom) of the simulation period is shown in Figure 417. A similar summary for the high scenario is provided in Figure 418. In the western region, the draft plan includes marsh and hydrologic restoration projects, but no structural protection alignments. The storm surge and wave investigation reveals changes in water surface elevation, relative to FWOA, that are generally less than 0.25 m for all storms simulated in years 10 and 25. This is reflected in the magnitudes of the changes in median 100-year flood depths in years 10 and 25 in both Figure 417 and Figure 418. Marsh creation projects around Calcasieu Lake and neighboring areas reduce the median 100-year flood depths in nearby areas in the year 50 results. Patterns are similar under the medium and high scenarios but are slightly more pronounced in the high scenario.

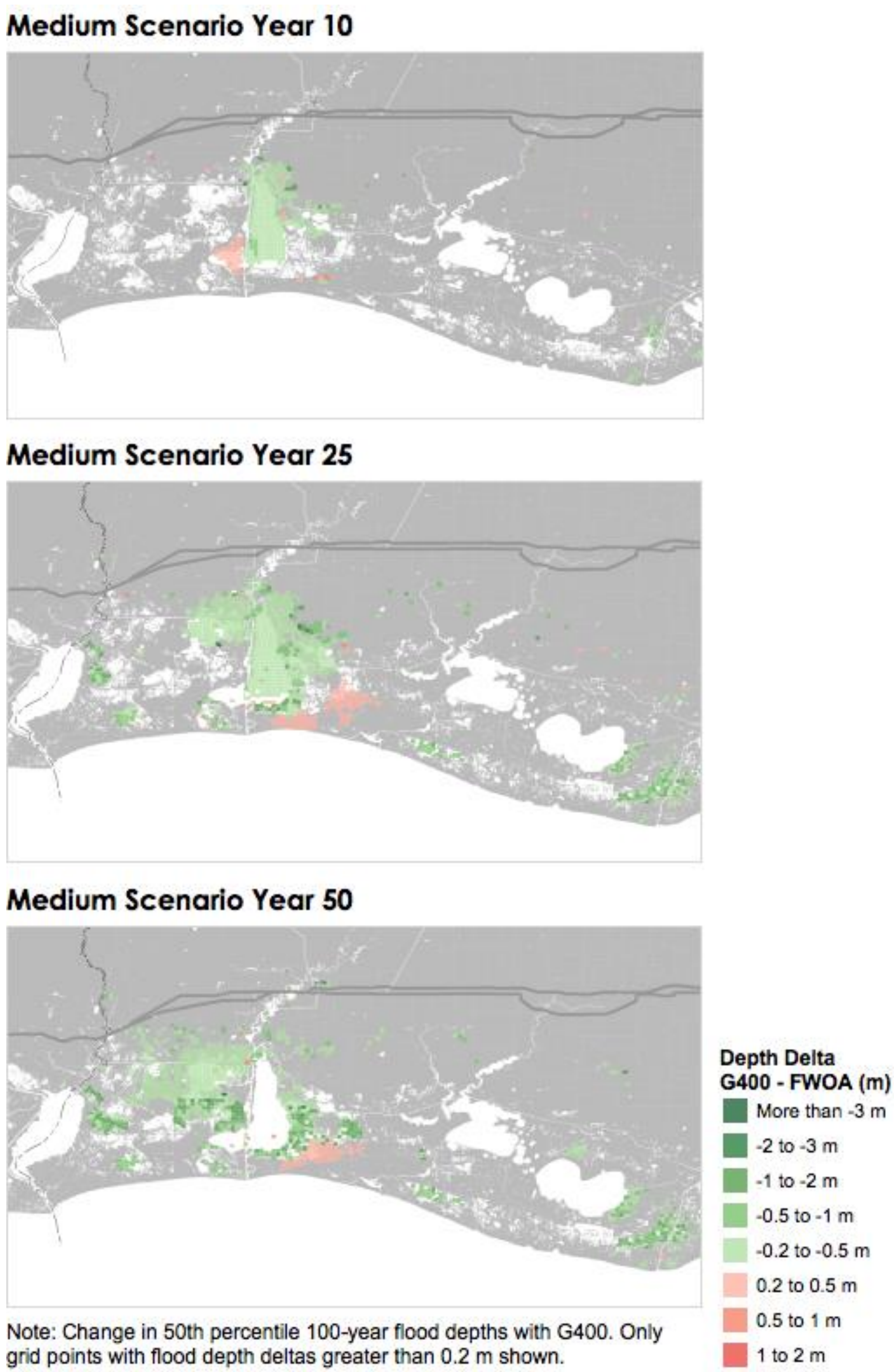
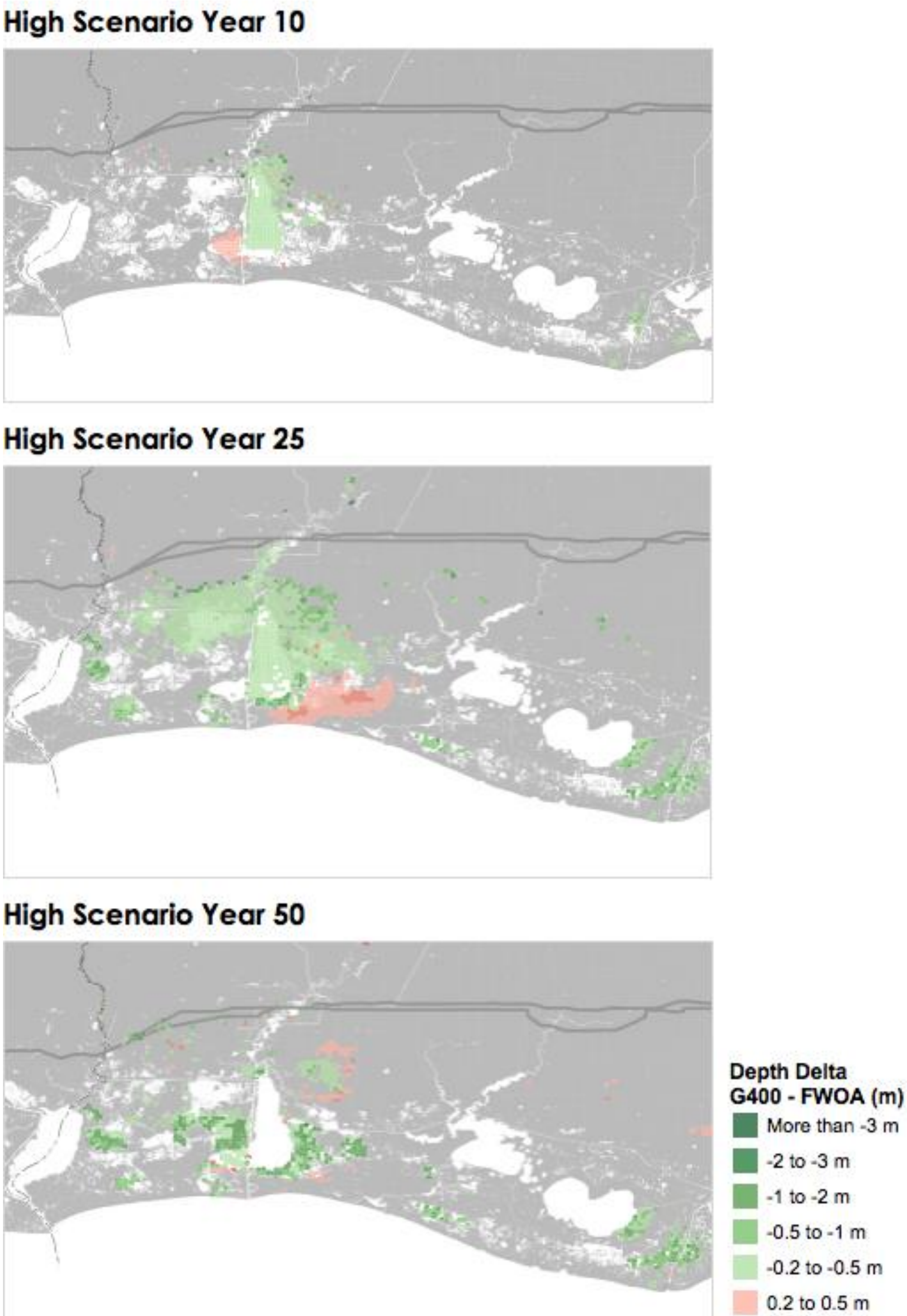


Figure 417: Difference in Median 100-Year Flood Depths for the Western Region due to Implementation of G400 compared to FWOA (years 10, 25, and 50; medium scenario).



