NORTH CAROLINA SEA LEVEL RISE IMPACT STUDY

FINAL STUDY REPORT

Produced by North Carolina Emergency Management
Geospatial and Technology Management

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DISCLAIMER

This document was prepared under a grant from the Federal Emergency Management Agency (FEMA), U.S. Department of Homeland Security (DHS). Points of view or opinions expressed in this document are those of the authors and do not necessarily represent the official position or policies of FEMA or DHS.

The report was developed by the North Carolina Department of Public Safety (DPS), North Carolina Emergency Management - Geospatial and Technology Management (NCEM-GTM). DPS and NCEM-GTM did not develop the sea level change or hurricane frequency assumptions for which the potential impacts described herein were based. Therefore this report did not prove or disprove any sea level rise or extreme weather projections or causations, nor does this report assign probabilities or likelihoods for a given sea level rise or hurricane scenario. As such, the study has no direct regulatory or insurance implications. Flood prevention ordinances and policy are set by the land use authorities. The North Carolina Floodplain Mapping Program does not plan to incorporate products of this Report into Flood Insurance Rate Maps. The National Flood Insurance Program (NFIP) regulations exclude future conditions in the development of Flood Insurance Rate Maps. Flood insurance rates under the NFIP are set by FEMA at the national level, thus, results from this Report will not affect rate levels.

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NOTE ON UNITS

U.S. standard units are presented throughout the report. Where parameters were defined for the study or cited literature sources presented values in the International System of Units, units are reported as the original values, with the U.S. standard equivalent reported in parentheses.

ACRONYMS

ADCIRC	ADvanced CIRCulation for Model for Oceanic, Coastal and Estuarine Waters
ALE	Annualized Loss Estimation
BCR	Benefit Cost Ratio
BFE	Base Flood Elevation
CCCL	Coastal Construction Control Line
CIKR	Critical Infrastructure and Key Resources
cm	centimeter
CO-OPS	Center for Operational Oceanographic Products and Services (NOAA)
CRC	Coastal Resources Commission (State of North Carolina)
CWMTF	Clean Water Management Trust Fund
DDF	Depth Damage Function
DEM	Digital Elevation Model
DENR	Department of Environmental and Natural Sciences (State of North Carolina)
DOL	Department of Labor (Federal or State)
DOR	Department of Revenue (State of North Carolina)
DHS	U.S. Department of Homeland Security
DPS	Department of Public Safety (State of North Carolina)
EM	Emergency Management
EPA	U.S. Environmental Protection Agency
EST	Empirical Simulation Technique
FDPO	Flood Damage Prevention Ordinance
FEMA	Federal Emergency Management Agency
FIMS	Flood Impact Management Strategies
FIS	Flood Insurance Study
FMA	Flood Mitigation Assistance
FPM	feet per mile

ft	foot/feet
FWS	U.S. Fish and Wildlife Service
GIS	Geographic Information System
GTM	Geospatial and Technical Management Office (State of North Carolina)
HBL	Hurricane Boundary Layer
HMA	Hazard Mitigation Assistance
HMGP	Hazard Mitigation Grant Program
HUD	U.S. Department of Housing and Urban Development
ICLUS	Integrated Climate and Land Use Scenarios
ICC	International Council Code
IHRM	Integrated Hazard Risk Management Study
IPCC	Intergovernmental Panel on Climate Change
JPM	Joint Probability Method
LACPR	Louisiana Coastal Protection and Restoration
LiDAR	Light Detection and Ranging
MBAR	milibar
MHHW	Mean Higher High Water
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
mm/yr	millimeters per year
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NAVD88	North American Vertical Datum of 1988
NCCES	North Carolina Cooperative Extension Service
NCDEM	North Carolina Division of Emergency Management
NCDOT	North Carolina Department of Transportation

NCFMP	North Carolina Floodplain Mapping Program
NDRF	National Disaster Recovery Framework
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetlands Inventory
OWI	Oceanweather Inc.
PA	Public Assistance
PBL	Planetary Boundary Layer
PDM	Pre-disaster Mitigation (Program)
RENCI	Renaissance Computing Institute
RMSD	Root Mean Square Difference
SHMO	State Hazard Mitigation Officer
SHPO	State Historic Preservation Officer
SLAMM	Sea Level Affecting Marshes Model
SLI	Strategic Lands Inventory
SLR	Sea Level Rise
SLRIS	Sea Level Rise Impact Assessment Study
SPR	Source-Pathway-Receptor
Sq mi	square mile
SRES	Special Report on Emissions Scenarios (IPCC)
SRL	Severe Repetitive Loss
SWAN	Simulating Waves Nearshore (model)
SWEL	Stillwater Elevation
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSEL	Water Surface Elevation
WW3	WaveWatch3

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- University of North Carolina, Wilmington
- URS

EXECUTIVE SUMMARY

The North Carolina Sea Level Rise Impact Assessment Study (SLRIS) was undertaken to comprehensively evaluate the exposure and potential impacts associated with sea level rise (SLR) along North Carolina's coast. The study was structured to quantify changes to the coastal flood hazard environment, assess possible exposure of the built environment at the structure level, and evaluate strategies to reduce long-term losses. Study efforts by the North Carolina Emergency Management - Geospatial and Technology Management (GTM) commenced in 2009 and concluded in 2013.

The SLRIS sought to answer four fundamental questions on how SLR may impact the State of North Carolina. Results from the assessment of these four questions are summarized in parallel with the questions below:

What changes to coastal flood hazards could occur between 2009 and 2100 as a result of SLR and changes in tropical storm intensity and frequency?

This study concluded that significant changes in coastal hazards will occur. These changes are in response to SLR scenarios of 20 centimeters (cm) (0.7 foot (ft)) and 40 cm (1.3 feet) that are based on future projections of observed historical trends across the State. A baseline condition of 0 cm was first established using detailed and quantitative flood modeling framework. Changes in the flood hazard for the 20- and 40 cm SLR scenarios were then computed and compared back to the baseline condition across a study area that encompassed the 20 coastal counties of North Carolina.

- ***Loss of land to inundation*** is anticipated across coastal North Carolina's extensive low-lying areas as a result of SLR:
  - 20 cm of SLR is projected to inundate approximately 250 square miles (Sq mi) of land, representing 3% of the land area in the 20 coastal counties.
  - 40 cm of SLR is projected to inundate approximately 800 Sq mi of land, representing 9% of the land area in the 20 coastal counties.
- ***Changes to the regulatory floodplain, especially expansion of floodplain boundaries,*** are expected and would affect a substantial number of additional buildings compared to the baseline condition.
  - 20 cm of SLR is projected to increase the size of the regulatory floodplain (the area inundated by the 1%-annual-chance flood) by approximately 175 Sq mi, representing an 8% change over the baseline condition.
  - 40 cm of SLR is projected to increase the regulatory floodplain by approximately 350 Sq mi, representing a 20% change over the baseline condition.
- ***Changes in the 10% annual-chance floodplain***, an area subject to repetitive flooding due to frequent, less intense storm activity than the 1%-annual-chance flood, are roughly double the size of the corresponding increases in the regulatory floodplain.
  - 20 cm of SLR is projected to increase the 10% annual-chance floodplain by approximately 350 Sq mi, representing a 27% change over the baseline condition.
  - 40 cm of SLR is projected to increase the 10%-annual-chance floodplain by approximately 600 Sq mi, representing a 47% change over the baseline condition.
- ***Changes in tropical storm frequency and intensity*** over the next 50 to 100 years have the potential to further modify the storm surge elevations that define the regulatory floodplain.
  - Plausible changes in tropical storm climatology would increase 1%-annual-chance elevations by approximately 15 to 25 cm (0.5 to 0.8 ft) over the historical climatology. These changes would be in addition to SLR.

What built and living systems would be exposed to changes in coastal flooding from SLR and changes in tropical storm intensity and frequency?

In conjunction with increases in flood hazards, potential exposure and impacts to coastal flooding were estimated to markedly increase with SLR. Flood exposure and impacts were calculated using comprehensive data assets at the individual building level. Exposure estimates are comparative to the study 0 cm baseline.

- The number of ***buildings lost to inundation*** were assessed and found to be significant for the study SLR scenarios.
  - 20 cm of SLR is projected to result in the loss of approximately 1,000 buildings with an estimated value of $215 million.
  - 40 cm of SLR is projected to result in the loss of approximately 5,000 buildings with an estimated value of $923 million.
- The increased number of ***buildings in the regulatory floodplain*** was projected in conjunction with the expansion of floodplain boundaries over the baseline condition:
  - 20 cm of SLR is projected to add over 11,000 buildings to the regulatory floodplain, a 38% increase over the baseline condition.
  - 40 cm of SLR is projected to add over 24,000 buildings, an 82% increase over the baseline condition.
- The number of ***buildings in the 10%-annual-chance floodplain*** was also projected to increase. The potential for flooding in this high-frequency but low impact zone highlights the need for coastal communities to prioritize the mitigation efforts in these areas to help maintain resilient communities.
  - 20 cm of SLR is projected to add over 3,700 buildings to the 10%-annual-chance floodplain, a 75% increase over the baseline condition.
  - 40 cm of SLR is projected to add about 10,000 buildings, a 202% increase over the baseline condition.
- ***Hurricane Fran*** had a considerable impact on the North Carolina coast in 1996. The study found the following increases in exposure when comparing the SLR scenarios to the baseline condition.
  - 20 cm of SLR would potentially impact 5,600 more buildings than the baseline condition, an increase of 33%. This corresponds to an increase of $1.3 billion in building replacement value.
  - 40 cm of SLR would potentially impact 16,000 more buildings than the baseline condition, an increase of 95%. This corresponds to an increase of $3.23 billion in building replacement value.
- ***Transportation infrastructure*** such as roadway access will also be significantly affected:
  - 20 cm of SLR is projected to permanently inundate 25 miles of coastal roadways, with up to an additional 400 miles subject to flooding by the 1%-annual-chance flood.
  - 40 cm of SLR is projected to permanently inundate 153 miles of coastal roadways, with up to an additional 830 miles subject to flooding by the 1%-annual-chance flood.

What possible consequences will occur on the exposed built and living systems as a result of SLR?

Consequences of the flood exposure to the baseline (0 cm) and each SLR scenario were calculated and compared through a robust loss-estimation framework leveraging individual building level attribute data.

- ***Annualized Loss Estimates (ALE)*** are a way of simplifying estimation of potential losses from coastal flooding to a monetary value that might be incurred for a specific building or area on an annual basis. In conjunction with the projected increases in exposure, ALEs are calculated to increase significantly with SLR.
    - 20 cm of SLR is projected to increase ALEs from coastal flooding by $79 million compared to the baseline condition, a 57% jump.
    - 40 cm of SLR is projected to increase ALEs from coastal flooding by $190 million compared to the baseline condition, an increase of 137%. About 90% of these losses would be incurred by residential structures.
- ***Critical infrastructure*** including facilities associated with agriculture, food, banking, finance, commercial, education, energy, government, healthcare, manufacturing, transportation, and water are expected to experience increased losses with SLR.
    - 20 cm of SLR is projected to increase losses caused by the 1%-annual-chance flood by about $400 million, an increase of 55% compared to the baseline condition.
    - 40 cm of SLR is projected to increase losses caused by the 1%-annual-chance flood by about $950 million, an increase of about 130% compared to the baseline condition.
- ***The economy of North Carolina*** is projected to be impacted by these increased losses:
    - 20 cm of SLR is projected to result in $320 million in lost wages, $220 million in the government sector alone.
    - 40 cm of SLR is projected to result in $766 million in lost wages, $524 million in the government sector.
- ***Barrier islands and inlets*** are greatly influenced by storm activity, sediment dynamics, and anthropogenic influences. The SLRIS evaluated the response of the barrier islands and inlets to SLR with consideration only to increased water levels. In this context, it is anticipated that barrier islands and inlet conditions will be influenced, but not significantly impacted by, a 20-cm or a 40-cm rise in sea level.
- ***Marshes*** were found to have mixed response to a 40-cm SLR scenario depending on location:
    - In the northern area of North Carolina, although marsh losses to open water are projected at 28 Sq mi, low elevation gradients allow marshes to migrate and experience a projected net gain of 137 Sq mi at the expense of upland areas.
    - Steeper gradients in the Southern Province restrict the ability of marshes to migrate upland, resulting in an estimated net loss of 26 Sq mi of fresh and salt marsh.
    - It is anticipated that the projected trend in the northern area may negatively change with higher SLR scenarios as steepening and increasing water levels further restrict potential suitable marsh areas.

What short-term and long-term strategies might result in efficient and effective prevention and/or alleviation of exposure and consequences from possible SLR and increased storminess?

Leveraging the assessed impacts due to SLR, flood impact management strategies (FIMS) were developed to analyze and present a range of potential options that could be pursued if deemed appropriate. Strategies were then evaluated through qualitative and/or quantitative mechanisms to evaluate potential effectiveness. Qualitative assessment considered technical, administrative, political, legal, fiscal, and environmental feasibility, as well as their potential benefits in terms of reduced flood *impacts. A select number of FIMS were identified for quantitative benefit cost analysis through the capability and qualitative assessment, and the availability of supporting study data.*

Effective Strategies were identified for mitigating potential impacts of SLR. Strategies were evaluated for implementation at two points of time consisting of 2010 and 2025. Across multiple strategies, there was, on average, a 3-fold improvement in the benefit cost ratio (BCR) for implementing FIMS in 2010 versus waiting until 2025. All analyzed strategies yielded a BCR above 1 (a cost-effective beneficial strategy requires the BCR to be greater than 1) when evaluated for implementation in 2010, and all but one of the five quantitatively evaluated strategies had a benefit cost ratio above 1 for implementation in 2025. Of the strategies evaluated, two emerged with highly positive BCRs:

1) Relocation of critical facilities outside the 1%-annual-chance floodplain, and
2) Elevation of existing and proposed critical facilities currently located within the 1%-annual-chance floodplain.

Although Executive Order 11988 directs that any construction that involves Federal investment or funding should not impact floodplain functions, considerable amounts of infrastructure are owned by private stakeholders. Much of the State's critical infrastructure was shown to be at risk to SLR. Even though it is clear that this is likely a prohibitively expensive proposition in the case of existing facilities, the large benefits that accrue from this strategy underscore the value of mitigating potential impacts to existing infrastructure and considering SLR when evaluating proposed critical facilities.

PREFACE

This report is intended to present results of the SLRIS in a clear manner and explain the potential impacts of Sea Level Rise (SLR) in the State of North Carolina. The report provides an overview of the study processes and methodologies. Detailed documentation of the study approach is available under separate cover. Further information about accessing additional technical documentation is provided in this section.

The report is organized into six chapters, covering study background, framework, results, and lessons learned. These main chapters are followed by cited literature and appendixes.

- Chapter 1 provides background information on the study effort, including organization, role of the advisory committee, framework, methodology development, and supporting technical information.
- Chapter 2 describes the SLR and tropical storm climatology scenarios analyzed in the study.
- Chapter 3 summarizes the projected changes to the coastal flood hazard in response to SLR and storminess scenarios. This includes a review of changes to the coastal landscape, changes to probabilistic coastal flooding events, how storminess may influence future coastal flood levels, and projections of damages from a storm equivalent to Hurricane Fran for future scenarios.
- Chapter 4 details how the projected changes to the coastal flood hazard will impact the natural and built environments. It describes impacts to key receptors such as Land; Buildings and Structures; Critical Infrastructure sectors; Transportation, Societal, and concomitant economic impacts of losses across the receptors.
- Chapter 5 provides a summary of potential strategies to reduce possible impacts of SLR. The chapter includes a review of potential strategies, quantitative cost/benefit analysis of strategy application, as well as an assessment of the capabilities of existing State and Federal agencies to implement mitigation and adaptation measures.
- Chapter 6 includes a discussion of lessons learned from the execution of the study and identifies areas for additional research and development.

Study Limitations and Exclusions

The study effort was focused on an assessment of SLR impacts to coastal inundation and flooding, as well as the related effects of such flooding for the selected scenarios. Further alterations of the sources of natural hazards other than tropical storm activity and changes in coastal flooding due to SLR may occur as a result of climate change. The SLRIS authors acknowledge that future changes to climate may impact natural hazards; however, at this time it is not certain whether the state of the science (including data, models, and methodologies) is adequate to address them holistically or predict them accurately. In addition, because of both the uncertainty and complexity of evaluating these issues, the scope of the study excludes these additional potential influencers.

The following limitations should be noted. Further detail on these factors is provided throughout this report:

- **Sea Level Rise.** The information presented is limited to SLR scenarios based on historical trends in the observed data and does not represent the full spectrum of projections by the scientific community.
- **Shoreline and Barrier Island Evolution.** This study does not attempt to project how coastal sediment dynamics will influence shoreline position or the evolution of barrier islands.

- **Projections of Future Land Use.** Population projections and in turn, projections of land use and development for future timeframes are subject to many factors and are highly uncertain. The analysis presented in this reports seeks only to estimate a range of potential future impacts that considers future land development.
- **Impacts to the Natural and Built Environments.** The analytical framework and data assets used to assess changes to the hazards and impacts considered by this study represent a considerable investment by the Federal Emergency Management Agency (FEMA) and the North Carolina Division of Emergency Management (NCDEM). The content of this report represents a good faith effort to leverage that investment through reasonable approaches and provide a credible evaluation to assess the potential impacts of SLR on North Carolina. Uncertainty is intrinsic to all data, and as such, the study focuses, where possible, on metrics that communicate the *changes* in hazard and impacts anticipated with SLR.
- The following items were excluded from consideration in the SLRIS:
    - Causation theories for climate change and/or actions to reduce greenhouse gas emissions or enhance carbon sinks;
    - Adherence to any specific SLR projection;
    - Specific risk probabilities from SLR;
    - Potential changes to inland rainfall flooding;
    - Potential changes in the effects of flooding caused by storm surge and precipitation;
    - Potential changes to wind hazards; and
    - Potential changes to other natural hazards (e.g., drought, heat waves, etc).

Study Website, Data Access, and Supporting Documentation

Detailed documentation is available for elements such as the study plan, conceptual model, and analytical methodologies through the study web portal (http://slris.ncem.org/slris) or on request from GTM. The available documents are listed below.

- **Study Plan**: provides an overview of the initial study framework, objectives, and organization.
- **Study Scoping Workshop Report**: provides a summary of the proceedings of the Study Scoping Workshop and recommendations on study scope and activities by stakeholder working groups.
- **Conceptual Model Report**: provides documentation on the formulation of the study conceptual model and lists study questions by receptor in summary tables.
- **Hazard Assessment Methodology Report**: provides additional documentation on the data resources, methodologies, and processes employed to assess changes in the coastal landscape, coastal flooding, and hazard product development.
- **Impact Assessment Methodology Report**: provides further documentation on the data resources, methodologies, and processes employed to assess the impact of flooding on the natural and built environments.
- **Flood Impact Management Strategies**: provides additional documentation on the initial evaluation and development of adaptation strategies to address SLR impacts. It includes information on review of the adaptation capability of existing State-level programs, evaluation of case studies, identification of strategy pathways for North Carolina, as well as qualitative assessment and selection of strategies for quantitative assessment.

Requests for supporting data or data outputs should be sent to GTM.

1 BACKGROUND

North Carolina, along with Florida and Louisiana is one of three U.S. States with significant vulnerability to SLR (Titus and Richman, 2001). The State possesses one of the largest estuarine systems on the U.S. Atlantic coast, with an extensive barrier island chain and over 2,300 Sq mi of coastal land. In response to these findings, the State of North Carolina assessed existing information and concluded that North Carolina would benefit from:

- A statewide, empirical financial impact assessment for potential future flood losses;
- A quantitative framework to calculate and track the impacts of potential sea level changes; and
- A quantitative framework to assess the cost effectiveness of specific loss avoidance strategies.

On the national level, there was concern in the United States Congress that the Federal Emergency Management Agency (FEMA) was not considering the potential impact of climate change in terms of disaster preparedness, mitigation and response, management of the National Flood Insurance Program (NFIP), and in floodplain mapping (House Report 110-862). As a result, the State of North Carolina was awarded a grant by FEMA to fund the statewide Sea Level Rise Impact Study (SLRIS). The purposes of the grant were to provide support to North Carolina to perform a hazard, impact, and mitigation strategy assessment of the potential impacts of SLR. Other intended benefits of the effort were to inform FEMA of the financial implications, as well as help guide future assessment efforts.

One of the key initial findings during the study was the lack of consensus from the scientific community on future SLR projections. Although analysis was conducted on five SLR scenarios (up to 100 centimeters (cm) (3.28 feet (ft)) in increments of 20 cm (about 0.67 ft)), this report presents an assessment of impacts performed for SLR scenarios that can be quantifiably defined based on historical trends. The report presents those scenario levels (20 cm and 40 cm, equivalent to 0.67 ft and 1.3 ft) that are best aligned with the anticipated SLR that may occur by 2010 based on historic rates. In addition, a baseline scenario representing today's conditions was established to provide for a foundation for comparison of changes in hazard, exposure, and impacts.

The foundation of the study was an assessment of the change in coastal flood hazards. The approach was incremental and began with modeling of the changes to tidal dynamics for each increase in sea level. These tidal conditions were input into a marsh evolution model, calculations of inlet change, and relict feature analysis for barrier island inundation. Outputs from these processes were integrated back into a coastal flood hazard model to re-assess return-period storm surge elevations for each SLR scenario. This integrated approach allowed further insight into how flood elevations may change as a response of the increased water levels caused by SLR than typical "bathtub" approaches were water levels are simply increased on a static coastal landscape and land losses are tallied to the extent of inundation.

The second building block of the study was to assess impacts to the built environment. Outputs from the modeling effort were rendered into geospatial products for the 10%-, 4%-, 2%-, 1%-, and 0.2%-annual-chance coastal flood conditions and input into a quantitative assessment framework to derive direct economic losses. The impact of each flood frequency was assessed across the State at the individual structure level for each scenario. Results were then broken into occupancy classes to estimate impacts to critical infrastructure and key resource sectors. Indirect loss calculations provided further insight into potential economic impacts. Potential impacts to the road network, including key evacuation routes and social vulnerability were also assessed.

The study effort was finalized with an assessment of flood impact management strategies (FIMS) organized across the study flood hazard receptors (people, industries, and built and natural environments that may be affected by the flooding hazard). The FIMS were evaluated qualitatively by developing an inventory of some of the most pertinent laws, regulations, pre-and post-disaster policies, programs, and other existing authorities that the State of North Carolina currently has in place. Based on the initial capability assessment, the identification of other strategies found through case study research, and an evaluation of the data needed to conduct the analysis and derived from the study's impact assessment we identified a smaller number of FIMS that could be assessed quantitatively, taking into consideration benefits (losses avoided) and costs of implementation.

1.1 Study Organization

The SLRIS was organized into 10 phases (Figure 1), beginning with study scoping in 2008 and concluding with the final report in 2013. The study was accomplished through a partnership between the State of North Carolina, the North Carolina University System, the study management contractor, and other stakeholders as identified in the Acknowledgments Section. These entities collaborated to develop methodologies and production processes for the key study elements, which included: conceptual modeling; analytical modeling and programming; coastal landform evolution and response; future land use projection; assessment of hazards and consequences to buildings and coastal structures, critical infrastructure, and finally, FIMS.

Preliminary work consisted of study Phases 1-4 (Study Scoping, Literature Review, Conceptual Modeling, and Methodology Development). These efforts were directed toward refining the study scope and developing appropriate methodologies to address unique aspects of the study. These included items such as coastal landscape evolution, future storm conditions, future land use, and the FIMS framework. Work on these phases concluded in mid-2010.

Phases 5 (Data Acquisition) and 6 (Database and Model Development) were carried out in conjunction with efforts by the North Carolina Emergency Management (NCEM) to establish a robust quantitative framework for risk assessment from multiple hazards through the North Carolina Integrated Hazard Risk Management Study (IHRM). The SLRIS directly leveraged the IHRM analytical framework to assess the impacts of the SLR scenarios on the built environment. Development of the framework was completed in late 2011. In the meantime, structure attribute data such as footprints, first-floor elevations, and construction characteristics were developed across the study area to support the input requirements of the IHRM tool. Data collection and post-processing were completed in mid-2012.

Phase 7 (Hazard Assessment) began with the initiation of numerical modeling in late 2011 and closed with geospatial product generation in late 2012. Phases 8 (Impact Assessment) and 9 (FIMS) were initiated in successive 6-month increments from the start of Phase 7 and continued in a parallel tract until they closed out in mid- 2013. The final report was completed in late 2013.

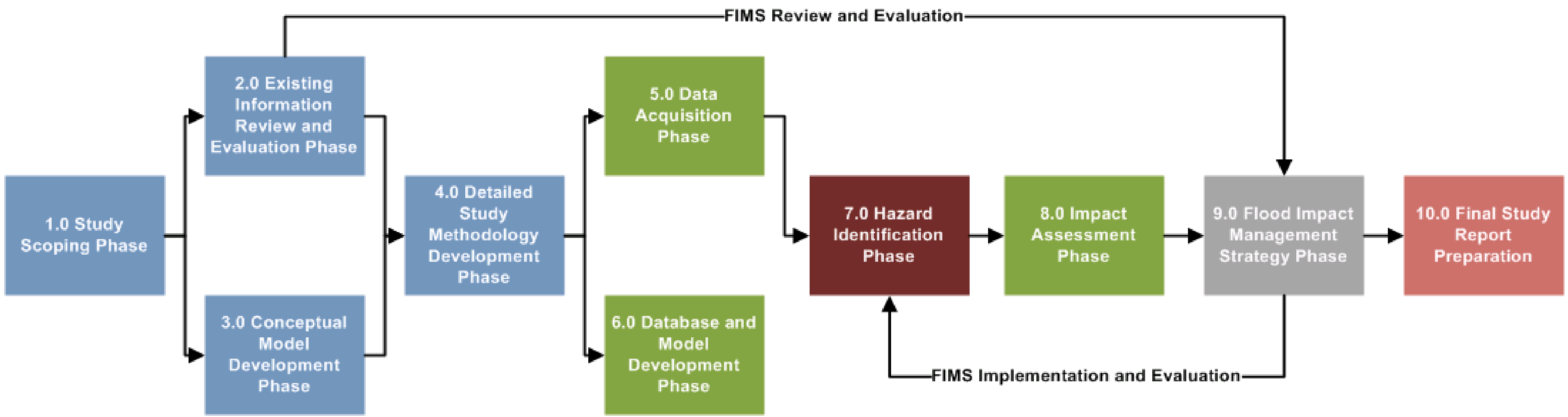


FIGURE 1. THE NC SLRIS WAS BROKEN INTO 10 PHASES OVER A 4-YEAR PERIOD FROM 2009 TO 2013.

1.2 Advisory Committee

The study Advisory Committee was comprised of various State, Federal, and community stakeholders and provided input and feedback regarding the study scoping and methodology development. Three Advisory Committee meetings were held throughout Phases 1, 3, and 4 of the study process (Figure 1). Key contributions of the committee were to advise on study scope and analytical approaches. Feedback from the committee was gathered through the meetings and integrated into the study process. Representatives of the following institutions participated in the Advisory Committee:

- Carolina Integrated Sciences and Assessments
- Beaufort County
- Carteret County
- Coastal States Organization
- Department of Defense: Strategic Environmental Research and Development Branch
- U.S. Environmental Protection Agency
- Federal Emergency Management Agency
- Johns Hopkins University
- NC-20
- National Oceanic and Atmospheric Administration: Center for Sponsored Coastal Ocean Research; Coastal Services Center; and National Climatic Data Center
- North Carolina Chapter of the American Planning Association
- North Carolina Department of Agriculture and Consumer Services
- North Carolina Department of Transportation
- North Carolina Division of Public Health
- North Carolina Retail Merchants Association
- University of North Carolina, Chapel Hill, Center of Excellence for the Study of Natural Disasters, Coastal Infrastructure and Emergency Management; and Institute for Government
- University of Maryland
- U.S. Army Corps of Engineers
- U.S. Department of Homeland Security
- U.S. Fish and Wildlife Service
- U.S. Geologic Survey

1.3 Study Area

The study covers the 20 coastal counties of North Carolina: Beaufort, Bertie, Brunswick, Camden, Carteret, Chowan, Craven, Currituck, Dare, Gates, Hertford, Hyde, New Hanover, Onslow, Pamlico, Pasquotank, Pender, Perquimans, Tyrrell, and Washington Counties (Figure 2). These counties encompass a wide range of coastal features, including about 325 miles of ocean shoreline punctuated by 23 inlets, and more than 3,000 Sq mi of brackish-water estuaries with over 5,000 miles of estuarine shoreline (Riggs et al., 2008).

The combination of North Carolina's extensive low-lying lands and frequently occurring tropical storm and hurricane activity result in a relatively high potential for coastal flooding. The study area comprises about 9,544 Sq mi of land area, much of it at low elevation. Over 2,500 Sq mi are at less than a 5-foot elevation, and 4,200 Sq mi are at less than a 10-foot elevation (Figure 3). The location and orientation of North Carolina's coast also make the State especially prone to hurricane landfall. Return periods (period of time between events) for minor and major hurricanes are some of the lowest in the United States (NOAA, 2013) (Figure 4).

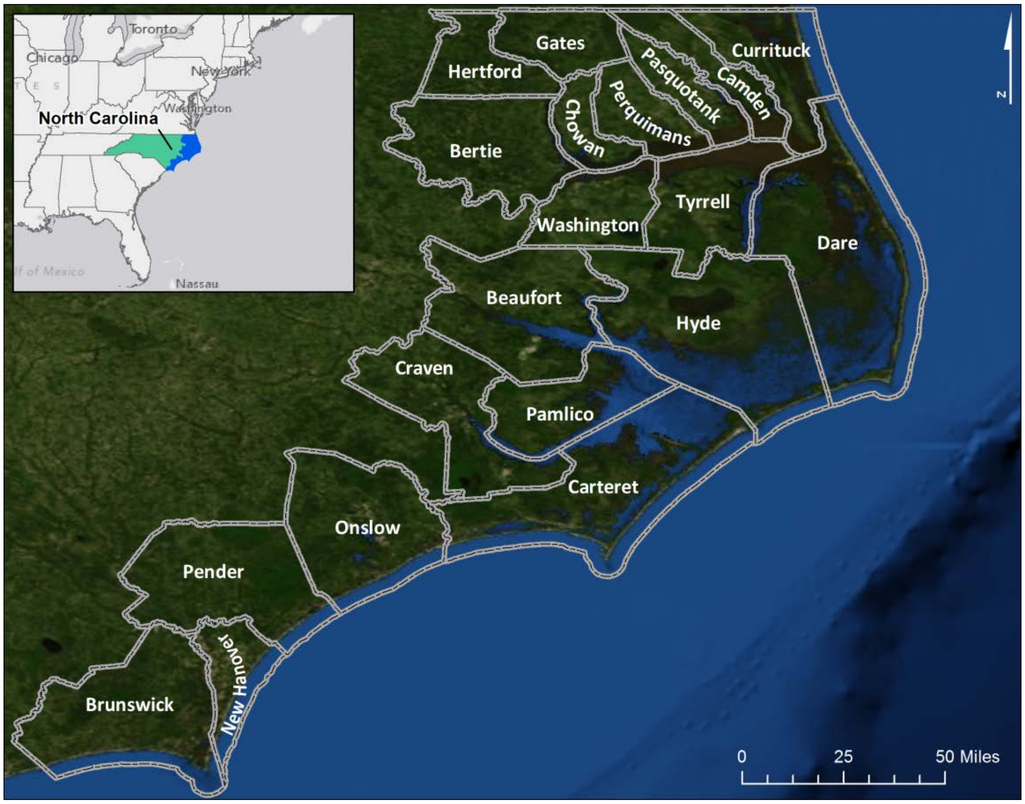


FIGURE 2. THE STUDY AREA FOR SLRIS INCLUDED THE 20 COASTAL COUNTIES OF NORTH CAROLINA.