Note: Change in 50th percentile 100-year flood depths with G400. Only grid points with flood depth deltas greater than 0.2 m shown.

Figure 418: Difference in Median 100-Year Flood Depths for the Western Region due to Implementation of G400 compared to FWOA (years 10, 25, and 50; high scenario).

6.3.1.2 Central Region

The draft plan proposes a number of hurricane protection, marsh creation, and ridge restoration projects in the central region of coastal Louisiana. Foremost among the hurricane protection projects are (west-to-east) the St. Mary/Iberia Upland Levee (03b.HP.14), Franklin and Vicinity (03b.HP.12), Amelia Levee Improvements (03b.HP.08), and Morganza to the Gulf (03a.HP.02b). Figure 419 shows the change in median 100-year flood depths in the medium scenario in years 10 (top), 25 (middle), and 50 (bottom) of the simulation period. Figure 420 displays similar results in the high scenario. Note the substantial and widespread impacts of the St. Mary/Iberia Upland Levee (03b.HP.14) improvements in year 25 and particularly year 50. There are many areas behind the levee reporting reductions in 100-year flood depths in excess of 3 m. Depth reduction is also observed in the Amelia vicinity in the eastern portion of the figures.

The Morganza to the Gulf project (03b.HP.02b), assumed to be constructed by year 25, yields notable changes over a wide area of the coast. The alignment primarily affects Terrebonne Parish, but effects also extend north and west to Assumption and Lafourche parishes. As shown in these figures, 100-year depths are reduced by 0.2 m to more than 2 m over a wide area behind the new alignment in both the medium and high scenarios. This project also interconnects with the Larose to Golden Meadow (03a.HP.20) project, and proposed Upper Barataria Risk Reduction (002.HP.06) project (discussed in the next section), providing an unbroken line of protection extending to the Mississippi River. On the unprotected, coastal side of this alignment, however, flood depth increases are noted in the simulation results. Depth increases in front of the alignment range from 0.2 m to upwards of 0.5 m compared with FWOA in some areas, present in both the medium and high scenarios.

Marsh restoration projects have notable impacts on Marsh Island and on the mainland in the area due west of Marsh Island in year 25 and 50 results shown in Figure 419 and Figure 420. There is additional evidence of the benefits of marsh creation projects in the year 50 results in the area on the coast on the west side of Terrebonne Parish. Here again, the medium and high scenario results are very similar.

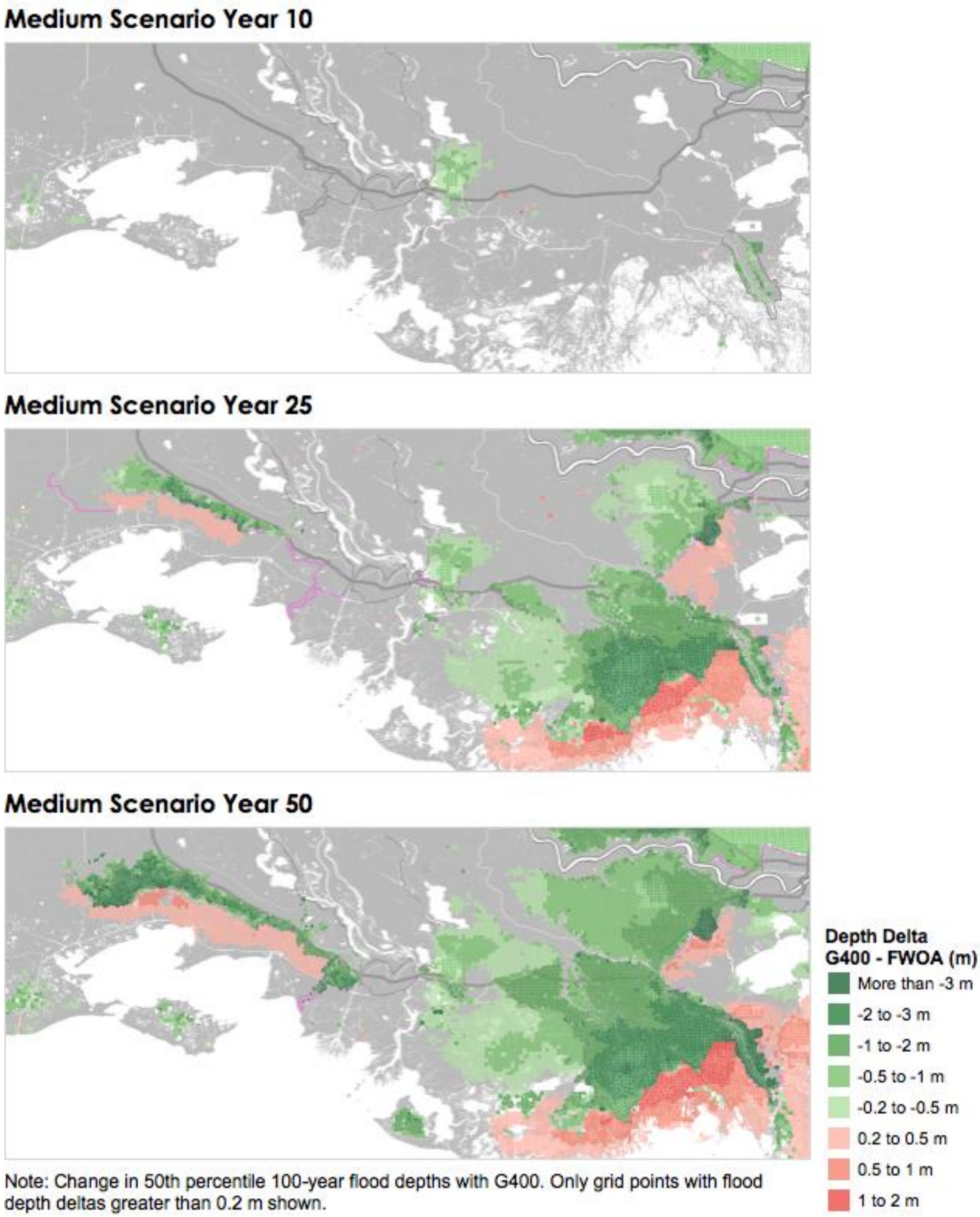


Figure 419: Difference in Median 100-Year Flood Depths for the Central Region due to Implementation of G400 compared to FWOA (years 10, 25, and 50; IPET fragility scenario; medium scenario).

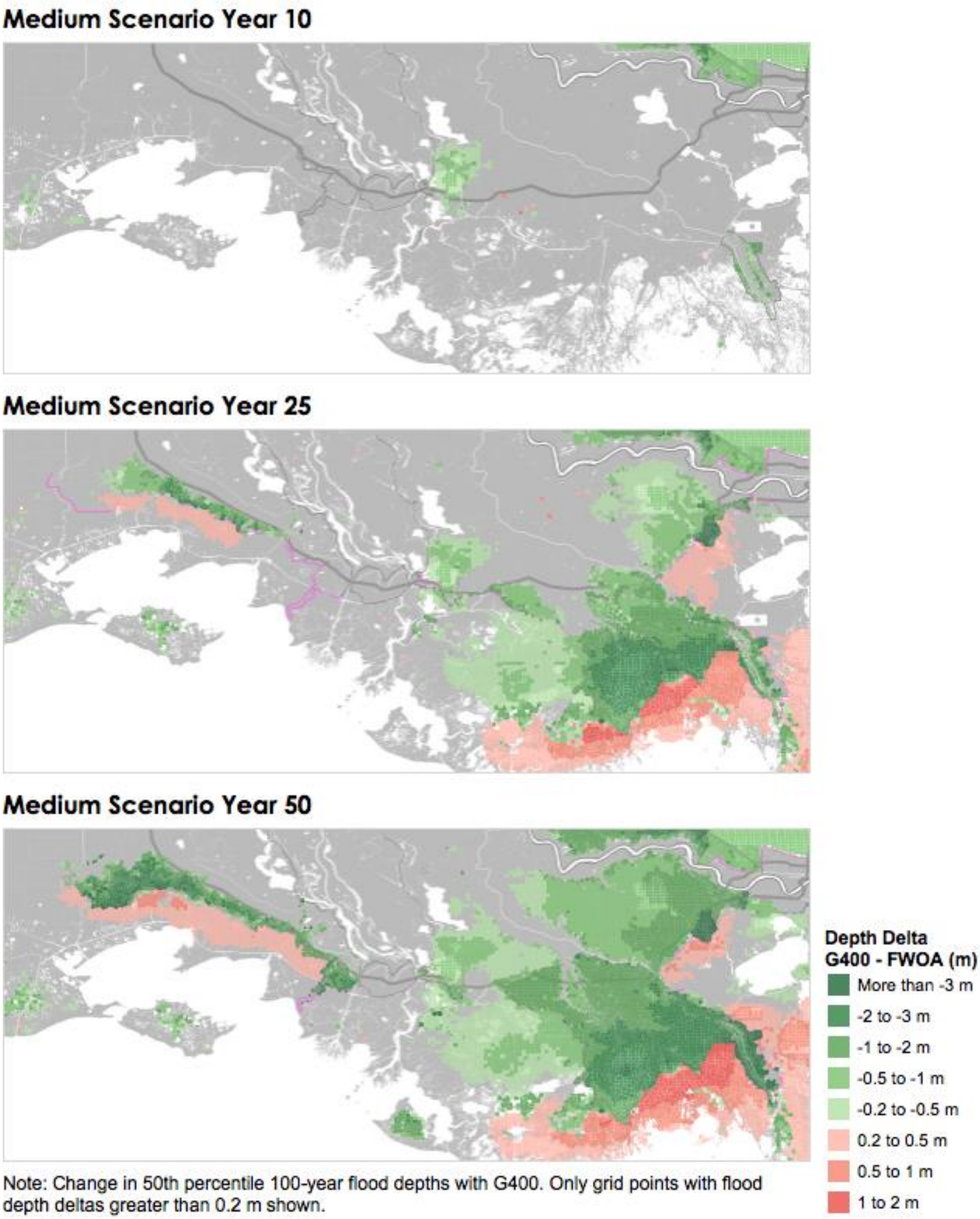
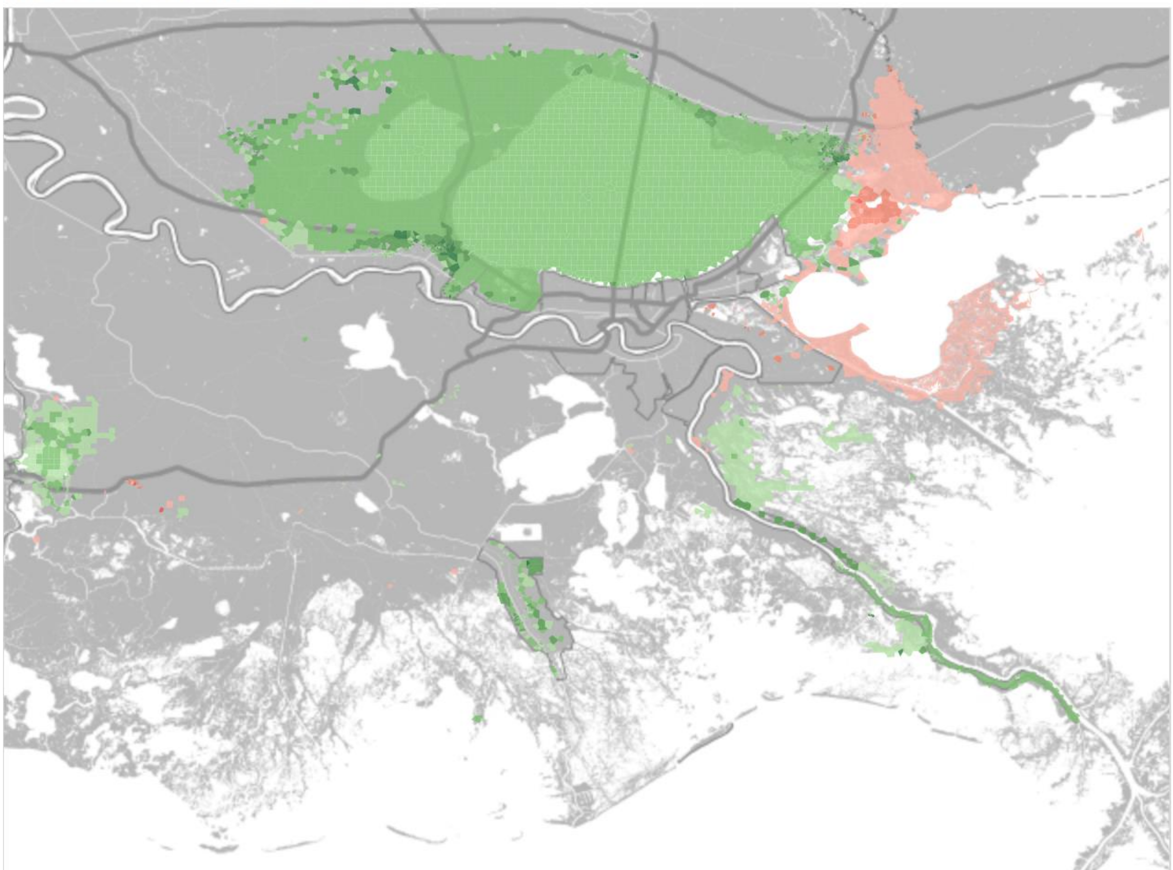


Figure 420: Difference in Median 100-Year Flood Depths for the Central Region due to Implementation of G400 compared to FWOA (years 10, 25, and 50; IPET fragility scenario; high scenario).

6.3.1.3 Eastern Region

In the eastern region of the coast, the draft plan includes several large-scale hurricane protection projects and levee improvements, including construction of Upper Barataria Risk Reduction (002.HP.06), a Lake Pontchartrain Barrier (001.HP.08), and additional projects in the Pontchartrain Basin: West Shore Lake Pontchartrain (001.HP.05); Slidell Ring Levees (001.HP.13); and Greater New Orleans High Level (001.HP.04). Figure 421 provides the changes in 100-year flood depths in this region under the medium scenario in year 10 of the simulation period, with most of the Pontchartrain area projects assumed to be in place. Flood depths are reduced in Lake Pontchartrain and areas due west of the lake, as well as along the Mississippi River near Point a La Hache. There is some evidence of induced flooding, particularly east of the Lake Pontchartrain Barrier (001.HP.08) project. The Upper Barataria Risk Reduction (002.HP.06) is not yet implemented by year 10, so no change in flood depths is seen north of Larose to Golden Meadow in Figure 421.

Medium Scenario Year 10



Note: Change in 50th percentile 100-year flood depths with G400. Only grid points with flood depth deltas greater than 0.2 m shown.