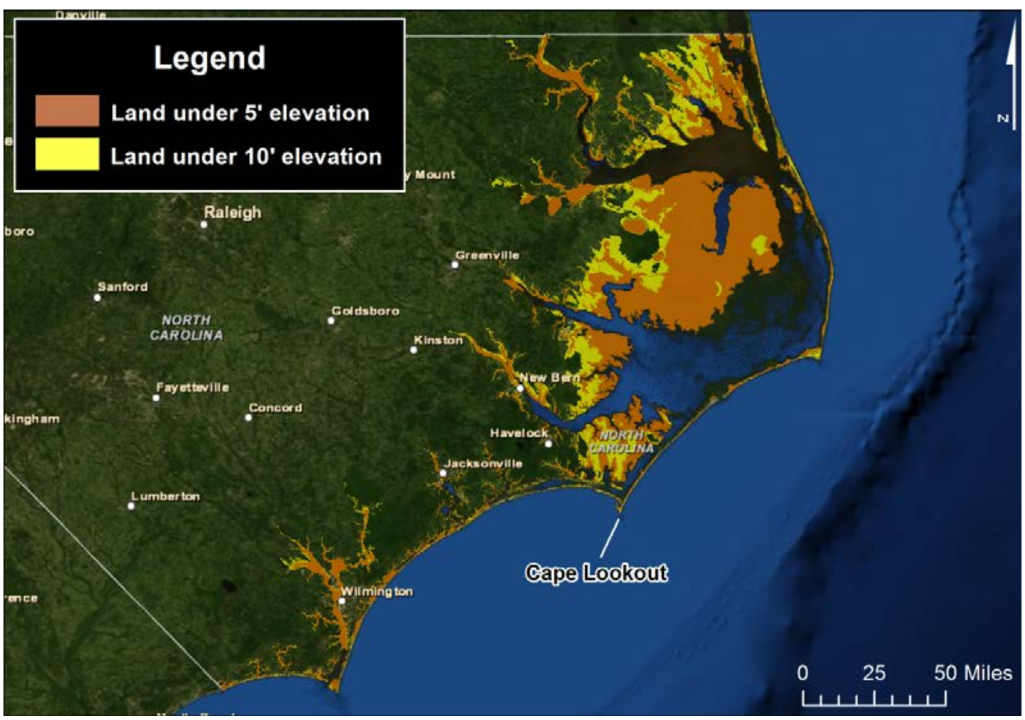


FIGURE 3. SPATIAL DISTRIBUTION OF LAND UNDER 5 AND 10-FOOT ELEVATIONS RELATIVE TO NAVD88.

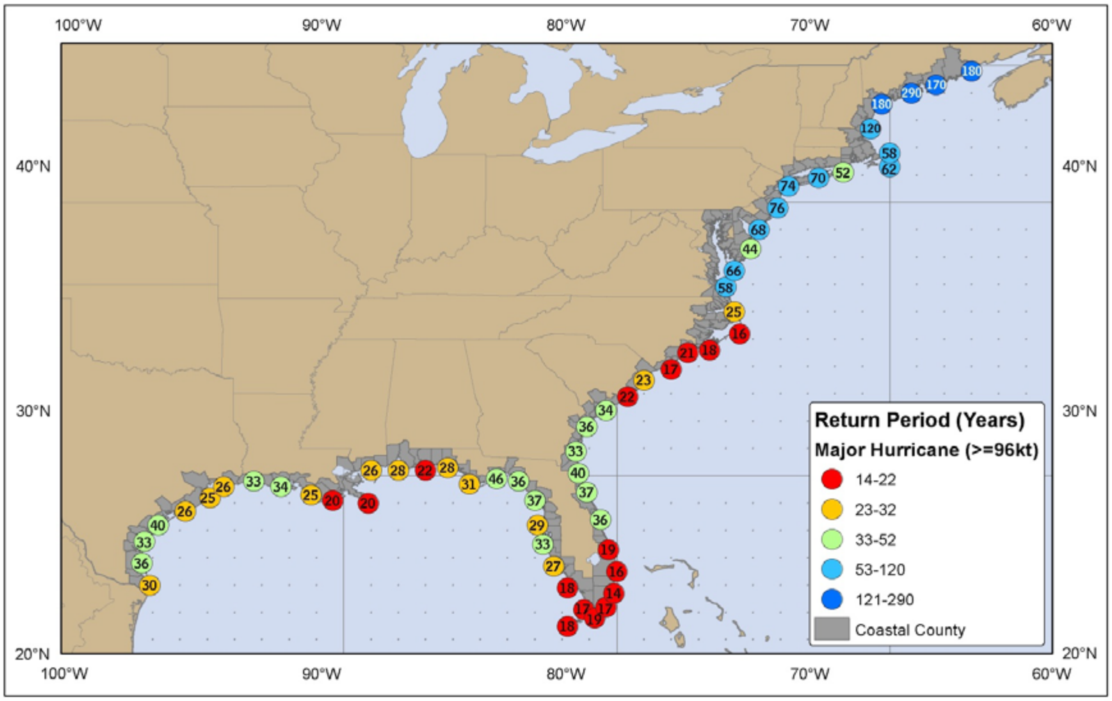


FIGURE 4. NORTH CAROLINA IS REGULARLY EXPOSED TO FLOODING IMPACTS FROM LANDFALLING HURRICANES, AND HAS ONE OF THE LOWEST RETURN PERIODS (TIME BETWEEN EVENTS) IN THE U.S. FOR MAJOR HURRICANES (NOAA, 2013).

The underlying geologic framework of the North Carolina coastal plain directly influences differences in the character of the State's coastal system, including barrier islands, inlets, and estuaries with particular wave and tidal energies and processes. A line can be drawn from Raleigh through Kinston and Cape Lookout to separate the coastal system into the northern and southern coastal provinces (Figure 5).

Pilkey et al. (1998) describe the differences between the coastal provinces, summarized here. The coastal system in the Southern Province, from Cape Lookout south to the South Carolina border, is underlain by aged strata generally composed of relatively hard sedimentary rocks including mudstone, sandstone, and limestone. On top of this substrate is a thin surficial layer of younger sands and clays. The hard sedimentary rocks are associated with the Carolina Platform, a geologic structure that underlies the region between Myrtle Beach, SC, and Cape Fear, NC. In contrast, the Northern Province coastal system, from Cape Lookout north to the Virginia border, is underlain by primarily younger sediments deposited during sea level fluctuations that occurred during the Ice Ages. These units consist of unconsolidated muds, muddy sands, and peat sediments that thicken northward to fill the slightly subsiding Albemarle Embayment with up to 230 feet of sediments.

Coastal elevation and vulnerability to coastal flooding are partially controlled by these two different geologic frameworks and their respective land slopes in the coastal zone. The Southern Province is characterized by a relatively steep slope of 3 feet per mile (FPM), whereas the Northern Province has a shallow average slope of 0.2 FPM. This difference largely influences the Northern Province's lower elevations, and in turn, greater vulnerability to coastal flooding. Areas within the Northern Province are subject to relatively higher amounts of inundation as a result of shallower slopes from the coast inland. These geologic factors are reflected in the high resolution/accuracy Digital Elevation Models (DEMs) used as inputs for all study processes and for development of study products.

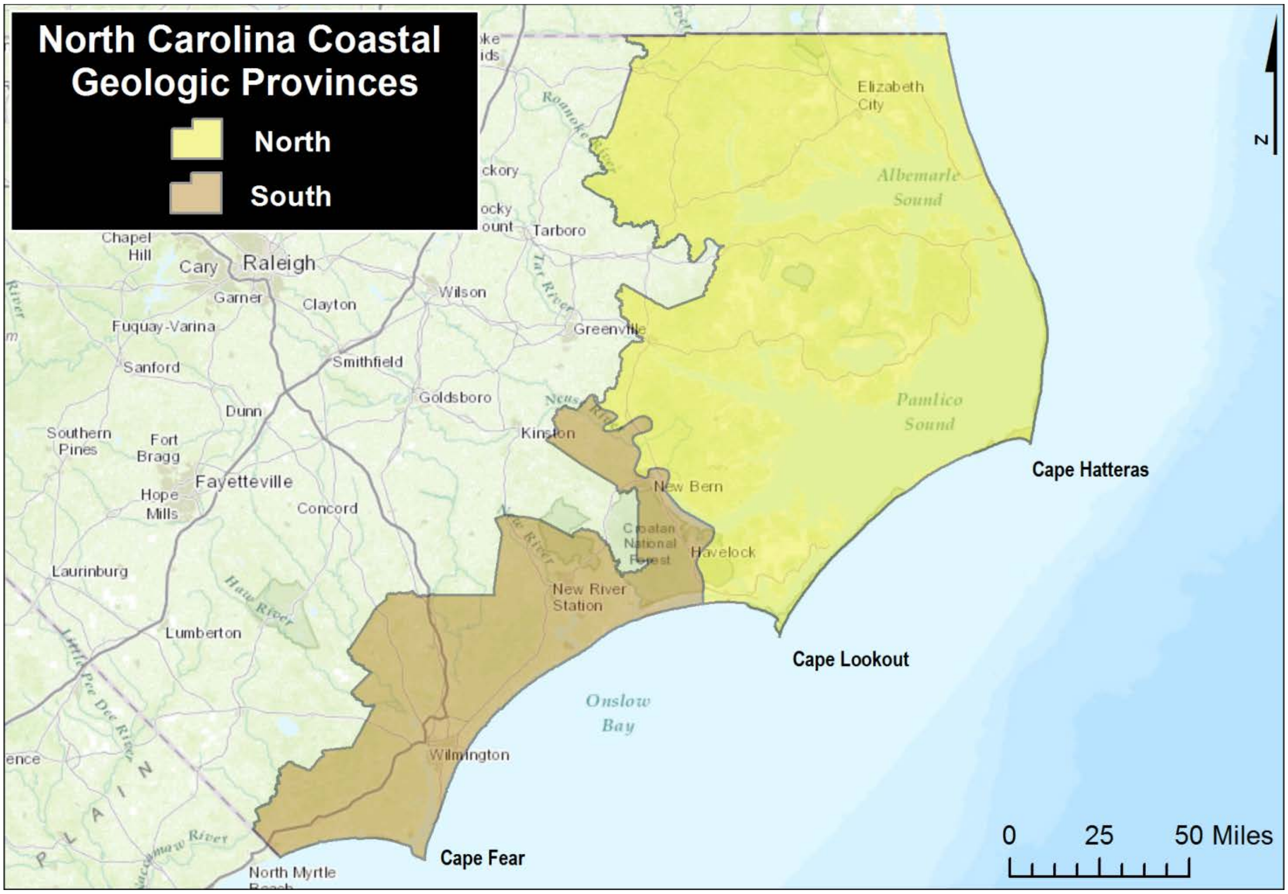


FIGURE 5. GENERALIZED GEOLOGIC MAP OF NORTH CAROLINA.

1.4 Study Scope

The study scope was refined at specific steps over the study effort. The overall development involved six steps, including:

1. **Initial Study Plan**: The initial study plan, developed in late 2008, provided a broad outline for the goals of the study and scope of analysis. This document identified the study framework, broad conceptual model, and receptor groups to assess for impacts. Distinctive scope items, such as coastal landscape evolution, storminess, and cost-benefit analysis for adaptation strategies, were identified through this effort.

   The Study Plan developed the analytical framework through a Source-Pathway-Receptor (SPR) framework model (DETR, 2000) for assessing flood risks (Figure 6). In the SPR framework as applied to SLRIS:

   - **Sources** are climate or weather events (e.g., SLR, hurricanes) that drive flood hazards;
   - **Pathways** are the routes that sources take to reach receptors, such as coastal landforms and flood control structures that convey floodwaters that originate as weather events to places where they may impact on receptors; and
   - **Receptors** are the people, industries, and built and natural environments that may be affected by the flooding hazard.

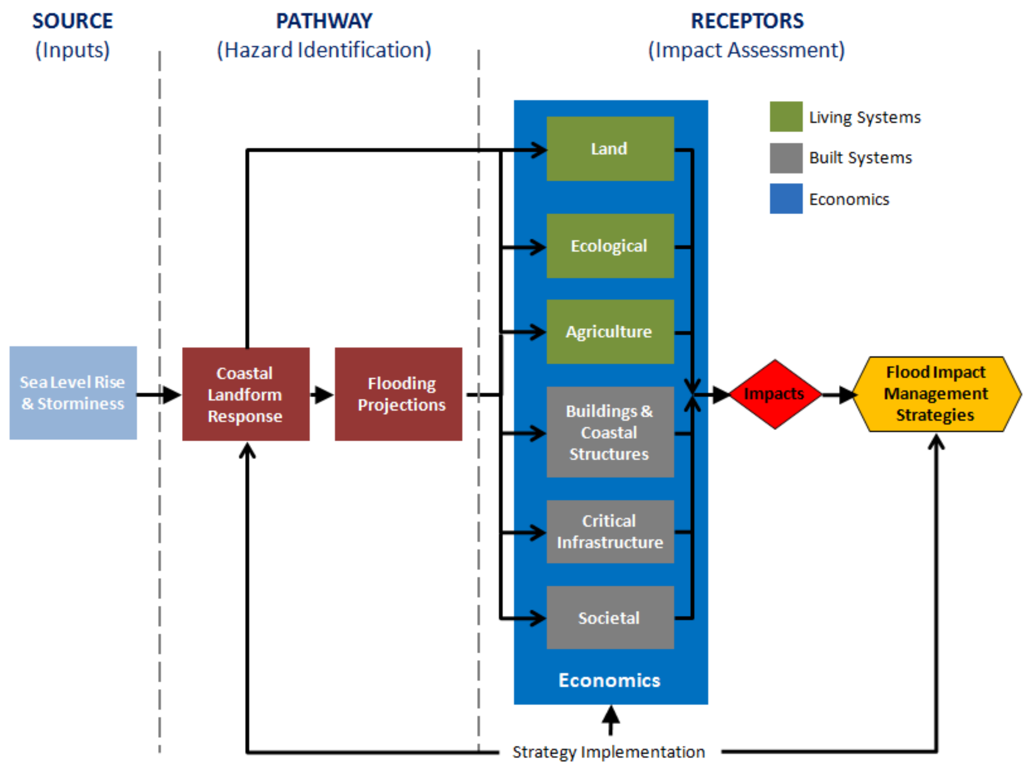


FIGURE 6. SLRIS HIGH-LEVEL CONCEPTUAL MODEL CREATED DURING THE SCOPING PHASE.

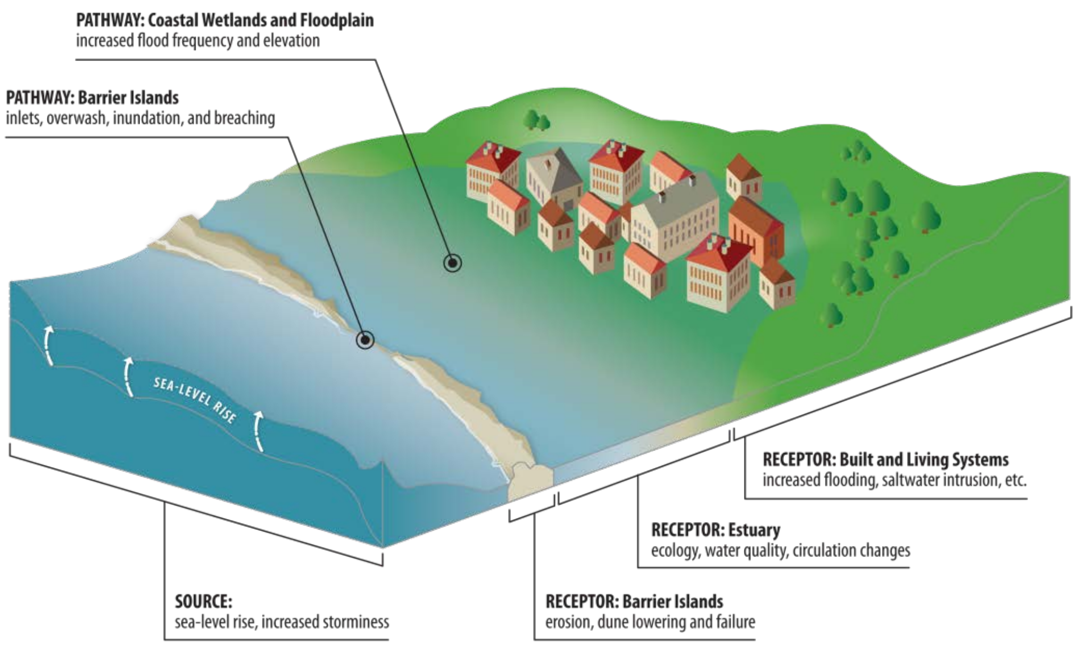


FIGURE 7. CONCEPTUAL DEPICTION OF APPLICATION OF THE SPR FRAMEWORK.

2. **Study Scoping Workshop:** The Study Scoping Workshop was held in April 2009 and attended by approximately 100 Federal, State, and local government officials and representatives of non-governmental organizations and academia. The workshop began with an overview of study goals, and then transitioned to an open session on the project scope, followed by breakout sessions.

Seven pre-identified work groups met over a two-day period and discussed scope and potential methodologies. The workshop closed with an overview of the findings of each work group and a question and answer session. The proceedings and work group materials and recommendations were summarized in the Study Scoping Workshop Report.

3. **Conceptual Model:** The first evolution of the high-level conceptual model occurred as a result of input from the participants in the Scoping Workshop and the study management team. The conceptual model applied the elements of the SPR framework to clearly identify the constituent attributes of SLR impacts investigated by the study, as well as the information and analyses required to define them. This facilitated a framework around which a transparent, consistent analytical approach was developed for the study. When considering future management strategies, this framework enables the development of targeted approaches that will either: 1) reduce the probability of a hazard through the source or pathway stages, or 2) reduce the exposure or vulnerability of one or more receptors.

   The conceptual modeling effort first focused on a top-down, high-level approach that defined how the hazards and risks advanced through the SPR framework to the various receptor groups (Figure 7). Inter-relationships and dependencies were noted, and then the data were organized into tables representing the SPR framework as applied to the study. Conceptual model development was refined through a workshop in June 2009 with a group of individuals representing a cross section of appropriate expertise across the identified subject matter. Four overarching questions were posted to the attendees to help shape their effort:

   - What changes to coastal flood hazards might occur between 2009 and 2100 as a result of SLR and storminess?
   - What built and living systems would be exposed to changes in coastal flooding from SLR and increased storminess?
   - What consequences could result to exposed built and living systems?
   - What short-term and long-term strategies might result in efficient and effective prevention and/or alleviation of exposure and consequences from possible SLR and increased storminess?

   The focus of the workshop was to determine what the study needed to accomplish, rather than how to accomplish it, thereby developing the conceptual framework from the bottom up. The group was asked questions at the receptor level of the SPR framework and asked to identify associated inputs and interdependencies, as well as methodologies by which to resolve the question.

4. **Advisory Committee Feedback:** The Advisory Committee provided input on the scope primarily through the first two committee meetings. General feedback on study scope was provided during the first Advisory Committee meeting, held in July 2009. The second Advisory Committee meeting in October 2009 facilitated review and comment on the draft conceptual model. This included a discussion of results of a study scope prioritization survey completed by the committee members. The conceptual model was revised following the meeting to reflect the survey results, committee meeting discussion, and known limitations in the analytical framework.

5. **Methodology Development:** Methodology development by study partners progressed and culminated in a presentation of the approaches at the third Advisory Committee meeting in June 2010. Additional methodology development was carried out through summer 2011. Throughout the methodology development process, it was recognized that specific aspects of the conceptual model would need to be removed from the study scope because of limitations in understanding or available analytical frameworks.

6. **Methodology Implementation and Data Resources:** The final adjustments to the study scope were made throughout the implementation of the study methodologies as the study progressed, usually as a result of previously unknown gaps in the analytical framework or to constrain the study scope.

Through these efforts, the study scope evolved to its final form. The main results of the assessment are presented in this document, and further detail on these efforts is provided in the Conceptual Model Report.

1.5 Detailed Study Methodology Development

Through the study scoping process, the study management team determined that additional methodology development was needed for specific items in the study scope. Key areas of methodology development included:

- Surge Modeling Approach
    - Goal: Efficiently adapt the North Carolina coastal Flood Insurance Study (FIS) framework to allow simulation of the identified SLR scenarios
- Assessment of Potential Future Storm Conditions
    - Goal: Assess projections in future storm frequency and intensity through the existing FIS storm surge modeling framework, and determine which future condition scenarios to consider
- Coastal Landscape Evolution
    - Goal: Project changes to coastal features such as barrier islands, inlets, and marshes in response to SLR; integrate such changes in the surge modeling process and assess impacts
- Future Land Use and Development
    - Goal: Project future population and related changes in the built environment to assess the potential additional exposure due to land development through the end of the century

University and private industry partners had recently established a storm surge modeling and statistical framework for NCEM-GTM to update coastal FISs throughout the State of North Carolina (Vickery and Blanton, 2008). These partners were retained by the study management team to assess and adjust the application of the FIS framework for the purposes of the SLRIS, including the storm surge modeling framework and assessment of future storm conditions on surge elevations. An overview of the approach is provided in Chapter 3 – Changes to the Flood Hazard and Pathway, and further documentation in support of these topics can be found in the Hazard Assessment Methodology Report.

Methodology development for Coastal Landscape Evolution and Future Land Use and Development were accomplished through the North Carolina University System. The study management team appointed a University Liaison at the Renaissance Computing Institute (RENCI) who helped identify appropriate candidates from State universities. Two work teams with expertise sourced from multiple institutions addressed the remaining methodology needs.

The final Coastal Landscape Evolution methodology was limited because of multiple challenges, including the diversity of North Carolina's coastal features, existing deficiencies in scientific understanding and quantitative modeling, as well as the scope and resources of the study. An overview of the final methodology is presented in Chapter 3, and further documentation is provided in the Hazard Assessment Methodology Report.

The methodology for Future Land Use and Development was developed by academic representatives and implemented by private industry partners. An overview of the approach and implementation is presented in Chapter 5 – Flood Impact Management Strategies; further documentation is available in the Impact Assessment Methodology Report.

2 SCENARIOS FOR SEA LEVEL INCREASES AND FUTURE TROPICAL STORM CLIMATOLOGY

In the SPR framework, Sources are climate or weather parameters (e.g., SLR, hurricanes) that drive flood hazards. For the SLRIS, the source parameters are the SLR scenarios that are input into the analytical framework to assess changes to coastal flooding and the resultant impacts on the natural and built environments. The effects of possible changes in tropical storm frequency and intensity on future flood conditions were also considered. This chapter summarizes the SLR and storminess scenarios assessed through the SLRIS.

2.1 Contributing Factors to SLR

Changes in sea level are a result of several factors, including ocean temperatures, ocean currents, vertical land movement, introduction of water from land-bound glaciers and ice, and terrestrial water storage (Figure 8). A global trend in SLR has been observed and well documented at local water-level recording stations and more recently by satellite. Analysis has indicated that global mean sea level has been rising at an average rate of approximately 1.7 millimeters per year (mm/yr) based on tide gauge records since 1900 (Church and White, 2011). The rise is not uniform and is controlled regionally and locally by the aforementioned factors.

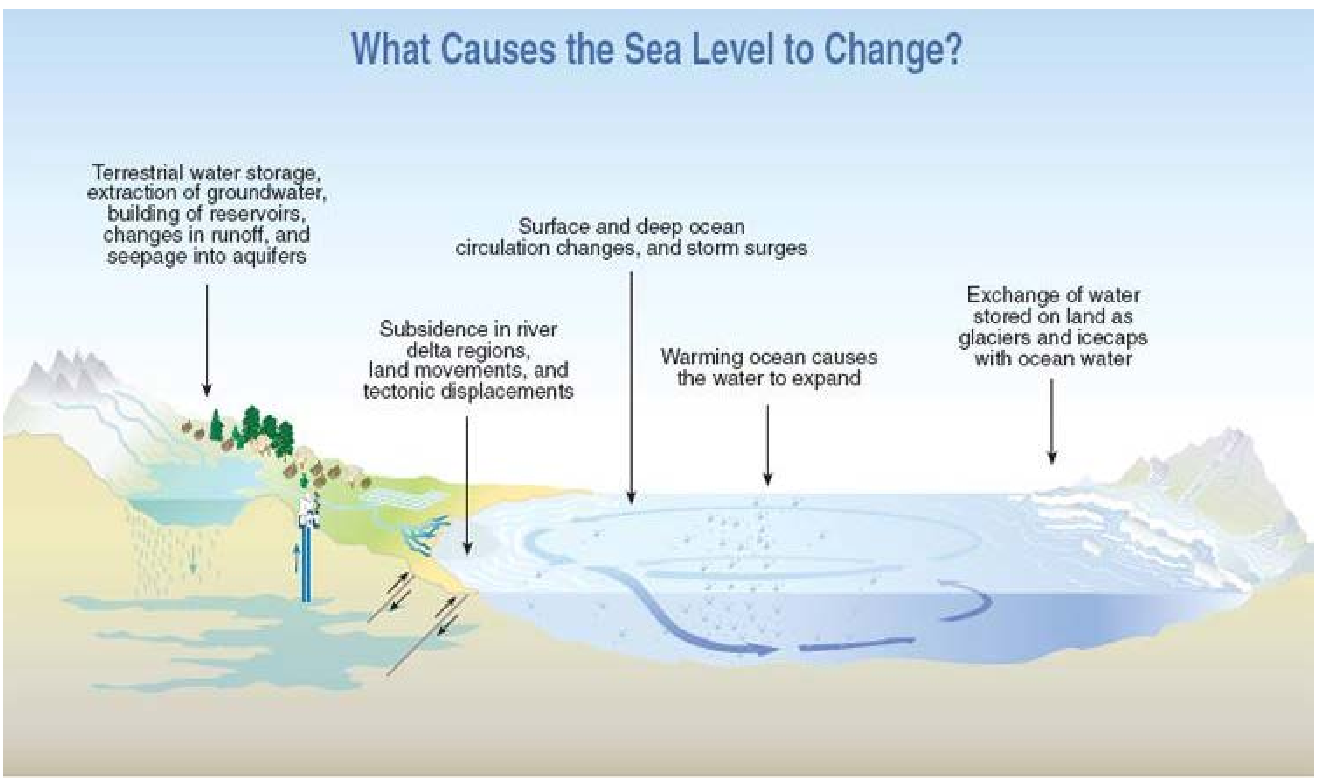


FIGURE 8. CAUSES OF SLR (IPCC, 2001).

2.2 Historical SLR in North Carolina

In the United States, the National Oceanic and Atmospheric Administration (NOAA), Center for Operational Oceanographic Products and Services (CO-OPS) provides public access to long-term water level observations (www.tidesandcurrents.com). CO-OPS provides historical records of more than 30 years for five stations in North Carolina, which are summarized in Table 1.

TABLE 1. OBSERVED RATES OF HISTORIC SLR IN NORTH CAROLINA (NOAA CO-OPS, 2013).

Station Name	Length of Record	Mean Sea-Level Trend mm/yr
Duck	1978-2011	4.59
Oregon Inlet Marina	1977-2012	3.75
Beaufort	1953-2012	2.70
Wilmington	1935-2012	2.00
Southport[1]	1933-2006	2.08
Average		*3.02*

[1]No update available; NOAA no longer shows this gage as active

Extrapolation of historical rates provides an empirical and quantifiable estimate of potential future sea level conditions. This calculation is accomplished by multiplying the historical sea level trend by the number of years over the time period of interest. Extrapolation of the average sea level trend out to the end of the century (2100) using the reference year 2010 would result in an average sea level increase of 27 cm (0.89 ft) for North Carolina.

Review of the values in Table 2 shows that observed trends in historic sea level are generally higher north of Cape Lookout, which can be mainly attributed to higher rates of land subsidence in the northern part of North Carolina's coast. Different projections of SLR may be derived if the historical trends for stations to the north and south of Cape Lookout are averaged. This results in end-of-century historical trend extrapolations of 38 cm (1.23 ft) for the northern coast and 20 cm (0.67 ft) for the southern coast from the reference year 2010 (Table 2). Representative values of 20 to 40 cm (0.7 ft to 1.2 ft) were selected for analysis through the study framework to represent this range of SLR expected between 2010 and 2100 based on the historical trends across the State.

TABLE 2. EXTRAPOLATED HISTORICAL SEA LEVEL TRENDS FOR QUARTER-CENTURY INTERVALS THROUGH 2100.

Extrapolated Sea-Level Trend, ft				
	2025	2050	2075	2100
North	0.21	0.55	0.89	1.23
South	0.11	0.30	0.48	0.67
Extrapolated Sea-Level Trend, cm				
	2025	2050	2075	2100
North	6	17	27	38
South	3	9	15	20

2.3 Projections of Global SLR

Much uncertainty exists in projections of future sea level due to differing scientific assumptions and models used in the process (Figure 9). Observations at water-level stations and satellite records along the U.S. Atlantic Coast have been analyzed for acceleration with differing results (Houston and Dean, 2011; Sallenger et al., 2012; Boon, 2012).

The following graph (Figure 9) illustrates the vast differences in reports defining possible future SLR projections. As noted in other parts of this report, because of uncertainty in the science and lack of consensus among the scientific community in defining future SLR, the SLRIS study and report are based on local, historically observed water trends.