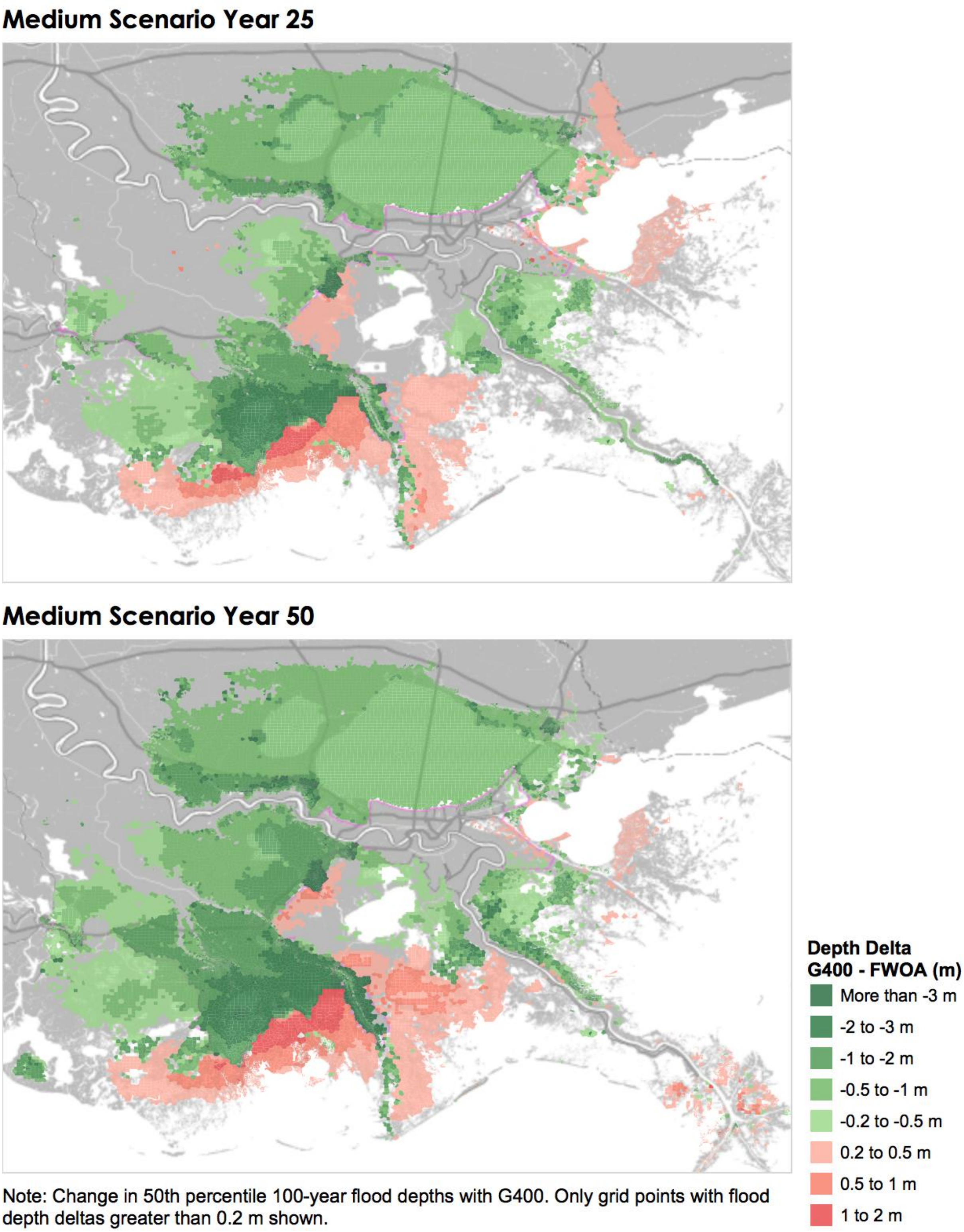
Depth Delta G400 - FWOA (m)

More than -3 m | -1 to -2 m | -0.2 to -0.5 m | 0.5 to 1 m
-2 to -3 m | -0.5 to -1 m | 0.2 to 0.5 m | 1 to 2 m

Figure 421: Difference in Median 100-Year Flood Depths for the Eastern Region due to Implementation of G400 compared to FWOA (year 10; IPET fragility scenario; medium scenario).

Figure 422 shows the same region with year 25 and 50 results. In these future years, the Upper Barataria Risk Reduction (002.HP.06) and West Shore Lake Pontchartrain (001.HP.05) projects yield substantial 100-year depth reduction, ranging from 0.2 m to more than 3 m. These effects span a wide geographic area, yielding depth reductions in much of Lafourche Parish and into St. James, St. Charles, and other parishes by year 50. The depth of flooding is greater in year 50, so the corresponding depth reduction shown in the figure is also greater in year 50 than in year 25. There is also, however, evidence of induced flooding in front of the Upper Barataria Risk Reduction (002.HP.06) project in this region, with 100-year flood depths increasing by 0.2 m to upwards of 0.5 m compared with FWOA in some areas.

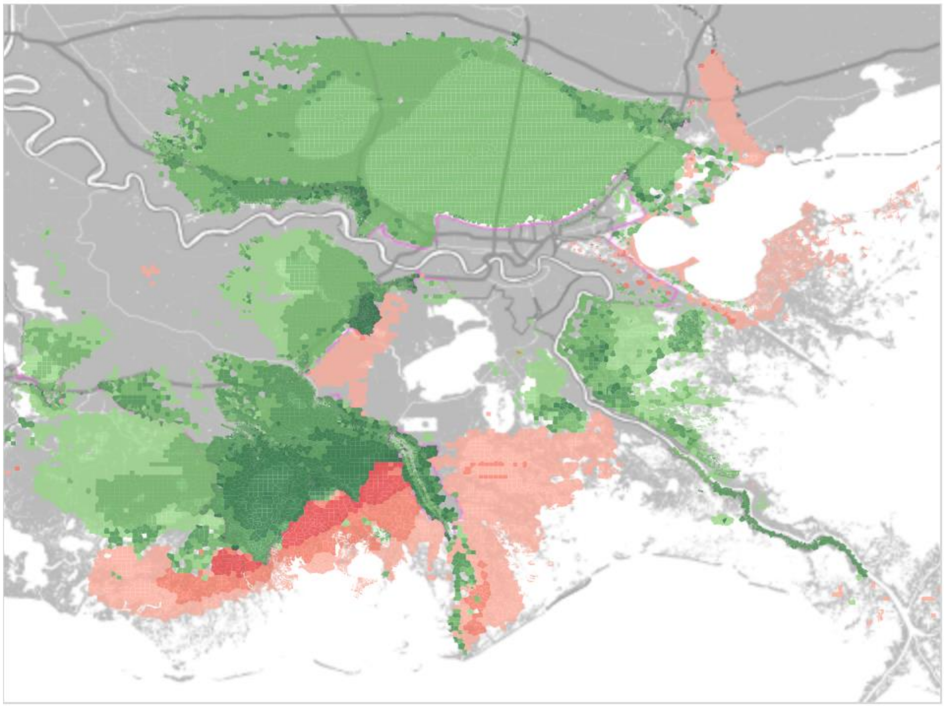
Figure 423 shows the same results in the high scenario, year 25, and 50. Patterns in the high scenario are generally similar to those in Figure 422, with effects generally becoming even more pronounced due to the higher depths observed in FWOA.



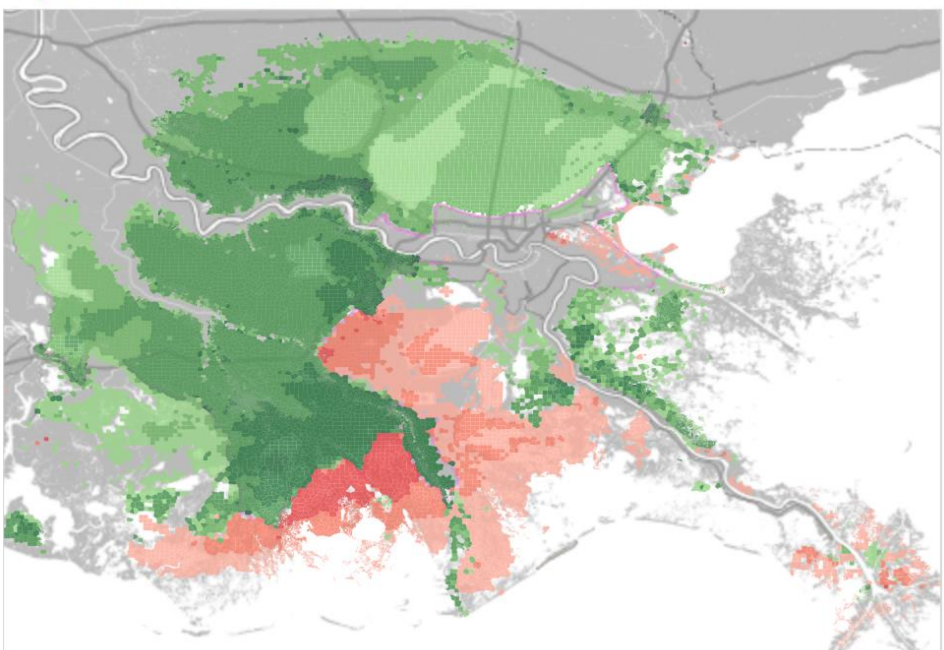
Note: Change in 50th percentile 100-year flood depths with G400. Only grid points with flood depth deltas greater than 0.2 m shown.

Figure 422: Difference in Median 100-Year Flood Depths for the Eastern Region due to Implementation of G400 compared to FWOA (years 25 and 50; IPET fragility scenario; medium scenario).

High Scenario Year 25



High Scenario Year 50



Note: Change in 50th percentile 100-year flood depths with G400. Only grid points with flood depth deltas greater than 0.2 m shown.

Depth Delta
G400 - FWOA (m)

- More than -3 m
- -2 to -3 m
- -1 to -2 m
- -0.5 to -1 m
- -0.2 to -0.5 m
- 0.2 to 0.5 m
- 0.5 to 1 m
- 1 to 2 m

Figure 423: Difference in Median 100-Year Flood Depths for the Eastern Region due to Implementation of G400 compared to FWOA (year 10; IPET fragility scenario; high scenario).

With the draft plan, enclosed areas also experience a mixture of lower and higher flood depths. Figure 424 illustrates 500-year depths in the high scenario, showing the change in flood depth within HSDRRS for years 10, 25, and 50 across all three fragility scenarios. East Bank HSDRRS shows depth reduction from the Greater New Orleans High Level (001.HP.04) project and Lake Pontchartrain Barrier (001.HP.08) project in the scenarios that include levee fragility (IPET and MTTG). Alternately, the Upper Barataria Risk Reduction (002.HP.06) project exhibits the potential to induce surge and wave heights along the HSDRRS West Bank alignment, producing greater flood depths at the 500-year recurrence interval on the enclosed side due to an increased likelihood of levee failure. These areas of the West Bank show inducement in year 50 of 0.2 to 2 m in some locations, depending on scenario, though the magnitude and extend of inducement is reduced compared to the G301 or G303 simulations without the effects from the Lafitte Ring Levees (002.HP.07) project. A lower level of inducement, typically less than 0.5 m, is also observed in the enclosed St. Bernard Parish, including the Lower Ninth Ward, in the IPET or MTTG fragility scenarios.

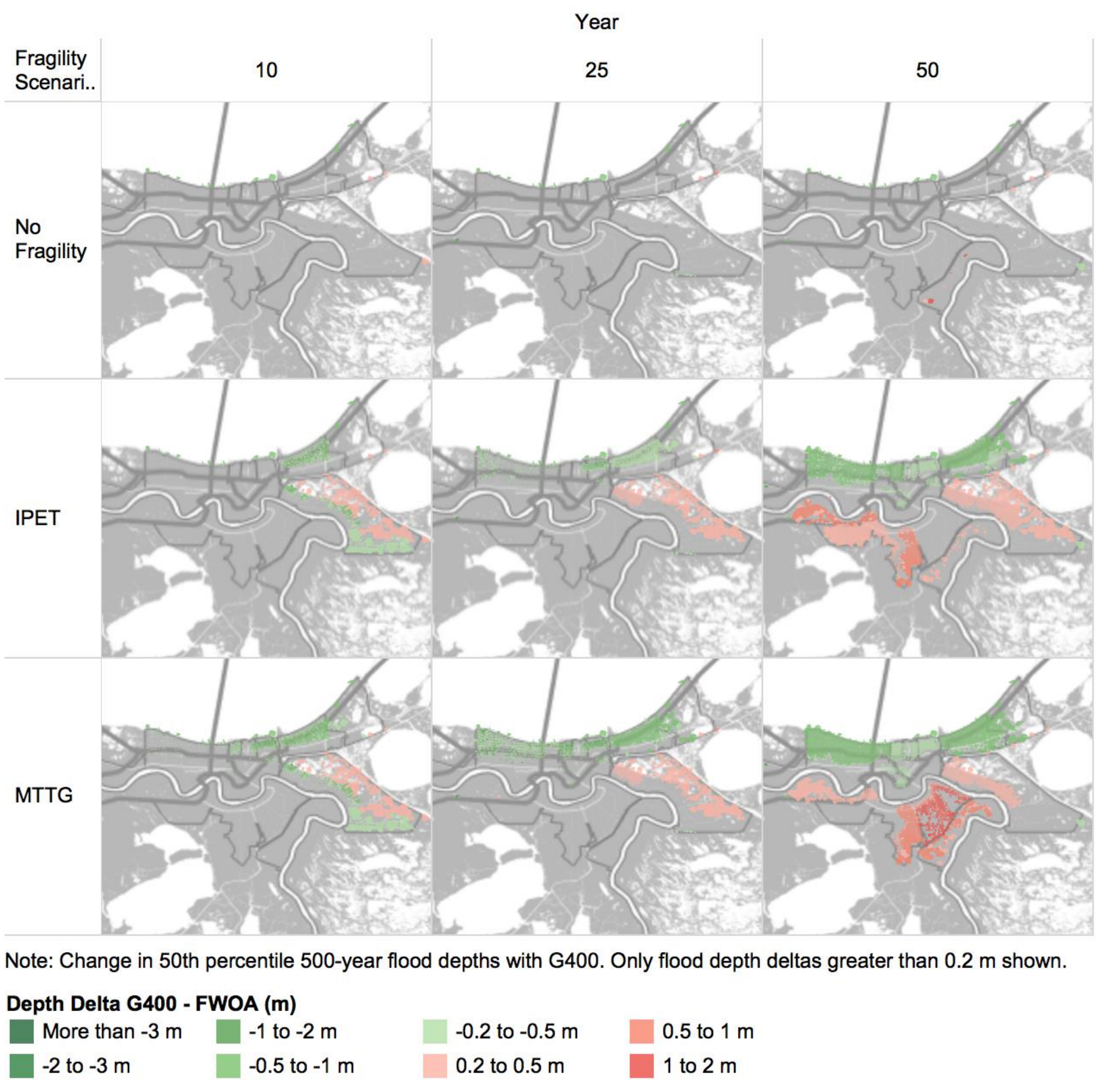


Figure 424: Difference in Median 500-Year Flood Depths due to Implementation of G400 compared to FWOA, Greater New Orleans HSDRRS only (all fragility scenarios); Years 10, 25, and 50; High Scenario.

6.3.2 Flood Damage Reduction

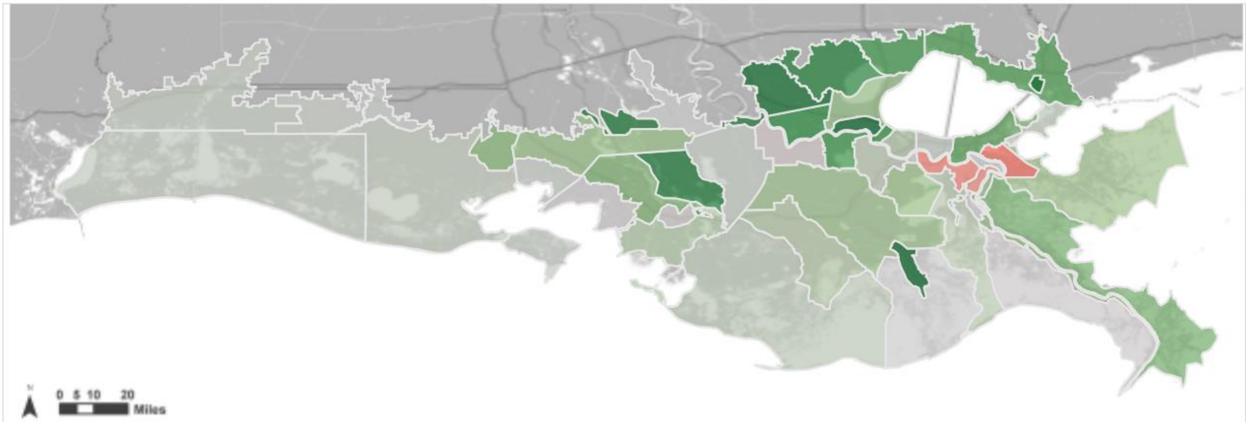
6.3.2.1 Coast Wide Benefits

The changes in flood depth observed in the simulation results from structural protection and restoration projects in the draft plan also yield substantial changes in economic damage, measured as expected annual damage (EAD). EAD is also reduced through the implementation of a series of nonstructural risk reduction projects.