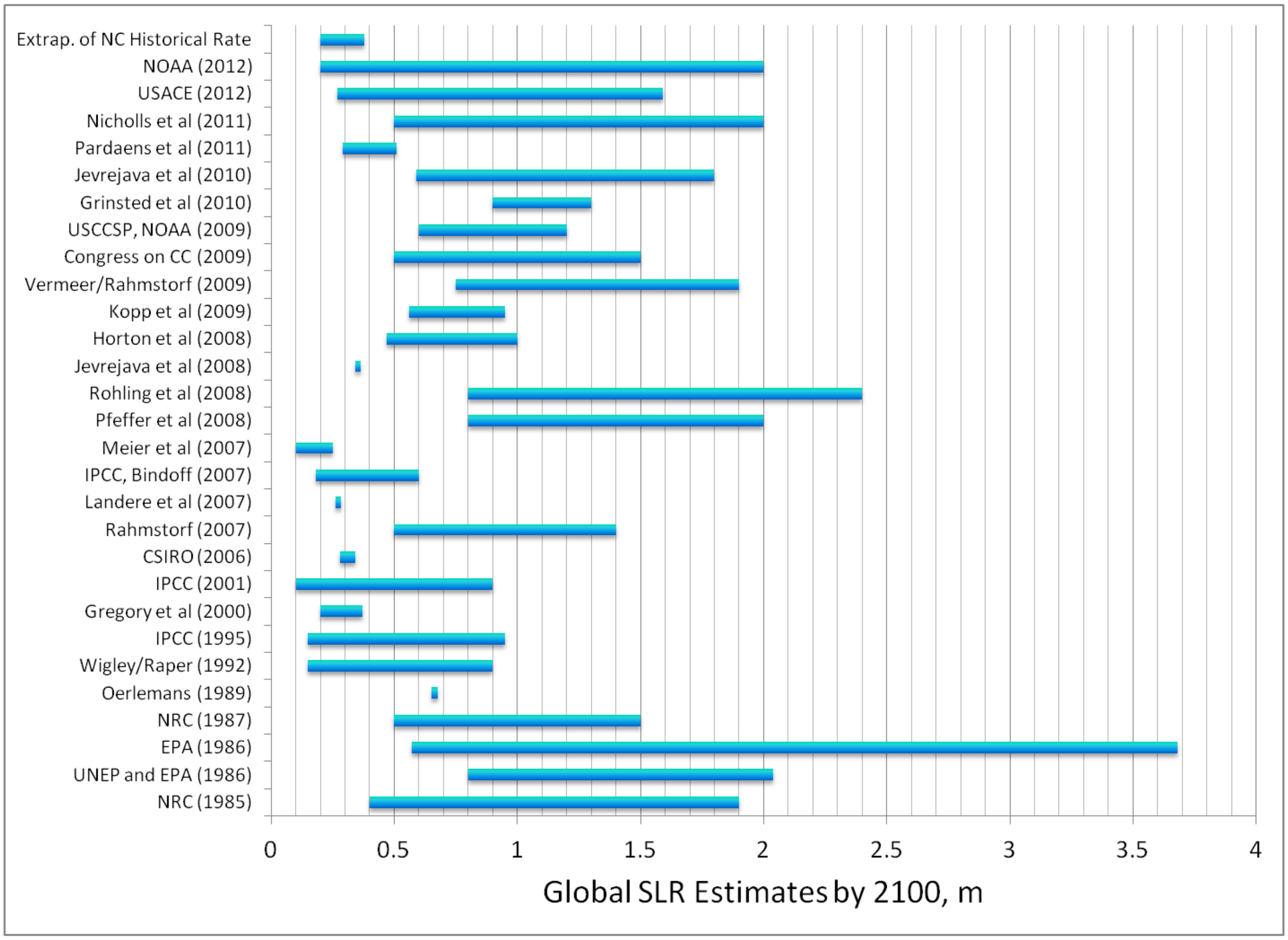


FIGURE 9. SUMMARY OF GLOBAL SLR PROJECTIONS DEMONSTRATING VARIABILITY AND BROAD RANGE OF PROJECTIONS*.

*The U.S. Army Corps of Engineers (USACE, 2012) value reflects projection for Beaufort, NC (**http://corpsclimate.us/ccaceslcurves.cfm**).

2.4 Study SLR Scenarios

The goal of the SLRIS is to examine the relative impact of SLR under a range of scenarios; it is not centered on the intricacies of climate change. The SLR scenario selection process evolved through the study in response to ongoing parallel efforts within the North Carolina State Government.

The Study Plan called for evaluation of the impacts of SLR scenarios from 2010 to 2100, specifically the four years 2025, 2050, 2075, and 2100. The SLRIS initiated SLR scenario development independently in late 2009. Initially, four future SLR curves were to be developed based on modeling the potential SLR response to the Intergovernmental Panel on Climate Change (IPCC) emission scenarios A1B, A2, B1, and B2.

Concurrently, the North Carolina Coastal Resources Commission (CRC) Science Panel on Coastal Hazards produced an assessment of future SLR projections that should be taken into account in the State's policy development and planning activities (North Carolina CRC, 2010). Based on recorded sea level trends in the State, the panel recommended that projections of potential future SLR assume the highest of these recorded rates (4.27 mm/yr, based on the station at Duck, NC) as the initial rate of rise for all sections of the State. The Science Panel then developed three scenarios (curves) of potential future sea level from this 4.27 mm/yr starting point in 2010. The three curves represent:

1. A linear projection of this recorded rate, giving a total rise of 40 cm (1.3 ft) above 2010 by 2100;
2. An acceleration in the rate of SLR, resulting in an increase of 100 cm (3.28 ft) over 2010 by 2100; and
3. A faster acceleration in the SLR rate, resulting in a 140 cm (4.59 ft) increase by 2100.

The second and third curves were developed based on review of the projections in published literature (i.e., 100 cm and 140 cm) and curves generated using a constant acceleration model.

To promote consistency in projections within the State, the SLRIS initially established four sea level curves resulting in 40 cm, 70 cm, 100 cm, and 140 cm of SLR by 2100. The 70 cm curve was added by the SLRIS to represent the lower end of SLR acceleration and was intended to fill out the range under the adopted 40, 100 and 140 cm CRC projections. From these three curves, the study team selected five representative water levels to represent changing conditions across the four curves and study time slices. These included 25, 40, 70, 100, and 140 cm.

In response to feedback from the State Legislature over the CRC scenarios and the lack of consensus in the scientific community over SLR acceleration modeling, the SLRIS scenarios were revised in late 2011. The revisions established six incremental water levels for evaluation, independent of any specific SLR projection, including 20, 40 60, 80 and 100 cm. Scenario water levels of 20 cm and 40 cm are best aligned with the anticipated SLR based on historic rates. These scenarios are referred to throughout the report in metric units of centimeters. Unit equivalents for the presented scenarios are shown in Table 3.

TABLE 3. METRIC AND U.S. STANDARD UNITS FOR PRESENTED SLRIS SCENARIOS.

Meters	Centimeters	Inches	Feet
0.2	20	7.8	0.66
0.4	40	15.7	1.31

2.5 Storm Climatology Scenarios

In addition to evaluating the potential impact of SLR, the Study Plan also called for evaluation of the potential effects of changes in storm frequency and intensity on coastal flooding (Figure 10). Tropical storm frequency and intensity have unclear ties to climate, and inter-annual/multi-decadal changes in tropical storm activity remain poorly understood. The science of climate-induced alterations to hurricane parameters is rapidly evolving and, although much uncertainty remains, the IPCC (2007) identified that the studies of potential tropical storm activity under a future warmer climate are somewhat consistent in projecting an increase in peak wind speeds (intensity), together with a less certain suggestion of decreased numbers of less intense storms, and a decrease in the total number of tropical cyclones. These findings are largely supported by the research published since the IPCC Fourth Assessment Report in 2007 (CCSP, 2008, Bender et al., 2010).

The findings of Bender et al. (2010) on potential future changes in tropical cyclone activity in the Atlantic Basin represented the current state of the science, building on previous research in this area. This research suggested that under a scenario of future warming (where modeling analyses were based on the Special Report on Emission Scenarios (SRES) A1B type scenario), by 2100 there could be up to a doubling of frequency Category 4 and 5 hurricanes. However, the research suggested significant reductions in the frequency of all tropical storm and Category 1-3 hurricanes[1].

Two scenarios of future storm climatology were considered in the SLRIS. These representations of the future hurricane climate represent the range of the Bender et al. (2010) results:

1. Scenario A: An overall reduction in storm frequency of 10%, with a 40% increase in the frequency of Category 4 and 5 events. This scenario is intended to represent a mid-century condition if assumptions that are key to achieving Scenario B (below) are achieved; and

2. Scenario B: An overall reduction in storm frequency of 20%, with an 80% increase in the frequency of Category 4 and 5 events. This scenario projected approximate changes by the end of century.

Scenarios A and B were translated to the North Carolina coast by systematically adjusting the historical storm climatology established for the statewide Flood Insurance Study update of coastal storm surge elevations (Vickery and Blanton, 2008). This was accomplished by first increasing and/or decreasing the number of hurricanes in the historical dataset as necessary for each hurricane category. Next, estimates of the landfall rate of hurricanes for the future climate scenario were developed using the changes in the future number of hurricanes by category in conjunction with the probability distribution of each landfall category, conditional on the maximum category over the life of the storm. Finally, central pressure differences versus return periods were developed using Weibull cumulative distribution function models coupled with hurricane arrival rate assumptions (Figure 11). This information was then used to update parameters within the Joint Probability Method statistical model employed to develop return period elevations from storm surge response data. A full description of the future climatology scenario development and implementation within the statistical framework is provided in the **Hazard Assessment Report**.

Extratropical storms, also known as northeasters, are an important consideration on the North Carolina coast. Existing research (CCSP, 2008) suggests that (like tropical storms) the trend under scenarios of

[1]While there appears to be an increase in the number of Category 4 and 5 Atlantic hurricanes, there has been no observed increase in the number of Category 4 and 5 hurricanes making landfall in the continental United States.
The number of hurricanes making landfall in the continental U.S. as a category 4 or 5 storm include seven from 1851 to 1900, nine from 1901 to 1950, and six from 1951 to present.

future climate change is likely to be more frequent strong storms but a reduction in the total number of storms (i.e., a reduced number of lower intensity storms). However, the level of consensus on future trends in extratropical storm activity is significantly lower than that for tropical storms. Although it would be possible to develop scenarios for extratropical storms, the current science is not considered sufficiently robust to support the development of future change scenarios. Consequently, future analysis scenarios for the SLRIS considered extratropical storms characteristics as presently defined (i.e., present-day levels derived from historical analysis).

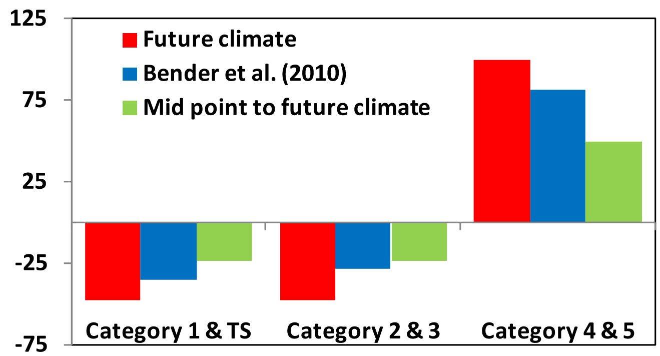


FIGURE 10. RANGES IN PROJECTED CHANGES IN HURRICANE FREQUENCY IN THE 21ST CENTURY FOR THE SLRIS STORMINESS SCENARIOS.

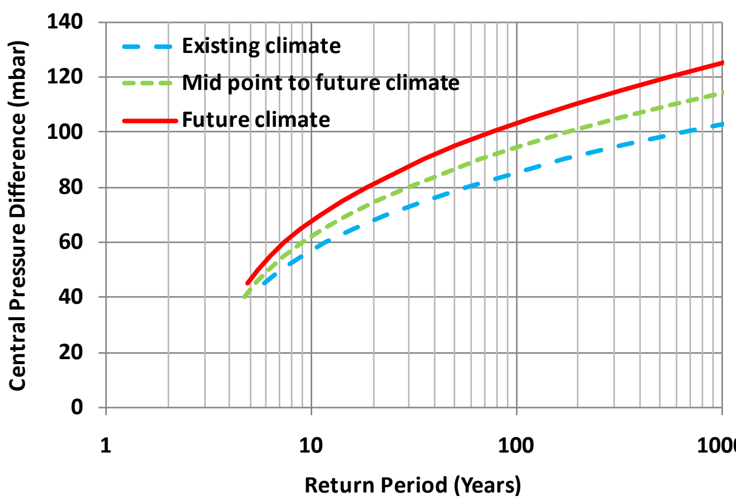


FIGURE 11. EXAMPLE OF THE IMPACT OF CLIMATE CHANGE ON CENTRAL PRESSURE DIFFERENCE VS. RETURN PERIOD FOR NORTH CAROLINA HURRICANES.

3 CHANGES TO THE FLOOD HAZARD AND PATHWAY

The SLRIS resolved changes to the coastal flood hazard through detailed hydraulic modeling of the study scenarios, with partial integration of projected changes to the coastal landscape. The effort encompassed evaluating changes to tidal dynamics and elevation, as well as coastal storm surge. A comparative base was established by first modeling tidal and flood elevations for a baseline water condition of 0 cm through the study numerical modeling framework. Water level increases of 20 and 40 cm were then imposed in the framework, and the modeling processes were completed in a consistent manner to resolve changes. Over 900 storm events were evaluated through the SLRIS statistical framework to resolve changes to the coastal flood hazard for the study scenarios presented in this report.

Uncertainty in Coastal Landscape Change: *Quantification of changes to the coastal landscape is an evolving science. Barrier island evolution and shoreline change are controlled by diverse complex factors that are difficult to model and project for the scale of this project in a defendable, objective manner. The timing and sequencing of storm activity may overwhelm long-term processes in coastal evolution.*

Results of the analysis are presented first, followed by a summary of the methodologies and product development.

3.1 How does the Coastal Landscape Change?

Flood pathways are defined as the form of the landscape over which floodwaters flow. Determining elements for the flood pathway encompasses the extent and elevation of the coastal landscape. In greater detail, this includes barrier islands, shoreline position, dune morphology, and terrain elevation. The coastal landscape is dynamic, and as such, all of these elements are expected to respond to projected increases in sea level. Inlet scour or opening, barrier island overtopping, fragmentation and breaching, and shore and dune erosion can contribute to changes in flood conveyance.

The SLRIS evaluated locations of potential barrier island overtopping, expected inlet changes, and projected marsh evolution. Results of these analyses are presented below:

3.1.1 Where Will the Barrier Islands be Overtopped?

North Carolina’s extensive barrier island chain serves as a unique coastal habitat and recreation area that also protects the inland coast from higher storm surge elevations. For example, in Dare County, storm surge elevations associated with the 1%-annual-chance event (100-year storm) decrease by about 3 feet (91 cm) from the ocean to the Albemarle Sound side of the barrier island.

Barrier islands are highly dynamic features that are subject to erosion from wind and wave activity associated with coastal storms. The short and long-

As evidenced by barrier breaching and inlet formation in the wake of Hurricanes Isabel, Irene, and Sandy, storm activity and associated coastal erosion have much greater influence on future inlet formation than do changes in tidal hydraulics. It is expected that the impacts of future storm activity, sediment transport processes, and coastal management policy will have much greater control over inlet evolution than SLR in North Carolina.

term evolution of barrier islands is controlled by several natural factors, including sea level change, sediment supply, and storm activity. Man also plays a significant role in barrier island dynamics through coastal management actions such as land development, beach nourishment, dune modification, and construction of shore protection structures.

FIGURE 12. BREACHING OF HATTERAS ISLAND DURING HURRICANE IRENE (FEMA NEWS PHOTO).

The SLRIS assessed where the North Carolina barrier island chain may be subject to tidal overtopping and loss of features isolated by local inundation. In response to 20- and 40 cm scenarios of SLR, tidal inundation of the barrier island is limited to a short reach in Brunswick County in the vicinity of Buzzard Bay (Figure 13). This area is presently subject to periodic overtopping by coastal storm activity, as indicated by the presence of sand deposits (overwash fans) on the bay-side of the barrier.

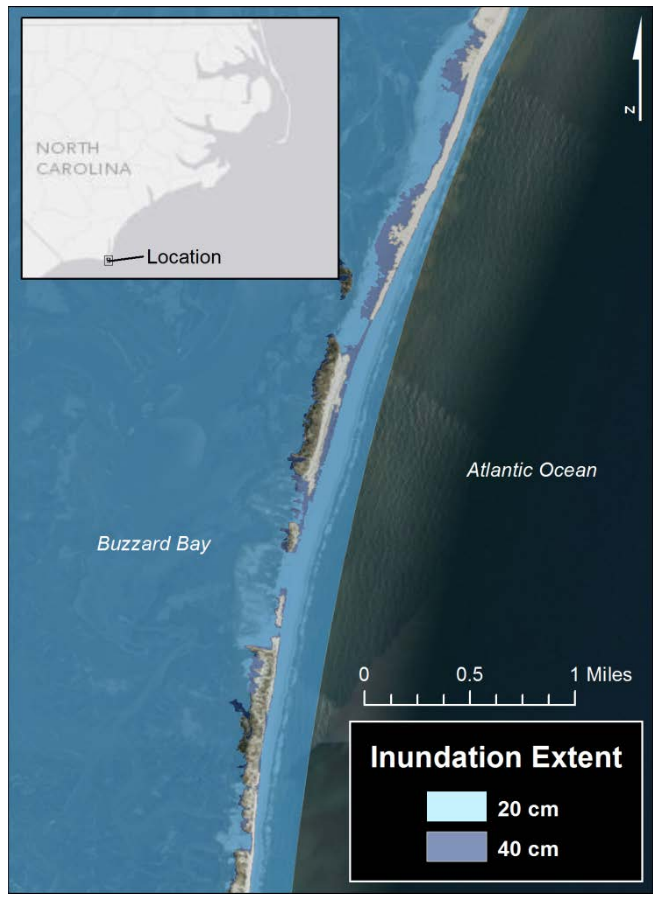


FIGURE 13. LOCATION OF BARRIER INUNDATION IN BRUNSWICK COUNTY, IN RESPONSE TO BOTH 20 AND 40 CM OF SLR.

Although the remainder of the North Carolina barrier island chain is subject to inundation along low-lying areas, scenarios of SLR up to 40 cm are not projected to result in tidal overtopping across the islands in other locations.

Barrier island impacts as projected by the SLRIS are an underestimate of expected changes due to a lack of full representation of controlling processes, such as storm activity, sediment dynamics and anthropogenic influences. These elements potentially have greater control over barrier island evolution than increases in sea level. The magnitude of coastal erosion by recent storm events (e.g., Hurricane Sandy) surpasses the influence of increases of the SLR scenarios presented in this report. It is expected that a holistic assessment of barrier island evolution, including these processes, would find further deterioration of the islands with increased sea levels.

3.1.2 How Will the Inlets Respond?

Coastal inlets are an essential pathway for storm surge propagation, providing a hydraulic connection from the open ocean to the back-bay environment. Inlet formation, migration, and shoaling occur due to interactions among local sediment transport, wave action, and tidal flow through the inlet. Increased water levels caused by SLR would result in changes to tidal dynamics at inlets, serving mainly to increase the volume of water flow through the inlets over a tidal cycle. Existing inlet channel capacity would need to increase or additional inlets would need to be

FIGURE 14. BREACHING OF HATTERAS ISLAND CAUSED BY HURRICANE ISABEL (FEMA NEWS PHOTO).

formed in order for the additional water to move through the inlets. An increase in channel capacity would occur naturally in response to SLR through scouring of the channel by the increased water velocities through the inlet.

The SLIRS evaluated the response of inlets to SLR through a hydraulic approach that considered inlet channel geometry, water velocity, and tidal range.

For the scenarios presented in this report, the analysis found that minimal changes to the existing inlet channel characteristics are anticipated.

3.1.3 How Will the Marshes Respond?

Salt marsh ecosystems play a vital role in the dissipation of wave energy, accretion of sediment, filtration of nutrients, and as habitats for commercially important fisheries. Tidal marshes are among the ecosystems most susceptible to climate change, especially SLR, because of the intricate balance among elevation, sedimentation, and inundation that is needed for marsh health. In response to SLR, many coastal areas will experience increased levels of flooding, accelerated erosion, loss of wetlands and low-lying terrestrial ecosystems, and saltwater intrusion into freshwater sources as a result of SLR and potentially enhanced storm frequency and severity. Rising sea level may result in tidal marsh submergence and habitat migration as salt marshes transgress landward and replace tidal fresh water and brackish marsh (Park et al., 1991); however loss of marsh due to SLR may be offset by sedimentation and accretion.

The SLRIS evaluated how the marshes in North Carolina would respond to increased sea level in scenarios of 40 cm or greater. The study team and Advisory Committee did not believe the study framework would provide meaningful results for scenarios of lower than 40 cm.

In response to 40 cm of SLR:

- Overall, a greater extent of change in habitat was predicted in the northern part of the State, mainly because of the underlying geologic framework and lower coastal gradients (Table 4);
- The northern part of the State is projected to lose about 28 Sq mi of marsh to open water, about twice as much as the southern areas (13 Sq mi);
- In the Northern Province, low coastal gradients support increases overall marsh area through marsh migration to upland areas, resulting in a projected gain of 137 Sq mi of marsh. Both high marsh and salt marsh are anticipated to increase by approximately 91 and 55 Sq mi, respectively, as the marshes migrate into the upland, although 43 Sq mi of low-lying marshes are predicted to convert to tidal flats and open water;
- Steeper gradients in the Southern Province restrict the ability of marshes to migrate upland, resulting in an estimated net loss of 26 Sq mi of fresh and salt marsh. An overall loss of marsh, about 22 Sq mi between high and salt marsh, is predicted in conjunction with 36 Sq mi of marsh lost to tidal flats and open water;

Overall, for this level of SLR, it is anticipated that overall marsh area will increase in the Northern Province through a process of upland migration into a landward footprint. The land gradients in the Northern Province allow for 4.1 Sq mi of upland marsh migration for each square mile of marsh lost to tidal flats or open water. On the other hand, due to the relative steepness of the land in the Southern Province, marsh loss is projected, with only 0.2 Sq mi of marsh migrating upland per square mile lost to flats or open water. It is anticipated that ratios may negatively change with higher SLR scenarios as the combination of relatively steep gradients and increasing water further restrict potential suitable marsh areas.

TABLE 4. CHANGES IN MARSH VEGETATION IN RESPONSE TO A SLR SCENARIO OF 40 CM.

Geologic Province	Upland	Fresh Marsh	High Marsh	Salt Marsh	Brackish Marsh	Beach	Flat	Water	Cypress Swamp	Tidal Swamp
Northern	-177.0	-5.5	91.3	55.2	-0.6	-3.1	15.9	27.5	-0.5	-3.2
Southern	-8.4	-2.3	-1.1	-21.4	0.0	-1.0	22.8	12.9	-0.1	-1.4

Units are in Sq mi.

3.2 What are the Changes to Coastal Flooding?

One key objective of the SLRIS was to evaluate how coastal flooding would evolve under future SLR scenarios. Changes to flooding were evaluated at the 10%-, 4%-, 2%-, 1%- and 0.2%-annual-chance flood frequencies, which correspond to the 10-, 25-, 50-, 100-, and 500-year events. The 1%-annual-chance (or 100-year) event corresponds with the FEMA regulatory floodplain as shown on Flood Insurance Rate Maps (FIRMs), the hazard level with which most individuals are familiar.

3.2.1 Changes to Flood Elevations

Most studies addressing SLR-induced inundation, flooding, and associated impacts rely on a simplistic approach to implement a SLR scenario. Typically, the existing sea level is raised by the value of the SLR scenario, an approach known as linear superposition, where 1 foot of SLR is equivalent to an additional 1 foot of flooding and or inundation. For example, to evaluate flooding and inundation caused by 1 foot of SLR, we would simply add 1 foot to the existing water level and then assess the impacts to the environment. This approach has limitations in representing dynamic changes.

The SLRIS assessed how SLR would affect flooding and inundation through dynamic modeling of storm events. The water level was raised to each scenario in the model, then tides or a series of storm events were simulated to capture flood elevations representative of the physical changes to hydraulics caused by the increased water level. Flood elevations were then compared to a baseline condition consisting of a 0 cm water level to determine the degree of change introduced by the SLR scenarios.

Across the study area, analysis indicated that the changes to surge elevations associated with the scenarios presented in this report are mostly linear.

Uncertainty in Floodplain Analysis: *Quantification of changes to the floodplain is relatively certain. The approach used in the SRLIS included detailed numerical modeling, statistical analysis, and mapping techniques consistent with standards established for FEMA Flood Insurance Studies.*

For 20 cm of SLR:

- Comparison of the detailed modeling results to the baseline condition reveal that changes in the 1%-annual-chance value had an approximate 1-to-1 linear relationship with the increase in sea level, supported by the relatively tight distribution of change values around the scenario sea level increase of 20 cm (about 0.65 ft). The root mean square difference (RMSD) between the values for the two scenarios was equivalent to the scenario value (20 cm or 0.6 ft), and although some spread does exist, more values tend to fall below the scenario SLR than above it (Figure 15).

For 40 cm of SLR:

- Comparison of the 40 cm SLR 1%-annual-chance values against the baseline condition of 0 cm shows that the RMSD (40 cm or 1.3 ft) have a mean change following a linear relationship.
- As opposed to the 20 cm scenario's near-normal distribution, the distribution for the 40 cm scenario has become bi-modal, with one peak above, and one peak below the scenario value (Figure 16). The separation of the distribution into the bi-modal peaks suggests that the response is moving toward a non-linear relationship.

Overall, the results here show that detailed modeling analysis result in potential water elevations for scenarios of 20 and 40 cm of SLR that would be virtually equivalent to the simplistic approach. Statistical distributions of change at the 40-cm scenario suggest that further increases in sea level may begin to stray from a linear relationship. For or the scenarios presented in this report, minimal variation was observed across the frequency range (10%- to 0.2%-annual-chance events).

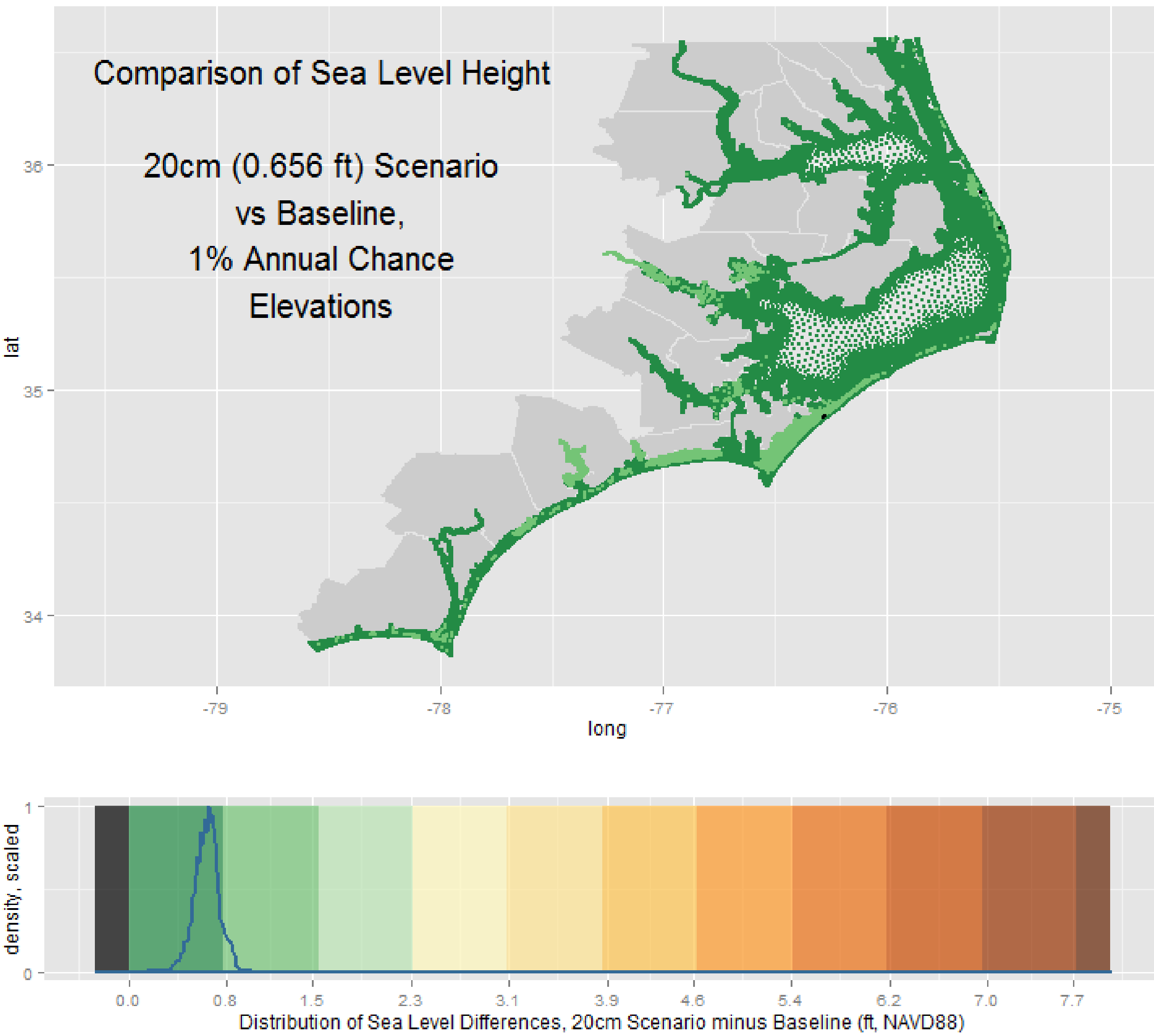


FIGURE 15. SPATIAL DISTRIBUTION AND HISTOGRAM OF 1% SURGE ELEVATION DIFFERENCES BETWEEN THE BASELINE AND 20 CM SLR SCENARIO.*

*Differences have a near-normal distribution around the scenario value with some skewness towards a value lower than the scenario.