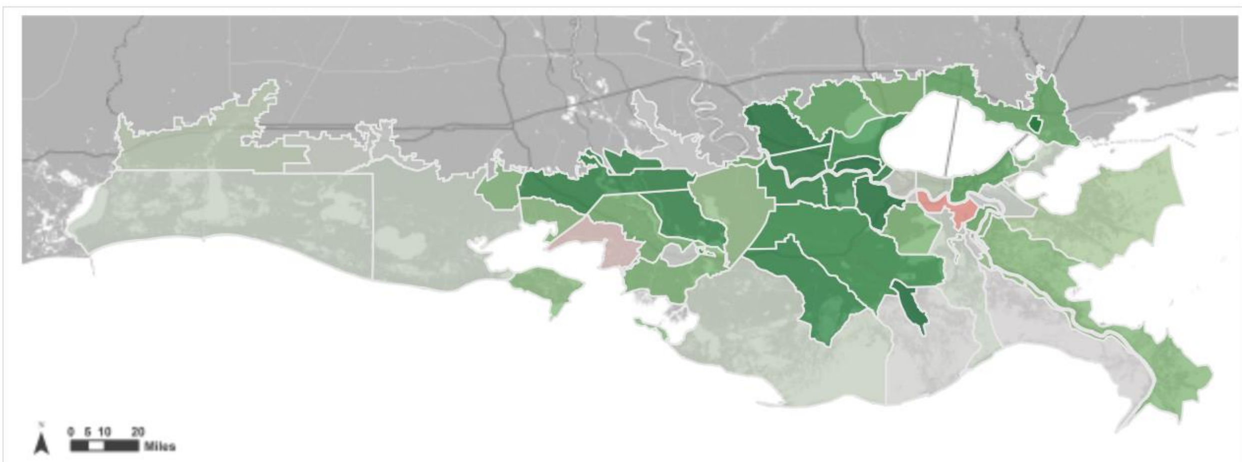
Figure 425 shows the change in EAD (percent reduction) by risk region under the medium scenario in years 10, 25, and 50 for one set of fragility and population growth assumptions. Damage reduction generally tracks the spatial pattern of depth reduction noted previously. By year 50, there is 50 percent or greater damage reduction compared with FWOA in Houma, Laplace/Reserve, Raceland, Morgan City, Larose to Golden Meadow, Slidell, and Hahnville/Luling. Other parishes, such as those targeted for nonstructural risk reduction only (discussed below), show a lesser degree of damage reduction effects. Induced damage is also noted in several areas where flood inducement occurs, particularly lower Terrebonne and Barataria (outside of the levee alignments), HSDRRS West Bank, and enclosed St. Bernard Parish. In the medium scenario, inducement effect sizes are generally low, in terms of absolute EAD increases (not shown) as well as the percent change relative to FWOA.

Figure 426 shows the results from the high scenario. Patterns of damage reduction are similar to the medium scenario, with a similar percentage reduction in EAD compared with the FWOA. However, absolute EAD reduction is greater due to the higher baseline damage in the high scenario, especially in year 50. Greater damage inducement is also noted in the West Bank HSDRRS region, particularly in the year 50 results. The magnitude of damage inducement by risk region under the high scenario, measured in terms of economic damage, is generally much lower than the simulated benefits, with the exception of West Bank HSDRRS where population and asset density is high.

Medium Scenario Year 10



Medium Scenario Year 25



Medium Scenario Year 50

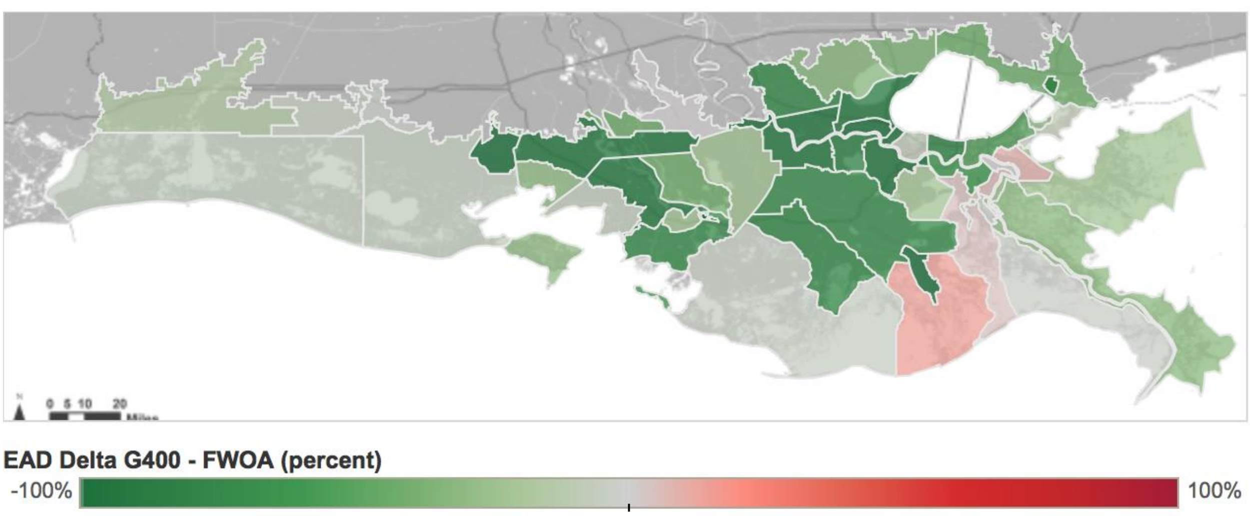
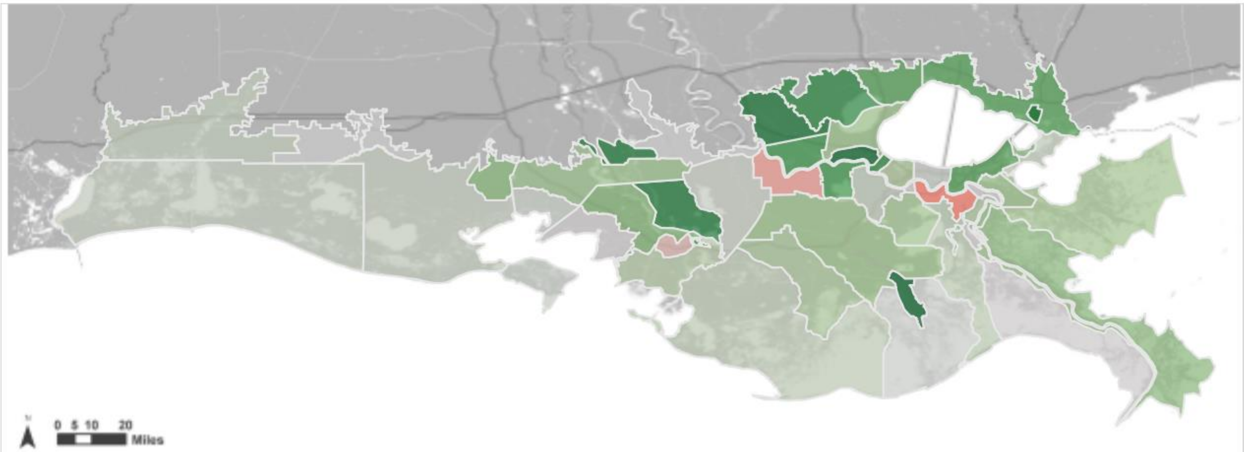
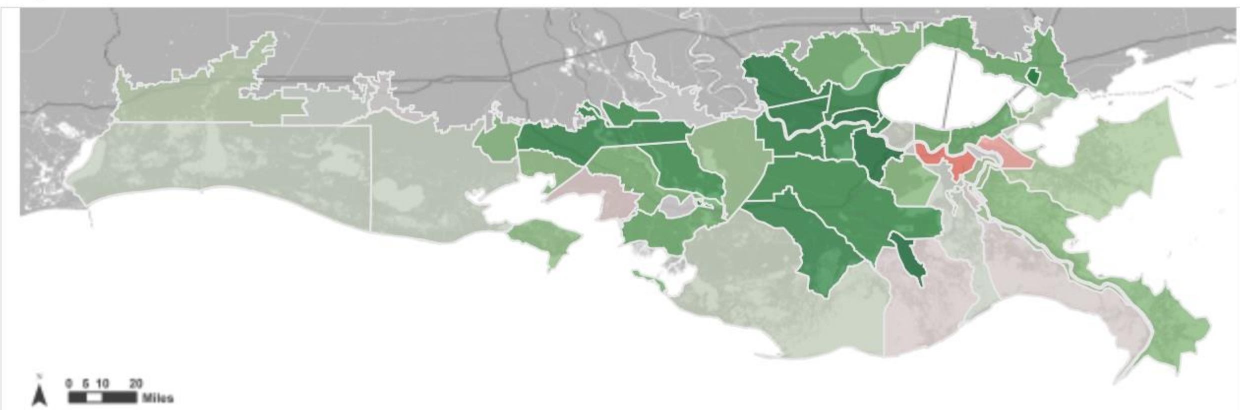


Figure 425: EAD Reduction with the Draft Plan compared to FWOA (years 10, 25, and 50; historical growth and IPET fragility scenarios; mean estimates; medium scenario).

High Scenario Year 10



High Scenario Year 25



High Scenario Year 50

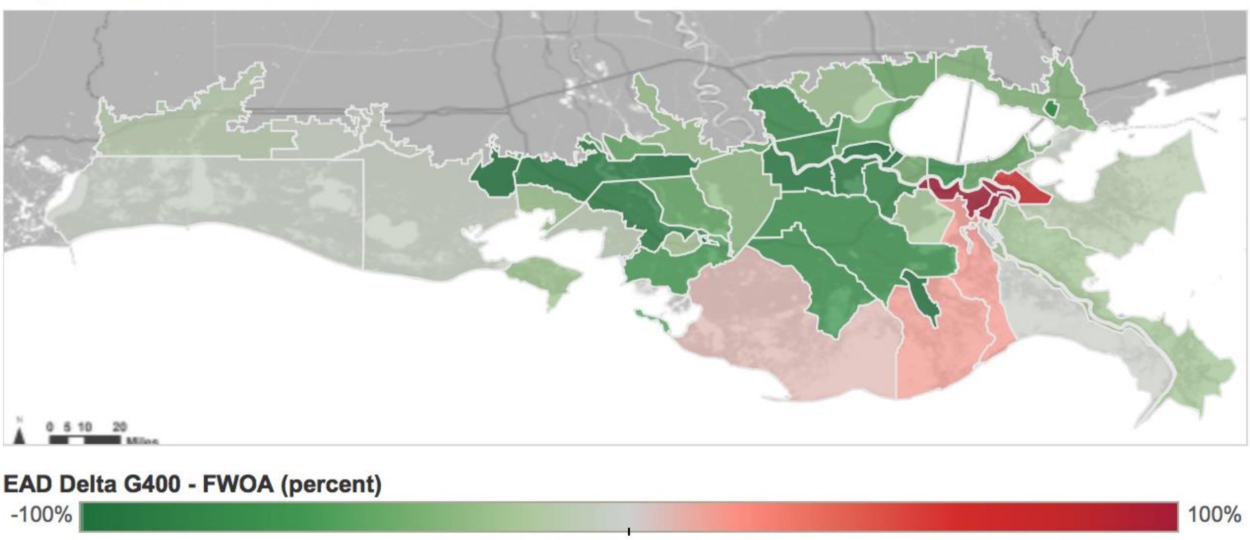


Figure 426: EAD Reduction with the Draft Plan compared to FWOA (years 10, 25, and 50; historical growth and IPET fragility scenarios; mean estimates; high scenario).

Figure 427 aggregates EAD coast wide by year and landscape scenario for both FWOA and the draft plan. The draft plan substantially reduces expected economic damage coast wide in all time periods and landscape scenarios. The benefits are most pronounced under the more extreme cases considered. For example, damage reduction of $3.9 billion is simulated in the low scenario (from $6.1 in the FWOA to $2.2 billion with the draft plan), compared to a reduction of more than $11 billion in year 50 of the high scenario (from $18.9 billion to $7.7 billion).

Figure 428 instead shows the coast wide EAD reduction benefit, in absolute and relative terms, by year and landscape scenario. Percent reduction ranges from 29-31 percent in year 10 to 56-66 percent in years 25 and 50, when a more complete range of projects are implemented. The magnitude of coast wide damage reduction increases when looking further into the future and is higher in the more adverse landscape scenarios.

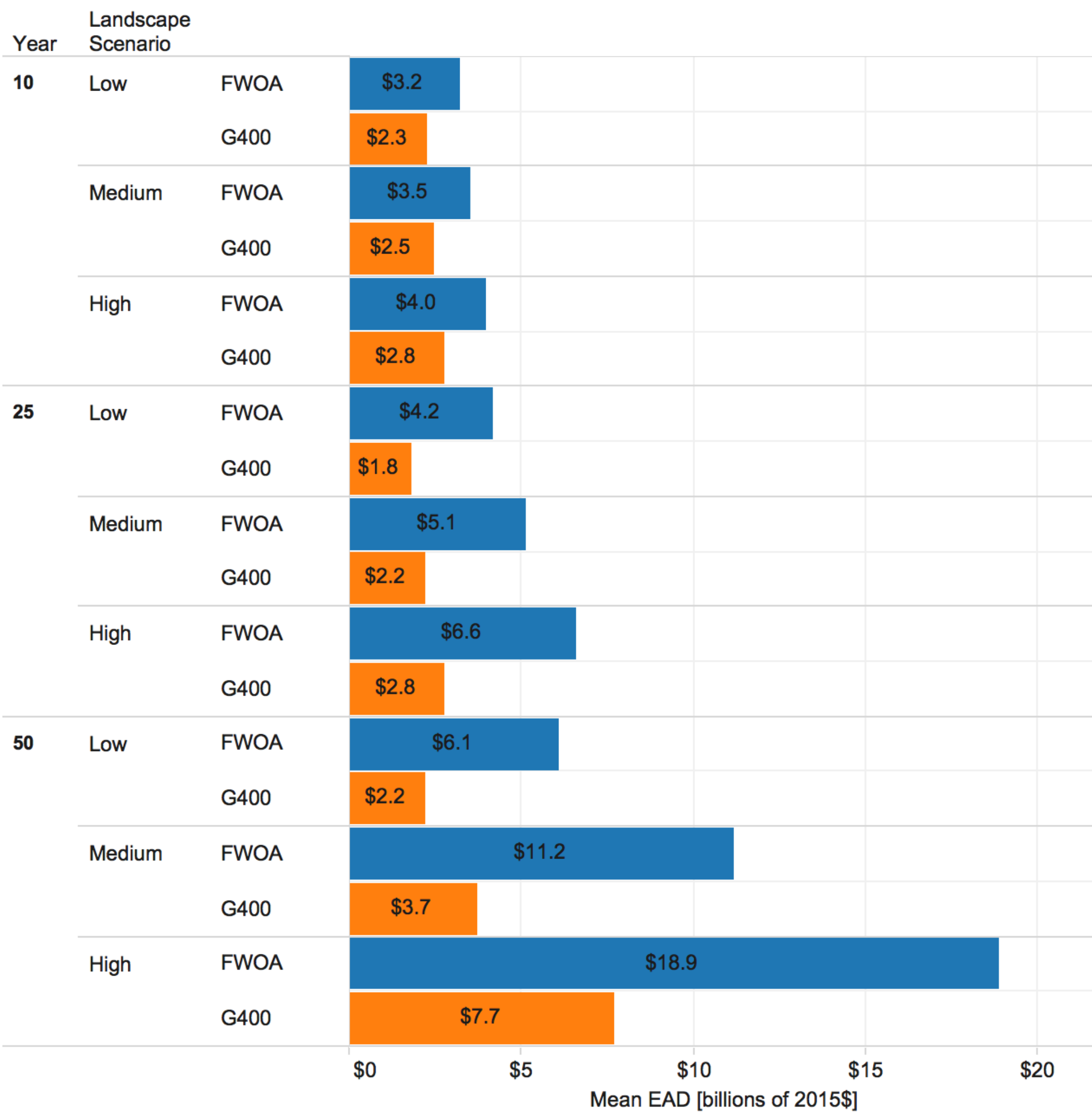


Figure 427: EAD in FWOA (blue) and with the Draft Plan (orange); Historical Growth and IPET Fragility Scenarios.