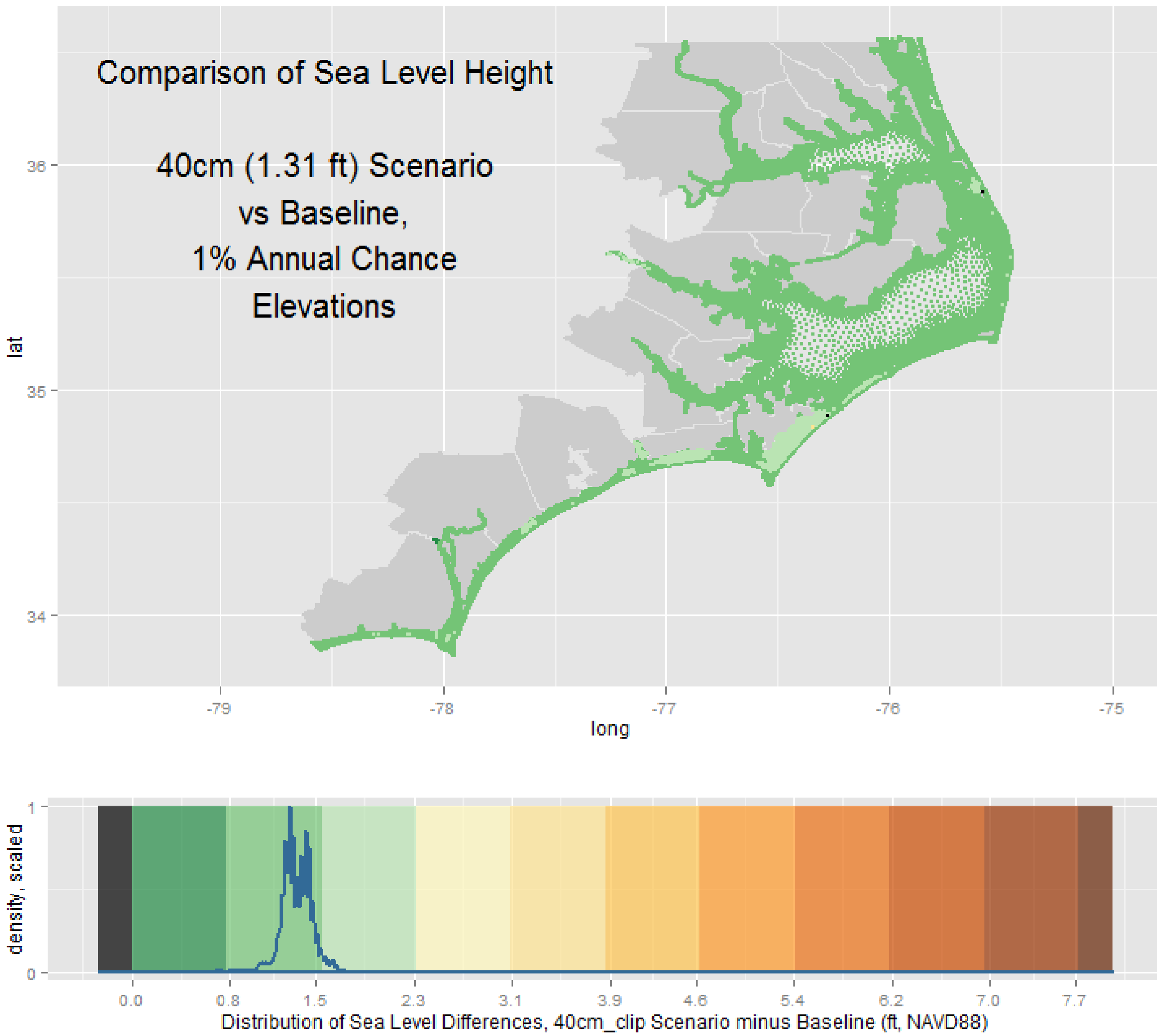


FIGURE 16. DIFFERENCES IN SURGE ELEVATIONS BETWEEN THE BASELINE CONDITION AND THE 40 CM SLR SCENARIO.*

*Differences are mostly linear, but have a have a bi-modal distribution skewed towards a value greater than the SLR scenario. The lower node and high nodes have values of 1.28 and 1.41 ft, respectively.

3.2.2 Changes to the Regulatory Floodplain

Across the study area, analysis indicated that the size of the regulatory floodplain will increase with SLR:

- **For 20 cm of SLR:** The regulatory floodplain is expected to increase by approximately 175 Sq mi, representing an expansion of 8% over the baseline condition water level of 0 cm.
- **For 40 cm of SLR**, it is projected that the regulatory floodplain will increase by approximately 348 Sq mi, representing an expansion of 20% over the baseline condition.

A summary of relative exposure across the State is shown in Figure 17. A county-by-county summary of the anticipated change in the floodplain in response to the study SLR scenarios is provided in Appendix A.

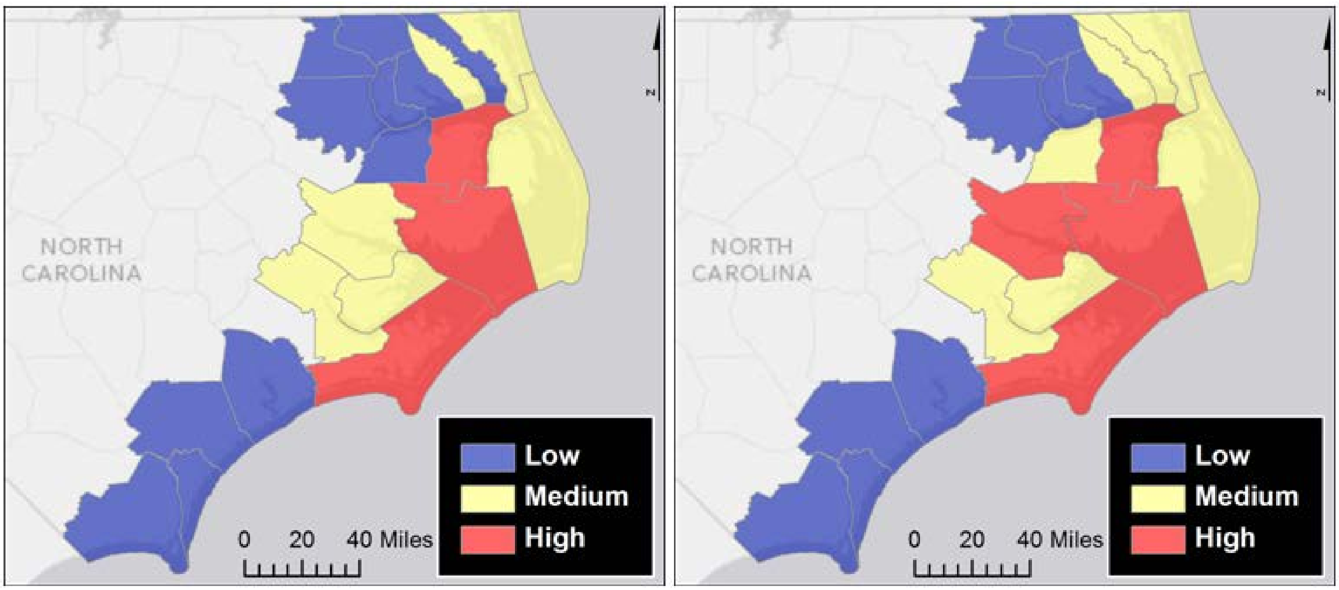


FIGURE 17. RELATIVE EXPOSURE TO CHANGES IN THE AREA OF THE REGULATORY FLOODPLAIN FOR 20 CM SLR (LEFT) AND 40 CM SLR (RIGHT).

3.2.3 Changes to the High-Frequency Floodplain

In terms of recurring flood losses, the higher frequency events are of much greater meaning for floodplain management. The regulatory floodplain represents flood conditions for a relatively infrequent event. To place this in context, a 1%-annual-chance flood has about a 26% chance of occurring within the life of a 30-year mortgage, whereas a 10% annual chance event (10-year event) has a 96% chance of occurring over 30 years. Structures located in the 10% (or 10-year) floodplain may experience repetitive flooding and are a priority target for flood hazard mitigation efforts.

Study results show much greater changes in the high-frequency floodplain (Figure 18) in response to SLR, with changes that more than double the expected increases in the size of the regulatory floodplain:

- **For 20 cm of SLR:** The 10%-annual-chance floodplain is expected to increase by approximately 344 Sq mi, representing an increase of 27% over the baseline condition of 0 cm.
- **For 40 cm of SLR:** An increase of approximately 592 Sq mi in the 10% annual-chance floodplain is expected, which is a 47% increase over the baseline condition.

Relative change of the 10% floodplain across the State is presented in Figure 19. A county-by-county summary of the changes to the 10% floodplain is presented in Appendix A.

The changes observed in the 10%-annual-chance floodplain were the highest of any of the evaluated frequencies (Table 5). The analysis of change in flood elevations found consistent increases across the frequencies; thus the greater changes in the higher frequency floodplains can be tied to the distribution of ground elevations throughout the study area. The prominent increases in the 10%-floodplain and decreasing change with the lower frequencies show that the elevation range of the higher frequency flood elevations cover large amounts of land. As the flood elevations increase during large events at lower frequencies, they occur over steeper slopes, which in turn decrease the extent of the inundation. The amount of change noted for the higher frequency floodplains should raise concern that repetitive flooding and losses may increase with SLR.

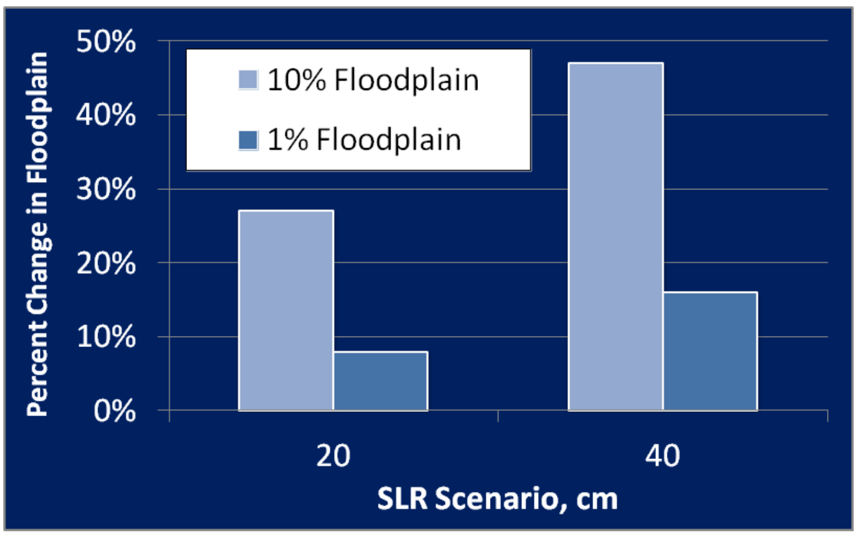


FIGURE 18. THE HIGH-FREQUENCY 10% FLOODPLAIN INCREASES AT ROUGHLY DOUBLE THE RATE OF THE REGULATORY FLOODPLAIN IN RESPONSE TO SLR.

TABLE 5. OVERVIEW OF CHANGES TO THE STUDIED FLOOD FREQUENCIES ACROSS NORTH CAROLINA'S COASTAL COUNTIES IN RESPONSE TO SLR.

Annual % Chance of Flooding	20 cm SLR		40 cm SLR	
	Change in Area (Sq mi)	Percent Change	Change in Area (Sq mi)	Percent Change
10%	343.5	27%	592.0	47%
4%	224.0	13%	422.4	25%
2%	194.4	10%	374.0	20%
1%	175.0	8%	348.2	17%
0.2%	157.8	7%	326.4	14%

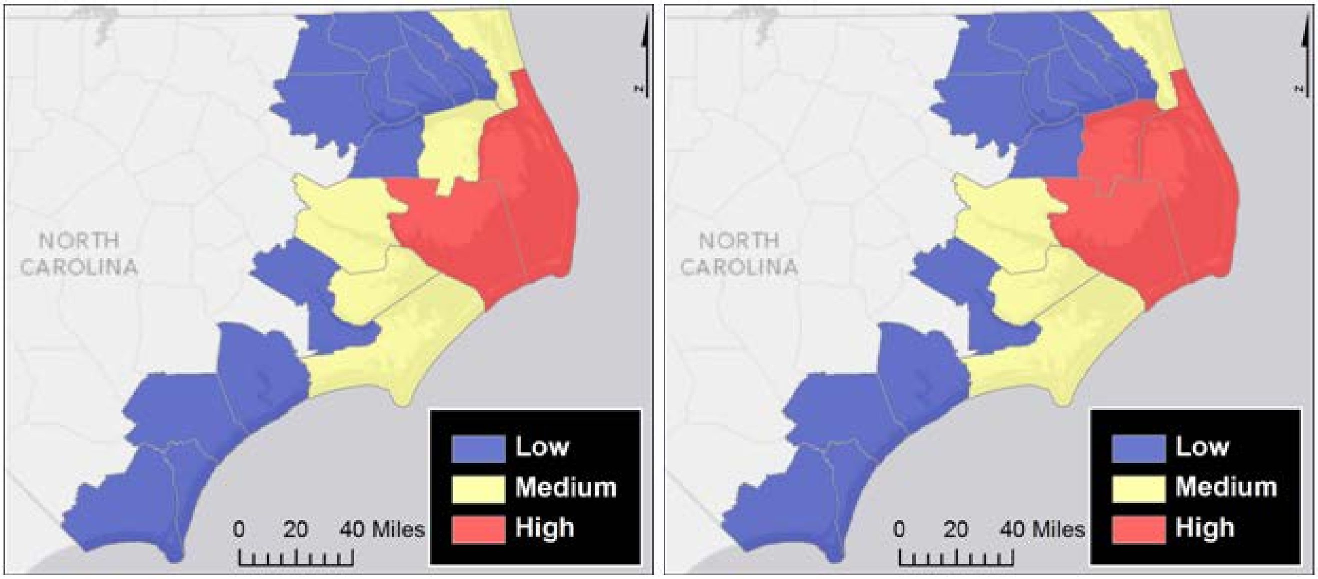


FIGURE 19. RELATIVE EXPOSURE TO INCREASES IN 10%-ANNUAL-CHANCE FLOODPLAIN CAUSED BY 20 CM SLR (LEFT) AND 40 CM SLR (RIGHT).

3.3 How Would SLR Change the Impact of Hurricane Fran?

Hurricane Fran was selected to highlight how projected SLR would increase the impact from an historical event. Fran was chosen over other events because of the extensive damages incurred in the North Carolina's coastal counties, caused mainly by storm surge. Examination of how significant hurricane events could be altered by increased sea levels can raise awareness of the potential for increased impacts in the future. Any past event is unique in that it is not expected to reoccur with identical meteorological and flood characteristics; however, a similar-magnitude event may result in comparable impacts. The potential for increased impacts from Hurricane Fran was evaluated under the SLR scenarios of 20 and 40 cm.

FIGURE 20. EXAMPLE OF STRUCTURAL DAMAGE IN THE WAKE OF HURRICANE FRAN (FEMA NEWS PHOTO).

After a relatively quiet period of hurricane activity in North Carolina from 1955 to 1996, the State suffered several strikes from major hurricanes between 1996 and 1999. Hurricane Fran made landfall on the North Carolina coast on September 5, 1996, as a Category 3 storm. It resulted in significant flooding from storm surge, as well as extensive wind damage and river and flash flooding (NOAA, 1997).

Fran made landfall on a North Carolina coast already weakened by the July 1996 landfall of Hurricane Bertha, which had storm surge elevations up to 13 feet (NOAA, 1997). Fran was estimated to have destroyed over 40,000 homes at a cost of $2.24 billion, damaging 115,000 structures in five coastal counties, and damaging close to 90% of oceanfront homes along a 100-mile reach of coast (Platt et al., 2002). Reports detail that approximately 6,700 structures were destroyed or damaged in North Topsail Beach alone (NOAA, 1997). At the time, Fran was the worst recorded natural economic disaster to have occurred in North Carolina (NOAA, 1997), estimated to be a $7-billion disaster including governmental, insured, and uninsured losses (Platt et al., 2002), supplanted later by Hurricane Floyd in 1999.

FIGURE 21. SATELLITE VIEW OF HURRICANE FRAN (IMAGE COURTESY OF THE NATIONAL AURONAUTICS AND SPACE ADMINISTRATION (NASA)).

In the SLRIS analysis, Hurricane Fran was simulated in the modeling framework, and the resulting flood elevations were assessed against the first-floor elevations of residential and commercial structures. In comparison to the baseline water elevation of 0 cm. it is projected that a storm equivalent to Hurricane Fran would result in the following increased impacts to the built environment:

For 20 cm SLR:

- It is estimated that 5,600 more buildings would be subject to flood damages, representing an increase of 33% over the baseline water level of 0 cm.
- This increase corresponds to a 21% change in replacement value of exposed buildings, an increase of $1.3 billion over the baseline condition.

For 40 cm SLR:

- It is estimated that there would be a 95% change in number of exposed buildings, an increase of 16,000 over the baseline condition.
- This increase corresponds to a 53% change in replacement value of exposed buildings, an increase of $3.23 billion over the baseline condition.

3.4 How Could Changes in Storminess Impact Coastal Flooding?

The impact of anticipated changes in storm activity, including both intensity and frequency, was evaluated as part of the SLRIS hazard assessment. As previously discussed in Section 2.5 - Storm Climatology Scenarios, potential exists for changes in Atlantic hurricane activity through the end of the 21st century. The study evaluated two scenarios of changes of storminess in the Atlantic Basin representing a range of projected changes discussed in Bender et al. (2010). A brief discussion of how these scenarios are related to North Carolina is provided in Section 2.5; a full description is provided in the **Hazard Assessment Report.**

Significant uncertainty exists in the science of future tropical storm climatology*. The analysis provides a snapshot of the evolving science and is intended to provide only an insight into how the flood hazard may be further altered by future environmental conditions.*

Scenario A considered a 40% increase in Category 4 and 5 storms, with a 10% decrease in overall storm frequency (all storm categories). This scenario represents potential storm climatology at mid-century or a more moderate change by the end of the century and was evaluated for SLR conditions of 20 and 40 cm.

Evaluation of Scenario A, at a SLR scenario of 20 cm showed that:

- Projected changes in tropical storm climatology would increase 1%-annual-chance elevations by a root-mean square difference (RMSD) of 16 cm (0.53 ft) over the historical climatology.
- Areas in the southern part of the State generally showed increases from 15 to 30 cm (0.5 to over 1 foot, Figure 22). The higher increase in this geography corresponds with the higher incidence of hurricane landfall south of Cape Hatteras.
- The total potential change in the 1%-annual-chance elevation would be 36 cm (1.2 ft), if both changes to sea level and tropical storm climatology are considered.

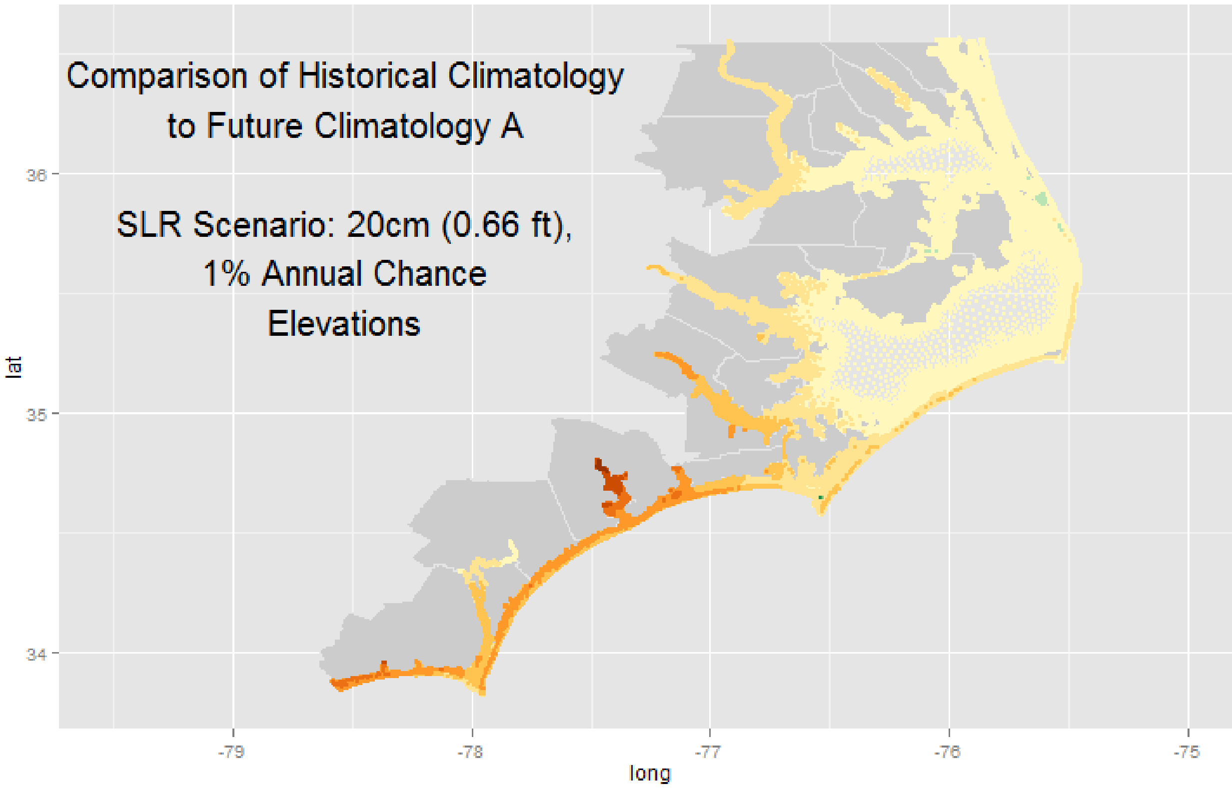
Evaluation of Scenario A, at a SLR scenario of 40 cm, showed that:

- On average, results indicated an increase of about 0.77 foot RMSD over the historical climatology.
- Areas in the southern part of the State generally showed increases greater than 23 cm (0.75 ft) and up to 53 cm (1.75 ft, Figure 23). Similar to the 20-cm SLR scenario, the higher increase in this area is attributed to the higher incidence of hurricane landfall south of Cape Hatteras.
- The total potential change in the 1%-annual-chance elevation would be 63 cm (2.1 ft), if both changes to sea level and tropical storm climatology are considered.
- Both the 20 and 40 cm conditions for Scenario A showed greater differences in elevation with decreasing flood frequency. (The differences were greater for the 0.2%-annual-chance condition than the 10%-annual-chance condition).

Scenario B considered an 80% increase in Category 4 and 5 storms, with an associated 20% decrease in overall storm frequency. This scenario represented a potential climatology for the end of the century or a more substantial change by mid-century.

For projected changes in tropical storm activity at end-of-century, the results for Scenario B, with 40-cm SLR, were very similar to the Scenario A climatology for 40-cm SLR. A negligible increase of 3 cm (0.1 ft) over the Scenario A climatology for the 1%-annual-chance frequency was noted. The small magnitude of this increase is not significant considering the uncertainty in the analysis.

Plots for all flood frequencies for the 20 and 40 cm conditions and climatological scenarios are located in Appendix A.



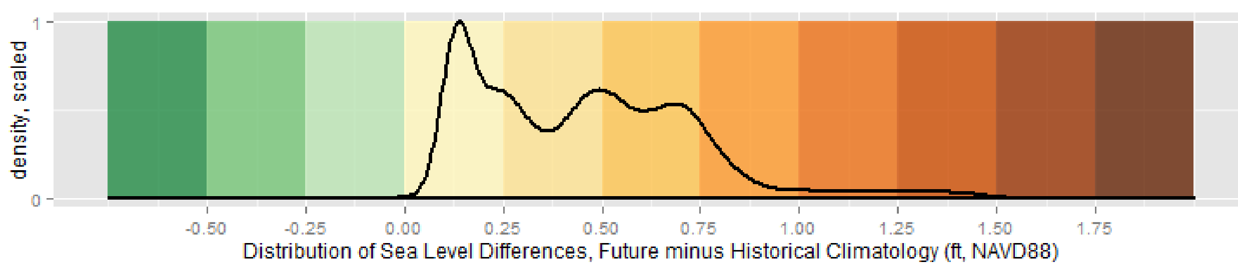


FIGURE 22. HISTOGRAM AND SPATIAL DISTRIBUTION OF PROJECTED DIFFERENCE IN THE 1%-ANNUAL-CHANCE STORM SURGE ELEVATION CAUSED BY CHANGES IN TROPICAL STORM ACTIVITY*.

*The distribution of values is skewed by the negligible change in the northern part of the coast.

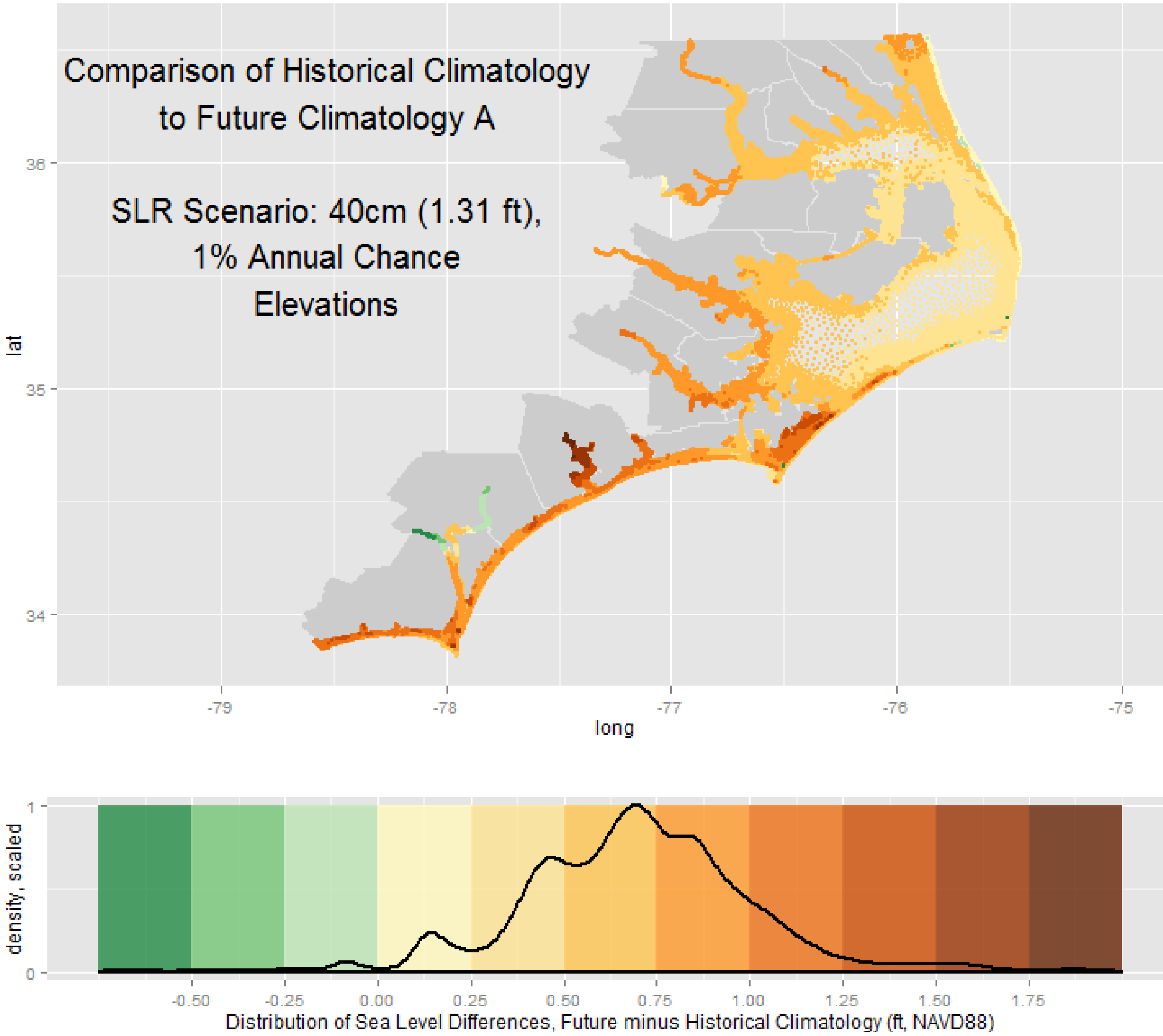


FIGURE 23. CHANGES IN THE 1%-ANNUAL-CHANCE STORM SURGE ELEVATION FOR 40 CM OF SLR FOR SCENARIO A.*

*The distribution is more normal with a RMSD of about 0.8 foot.

3.5 How Were the Changes to Coastal Flood Hazards Assessed?

An overview of the analytical approach and framework is provided in this section. For further detail, refer to the **Hazard Assessment Report**.

3.5.1 How Was Storm Surge Modeled?

To address the evaluation of the coastal flood hazard component for the SLRIS, the study essentially followed the application of the tidal and storm surge model for computing flood hazard levels for the recent updating of coastal FISs by the North Carolina Floodplain Mapping Program (NCFMP). The FIS approach uses a high-resolution numerical model grid for storm surge and waves based on recent topographic surveys and best-available bathymetric data (Blanton and Luettich, 2008), as well as advanced statistical techniques for modeling North Carolina's tropical storm climate.

The computational system (Blanton, 2008) developed for the FIS approach uses a suite of state-of-the-art numerical wind, wave, and surge models to compute stillwater elevations (SWELs) along the North Carolina coast. The model suite, shown in Figure 24, consists of the Hurricane Boundary Layer (HBL) wind model for tropical storms (hurricanes) and Oceanweather Inc.'s (OWI) Planetary Boundary Layer (PBL) model for extratropical storms; the wave-field models WaveWatch3 (WW3) and Simulating Waves Nearshore (SWAN), and the storm surge and tidal model ADvanced CIRCulation Model for Oceanic, Coastal and Estuarine Waters (ADCIRC).

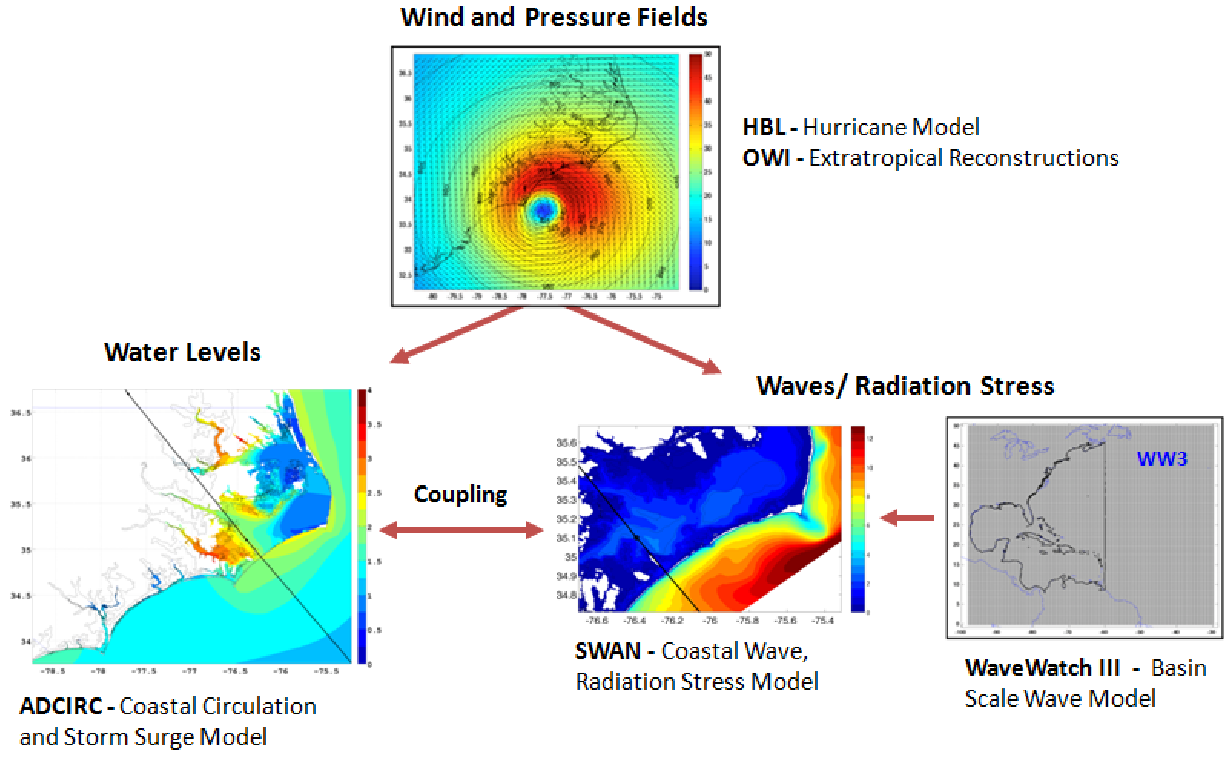


FIGURE 24. OVERVIEW OF THE NUMERICAL MODELING FRAMEWORK USED TO RESOLVE CHANGES IN THE COASTAL FLOOD HAZARD.

ADCIRC is the industry-standard coastal hydraulic model. It has been used in combination with SWAN in worldwide applications and is also commonly used in the modernization of coastal FISs within the NFIP. Based on results from the update of storm surge elevations for the statewide coastal FIS update, and many prior successful applications of this framework, it was deemed acceptably robust for the purposes of SLRIS (Figure 25). Full technical detail on this modeling system can be found in Blanton (2008).

Modifications were made to adapt the FIS models and statistical approach for use in the SLRIS. The primary driver behind these changes was to reduce the level of effort needed to run the storm surge modeling simulations in order to allow computations of the multiple SLR scenarios (Figure 26). Three elements were addressed that allowed the SLRIS to reduce computing time over the North Carolina FIS approach:

1. The FIS wave model was substituted for an updated version that allowed direct computation on the ADCIRC grid to improve computational efficiency;

2. The size of the FIS ADCIRC grid was reduced by removing unnecessary detail in areas outside of the primary study area, some upland extents and reducing resolution for previously highly resolved riverine areas. A net reduction of 35% in the number of grid nodes was achieved by these changes. These changes allowed an increase in time step and also reduced simulation times.

3. The storm track population was optimized to reduce the number of simulations for statistical analysis, which resulted in a reduction of the storm suite from 675 to 294 storms. Sensitivity analysis was performed to ensure that this reduction produced comparable results to the full FIS approach.

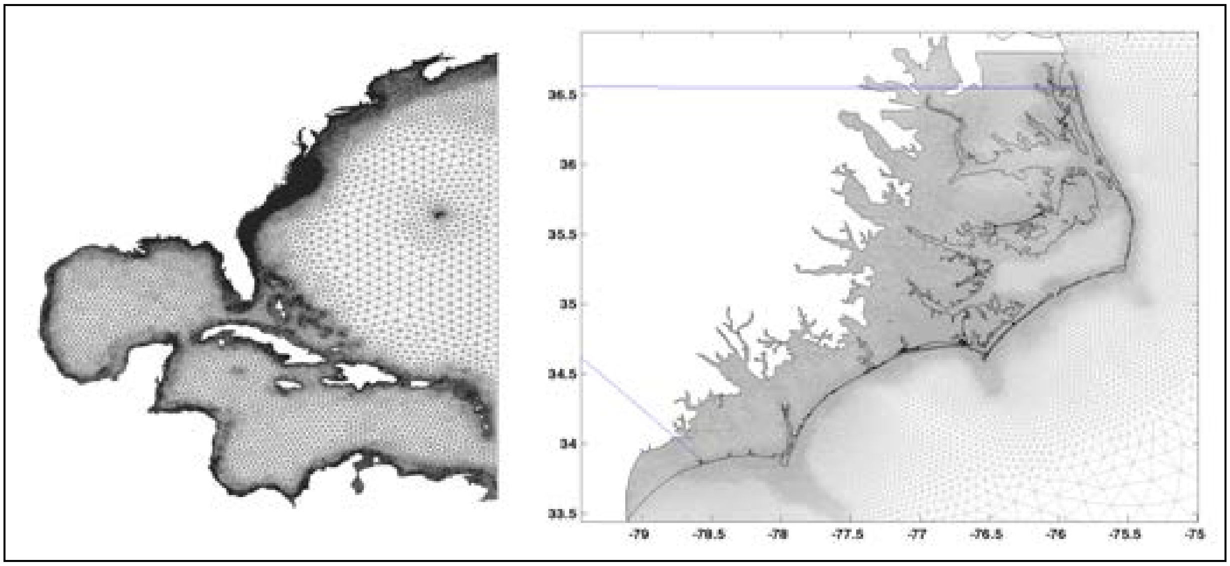


FIGURE 25. EXAMPLE OF FULL ADCIRC GRID EXTENT (LEFT) AND DETAIL IN THE NORTH CAROLINA STUDY AREA (RIGHT).

3.5.2 How Were Storm Surge Return Period Elevations Established for Each Scenario?

Return period elevations for storm surge elevations associated with tropical storms were calculated through the Joint Probability Method (JPM). The JPM approach is a simulation methodology that relies on developing statistical distributions of key hurricane input variables (central pressure, radius of maximum winds, Holland B parameter, translation speed, and heading) and sampling from these distributions to develop model hurricanes. The simulation results in a family of modeled storms that preserves the relationships between the various input model components, but also provides a means to model the effects and probabilities of future storms.

Following the methodology used by the USACE in the 2007 Louisiana Coastal Protection and Restoration (LACPR) project and in the coastal Mississippi FIS, only hurricanes affecting the North Carolina coastline between 1940 and the present were used to develop the statistical distributions for key-input storm variables. This period of activity was selected over the full historical record due to the lack of high-quality data records for storms prior to 1940. To develop statistical distributions for the key hurricane parameters, the storms were divided into two classes, with the statistical distributions for some parameters (e.g., storm heading and occurrence rate) within each class developed separately.

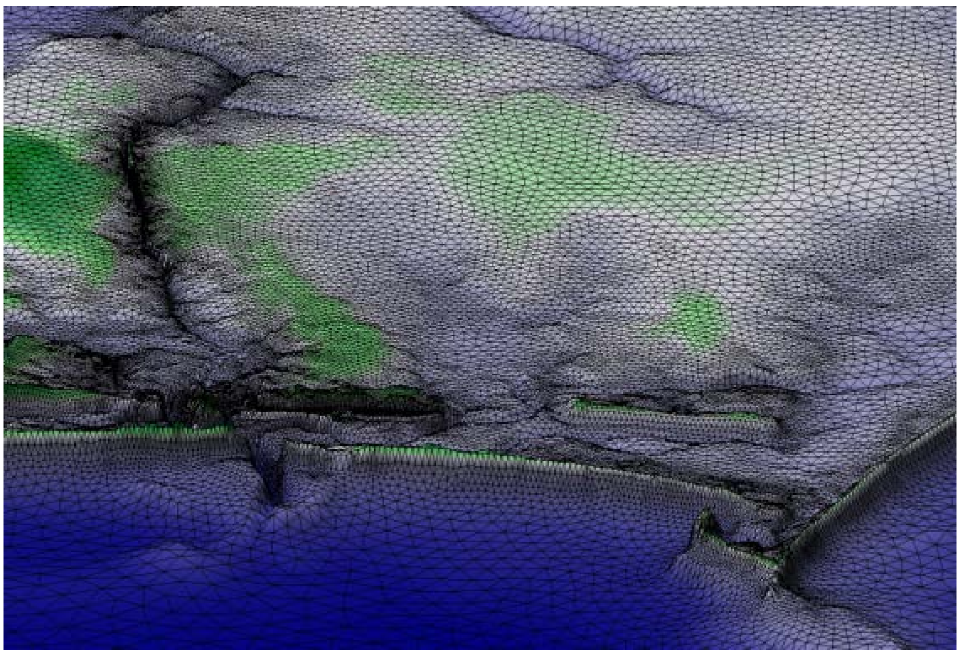


FIGURE 26. VERTICALLY EXAGGERATED 3D VIEW OF THE ADCIRC STORM SURGE MODELING GRID SHOWING REPRESENTATION OF COASTAL FEATURES AND HYDRAULIC CHANNELS.

The first class consisted of all hurricanes that made landfall along the North Carolina coast (Figure 27). The second class consisted of bypassing hurricanes, which includes all storms that did not make landfall along the landfall line segment but crossed a line extending from Cape Lookout eastward to a point positioned 300 km (186 mi) to the east (Figure 28).

Statistical analysis was performed on the two classes of storm tracks to establish the numerical values and statistical weights to characterize hurricane activity in North Carolina. In total, just under 300 synthetic events were established to characterize the historical tropical storm and hurricane climatology for North Carolina. Wind and pressure fields were established for each event by inputting their characteristics and track into the parametric boundary layer model HBL (Vickery et al., 2009). For each scenario, this suite of events was simulated over the surface water level adjusted for SLR to quantify changes in storm surge. The maximum surge elevations were extracted for each event, and then compiled for return period analysis through the JPM approach.

The track characteristics were established so as to accurately account for the historical climatology, while considering modeling of future climate scenarios. The goal was to ensure that, by varying the statistical weights associated with the model hurricanes, a future climate scenario could be modeled without the requirement that ADCIRC simulations be re-run, which would be a significant cost and time savings. JPM weights were updated to characterize changes in intensity and frequency associated with each future tropical storm climatology scenario.

Return period elevation for storm surge elevations associated with extratropical storms (commonly referred to as nor'easters) were calculated in a separate process known as the Empirical Simulation Technique (EST). The existing selection of 21 extratropical storm events from the North Carolina coastal FIS study update was carried over without change for the purposes of the SLRIS. Wind and

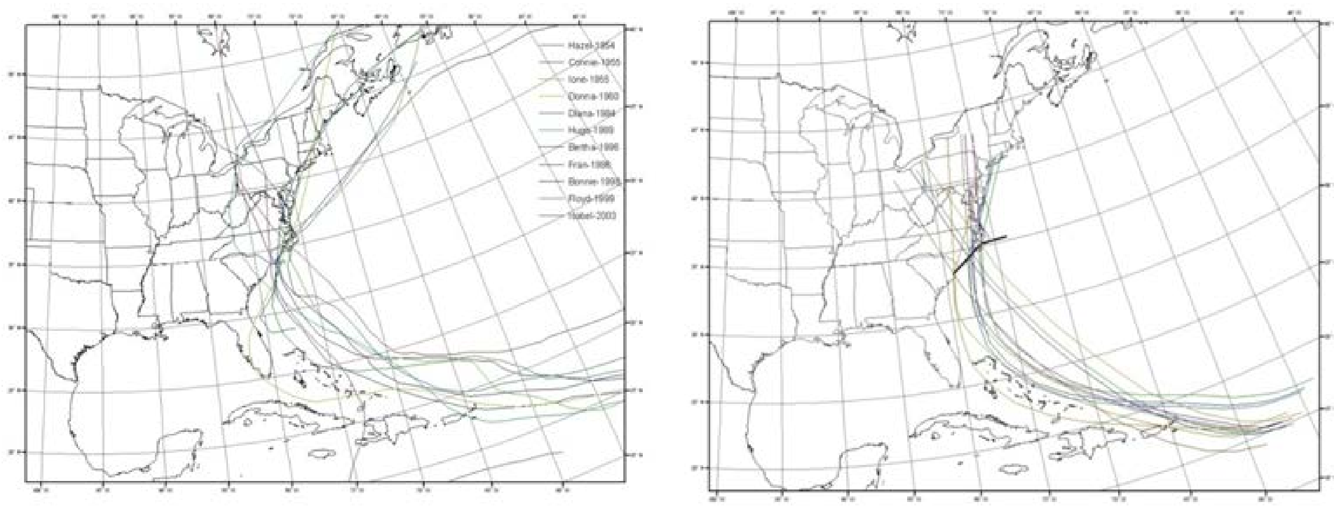


FIGURE 27. TRACKS OF ALL HISTORICAL LANDFALLING HURRICANES (CENTRAL PRESSURE < 980 MILIBAR (MBAR) DURING THE PERIOD 1940-2007 (LEFT) AND TRACKS OF MODEL LANDFALLING HURRICANES (RIGHT).

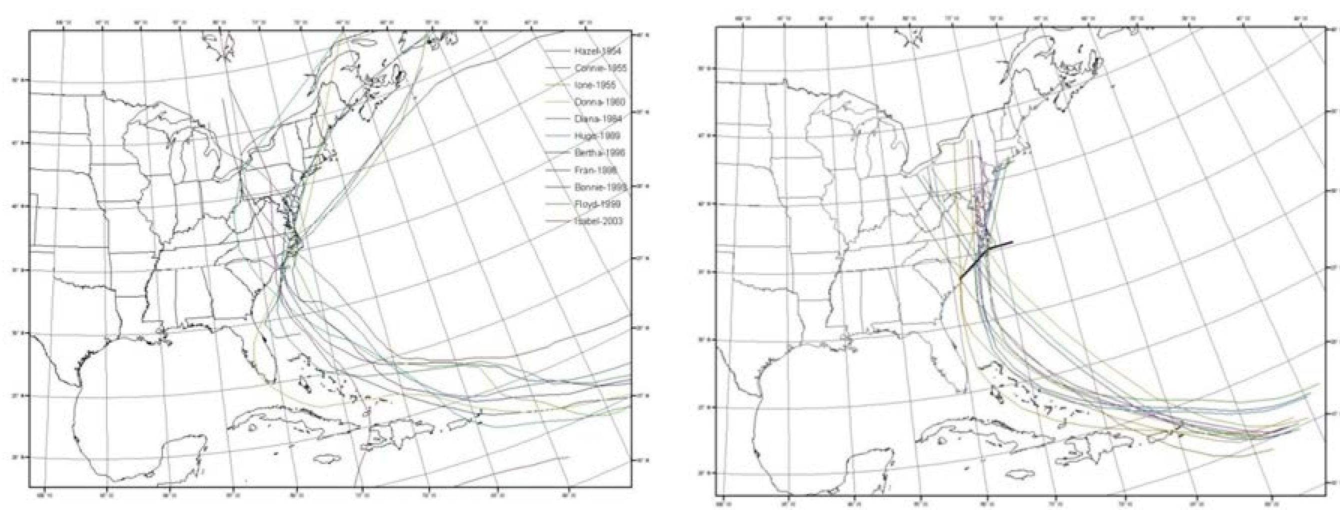


FIGURE 28. TRACKS OF ALL HISTORICAL BYPASSING HURRICANES (CENTRAL PRESSURE < 980 MBAR) DURING THE PERIOD 1940-2007 (LEFT) AND TRACKS OF MODEL BYPASSING HURRICANES (RIGHT).

pressure fields provided by OWI were simulated for each scenario, and then extratropical return period elevations were determined via EST for all ADCIRC nodes meeting a minimum data population criterion. On completion of the JPM and EST analyses, the combined storm surge return period elevations were calculated based on standard techniques.

The effects of SLR on the impacts of a storm equivalent to Hurricane Fran were evaluated by simulating storm surge in response to a re-creation of the storm's meteorological conditions. Sea level was adjusted in the surge model, and then the storm was simulated to capture the dynamic changes to surge propagation caused by SLR. The resulting storm surge elevations were overlaid on high-resolution topography to determine storm surge flooding extent and depth. Finally, these parameters were compared to the existing building locations and characteristics to determine potential exposure and damages at the individual building level.

Storminess was evaluated by changing frequency and intensity parameters in the statistical model to reflect the expected conditions for each climatological scenario. Storm surge return period elevations were then recomputed for each SLR scenario using the updated parameters in the statistical framework described in Section 3.5.2. Further detail on the scenarios can be found in Section 2.5.

3.5.3 How Were Changes to the Tidal Datums Modeled?

Tidal datums were then computed at each ADCIRC grid node from the global harmonic analysis file of the equilibrium tidal solution. This includes the expected tidal datums of Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Low Water (MLW), and Mean Lower Low Water (MLLW), as well as cumulative distributions of tidal heights needed for the subsequent JPM and EST statistical analyses. Geographic Information System (GIS)-compatible files for each datum were also produced.

Each surface is initially defined only over water, since the harmonic analysis results are sensitive to the percent of time that a node is encounters water during the harmonic analysis period. In order to use the tidal datums over land for the surge statistical analyses, the datum surfaces are extended inland to cover the areal extent of the surge results. The datums are computed in mean sea level (MSL) and then converted to North American Vertical Datum of 1988 (NAVD88) for analysis against the topography.

3.5.4 How Were Changes to the Coastal Landscape Considered?

An objective of the study effort was to consider and integrate dynamic change in the coastal landscape into the modeling approach. Past large-scale studies of SLR impacts have ignored coastal erosion or treated it as a separate aspect. Landforms in these studies were left static in what is termed a "bathtub" approach, where water level is simply raised and land losses are tallied to the extent of inundation. Such an approach underestimates the impact by not allowing additional flood conveyance and by underestimating land losses (ignoring erosion).

Through study scoping and methodology development efforts, the study team noted that methods for quantitative projection of barrier island changes are still nascent. No comprehensive approach exists to predict how barrier islands and shorelines in complex coastal systems may evolve. Although several approaches were proposed, various concerns were expressed, and ultimately it was decided that a single approach could not be applicable across the large and diverse study area. Study resources and schedule were finite, and it was not within the SLRIS scope to fund a full-fledged research effort.

The study decided to limit the scope of the open coast geomorphic evolution assessment as a result of the restrictions of existing methodologies, in the interest of producing a more defendable product and reducing overall subjectivity of results. Several options were evaluated for a revised approach and a method was selected that focused on “surge-relevant” processes. Because of the issues mentioned, projection of shoreline changes was omitted from the final approach.

The final approach entailed addressing changes key to storm surge conveyance such as those to marshes and inlets and barrier overtopping. The approach was comprised of five key elements. Landscape change was assessed for scenarios of 40 cm or greater.

1. **Evaluation of the dynamic change to the tidal dynamics and datums.** Tidal datum analysis served as input to marsh evolution modeling and identification of tidally inundated areas. This was accomplished by numerical modeling of the tidal datums for each scenario, as described in Section 3.5.3.

2. **Assessment of the barrier islands for overtopping and removal of features.** Modeling grids provide “representative” terrain. Although the modeling grid is derived from the topographic digital elevation model (DEM), limitations in the resolution of the model grid in turn limit feature representation. As a result, grids typically are more representative of larger scale features than smaller scale. For example, a dune line down a barrier island would be more representative of the island’s overall elevation and may miss limited areas with low elevation. An intention of this assessment was to identify and correct the grid in such areas to ensure that hydraulic overtopping of the barrier was fully represented for each SLR scenario.

   The method implemented for evolving the barrier island geomorphology consisted of an application of static inundation, with an additional component of feature removal. For the reasons previously discussed, the intention of this aspect was to ensure the grid represented barrier overtopping for each scenario. Additionally, as SLR further inundated the barrier island from the ocean and bay shorelines, dune features became isolated due to inundation. Such features were defined as “relict” and not expected to be present given the surrounding depth and extent of inundation for a given SLR scenario. In the evaluation of relict features, consideration was given to local extent and depth of inundation, topographic elevations and geomorphic feature, local and regional shoreline change rates, and the U.S. Geologic Survey (USGS) Coastal Vulnerability Index (USGS, 2001).

   An example of a relict feature would be a dune that is not inundated although the surrounding land areas across the barrier are inundated, as illustrated in Figure 29. In such cases, it would be assumed that the dune would fail and the material that comprised it would disperse. Features identified as relict are removed from the hydraulic model grid. In practice, most land features were considered persistent, and only a small percentage of features were classified as relict, with classification depending on physical factors controlling the perceived permanence of the feature.

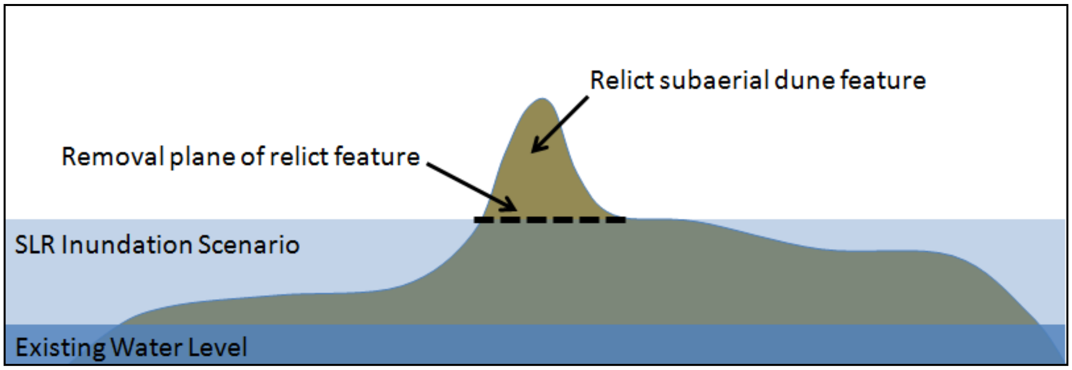


FIGURE 29. ILLUSTRATION OF AN IDEALIZED RELICT DUNE FEATURE FOR A GIVEN SCENARIO.

3. **Evaluation of inlet stability to determine potential change in conveyance and cross-sectional requirements**. This analysis was established to determine if inlets along the North Carolina coast would have adequate capacity, or cross-sectional area and depth, to accommodate the anticipated changes to the volume of water flowing through the existing inlet channels due to SLR. The key questions to answer through this analysis were:

   - Will increases in the amount of water flowing through the inlets as a result of SLR exceed the hydraulic capacity of the existing features?
   - How much will the cross section of the existing inlets need to increase to accommodate the additional flow?
   - Will additional inlets be required to accommodate changes in flow?

   The methodology utilized a combination of coastal engineering theorems, including tidal prism and inlet stability calculations leveraging cross-sectional data from the seamless DEM developed for the FIS ADCIRC model, and the tidal SLR scenario simulations to obtain tidal parameters, inlet velocity, and depths. Baseline conditions were established, and then the analysis was repeated for scenarios greater than 40 cm. When the analysis revealed that the inlet required an increase in cross section to convey the additional flow of water, it was assumed that the channel would scour. The required cross-sectional area was then calculated and implemented to reflect anticipated scour (channel depths were increased) and return the hydraulic state back to equilibrium.

4. **Modeling of marsh evolution; determining marsh platform elevation and land cover change.** Marsh evolution was evaluated using the Sea Level Affecting Marsh Model (SLAMM) Version 6.1, which is a numerical model that simulates the dominant processes involved in wetland conversion and shoreline modification during long-term SLR. For SLRIS, SLAMM was used to model marsh migration on the back barrier and sound-side marshes of the study area. The model simulates the impacts of SLR by incorporating information on the ecologic, hydrologic, and geologic processes of the study area, and it includes estimates for inundation, erosion, and accretion. Cell-by-cell calculations following a complex decision tree are incorporated to determine how particular habitats will change.

   The SLAMM model converts one habitat class to another on the basis of the relative change in elevation and the elevation range of the class affected by that change. Inundation is a function of a cell's elevation and slope. SLAMM offers a more realistic approach than simple "bathtub" models because it considers processes that alter the relative rates of SLR. Sustainability of wetlands is related to the ability of the marsh to keep up with the rate of SLR. Numerous feedback relationships exist between wetlands and SLR, including increased sedimentation and therefore accretion, with increased flooding and an increase in plant productivity.

Inputs to SLAMM include National Wetlands Inventory (NWI) data reclassified according to SLAMM conventions, a DEM developed from Light Detection and Ranging (LiDAR), slope derived from the DEM, dikes derived from the NWI, tidal datum and SLR trend data from CO-OPS stations and the SLRIS tidal datum modeling, as well as site-specific geomorphic parameters derived from multiple academic sources.

The SLRIS study team thoroughly vetted SLAMM prior to application for the study and found outputs to be of suitable quality for the application. The model was implemented in subsites across the study area to account for varying input parameters. Simulations were run incrementally using input from the ADCIRC tidal datum analysis. Outputs included land cover change and elevation change within the marsh platforms.

5. **Implementation of elements 2-4 into the hydraulic model grid.** Removal of relict dunes, inlet cross-sectional changes, and land cover and elevation related to marsh evolution analysis were integrated back into the modeling grid for SLR scenarios of 40 cm and greater. Where features were determined to be relict, representative elevations in the model grid were adjusted to reflect the adjacent grade of the removed feature. Inlet depths were adjusted where necessary to reflect any needed increase in channel area. Marsh change was implemented by updated marsh platform elevations, as well as the model land cover friction parameters.

An overview of the overall modeling process, including the integration of the above elements and geomorphic evolution outputs into the surge modeling effort, is shown in Figure 30. A full description of the methods and processes can be found in the **Hazard Assessment Report**.

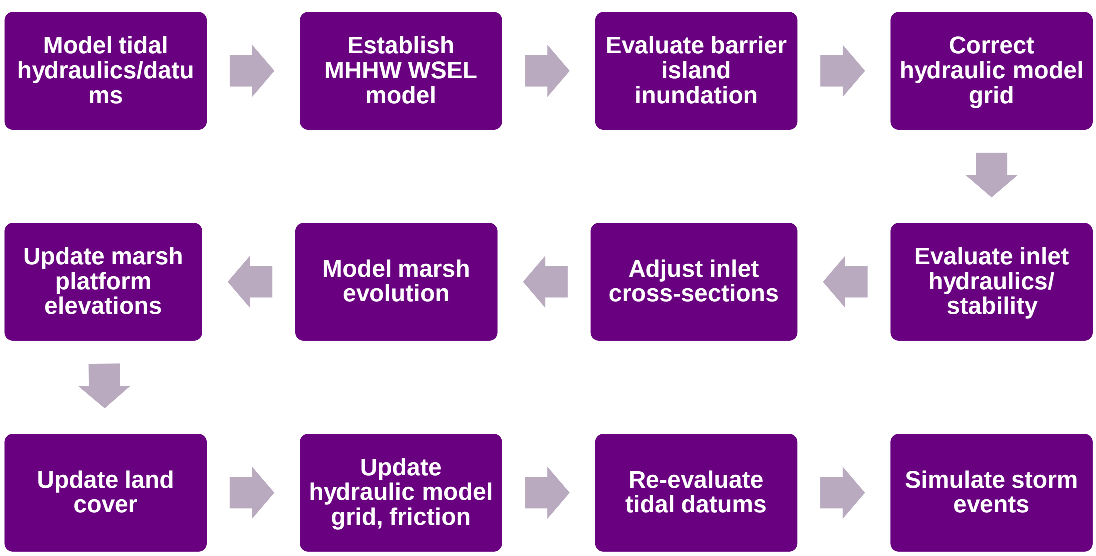


FIGURE 30. OVERVIEW OF GEOMORPHIC EVOLUTION ANALYSIS WORKFLOW AND INTEGRATION INTO SURGE MODELING EFFORT.

3.6 Flood Hazard Products

The study was focused on evaluating changes to both permanent inundation and episodic coastal flooding.

Permanent inundation was defined as land with elevations falling below the local MHHW as determined for each scenario. NOAA defines MHHW as the average of the higher high water height of each tidal day observed of the National Tidal Datum Epoch (NOAA, 2000). MHHW is used over MSL to differentiate between lands subject to tidal action. It represents "elevation of the normal daily excursion of the tide where the land area is normally inundated" (NOAA, 2010).

Areas subject to coastal flooding were defined as land with elevations less than the 10%-, 4%- 2%-, 1%- and 0.2%-annual-chance storm surge elevations as determined by the storm surge modeling framework in accord with procedures established by FEMA. The 1%-annual-chance floodplain is defined as the area that will be inundated by the flood having a 1% chance of being equaled or exceeded in any given year; it is also referred to as the base flood elevation or 100-year flood elevation. The Special Flood Hazard Area (SFHA) is delineated on FEMA FIRMs. Similarly, the 0.2%-annual-chance elevation reflects the FEMA 500-year floodplain.

The hazard products were specified to facilitate identification of flood hazard exposure to each scenario, as well as the potential exposure and damages to structures developed as part of the Impact Assessment. The first products, and the foundation for the remaining products, were water surface elevation (WSEL) models established from the outputs of the storm surge modeling framework. The remaining products were generated by overlaying the WSELs against the topographic base data and applying the appropriate geospatial processing and calculations. The products of the hazard assessment effort included:

- Extent of land below (inundated) the MHHW elevation for each scenario;
- WSELs for the 10%-, 4%-, 2%-, 1%-, and 0.2%-annual-chance flood conditions for each scenario;
- Flood extents of the 10%-, 4%-, 2%-, 1%-, and 0.2%-annual-chance flood conditions for each scenario;
- Depth grids for the 10%-, 4%-, 2%-, 1%-, and 0.2%-annual-chance flood conditions for each scenario;
- Depth grids, including wave effects for the 10%-, 4%-, 2%-, 1%-, and 0.2%-annual-chance flood conditions, for each scenario; and
- Annual and 30-year probability flooding grids for each scenario.

Creation of the hazard assessment geospatial layers involved a multi-step process executed in a GIS software environment, starting from the outputs of the storm surge modeling framework and ending with the final raster products. Formalized quality assurance and step-wise quality control reviews were integrated into the production process. Additional information can be found on geospatial product development and quality procedures in the **Hazard Assessment Report**.

4 POTENTIAL IMPACTS OF SLR

The SLRIS used a robust impact assessment framework to examine the future impacts of SLR. Largely powered by GIS technology, this impact assessment was broken down by receptor in order to pinpoint as specifically as possible the cumulative impact of SLR. These receptors include the features that are most readily seen by residents on a given day along the North Carolina coast, such as:

- Beaches and Coastal Lands
- Buildings and Structures
- Transportation (Roads)
- Society

All economic data are presented in today's valuation; no adjustments were made for inflation

The following section will examine by each receptor the cumulative impacts of 20 cm and 40 cm of SLR. In general, losses are presented in terms of increases over today's current sea levels. However, today's current sea level or baseline is displayed against future population and development to reflect potential continuation of the baseline condition.

4.1 How Much Land Could Be Lost to Inundation?

As sea level rises, select areas of land become inundated as the increased water levels elevate the daily extent of tidal action. The amount of inundation is locally dependent on the slope of the land. With the same amount of SLR, steeper areas will experience less inundation, while areas with a gentle slope will experience more. As noted in the study area description, the geologic framework of North Carolina controls relative steepness; areas north of Cape Lookout have lower elevation gradients and higher susceptibility to coastal flooding and inundation impacts.

Coastal inundation was defined as land with elevations that are below the local MHHW, as determined for each scenario. NOAA defines MHHW as the average of the higher high water height of each tidal day observed in the National Tidal Datum Epoch, and notes that MHHW represents the "elevation of the normal daily excursion of the tide where the land area is normally inundated" (NOAA, 2000). MHHW is used over mean sea level to fully identify lands subject to tidal action.