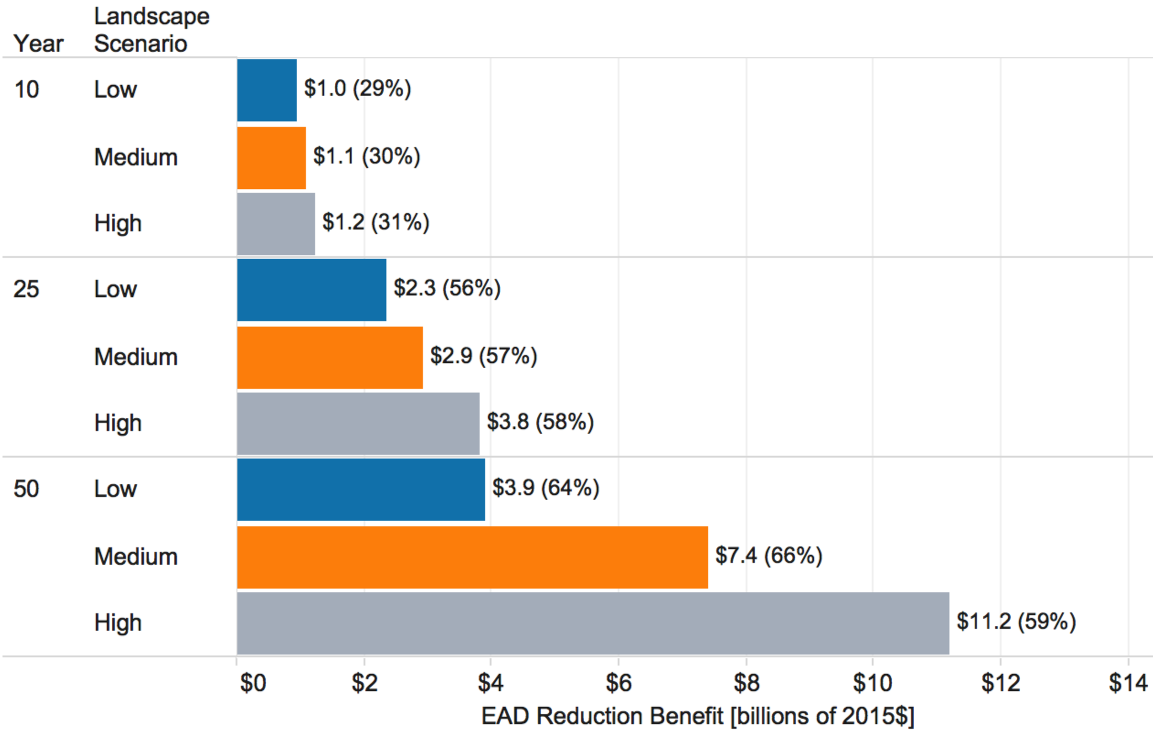


Figure 428: Coast Wide EAD Reduction with the Draft Plan (historical growth and IPET fragility scenarios; percent reduction in parentheses).

6.3.3 Nonstructural Risk Reduction

Nonstructural risk reduction projects are included as part of the draft plan in many risk regions across the entire coastal zone. While these projects do not alter flood depths, they contribute to the benefits by reducing the damage associated with flooding when compare to FWOA. Because of the spatial distribution of structural protection and coastal restoration projects that do impact the distribution of flood depths, it is difficult to isolate the contribution of nonstructural projects to the coast wide reductions in EAD depicted in Figure 428.

However, the western region, encompassing Calcasieu and Cameron Parishes, and portions of Vermilion Parish, does not receive additional structural protection under the draft plan. The draft plan's marsh creation and hydrologic restoration projects in the region have little impact on flood depths, particularly in the populated areas of Cameron Parish (as shown by Figure 417 and Figure 418). In these areas, any differences in EAD between the draft plan and FWOA can be attributed primarily to the impact on nonstructural projects. These outcomes are summarized for the Cameron, Calcasieu, and Vermilion risk regions (the latter of which excludes the Vermilion – Abbeville/Delcambre region protected by the Abbeville and Vicinity (004.HP.15) project in Figure 429.

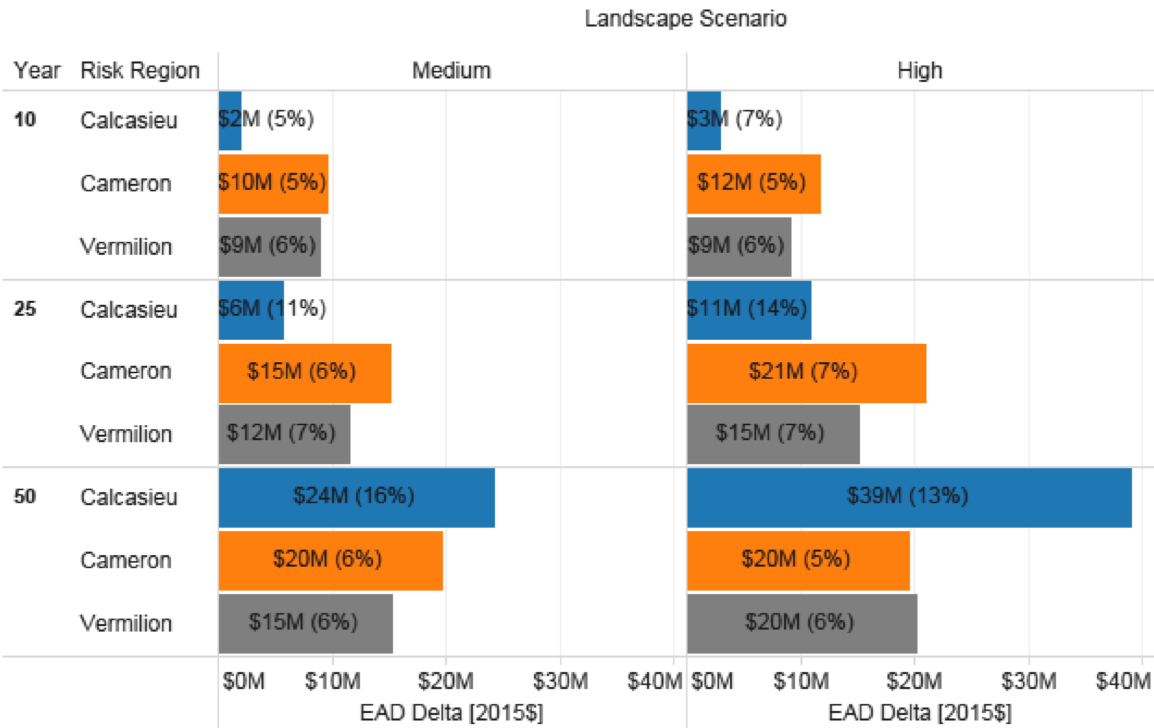


Figure 429: G400 EAD Reduction, Relative to FWOA, by Risk Region in the West Region (historical growth scenario; mean estimates).

EAD reduction is provided in absolute terms and as a percentage of the EAD in FWOA. It is important to note that the nonstructural project in Calcasieu Parish is not implemented during years 10 and 25 in the draft plan, so the benefits in those years are attributable to restoration measures (the EAD reduction in year 10 is not statistically significant, however). Nonstructural projects are included in all three time periods in the other two risk regions. Damage reduction from nonstructural projects in these regions ranges from 6-16 percent when compared with FWOA values.

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