MHHW was identified by modeling tidal dynamics (Section 3.5.3) and establishing updated relationships between tidal datums for each scenario. Elevations from this effort were used to create three-dimensional models of the MHHW WSEL. These WSEL models were then overlaid on the high-resolution DEM to identify areas beneath the MHHW elevation for each scenario.

4.1.1 How Much Land Will Be Inundated?

Across the 20 coastal counties of North Carolina, it is estimated that by 2100:

- For a 20 cm SLR: a total of 247.1 Sq mi of land is subject to inundation, representing 3% of the total land area of those counties.
- For a 40 cm SLR: a total of 795.5 Sq mi of land is subject to inundation, representing 9% of the total land area of those counties.

A breakdown of exposure across the study area is provided in Table 6, and relative exposure across the state is highlighted in Figure 31.

TABLE 6. SUMMARY OF EXPOSURE TO INUNDATION BY COUNTY FOR A 20 CM AND 40 CM RISE IN SEA LEVEL.

County	Land Inundated by 20-cm SLR (Sq mi)	Percent of Land in County Subject to Inundation by 20cm SLR	Land Inundated by 40 cm SLR (Sq mi)	Percent of Land in County Subject to Inundation by 40-cm SLR
Beaufort	8.8	1%	30.8	4%
Bertie	24.8	4%	36.7	5%
Brunswick	4.9	1%	8.9	1%
Camden	8.5	4%	34.1	14%
Carteret	20.6	4%	57.3	11%
Chowan	2.4	1%	6.4	4%
Craven	11.2	2%	17.4	2%
Currituck	11.6	5%	46.5	18%
Dare	19.8	5%	113.2	30%
Gates	10.5	3%	26.5	8%
Hertford	7.7	2%	13.6	4%
Hyde	12.9	2%	150.5	22%
New Hanover	4.9	3%	9.4	5%
Onslow	9.9	1%	16.5	2%
Pamlico	11.8	3%	38.2	11%
Pasquotank	6.2	3%	11.7	5%
Pender	8.4	1%	13.7	2%
Perquimans	4.5	2%	7.8	3%
Tyrrell	49.3	13%	135.8	36%
Washington	8.3	2%	20.5	6%

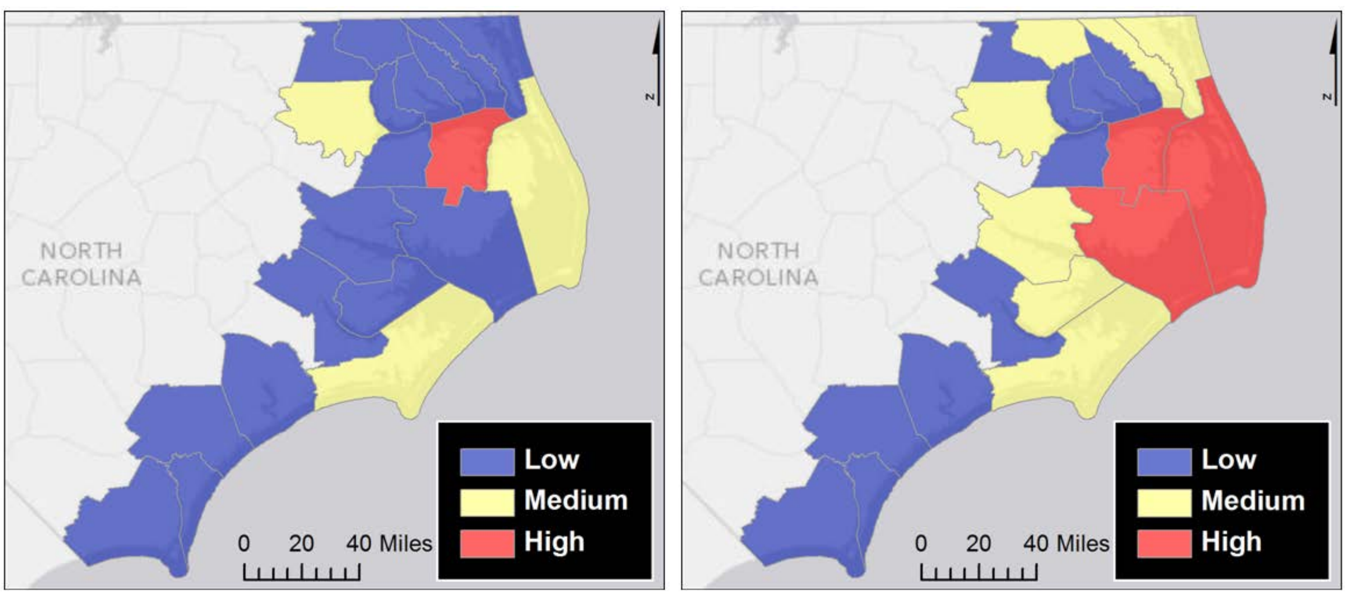


FIGURE 31. RELATIVE EXPOSURE TO PERMANENT INUNDATION DUE TO SLR (LEFT: 20 CM SLR; RIGHT: 40 CM SLR)*.

*Overall, exposure reflects a combination of the controlling geologic framework and local elevation gradients.

4.1.2 What are the Relative Impacts from Inundation by Scenario?

Of the impacts stemming from permanent inundation, the number of buildings inundated by SLR is most significant. Based on the 40 cm scenario, over 5,000 structures are expected to become permanently inundated, representing nearly $1 billion in lost property. Counties with barrier island communities incur significantly higher numbers of permanently inundated structures than the other counties. Some of the more densely populated counties in the southern portion of the study area are also significantly impacted by increases in MHHW (Figure 32).

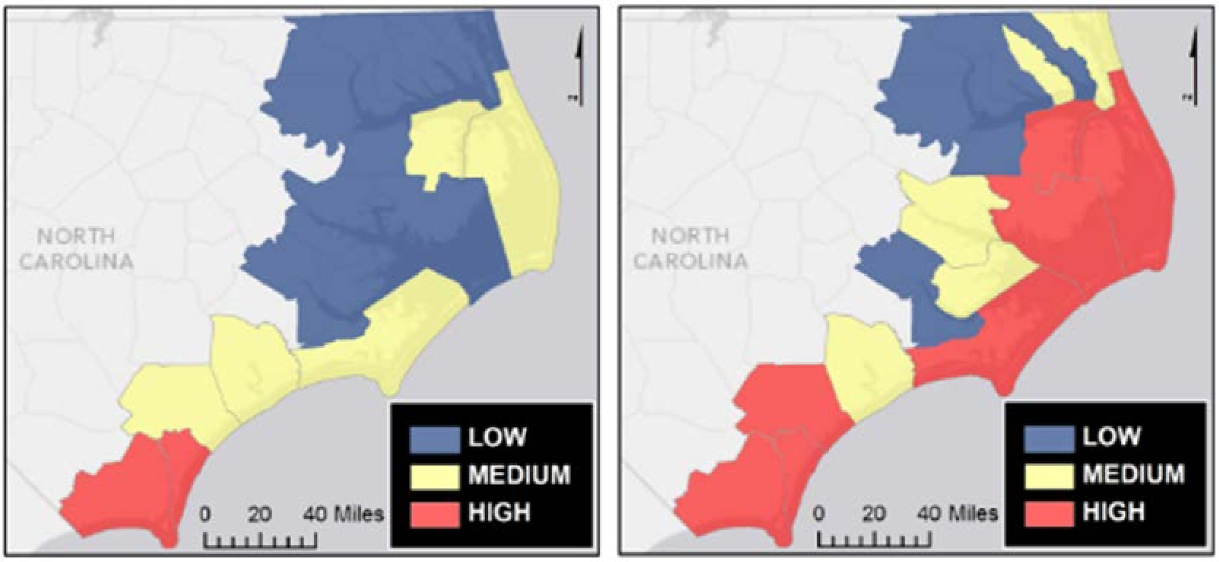


FIGURE 32. RELATIVE INCREASE IN THE NUMBER OF STRUCTURES INUNDATED BY MHHW.

- About 1,000 structures will become permanently inundated with 20 cm of SLR, as opposed to 5,054 structures permanently inundated with 40 cm of SLR.
- The 5,054 structures inundated at the 40 cm level is a number five times greater than the 1,002 structures inundated at the 20 cm level.

TABLE 7. SUMMARY OF PROJECTED BUILDING LOSSES DUE TO PERMANENT INUNDATION OF STRUCTURES FOR THE 20 COASTAL COUNTIES.

County	20 cm Scenario		40 cm Scenario	
	Structures Inundated	Real Estate Value	Structures Inundated	Real Estate Value
Beaufort	18	$1,851,000	156	$16,574,000
Bertie	1	$451,000	4	$898,000
Brunswick	239	$42,648,000	579	$124,609,000
Camden	4	$386,000	22	$1,225,000
Carteret	106	$14,400,000	789	$88,149,000
Chowan	2	$422,000	13	$1,813,000
Craven	9	$1,686,000	27	$4,348,000
Currituck	23	$1,259,000	120	$8,748,000
Dare	62	$11,383,000	529	$80,721,000
Gates	2	$212,000	4	$301,000
Hertford	6	$47,000	35	$1,202,000
Hyde	24	$1,721,000	766	$125,539,000
New Hanover	171	$107,371,000	474	$323,565,000
Onslow	82	$10,718,000	285	$40,298,000
Pamlico	33	$1,131,000	220	$20,356,000
Pasquotank	15	$798,000	129	$11,708,000
Pender	87	$11,971,000	456	$47,922,000
Perquimans	10	$1,925,000	33	$6,670,000
Tyrrell	107	$4,503,000	406	$17,786,000
Washington	1	$36,000	7	$215,000
Total	1,002	$214,917,000	**5,054**	**$922,647,000**

4.2 What Are the Impacts to Buildings and Structures?

The buildings and structures analyzed in the SLRIS are derived from the NC iRISK project. Information regarding the building occupancy, construction type, and value, among other attributes, was evaluated against flood hazard information to calculate potential losses due to SLR. In total, the SLRIS framework predicts that over 11,000 *additional* structures are expected to be damaged to some degree by the 1%-annual-chance flood for the 20 cm SLR scenario, and over 29,000 structures in the 40 cm scenario. These values represent 16% and 41% increases over existing conditions, respectively. Some areas of the State are impacted more than others, especially those in the northern areas. The relative increase in the number of structures being added to the 1%-annual-chance floodplain by county is shown in Figure 33.

The SLRIS evaluated over 500,000 buildings in the 20 coastal counties for potential SLR impact.

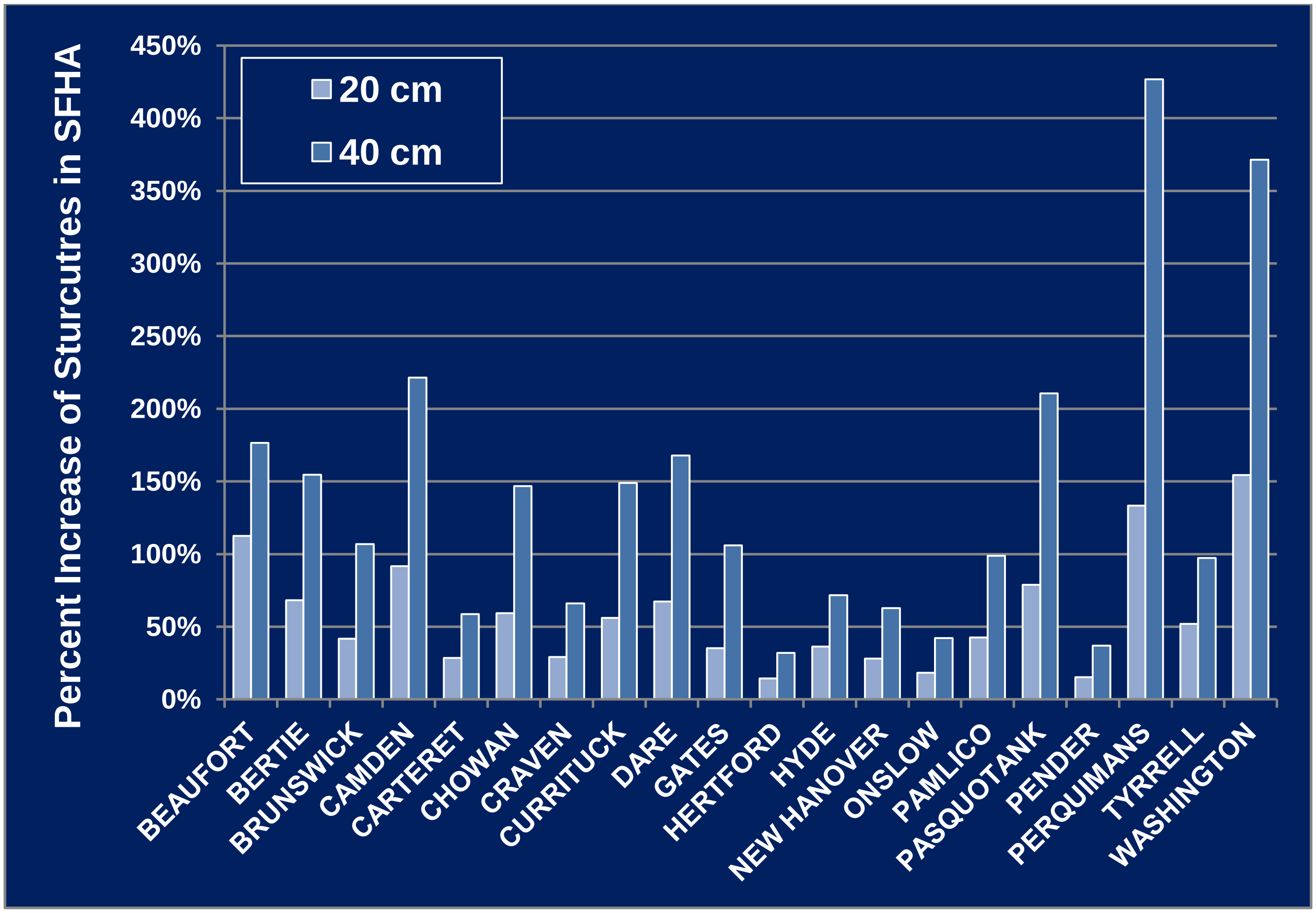


FIGURE 33. PERCENT INCREASE IN NUMBER OF STRUCTURES IMPACTED BY 1%-FLOOD EVENT BY COUNTY FOR 20 CM AND 40 CM SCENARIOS, AS COMPARED TO THE BASELINE CONDITION.

As shown in Figure 33, percentage increases associated with the 40 cm scenario are much higher than those for the 20 cm scenario during a 1%-annual-chance flood event. In total, the 40-cm scenario inundates 2.5 times as many additional structures than the 20-cm scenario. These losses are echoed by the financial losses represented by the inclusion of additional structures in the floodplain, as shown in Table 8.

Annualized Loss Estimation (ALE) is a way of characterizing the relative losses that might be incurred by a particular community or other geographic area on an annual basis. It is determined by using multi-frequency loss estimates for several modeled flood hazard areas (including the 10%-, 4%-, 2%-, 1%-, and 0.2%-annual-chance floodplains) and applying the statistical likelihood of each flood to the modeled losses. As a result, losses with a greater statistical likelihood on an annual basis (i.e., 10%- and 4%-chance) are given greater consideration than those with lesser likelihood (1%- and 0.2%-chance).

- **For 20-cm of SLR** – ALE increases by 57% over today's condition, representing an increase of nearly $80 million.
- **For 40 cm of SLR** – ALE increases by 137%, representing $190 million in additional annual exposure. This is more than double the exposure from the 20 cm scenario.

TABLE 8. INCREASE IN THE ALE FOR THE 20 CM AND 40 CM SCENARIOS.

County	0 cm Scenario	20 cm Scenario		40 cm Scenario	
	Total	Total Increase ($ Million)	Percent Increase	Total Increase ($ Million)	Percent Increase
Beaufort	$1.43	$3.44	241%	$8.04	563%
Bertie	$0.07	$0.06	96%	$0.18	264%
Brunswick	$5.30	$3.01	57%	$7.80	147%
Camden	$0.14	$0.23	161%	$0.77	538%
Carteret	$31.21	$18.67	60%	$45.78	147%
Chowan	$0.08	$0.11	133%	$0.32	387%
Craven	$8.26	$5.31	64%	$15.31	185%
Currituck	$0.63	$1.04	164%	$3.64	573%
Dare	$1.40	$2.45	175%	$7.82	557%
Gates	$0.02	$0.03	152%	$0.11	524%
Hertford	$0.10	$0.08	85%	$0.22	224%
Hyde	$2.84	$2.54	89%	$8.64	304%
New Hanover	$57.72	$28.44	49%	$56.53	98%
Onslow	$15.93	$5.90	37%	$12.48	78%
Pamlico	$2.36	$2.07	88%	$5.56	236%
Pasquotank	$0.94	$1.32	140%	$4.14	439%
Pender	$9.02	$3.39	38%	$8.01	89%
Perquimans	$0.02	$0.02	76%	$0.08	317%
Tyrrell	$0.81	$1.27	157%	$4.26	528%
Washington	$0.03	$0.06	200%	$0.24	766%
Total	$138.30	$79.46	57%	$189.90	137%

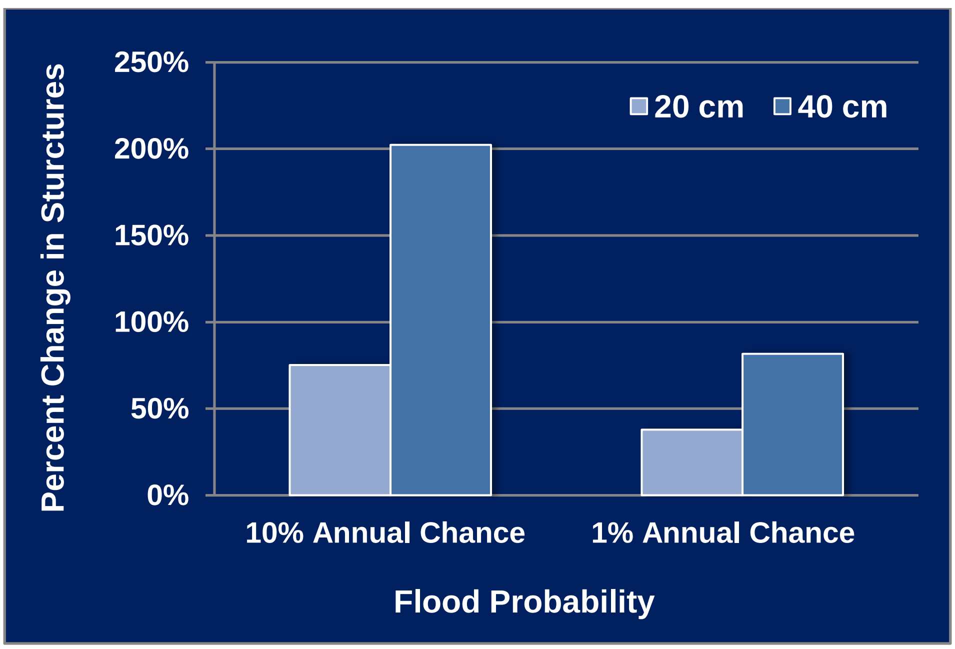


FIGURE 34. INCREASE IN PERCENTAGE OF STRUCTURES AFFECTED BY THE 10%- AND 1%-ANNUAL-CHANCE FLOOD EVENTS FOR THE 20 CM AND 40 CM SCENARIOS*.

*Note that the number of impacted structures associated with the 10%-annual-chance flood increases at a higher rate than does the number of structures impacted by the 1%-annual-chance flood.

For the 20 cm scenario (Figure 33), most coastal impacts are relatively low, with localized impacts along the barrier islands and low-lying inland communities. By the 40 cm scenario, however, the impacts are far more extensive, with medium to high impacts across the barrier islands and increased losses in back-bay communities.

Although annualized losses will certainly increase with rising sea level, another particularly striking outcome of the study is related to the increase in the number of structures that will enter the 10%-annual-chance floodplain, as shown in Figure 34. Like the amount of land subject to flooding by the 10%-annual-chance floodplain shown in Section 3.2.3., losses follow a similar pattern. This would indicate that the greatest opportunity to initiate flood protection and mitigation actions would focus less on the 1%-annual-chance flood, and more on the structures located within the 10%-annual-chance floodplain, particularly those structures that will become permanently inundated.

4.2.1 What are the Overall Losses by Occupancy Type?

The overall study revealed that approximately 24,500 structures might be added to the 40 cm, 1%-annual-chance floodplain, most of those structures are residential structures, such as single-family homes and multi-unit complexes. Residential structures account for approximately 90% of the same structures added to the floodplain in both the 20 cm and 40 cm scenarios (Figure 35).

With the addition of so many residential structures to the 1%-annual-chance floodplain, the State of North Carolina will see a corresponding increase in the number of flood insurance policies written for those structures (if not already in force). At the same time, new policies will also be needed for structures that fall within the other documented occupancy classes, shown in Table 10.

- **For 20 cm of SLR -** an additional 11,267 residential structures will be added to the 1%-annual-chance floodplain, as will by 377 commercial structures and 493 agricultural structures.
- **For 40 cm of SLR –** an additional 24,331 residential structures will be added to the 1%-annual-chance floodplain, along with 1,011 commercial structures and 854 agricultural structures.

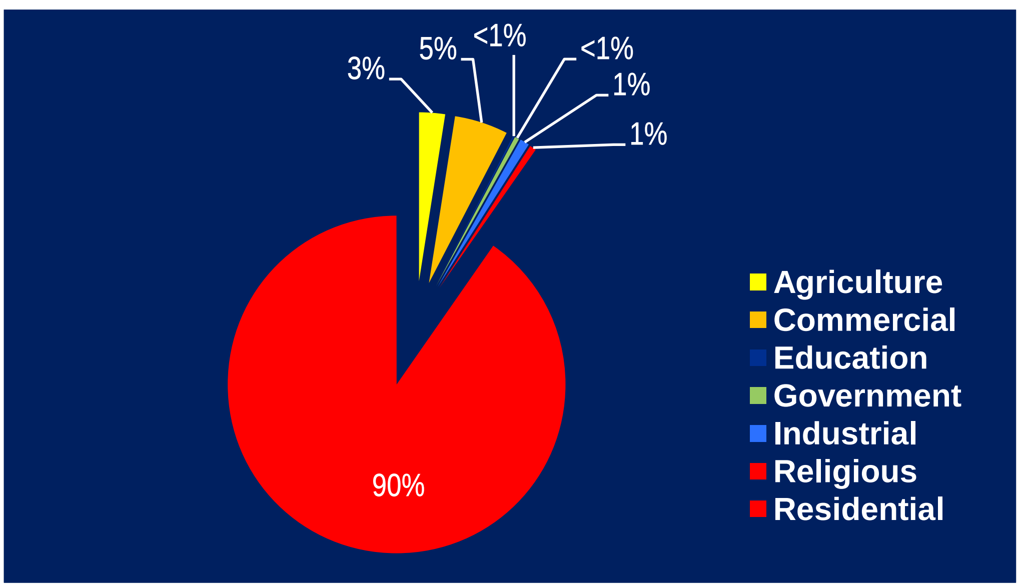


FIGURE 35. APPROXIMATE PERCENTAGE OF STRUCTURES BY OCCUPANCY TYPE AFFECTED BY UP TO 40 CM OF SLR.

TABLE 9. SUMMARY TABLE OF NUMBER OF BUILDINGS NEWLY ADDED TO THE 10%- AND 1%-ANNUAL-CHANCE FLOODPLAINS FOR THE 20 CM AND 40 CM SCENARIO.

	10% Annual Chance Flood Event					10% Annual Chance Flood Event				
County	0 cm Total Buildings	20 cm Additional Buildings	20 cm % Change	40 cm Additional Buildings	40 cm % Change	0 cm Total Buildings	20 cm Increase in Additional Buildings	20 cm % Change	40 cm Increase in Additional Buildings	40 cm % Change
Beaufort	20	166	830%	507	2,535%	1,435	1,614	112%	2,533	177%
Bertie	1	4	400%	8	800%	22	15	68%	34	155%
Brunswick	258	70	27%	283	110%	1,173	490	42%	1,253	107%
Camden	6	15	250%	70	1,167%	205	188	92%	454	221%
Carteret	1,507	1,349	90%	3,193	212%	7,964	2,275	29%	4,680	59%
Chowan	3	7	233%	27	900%	64	38	59%	94	147%
Craven	100	159	159%	533	533%	3,264	950	29%	2,156	66%
Currituck	28	156	557%	445	1,589%	794	445	56%	1,182	149%
Dare	88	219	249%	722	820%	1,244	838	67%	2,089	168%
Gates	1	0	0%	5	500%	17	6	35%	18	106%
Hertford	12	24	200%	39	325%	69	10	14%	22	32%
Hyde	516	273	53%	1,044	202%	2,250	817	36%	1,614	72%
New Hanover	738	348	47%	580	79%	3,256	917	28%	2,047	63%
Onslow	783	271	35%	583	74%	2,610	477	18%	1,101	42%
Pamlico	109	184	169%	524	481%	1,297	552	43%	1,281	99%
Pasquotank	47	79	168%	294	626%	735	580	79%	1,548	211%
Pender	635	192	30%	450	71%	2,180	332	15%	807	37%
Perquimans	1	3	300%	6	600%	15	20	133%	64	427%
Tyrrell	75	183	244%	632	843%	1,161	604	52%	1,130	97%
Washington	2	3	150%	25	1,250%	70	108	154%	260	371%
Total	4,930	3,705	75%	9,970	202%	29,825	11,276	38%	24,367	82%

TABLE 10. NUMBER OF STRUCTURES ADDED TO THE 1%-ANNUAL-CHANCE FLOODPLAIN BASED ON 20 CM AND 40 CM OF SLR

Occupancy Type	0 cm Scenario	20-cm Scenario		40-cm Scenario	
	Total Structures Impacted	Increase in Structures Impacted	Percent Increase	Increase in Structures Impacted	Percent Increase
Agriculture	638	377	59%	854	134%
Commercial	1,614	493	31%	1,011	63%
Education	46	13	28%	34	74%
Government	132	43	33%	94	71%
Industrial	282	81	29%	162	57%
Religious	179	79	44%	160	89%
Residential	26,903	10,181	38%	22,016	82%
Total	29,794	11,267	38%	24,331	82%

From a monetary loss standpoint, ALE by occupancy type is presented in Table 11. Not surprisingly, residential structures experience the biggest increase in losses. Commercial structures are a distant second. Nonetheless, residential losses do not necessarily represent the largest percent of change from today's conditions.

- **For 20-cm of SLR -** Residential ALE increases 57% while commercial ALE increases 26%, representing $63 million and $10.5 million in increases, respectively. All other occupancy increases are less than $2 million, yet these occupancy types increase at least 47% increase over baseline conditions.
- **For 40-cm of SLR -** While residential and commercial ALE more than double, other occupancy types see ALE increases in excess of 100%. Total ALE for all sectors more than doubles from baseline conditions.

TABLE 11. CHANGES IN ALE BY OCCUPANCY TYPE FOR THE 20 COASTAL COUNTIES.

Occupancy Type	0 cm Scenario	20 cm Scenario		40 cm Scenario	
	Total ($ Million)	Total Increase ($ Million)	Percent Increase	Total Increase ($ Million)	Percent Increase
Agriculture	$0.54	$0.42	78%	$1.25	232%
Commercial	$18.25	$10.52	58%	$26.38	145%
Education	$0.63	$0.57	90%	$1.65	262%
Government	$2.10	$1.54	73%	$4.35	208%
Industrial	$2.62	$1.23	47%	$3.56	136%
Religious	$1.71	$1.47	86%	$3.90	227%
Residential	$112.22	$63.47	57%	$148.03	132%
Total	$138.06	$79.21	57%	$189.11	137%

4.2.2 How Did the Modeled Losses Evolve?

Part of the SLRIS's goal was to assess the potential impacts of SLR on increasing population and changing future land use. As a result, an assessment was made of areas most likely to be developed in the future and the approximate losses that might be incurred to structures built into those areas. North Carolina provided, through the IHRM project, a dataset known as "ghost structures." These structures, which are placed on empty parcels throughout the State, take on the attributes of already constructed buildings that are located nearby. As a result, an empty parcel in an area with predominantly residential buildings would also be assigned a residential classification, with similar building construction attributes, replacement values, and other associated attributes.

This ghost buildings dataset was then combined with an analysis of future population projections and associated development. Ghost buildings that intersect this future development area were "turned on" for two different time points, the years 2050 and 2100. These years were selected because of the study team's relative confidence in the amount of SLR that could be expected by these time slices, based on observed historical trends across the State, with 20 cm SLR modeled for 2050, and 40 cm SLR modeled for 2100.

The ghost buildings that intersected potential areas of future development were run through the iRISK database to develop loss estimates. The results are presented in Table 12. It is important to note that for this modeling effort, all future development is assumed to be constructed according to existing floodplain management standards (i.e., first floor elevation at or above the Base Flood Elevation (BFE)).

- **By 2050 –** the ALE is expected to increase to $439 million.
- **By 2100 –** the ALE is expected to increase to $581 million.

TABLE 12. EVOLUTION OF LOSSES DUE TO INCREASES IN FUTURE DEVELOPMENT IN NORTH CAROLINA'S COASTAL COUNTIES.

Loss Type	Building Stock	Losses (Million $) by Scenario	
		20 cm 2050	40 cm 2100
Structures	Existing	$1,525	$3,097
	Predicted	$1,691	$1,105
	Combined	$3,216	$4,202
	Percent Increase	111%	36%
Contents	Existing	$640	$1,337
	Predicted	$678	$421
	Combined	$1,318	$1,758
	Percent Increase	106%	31%
ALE	Existing	$123	$242
	Predicted	$138	$72
	Combined	$261	$314
	Percent Increase	112%	30%

4.2.3 How Were They Assessed?

The SLRIS used a set of computer-based tools called iRISK to calculate and communicate the impact associated with coastal hazards in North Carolina. The expectation is that when provided with appropriate information about hazard impact and impact reduction or mitigation options, emergency responders, public decision makers, business owners, and citizens of North Carolina can make more informed decisions about their risks, strengthening their resilience to natural hazards. The iRISK Project, developed for the North Carolina IHRM program, includes the design of communication tools that will be used by a variety of audiences including property owners, emergency management responders, floodplain managers, business owners, engineers, and public decision makers and planners. The types of tools developed for the iRISK project range from guidance on mitigation strategies that homeowners can use to analytical models for preparers of county and/or jurisdictional mitigation plans. Additionally, the effectiveness of iRISK will strongly depend on the content of the iRISK database. When fully completed, the iRISK database will provide access to a comprehensive statewide dataset for hazard and risk communication in North Carolina. The iRISK Project draws data from a number of public sources; however, the synthesis and analysis of that data will provide the greatest value for the users.

Specifically, SLRIS makes use of the iRISK database's ability to house building attribute information and evaluate it against hazard information provided through other analyses, such as depth of flooding. Using these inputs, the database looks up the appropriate depth-damage function (DDF) and calculates a loss for that structure. These losses were then aggregated across the 20-county study area for a variety of geographic reporting levels (census block, damage summary grid, political area, county, and north/south geologic province). More detailed information on iRISK is available in the SLRIS **Impact Assessment Report**.

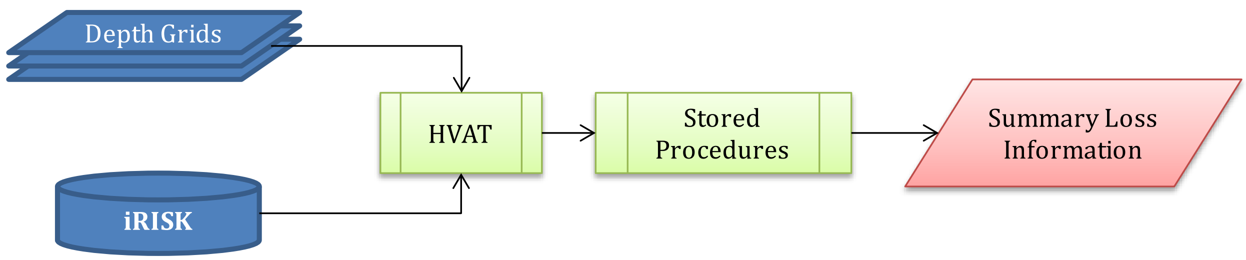


FIGURE 36. GENERALIZED IRISK IMPACT ASSESSMENT METHODOLOGY*.

*The hazard value assignment tool uses the output of the SLRIS hazard assessment combined with the structure and damage function information stored within iRisk to create summary loss information for over 500,000 structures in the 20-county study area.

4.2.4 How Does Future Land Use Change Potential Impacts?

The southern counties generally are expected to undergo the greatest change in population, and that change primarily represents an increase over today's conditions. Initial population projections were acquired through several sources, including the North Carolina Office of State Budget and Management, which is responsible for population projections in the State. With just over 1,000,000 current residents in the 20-county study area, approximately 500,000 additional persons are expected to be added over the next century (Table 13).

- **By the year 2050**, the increase in population is expected to yield a 74% increase in the amount of developed land.
- **By the year 2100**, population increase will have resulted in a 95% increase in developed land, to nearly 510,000 acres.
- The populations of several counties are expected to remain steady or decrease slightly as a result of outward migration and aging of the general population. Further changes can also be expected depending upon other socioeconomic factors such as access to jobs, changes in birth rates, or cost of living.

TABLE 13. PROJECTED CHANGES IN POPULATION AND CHANGE IN DEVELOPED ACREAGE FOR PRESENT DAY, 2050, AND 2100*.

County	Present Day - Baseline		2050 Projection		2100 Projection	
	Population	Developed Acres	Pop. Change	Projected Developed Acreage	Pop. Change from Present Day	Projected Developed Acreage
Beaufort	47,783	13,702	6,722	16,424	9,056	17,192
Bertie	21,237	5,867	-638	6,033	-619	6,036
Brunswick	108,071	39,341	52,955	97,072	96,716	118,931
Camden	10,006	900	-186	953	620	971
Carteret	66,711	24,915	20,914	31,309	25,685	32,542
Chowan	14,763	3,589	897	3,714	1,187	3,778
Craven	104,170	29,032	16,051	61,337	19,454	62,843
Currituck	23,652	5,031	478	5,333	1,762	5,467
Dare	34,015	13,249	13,778	14,160	35,816	15,710
Gates	12,192	1,950	-1,185	2,460	-744	2,555
Hertford	24,755	6,774	1,066	7,184	2,237	7,325
Hyde	5,800	4,652	81	4,847	119	4,853
New Hanover	203,254	46,369	103,837	56,342	191,973	63,764
Onslow	186,866	35,229	90,489	118,447	115,359	135,042
Pamlico	13,116	2,473	701	2,773	926	2,793
Pasquotank	40,643	6,355	1,113	6,793	1,188	6,800
Pender	52,452	13,029	28,409	16,003	62,097	19,255
Perquimans	13,490	2,057	1,883	3,399	2,764	3,733
Tyrrell	4,403	2,055	-39	2,157	-20	2,159
Washington	13,193	4,648	-728	5,037	-634	5,049
Total:	1,000,572	261,217	336,597	461,779	564,943	516,797

*All changes are presented in terms of change from present-day conditions

4.2.5 How Was Future Land Use Assessed?

Population projections were ascertained through the Office of State Budget and Management - State Demographics Office. The projected populations are based on the State's 2025 projections and county-level projections from the U.S Environmental Protection Agency (EPA) Integrated Climate and Land-Use Scenarios (ICLUS) model average of the SRES scenarios A1, B1, B2, and baseline scenarios for 2050, 2075, and 2100 (EPA, 2009). Several counties have experienced declining populations in recent years; however, it is unrealistic to assume that zero development will occur for a given future scenario. Therefore, when population declines from the previously projected scenario, the most recent time interval from the State's observed county population was examined and used to calculate the change in population for the most recent population growth.

Projected future developed land was determined from the estimate of the new population and the required new acres per new population, wherein new persons will generate "*x*" amount of new acres. Change in land use from 1996 to 2006 was determined using the NOAA Coastal Change Analysis Program (CCAP) data and the number of new persons or population growth from 1996 to 2006 was obtained from U.S. Census data. The projected developed acres were then allocated as residential and nonresidential development.

Allocation of new developed acres represents the conversion from non-developed land to developed status. The spatial allocation method is a hybrid approach, developed for this project that combines results from the Strategic Lands Inventory (SLI) land suitability analysis, with a rule based algorithm termed the Land Allocation Algorithm, a tool developed for use in GIS. This tool, and the specific methodology it employs, is further discussed in the SLRIS **Impact Assessment Report**.

4.3 What are the Impacts to Critical Infrastructure?

Critical infrastructure provides the essential services that underpin American society. Continuously-functioning and resilient critical infrastructure – including assets, networks, and systems – is vital to public confidence and the Nation's safety, prosperity, and well-being. As a result, critical infrastructure must be secure and able to withstand and rapidly recover from all hazards, including those exacerbated by rising sea levels. While most critical infrastructure owners and operators are uniquely positioned to manage risks to their individual operations and assets, an understanding of the impacts of SLR on critical infrastructure is important for a total understanding of SLR's impact on the North Carolina coast. Knowledge of these impacts is critical for the development of effective strategies to make this infrastructure more secure and resilient.

The Critical Infrastructure and other Key Resources (CIKR) receptor was analyzed on a structure-by-structure basis in the study. As a result, the information presented in this section represents a subset of all other structures in the study. As with those analyses, the iRISK tool was used to evaluate potential losses.

The following types of infrastructure were analyzed:

- **Agriculture and Food** – including farms, restaurants, and registered food manufacturing, processing, and storage facilities.
- **Banking and Finance** – financial institutions such as banks, credit unions, and brokerages.
- **Commercial Facilities** – a broad sector, this includes a number of subsectors including public assembly areas, sports leagues, gaming, lodging, outdoor events, entertainment venues, real estate such as office buildings and condominiums, and retail.
- **Education** – facilities including local schools, colleges, and universities.
- **Energy** – facilities used to generate or transmit power, such as power plants, substations, transformers, and more. This is a particularly critical sector because it serves to enable almost all other CIKR types.
- **Government** – a wide variety of buildings owned or leased by Federal, State, local, or tribal governments. The buildings facilitate commercial transactions, recreation, and public safety, among other functions.
- **Healthcare and Public Health** – professional medical facilities, including hospitals, doctor and dentist offices, and other specialties.
- **Manufacturing** – crucial to economic prosperity, this sector includes metal, machinery, electrical, appliance, component, and transportation equipment manufacturing.

- **Nuclear** – this sector includes nuclear power plants, non-power nuclear reactors used for research, manufacturers of nuclear components, and nuclear support facilities.
- **Transportation** – this sector covers a wide range of transportation modes used to move both people and commodities throughout the country. Subsets of this category include aviation facilities, highway maintenance and administration, ports, mass transit facilities, pipeline and pumping facilities, railroads, and postal services. For this study, this sector does NOT include linear roadway, railway, or pipeline infrastructure (such as miles of rail line or miles of pipeline).
- **Water** – facilities that handle water and wastewater treatment and distribution, such as treatment facilities, pumping stations, etc.

The results of the CIKR analysis (Table 14) show that for structural and contents losses:

- **For 20 cm of SLR -** total estimated losses will increase by 55% for the 1%-annual-chance flood.
- **For 40 cm of SLR -** total estimated losses will increase by 129% for the 1%-annual-chance flood.

Taking into account the susceptibility of lower lying areas to more frequent inundation by the 10%-annual-chance flood, however, the increases are, from a percentage change perspective, much higher for each scenario than for the 1%-annual-chance flood. The results show for the 10% annual chance flood that:

- **For 20 cm of SLR –** total estimated losses will increase by 115%.
- **For 40 cm of SLR –** total estimated losses will increase by 339%.

The most heavily impacted sectors however, from a structural and contents loss perspective, will be commercial, manufacturing, and transportation for the 1%-annual-chance flood, while in terms of a 10%-annual-chance flood, commercial, transportation, and government facilities are most heavily impacted.

TABLE 14. TOTAL ESTIMATED LOSS ESTIMATES* (STRUCTURAL AND CONTENTS) FOR THE 10%- AND 1%-ANNUAL-CHANCE FLOODS AS A RESULT OF SLR FOR THE 20 COASTAL COUNTIES FOR CRITICAL INFRASTRUCTURE AND KEY RESOURCES SECTORS.

Sector	0 cm - Baseline		20 cm		40 cm	
	10-year Event Total	100-year Event Total	10-year Event Increases	100-year Event Increases	10-Year Event Increases	100-year Event Increases
Agriculture and Food Distribution	$0.73	$10.87	$1.29	$9.46	$4.05	$27.36
Banking and Finance	$0.13	$4.87	$0.30	$1.45	$0.74	$5.60
Commercial Facilities	$31.25	$438.43	$35.28	$237.38	$94.97	$504.49
Education	$0.46	$18.79	$0.45	27.38	$2.54	$58.02
Energy	$0.12	$2.48	$0.06	$1.50	$0.59	$9.21
Government	$1.49	$60.74	$3.38	$41.04	$10.22	$113.70
Healthcare and Public Health	$0.51	$35.41	$2.27	$10.60	$6.87	$28.88
Manufacturing	$4.33	$49.22	$2.30	$28.40	$9.31	$73.99
Nuclear	$0.00	$0.21	$ -	$0.27	$ -	$1.03
Transportation	$3.68	$109.28	$3.19	$41.19	$14.62	$114.30
Water	$0.02	$7.15	$0.41	$5.33	$0.90	$18.70
Total	**$42.74**	**$737.76**	**$48.94**	**$403.99**	**$144.88**	**$955.26**

*Values in millions of dollars

4.4 What are the Impacts to Transportation?

Transportation data, representing most U.S., State, and local roads, was evaluated against the outputs of hazard assessment to determine the overall impact of increased sea level and flooding.

4.4.1 How Much Exposure is there to Inundation and Flooding?

Throughout the coastal counties, there are approximately 15,855 miles of roadways that were evaluated for this study. In total, just over 3,000 of those miles are affected by the effects of SLR.

In terms of permanent loss of roadways due to inundation (Table 15):

- **For 20 cm of SLR**: A total of 25 miles of roads will be inundated; however, no county has more than a 5-mile loss of roads. Moreover, the majority of counties have less than 1 mile of impacted roads.
- **For 40 cm of SLR**: The total road loss jumps to 153 miles. The majority of counties, however, have less than 5 miles of permanently inundated roads in the 40-cm scenario.
- Barrier island counties are prone to the most permanently inundated roads in both the 20 cm and 40 cm SLR scenarios (Figure 37).

TABLE 15. OVERVIEW OF ROADS LOST TO PERMAMENT INUNDATION AS A RESULT OF SLR.

All Roads Permanently Inundated		
County	20 cm Scenario	40 cm Scenario
	Total Change In Miles	Total Change In Miles
Beaufort	1.2	9.8
Bertie	0.1	0.2
Brunswick	3.3	8.8
Camden	1.2	13.3
Carteret	3.1	18.3
Chowan	0.0	0.4
Craven	0.6	1.2
Currituck	0.4	4.7
Dare	4.4	30.7
Gates	0.0	0.6
Hertford	0.2	0.8
Hyde	0.1	22.7
New Hanover	3.2	8.2
Onslow	0.9	3.3
Pamlico	0.6	5.4
Pasquotank	0.8	4.3
Pender	0.8	2.6
Perquimans	0.1	0.4
Tyrrell	3.6	16.3
Washington	0.3	1.0
Total	25	153

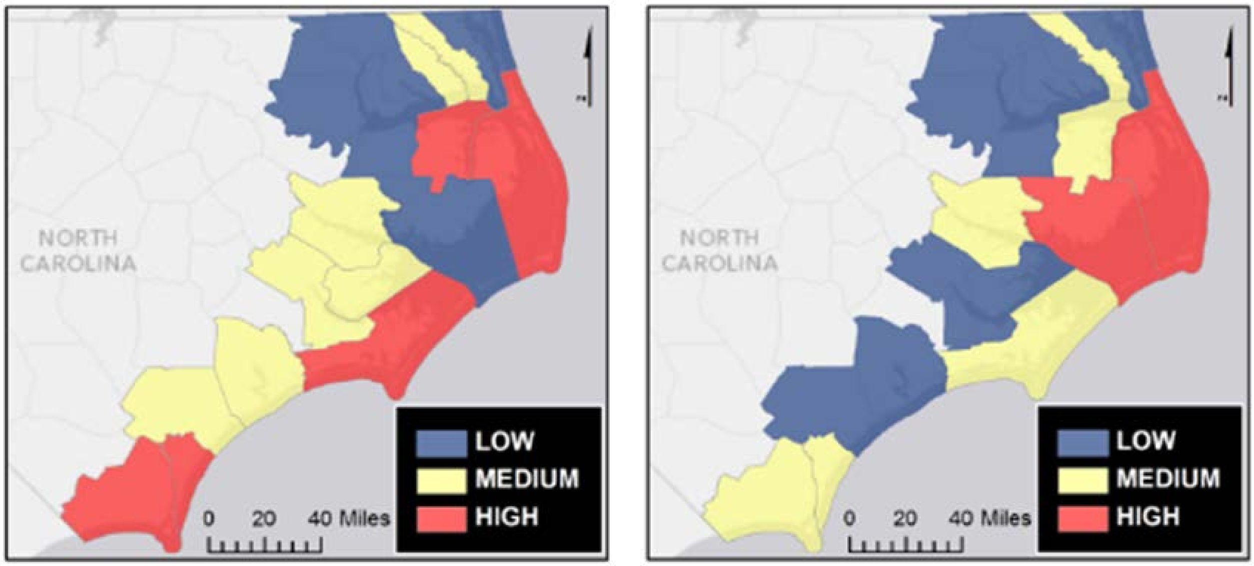


FIGURE 37. RELATIVE INCREASES IN THE NUMBER OF ROADS SUBJECT TO PERMANENT INUNDATION AS COMPARED TO THE BASELINE CONDITION DUE TO SLR FOR 20 CM OF SLR (LEFT) AND 40 CM OF SLR (RIGHT).

As roads are lost to inundation with increasing SLR, other roads subject to periodic flooding will experience changes in the flood depths associated with those floods. The SLRIS study utilized a 4-foot resolution DEM that was evaluated against the modeled 1%-annual-chance flood for each scenario. This created a depth grid for the entire road network, which was then classified according to a range of depths. These depths correspond with the ability of the traveling public and emergency equipment to traverse these flood depths. The categories include:

- Less than 0.5 feet – Shallow Flooding
- 0.6 foot to 1.0 foot – Difficult for Pedestrians
- 1.1 foot to 2.0 feet – Cars and Light Emergency Management (EM) Vehicles May Become Displaced
- 2.1 feet to 4.0 feet – Prohibits Passage of Most Large Emergency Vehicles
- Over 4.0 feet – Impassible

The results of this analysis indicate that coastal North Carolina will see significant increases in the number of roads with flood impacts. These results are presented in Table 16.

- **For 20 cm of SLR:** A total of 404.6 additional miles of roadway will be inundated by the 1%-annual-chance flood. The largest increase is in the number of roads where cars and light EM vehicles might be displaced.
- **For 40 cm of SLR:** The total number of roads impacted increases to 831.3 miles, more than double the number of roads impacted by the 20 cm scenario.

TABLE 16. SUMMARY OF ROAD MILES IMPACTS BY 1%-ANNUAL-CHANCE FLOOD BY FLOODING CATEGORIES. MILEAGES INCLUDE ALL ANALYZED ROADS WITHIN THE 20-COUNTY STUDY AREA.

Parameters	0 cm – Baseline	20 cm		40 cm	
	Total Miles	Total Change in Miles	New Total	Total Change in Miles	New Total
Shallow Flooding	892.4	-54.8	837.6	-101.2	791.2
Difficult for Pedestrians	436.7	19.7	456.4	-6.5	430.2
Cars/Light EM Vehicles Might Become Displaced	512.6	208.1	702.7	306.9	819.5
Passage of Most Large Emergency Vehicles Blocked	290.0	187.0	477	511.2	801.2
Impassible	105.0	44.4	149.4	120.8	225.8
Total Miles Inundated	2,236.7	404.6	2,641.3	831.3	3,068

4.4.2 What are the Impacts to Evacuation Routes?

Throughout the coastal Southeast, hurricanes, tropical storms, and other disturbances often leave lasting images of miles of traffic backups along hurricane routes as residents and visitors flee to the relative safety of the interior. With SLR increases, these evacuations may become more difficult as low-lying evacuation routes become subject to flooding and permanent inundation.

In terms of permanent inundation, the initial impact on evacuation routes is negligible, as nearly all of the coastal counties have less than 1.0 mile of permanently inundated evacuation routes in the 20 cm scenario. However, in the 40 cm scenario, most of these counties have more than 1.0 mile of evacuation routes subject to inundation, but no county has more than 5.0 miles.

- **For 20 cm of SLR:** The total road mileage inundated increases by 2.7 miles, or 12% from the existing condition.
- **For 40 cm of SLR:** The total road mileage inundated increases by 12.9 miles, or 56% from the existing condition.

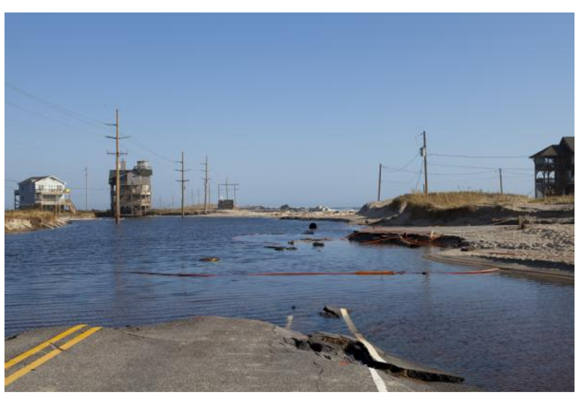


FIGURE 38. HURRICANE IRENE WASHED OUT STATE HIGHWAY 12 IN SEVERAL LOCATIONS ALONG THE OUTER BANKS.

TABLE 17. SUMMARY OF EVACUATION ROUTES PERMANENTLY INUNDATED BY SLR BY SCENARIO FOR EACH OF THE 20 STUDY COUNTIES. CHANGES ARE PRESENTED AS AN INCREASE FROM PRESENT-DAY CONDITIONS.

County	20 cm		40 cm	
	Total Change In Miles	Percent Change	Total Change In Miles	Percent Change
Beaufort	0.1	8%	0.3	25%
Bertie	0.0	0%	0.0	0%
Brunswick	0.3	23%	0.8	62%
Camden	0.0	0%	0.0	0%
Carteret	0.8	21%	4.6	121%
Chowan	0.0	0%	0.0	0%
Craven	0.3	27%	0.5	45%
Currituck	0.0	0%	0.3	150%
Dare	0.3	7%	1.2	29%
Gates	0.0	0%	0.0	0%
Hertford	0.1	100%	0.1	100%
Hyde	0.1	50%	1.7	850%
New Hanover	0.1	11%	0.8	89%
Onslow	0.1	9%	0.3	27%
Pamlico	0.0	0%	0.5	250%
Pasquotank	0.0	0%	0.5	250%
Pender	0.1	17%	0.4	67%
Perquimans	0.0	0%	0.1	8%
Tyrrell	0.3	18%	1.1	65%
Washington	0.0	0%	0.0	0%
Total	2.7	12%	12.9	56%

In terms of evacuation route flooding, most counties in the 20 cm scenario have at least a 20% increase in the mileage of roads impacted by 1%-annual-chance flooding based on the existing condition 20 cm. For the 40 cm scenario, at least a 60% increase occurs. Most of these increases occur in the northern coastal and barrier island counties (Figure 39).

- **For 20 cm of SLR:** Total roads flooded by the 1%-annual-chance storm increases by 80 miles, or 31% from the existing condition. All counties have less than 1.5 miles of impacted routes.
- **For 40 cm of SLR:** Total roads flooded by the 1%-annual-chance storm increases by 153 miles, or 61% from the existing condition.

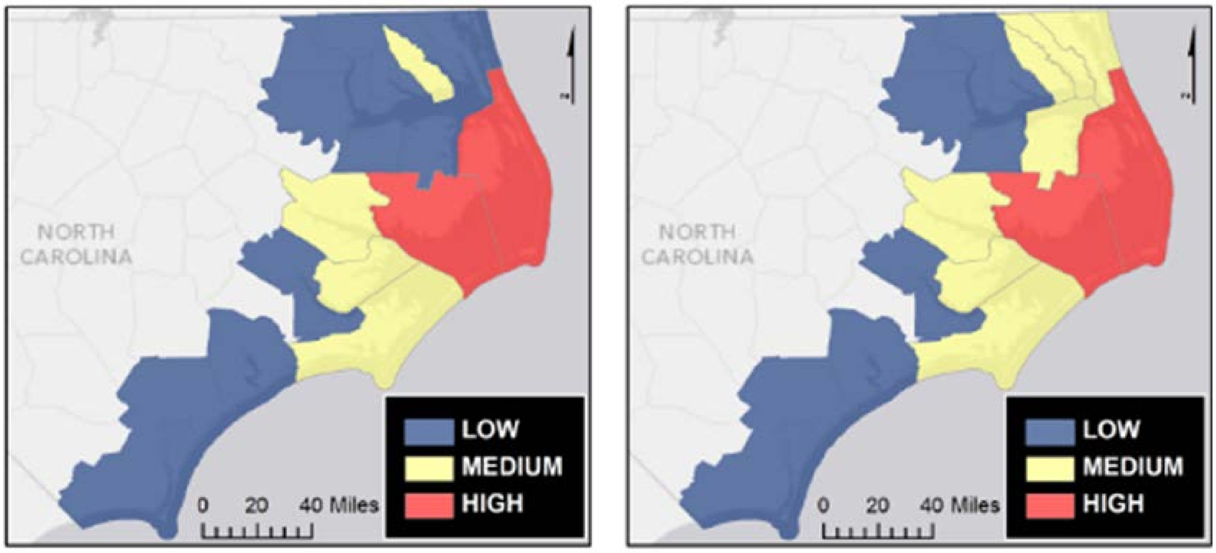


FIGURE 39. RELATIVE IMPACT OF SLR ON EVACUATION ROUTES FLOODED BY THE 1%-ANNUAL-CHANCE STORM FOR THE 20 CM SCENARIO (LEFT) AND THE 40 CM SCENARIO (RIGHT).

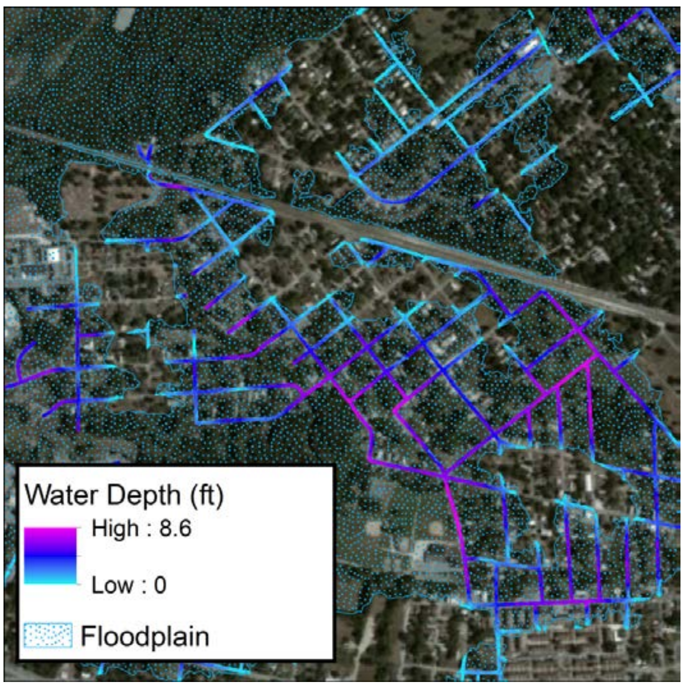


FIGURE 40. EXAMPLE ROADWAY DEPTH GRID USED FOR EVALUATING TRANSPORTATION IMPACTS IN THE SLRIS.

4.4.3 How Were the Impacts to Transportation Assessed?

The transportation impacts were assessed by first creating roadway depth grids by comparing the road DEMs provided by the NC GTMO with the water surface rasters developed in the hazard assessment portion of the study. The road DEMs were initially received as 1-foot resolution rasters, but due to constraints on the volume and size of datasets being produced, the DEMs were resampled to 4-foot resolution and only evaluated for the 1%-annual-chance flooding scenario. All MHHW evaluations were performed by intersecting the roadway lines with the MHHW polygons.

An ArcGIS ModelBuilder tool was created to automate the process and create depth grids for each scenario. This tool allows a user to select the appropriate county's hazard products database, specify a county road DEM, and export the completed depth grids automatically. An example of this depth grid is shown in Figure 40.

In order to create an impact assessment with meaningful units that also accounted for variability in transportation line width, it was necessary to design a process that married linear transport representation to polygons representing their surface for those given lengths. Road lines for all 20 counties within the area of interest were merged into a single feature class to allow points to be constructed at a set interval of 500 feet. (The merge is a side effect of tool limitations on ESRI's ArcMap suite). Each line feature was then split at all point features, resulting in a dataset composed, to the greatest extent practicable, of 500-foot road segment lines.

The road flooding depth rasters were then converted to polygons, which were then evaluated against the roadway line segments using an automated script in GIS. The tool was run using the 1%-annual-chance frequency for all six scenarios for each county. Results of the tool were joined to a table that held the information from the road segment line work, including segment length and evacuation route indication. This table can be queried for a number of different geographies, evacuation routes, and flooding impacts (MHHW or 1%-annual-chance flood) and is used to present the results in this section.

4.5 Societal Impacts

4.5.1 What is the Impact to Vulnerable Populations?

Depending on the source, social vulnerability is defined in one of several ways. Some social scientists contend that social vulnerability is a pre-existing condition independent of a hazard or disaster occurring. Others provide a much broader definition that assumes some increase in vulnerability as a result of a hazard or disaster event occurring. Although en a number of indices have been developed in recent times that attempt to quantify social vulnerability, there is not yet consensus on the primary factors that influence it or a method to assess it (i.e., Tapsell et al., 2010, California Department of Public Health, 2012).

> ***Vulnerable Population Characteristics include*** *Age, Housing Occupancy, Housing Tenure, Employment, and those living below Poverty Level.*

Demographic characteristics most often cited as indicating a high social vulnerability includes children, elderly, racial minorities, institutionalized, housing occupancy, housing tenure, employment, and the economically disadvantaged (Moser, 2012). The characteristics shown in Table 18 were used to determine the baseline population for comparison of vulnerability to SLR, specifically, the *2010 U.S. Census Profile of General Population and Housing Characteristics* (U.S. Census Bureau, 2010). The table shows the total demographic values for each county within the study area. Exposure and trends for each of the characteristics are further described below.

As part of this study's land use and economic modeling task, total population was projected at a county level through 2100. Projecting other future demographic information, however, was not within the scope of this analysis. As a result, only current population characteristics are discussed. Table 19 summarizes the census tract analysis at the county level for current conditions, as well as the 20 cm and 40 cm rise in sea level.

- **Total Population.** The study area of 20 counties contains nearly 1 million people (Table 18), of which 20.5 percent of the population resides in New Hanover County, followed by 18 percent of the total population in Onslow County. Camden, Hyde, and Tyrrell Counties each have populations of less than 10,000.
- **Populations under age 5.** Research shows that children are more vulnerable than adults to the impacts of disaster (United Nations Office for Disaster Risk Reduction, 2010). Children under 5 years of age make up 6.5 percent of the total study area population. Onslow County represents 26.3 percent of the under-5-year-old total population for the study region, 9.6 percent of the county's total population, and 1.7 percent of the study area population. New Hanover County represents 18.1 percent of the under-5-year-old total population for the study region, 5.8 percent of the county's total population, and 1.2 percent of the total population for the study area.
- **Population over 65.** Elderly people account for 14.8 percent of the total study area population. Over 20 percent of the county population in Brunswick, Perquimans, and Pamlico Counties is comprised of people over 65 years old. New Hanover County represents 19.2 percent of the elderly total population and 2.8 percent of the total population for the study area.
- **Population Living in Group Quarters.** People living in group quarters make up 7.2 percent of the total study area population. Onslow County accounts for 49.1 percent of the total group-quarters population for the study area, and 19.5 percent of the county's total population.
- **Renter-Occupied Housing Units.** One-third of the occupied units in the study area are classified as renter-occupied units. Onslow and New Hanover Counties have the highest number of renter-occupied units based on their county housing unit totals.
- **Unemployment Rate.** U.S. Department of Labor Bureau of Labor Statistics data was used to calculate a 5-year average unemployment rate. Only available at the county level, this data should be used as a consideration for vulnerable areas within the study region. Washington County has the highest 5-year average unemployment rate at 10.18 percent.
- **Population below Poverty Level.** Poverty is measured by comparing household income to the poverty threshold for a household of a given size. The threshold is adjusted yearly to account for cost-of-living changes. For example, the 2012 one-person household poverty threshold was $11,722, and for a two-person household it was $14,960 (U.S. Census Bureau, 2013). Nearly 10 percent of the study area population is within the poverty threshold. One-third of the population in the poverty level is located within New Hanover, Onslow, and Brunswick Counties.

Tyrrell and Hyde Counties have the largest percent of total population (>70 percent) and individual population characteristics indicative of vulnerable persons at risk. This is true under present-day conditions as well as future sea levels modeled for this study. This is primarily driven by the extent of SLR inundation relative to the total land area of each county.

Over 70 percent of the land area of Dare, Tyrrell, and Hyde Counties is potentially inundated under current conditions in a 1%-annual-chance flood. Dare and Tyrrell Counties are projected to experience inundation of over 80 percent of the land area during a 1%-annual-chance flood in the case of a 20- or 40 cm rise in sea level.

It is estimated that, at a minimum, 151,997 socially vulnerable people within the SLRIS area will be impacted by the baseline 1%-annual-chance flood scenario; 167,289 by the 20 cm scenario; and

184,417 by the 40 cm scenario. Of the characteristics included in this analysis, populations within renter-occupied housing units make up a large percentage of the total vulnerable population and as a result have a high at-risk population. Some of the characteristics analyzed are not mutually exclusive; for example, a person could be over 65 years old, living in a rental property, and be below the poverty level.

TABLE 18. 2010 US CENSUS DEMOGRAPHIC DATA FOR THE SLRIS STUDY COUNTIES.

2010 US Census Demographic Data, Unemployment Rate, and Poverty							
County Name	Total Population	Under 5 years	Over 65 years	Group Quarters	Renter Population	Unemployment 5-year Average*	Population below Poverty**
Beaufort	47,759	2,781	8,782	632	13,524	9.54	4,253
Bertie	21,282	1,176	3,656	1,406	5,441	9.88	2,200
Brunswick	107,431	5,828	23,026	897	26,327	8.98	13,158
Camden	9,980	595	1,283	34	1,700	6.9	679
Carteret	66,469	3,261	12,659	1,145	18,310	7.36	9,518
Chowan	14,793	879	2,908	302	4,504	9.94	1,000
Craven	103,505	7,681	15,810	8,138	34,615	8.54	8,685
Currituck	23,547	1,329	3,041	144	4,587	5.68	2,676
Dare	33,920	1,839	5,167	171	10,407	8.8	3,307
Gates	12,197	695	1,831	61	2,228	6.58	1,040
Hertford	24,669	1,415	3,898	3,033	7,376	8.64	2,071
Hyde	5,810	293	875	853	1,354	8.12	943
New Hanover	202,667	11,724	28,092	11,559	74,611	7.64	18,603
Onslow	177,772	16,991	13,262	34,723	67,951	7.28	14,386
Pamlico	13,144	599	2,857	717	2,757	8.22	1,452
Pasquotank	40,661	2,693	5,513	4,902	12,896	8.64	3,877
Pender	52,217	3,064	7,886	1,148	12,143	8.94	6,335
Perquimans	13,453	745	2,887	96	3,343	8.56	1,266
Tyrrell	4,407	233	742	638	1,066	9.14	361
Washington	13,228	857	2,414	174	4,097	10.18	1,237
Total	988,911	64,678	146,589	70,773	309,237	8.38	97,047

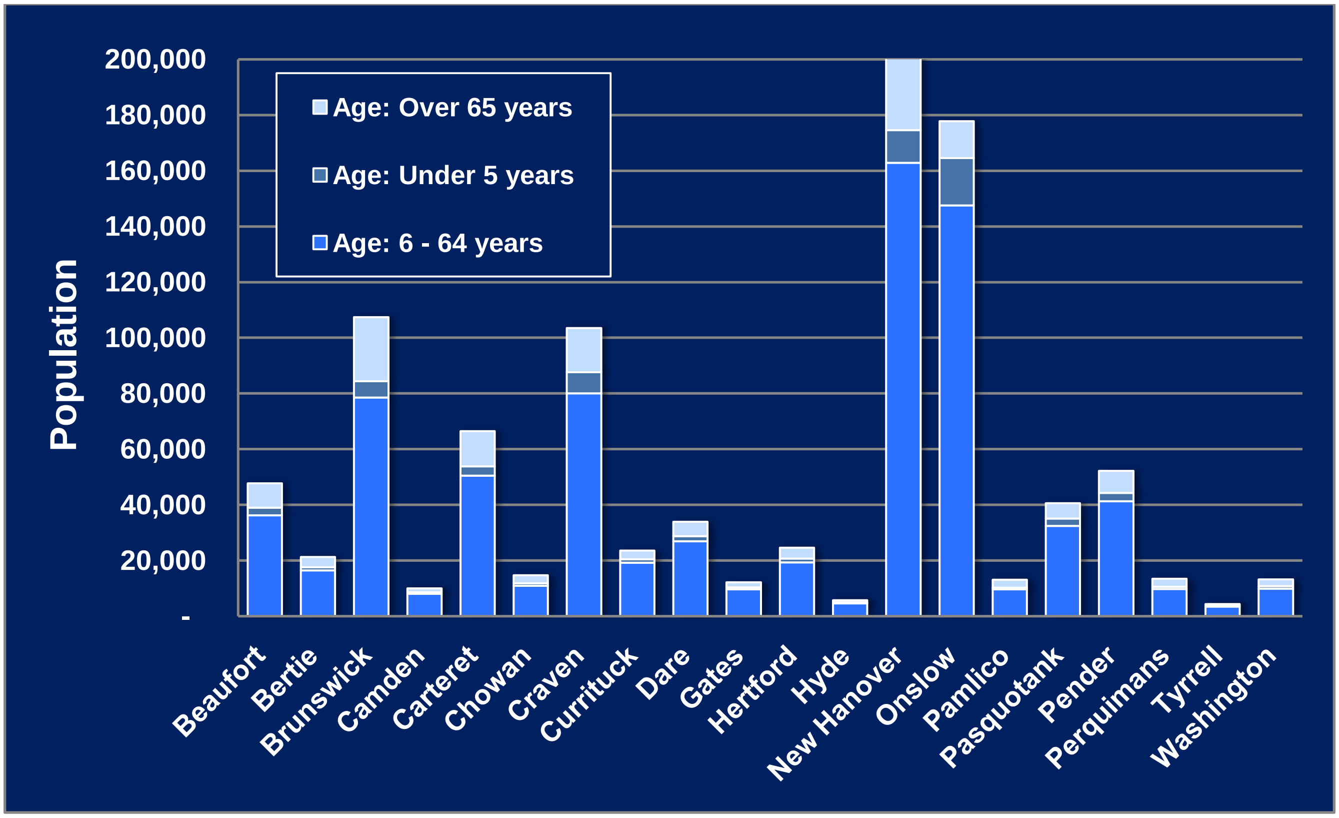


FIGURE 41. 2010 U.S. CENSUS POPULATION FOR THE 20 SLRIS COUNTIES BY AGE GROUP.

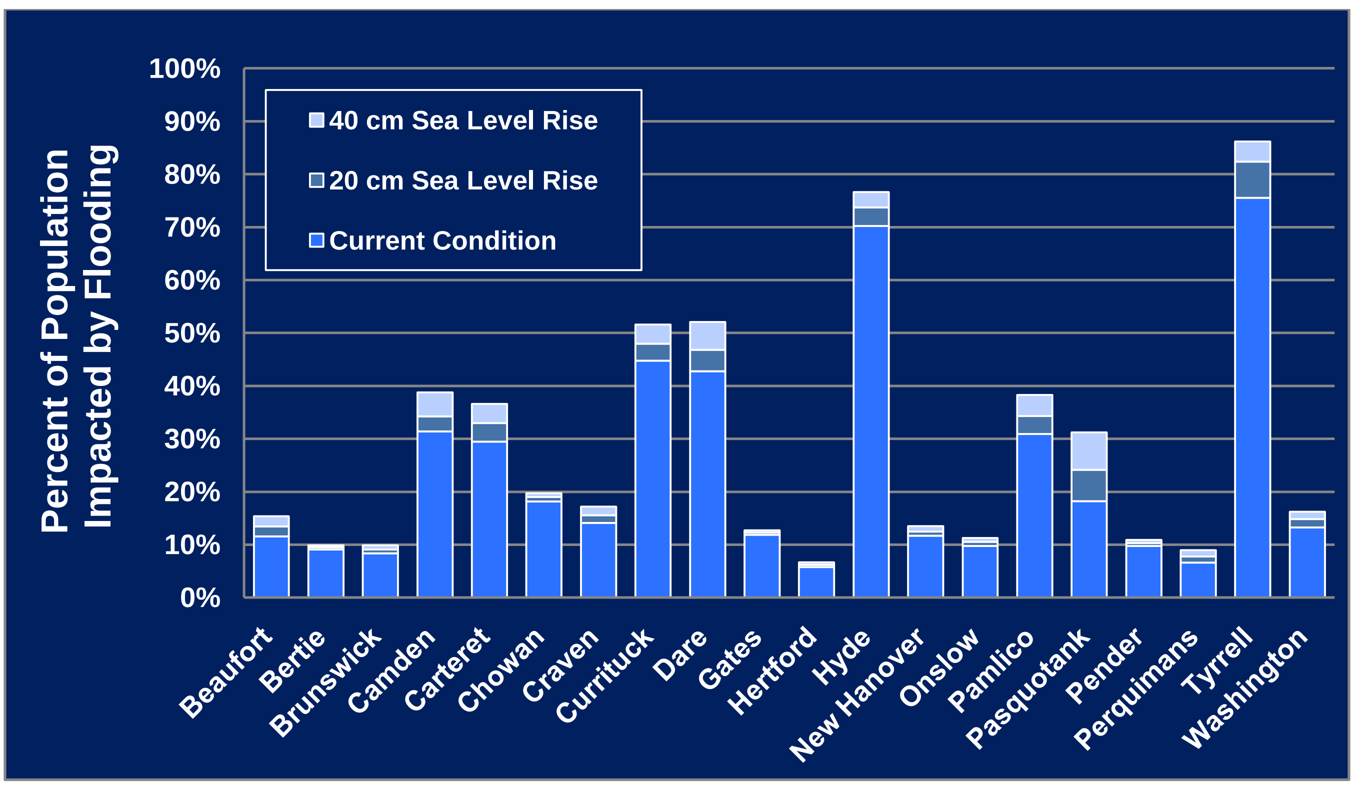


FIGURE 42. PERCENT OF COUNTY POPULATION TO BE IMPACTED BY FLOODING DURING A 1%-ANNUAL-CHANCE FLOOD FOR THE GIVEN STUDY SCENARIOS.

TABLE 19. VULNERABLE POPULATION CURRENT CONDITIONS FOR THE BASELINE SCENARIO, AND CALCULATED CHANGES FOR THE 20- AND 40 CM SLR SCENARIOS.

Change in Vulnerable Populations for 1%-annual-chance Flood																		
County Name	Total Population	20 cm SLR	40 cm SLR	Under 5 years	20 cm SLR	40 cm SLR	Over 65 years	20 cm SLR	40 cm SLR	Group Quarters	20 cm SLR	40 cm SLR	Renter Population	20 cm SLR	40 cm SLR	Population below Poverty	20 cm SLR	40 cm SLR
Beaufort	5,530	890	1,802	318	49	98	996	172	349	46	10	20	1,648	267	541	525	87	176
Bertie	1,941	87	157	96	4	8	342	15	28	300	13	23	490	22	39	170	7	14
Brunswick	8,996	759	1,645	440	33	75	2,062	188	399	61	5	12	2,381	202	436	1,255	103	222
Camden	3,135	280	733	180	17	43	427	37	98	9	1	2	595	51	134	221	20	51
Carteret	19,593	2,324	4,752	933	104	213	3,754	481	973	295	29	61	5,223	605	1,248	2,830	340	684
Chowan	2,687	120	232	186	7	14	565	23	45	102	2	5	1,114	37	72	175	8	15
Craven	14,589	1,526	3,187	1,041	102	212	2,738	292	601	656	59	126	5,490	534	1,119	1,398	153	320
Currituck	10,543	747	1,605	591	42	90	1,450	101	214	70	5	12	2,266	149	314	1,286	89	189
Dare	14,506	1,373	3,151	807	74	173	2,182	213	462	78	6	11	4,514	421	1,005	1,514	125	289
Gates	1,448	54	107	87	3	6	201	7	14	2	0	1	274	10	20	130	5	10
Hertford	1,422	108	218	74	6	12	205	15	32	191	12	24	399	32	67	106	9	17
Hyde	4,080	204	372	206	10	19	614	31	56	583	29	53	951	47	86	525	26	47
New Hanover	23,637	1,620	3,766	1,253	91	212	3,518	239	552	624	42	93	7,500	495	1,158	2,029	143	333
Onslow	17,322	1,425	2,664	1,478	128	238	1,251	89	166	3,334	308	593	6,306	536	997	1,514	108	204
Pamlico	4,061	448	977	168	17	36	918	116	251	384	20	43	839	85	185	425	48	104
Pasquotank	7,420	2,398	5,273	478	160	353	1,063	330	721	476	192	451	2,479	866	1,944	766	243	530
Pender	5,109	273	598	268	15	32	825	46	97	33	2	4	1,309	60	131	670	30	68
Perquimans	893	149	317	48	7	16	198	33	71	4	0	1	211	33	72	81	13	29
Tyrrell	3,330	300	469	176	16	25	561	50	79	478	43	67	806	72	113	273	24	38
Washington	1,756	204	393	113	12	23	323	38	74	15	1	2	516	52	101	144	20	38
Total	151,997	15,292	32,420	8,940	896	1,898	24,193	2,517	5,283	7,740	781	1,602	45,309	4,577	9,784	16,037	1,600	3,379

4.5.2 What is the Impact to Social Services?

Social services are provided by a variety of governmental agencies as well as not-for-profit and non-governmental organizations. Examining only those structures owned, maintained, or leased by the government, SLR will have an impact on that sector. Forty-four additional government structures (compared to present-day conditions) would be impacted by a 1%-annual-chance flood given a 20 cm rise in sea level. That number rises to 89 structures (compared to present-day conditions) given a 40 cm increase in sea level. The iRISK framework was used to calculate estimated values and is further detailed in Section 4.2.3.

- **For 20 cm of SLR:** Governmental building damage is likely to cause significant impact, as over $220 million in lost employee wages is expected.
- **For 40 cm of SLR:** As buildings are further damaged at the 40 cm level, over $500 million in total employee wages is likely to be lost.

TABLE 20. ECONOMIC IMPACTS OF SEA LEVEL RISE ON GOVERNMENTAL FACILITIES IN THE SLRIS STUDY AREA*.

Scenario	Buildings	Lost Output	Lost Income	Lost Wages	Relocation Cost
0 cm	121	$103.87	$8.36	$518.74	$10.57
20 cm	165	$151.72	$14.01	$739.72	$20.10
40 cm	210	$214.48	$20.09	$1,043.61	$33.72

*Amounts in millions of dollars

4.5.3 What is the Impact to Health Care Facilities?

Table 20 shows that 9 additional healthcare and public health structures (compared to present-day conditions) would be impacted by a 1%-annual-chance flood given a 20 cm rise in sea level. That number rises to 23 structures (compared to present-day conditions) given a 40 cm increase in sea level. The iRISK framework was used to calculate estimated values and is further detailed in Section 4.2.3.

- **For 20 cm of SLR**: Approximately $6 million in wages is lost. An additional $13 million in output (the value of services or products produced by an industry) is lost.
- **For 40 cm of SLR**: Lost wages swell by nearly $17 million over present day 1%-annual-chance flood losses, with output losses increasing by just shy of $40 million.

TABLE 21. ECONOMIC IMPACTS OF SLR ON HEALTHCARE FACILITIES IN THE SLRIS STUDY AREA.*

Scenario	Buildings	Lost Output	Lost Income	Lost Wages	Relocation Cost
0 cm	37	$67.66	$13.00	$30.28	$3.29
20 cm	46	$80.87	$15.54	$36.20	$3.82
40 cm	60	$106.33	$20.43	$47.60	$4.87

*Amounts in millions of dollars

4.5.4 What is the Impact to Education Resources?

Table 22 shows that 13 additional education facilities (compared to present-day conditions) would be impacted by a 1%-annual-chance flood given a 20 cm rise in sea level. With 40 cm of SLR, up to 34 additional facilities would be impacted. The iRISK framework was used to calculate estimated values and is further detailed in section 4.2.3.

- **For 20 cm of SLR:** A 1%-annual-chance flood can result in an increase of just over $20 million in lost wages and nearly $175 million in additional lost output.
- **For 40 cm of SLR:** Lost wages to $83.5 million, while lost output swells to $712 million.

TABLE 22. ECONOMIC IMPACTS OF SLR RISE ON EDUCATIONAL FACILITIES IN THE SLRIS STUDY AREA.*

Scenario	Buildings	Lost Output	Lost Income	Lost Wages	Relocation Cost
0 cm	46	$299.61	$14.35	$35.14	$3.61
20 cm	59	$474.95	$22.74	$55.70	$7.97
40 cm	80	$712.41	$34.11	$83.55	$12.60

*Amounts in millions of dollars

4.5.5 What is the Impact of SLR on Cultural Resources?

SLR has the potential to impact the State's places of historical significance and local landmarks:

- Of the approximately 390 structures identified by communities as being local landmarks and/or listed in the National Register of Historic Places and located within the Study area, 28 additional structures (compared to those impacted in present conditions) may be vulnerable to inundation during a 1%-annual-chance flood under a 40 cm SLR scenario.
- Under the same 40 cm SLR scenario, 14 additional historic structures (compared to present day) may be inundated during a 10%-annual-chance event.

4.5.6 How Were Societal Impacts Assessed?

Analysis was performed to determine the extent to which vulnerable populations would be impacted by SLR. Census tract boundaries were overlaid on each of the SLR scenarios to determine the area and populations potentially inundated. Results for the current conditions, 20 cm, and 40 cm SLR scenarios are presented in this report. Additional information is available in the SLRIS **Impact Assessment Report**.

Because of the format of available demographic data, the societal analysis was performed at the census tract level; to simplify the analysis, it is assumed that population and resources are evenly distributed within a census tract's boundaries. The following situation provides an example of equal distribution within a census tract: if the analysis calculates that 25 percent of a census tract would be inundated in a particular SLR scenario, and the census tract has a total population of 1,000, then 250 of the population would be considered at risk due to SLR. This method may underestimate the at-risk population for census tracts with populations clustered nearest the coast and may overestimate the at-risk population when population nearest the coast is sparse (Heberger, 2012).

Impacts to specific sectors that play a significant role in society were deduced based on results coming out of the study's Impacts Assessment. The full results and an explanation of the methods used to perform that analysis are described in the SLRIS **Impact Assessment Report**.

5 FLOOD IMPACT MANAGEMENT STRATEGIES

Given an understanding of changes to coastal flood hazards caused by SLR and the impacts it poses to built and living systems as a result, it is important to identify short-term and long-term strategies that would result in efficient and effective prevention and/or mitigation of SLR exposure and consequences.

Consistent with the impact assessment performed in the SLRIS study, the FIMS developed for North Carolina here are organized across six different receptors: physical landforms, ecology, agriculture, critical infrastructure, buildings, and the social well-being of North Carolina residents.

It is important to note that these FIMS are not intended to serve as recommendations, rather as researched/documented potential options for consideration.

5.1 Strategies

This section summarizes FIMS that span the six receptor groups. Each FIMS concept is explained using the following elements: a general description of the strategy, issues tied to the feasibility of its implementation, and possible mechanisms such as programs or funding that could be used to implement the strategy.

5.1.1 Land Receptor

Strategy 1.1: Acquire property subject to coastal flooding and maintain the property as open space in perpetuity.

Description: North Carolina can play a critical role in acquiring property that is vulnerable to flooding and adaptively reusing such properties to advance additional complementary goals. By acquiring properties subject to inundation and maintaining them as open space in perpetuity, the State can both remove significantly at-risk properties from the real estate market and add open space for conservation, recreation, or other public purposes. The acquisition of floodprone properties can also further environmental benefits (and ecological-based FIMS), including allowing for marshland migration and reducing non-point source pollution. The State and a number of local governments have extensive experience with the acquisition of floodprone properties following Hurricanes Fran and Floyd and as part of a number of ongoing pre-disaster hazard mitigation grant programs. It is important to note that the property in question may include developed and undeveloped lands.

Feasibility Considerations: The mapping of areas under consideration and calculation of costs to acquire the land can be done using available flood hazard risk assessment data derived from the NCFMP, IHRM program, North Carolina GIS, as well as local hazard mitigation plans. This data includes floodplain boundaries, first finished floor elevations of structures, and other relevant data needed to perform the benefit-cost analysis. This strategy must take into account the challenges of identifying willing sellers of property, determining the cost-effectiveness of acquiring the properties, acquiring contiguous properties (and avoiding the “checkerboard” effect whereby only some houses in a neighborhood are acquired, which requires the provision of services to remaining households), and the tracking those bought out to ensure that the funds are used by former property owners to acquire housing outside areas subject to SLR and coastal flooding. This strategy should draw on the flood hazard data that is readily available in North Carolina as well as lessons learned from the large-scale buyout of floodprone properties that has occurred in North Carolina since the 1990s (one of the largest single-State efforts of its kind in the United States). Lessons can also be drawn from land acquired by State agencies and land trusts.

Potential Implementation Mechanisms: The effective development of a comprehensive acquisition program will require the combined efforts of several State and Federal agencies. The State of North Carolina Hazard Mitigation Plan (HMP) and local HMPs describe implementation strategies for State and local governments, respectively, and should be reviewed to compile all relevant grants and programs related to this FIMS. Several State resource management programs can play an important role in this proposed effort, including the North Carolina Wildlife Resources Commission's Land Acquisition Committee, which purchases and manages land as wildlife conservation areas and recreational sites; the North Carolina Farmland Preservation program; and the North Carolina Clean Water Management Trust Fund.

The creation of a statewide, GIS-based repository of data layers can help foster a more coordinated effort across agencies by providing a common operating picture of environmentally sensitive areas; areas prone to flooding, SLR, and coastal erosion; past lands acquired (including differing funding source attributes); and lands prioritized for future purchase by differing groups. A number of pre- and post-disaster hazard-mitigation grant programs provide funding to engage in this effort. Examples include the FEMA's Hazard Mitigation Grant Program (HMGP), Hazard Pre-Disaster Mitigation (PDM) Assistance, and Flood Mitigation Assistance (FMA) programs. In addition, the Department of Housing and Urban Development's Community Development Block Grant (CDBG) Disaster Recovery funds are often used to acquire floodprone properties after a federally declared disaster. For additional implementation mechanisms, see the State of North Carolina HMP.

Strategy 1.2: Construct sea walls or other measures along the North Carolina coast against the 0.2%-annual-chance coastal flood.

Description: Adaptation strategies may require at-risk residents and property owners to move, uprooting their families and potentially modifying their lifestyles. Armoring the shoreline with a sea wall to withstand a 0.2%-annual-chance flood provides an alternative to moving away from known high hazard areas. A number of significant issues should be addressed before embarking on such a strategy. These include the extensive upfront capital cost of such an undertaking, the possible negative environmental effects (including the loss of the protective beach), determining the appropriate design standard (that may or may not account for some SLR and an increase in coastal storminess), and the resulting increase in development behind the protective barrier (which may result in a more devastating disaster when an event exceeds the design standard). Such a strategy would require the creation of clear criteria to identify and prioritize areas to be protected. Examples of criteria include, but are not limited to, population density, economic output, land and property values, historic and cultural significance, and number and type of critical public facilities protected.

Feasibility Considerations: Hard structures such as sea walls are a technically complex and extremely expensive undertaking. They can result in the loss of the natural beach through accelerated erosion rates (often necessitating an expensive beach re-nourishment program) and possible damage to other environmental features and natural habitat, such as blocking the ability of barrier islands to migrate toward the mainland or hindering the ability of marshlands to move in accordance with an inundated coastline as sea levels rise.

Sea walls in other coastal areas have led to increased landward development, thereby increasing overall exposure and loss should the design parameters of the structure be exceeded. The construction of hard structures in North Carolina would also require a change in State policy, which currently does not allow for the construction of structures like sea walls in the coastal zone (see the NC Department of Environment and Natural Resources (DENR), Division of Coastal Management). The design of a sea wall should take into consideration changes to the floodplain over time and the life expectancy of the protective measure. A critical question to answer will be whether or not building to today's 0.2%-annual-chance-flood will provide sufficient protection over the expected life of the wall or if the structure should be built to accommodate projected changes to the 0.2%-annual-chance floodplain.

Many examples of sea walls built for flood protection exist, both within the United States and internationally, and the experience of these projects can inform whether and how to pursue this strategy. While North Carolina has a ban on hardened structures on ocean beaches, sea walls and bulkheads already have been built on many coastal properties within the State. Motivated by the damage caused by Hurricane Ike in 2008, a proposal is being discussed to construct a coastal barrier, referred to as the "Ike Dike," to protect the Galveston Bay in Texas to be able to withstand a ~10,000-year storm. The Ike Dike project would dramatically extend the existing Galveston Seawall and provide flood protection to Galveston, the Bolivar Peninsula, the Galveston Bay Area, and Houston, including the substantial petrochemical industry located in the area. Opponents of the project question the expense and the efficacy of the proposed sea wall.

Internationally, the Netherlands has a long history with engineered flood control projects, as about two-thirds of the nation's area is vulnerable to flooding. Sea walls and flood defenses have been built and continue to be strengthened and raised over time. Currently, the sea walls along the most densely populated western coast of the Netherlands have a design standard to withstand a 10,000-year flood event, while the less densely populated areas are protected by structures built to withstand a 4,000-year event.

Potential Implementation Mechanisms: The USACE is the likely Federal entity that would undertake such an initiative if congressionally appropriated funds were in place. Another option to consider is the development of alternative cost-sharing arrangements to include revenues derived from local governments, residents, tourists, hotel/rental taxes, the State legislature, water-dependent corporations, and other Federal agencies.

Strategy 1.3: Transition developed properties to less intensive uses in areas subject to SLR.

Description: Increased coastal flooding and erosion associated with SLR may make certain areas unfit for intensive land uses like residential or commercial development. Many of those areas will remain suitable for less intensive uses like recreation or specific water-dependent uses. Maryland's climate change adaptation strategy, for example, includes existing programs that promote open space, using purchase of development rights and conservation easements as a means to transition to less intensive uses.

Feasibility Considerations: Local opposition by selective interest groups to certain kinds of down zoning is the primary constraint to this strategy. It may be possible to connect less intensive uses to current open space plans, HMPs, environmental conservation agendas, or other existing programs, thereby enhancing administrative feasibility.

Potential Implementation Mechanisms: A series of State resource management programs can play an important role in this proposed effort, including the North Carolina Wildlife Resources Commission's Land Acquisition Committee, which purchases and manages land as wildlife conservation areas and recreational sites. The North Carolina Farmland Preservation program, the North Carolina Clean Water Management Trust Fund, and the DENR "One North Carolina Naturally" initiative support the acquisition of property and the development of regional open space plans. The U.S. Department of Housing and Urban Development (HUD) Sustainable Communities Regional Planning Program also provides funds to support open space plans. Additionally, a number of pre- and post-disaster hazard-mitigation grant programs provide funding to engage in this effort. Examples include the Hazard Mitigation Grant Program (HMGP), Hazard Mitigation Assistance (HMA), Pre-disaster Mitigation (PDM) program, and Flood Mitigation Assistance (FMA) programs. In addition, HUD's Community Development Block Grant (CDBG) Disaster Recovery funds are often used to acquire floodprone properties after a federally declared disaster. Additional implementation mechanisms include the adoption of local land use policies to achieve this aim, the North Carolina Coastal Area Management Act, and green infrastructure plans that may note specific local implementation strategies. For additional implementation mechanisms see the State of North Carolina HMP.

Strategy 1.4: Identify and acquire prioritized freshwater resources.

Description: The report, *Analysis of Climate Change Adaptation Strategies for Southeast US Coastal Cities*, written by the U.S. Fish and Wildlife Service (FWS), identifies protecting freshwater supplies as a critical component of a regional effort to adapt to SLR. By identifying and acquiring priority freshwater resources, North Carolina can act on FWS's recommendation, ensuring an adequate supply of fresh water for agricultural, ecological, and human needs.

Feasibility Considerations: Like many public acquisition strategies, this strategy is likely to be costly, and it will require addressing a range of questions related to implementation, including which State agency/agencies would administer the acquisition process and manage the water supplies. Therefore, implementing this strategy will require addressing issues of economic and administrative feasibility.

Potential Implementation Mechanisms: The Clean Water Management Trust Fund (CWMTF) and the State Park System, both housed within the DENR, are potential avenues for acquiring freshwater resources for public use. Additional partners may include land trusts, recreational (including fishing and hunting) interests, and environmental groups. One option to consider is the provision of additional points in any prioritization/ranking system used to administer grants, to include criteria tied to the protection of existing freshwater supplies in areas prone to SLR. In addition, the use of a GIS-based system to identify and prioritize acquisition sites across stakeholders would be helpful for coordinating activities, including joint purchases and eventual management of the resource once obtained.

5.1.2 Ecological Receptor

Strategy 2.1: Utilize rolling easements to allow for the migration of barrier islands and wetlands while maintaining public access to the shore and coastal sounds.

Description: The dynamic nature of coastal ecology complicates coastal land use planning, as features like barrier islands and marshes migrate due to oceanographic, hydrological, and meteorological processes. In developed areas, governments and private landowners often attempt to hold back the sea by adding sand to beaches or building hardened structures like sea walls and revetments. Another option to address the natural dynamism of coastal environments, including the migration of wetlands and barrier islands, is to utilize rolling easements. Rolling easements are any institutional arrangement that takes away the landowner's expectation of holding back the sea and provides the assurance that the shore or public access along the shore can migrate inland instead of being squeezed between an advancing sea and a fixed property line or physical structure. The application of rolling easements has the additional benefit of helping to maintain public access along the State's shores and sounds, which also enhances important tourism and recreation-based economies. The EPA recently published a Rolling Easements Primer that outlines a range of approaches to rolling easements and the advantages and disadvantages of pursuing such a strategy (Titus, 2011).

Feasibility Considerations: Rolling easements depend on actual, immediate fluctuations in sea level rather than projections. As a result, this strategy sidesteps the inherent uncertainty and disagreements surrounding future levels. As indicated by the protracted debate over House Bill 819, much of the State-level opposition to SLR adaptation emanates from groups skeptical of prevailing climate science, which this strategy may help moderate. Developing a policy tied to actual changes may enhance the likelihood of gaining legal standing (e.g., relying on existing State coastal management rules) as well as political support. However, since structures seaward of this line would be removed at the owner's expense, under current State law, it may remain politically objectionable to some property owners.

Several States have coastal management programs that employ varied forms of rolling easements. Florida's Coastal Construction Control Line (CCCL) Program provides protection for Florida's beaches and dunes while assuring reasonable use of private property by establishing an area in which more stringent siting and design criteria are applied for construction and related activities. The control line represents the landward limit of a 100-year coastal storm, which could change due to coastal erosion, changes in sea level, or intensification of coastal storms (Florida Dept. of Environmental Protection). The Texas Open Beaches Act, established in 1959 and amended in 1991, guarantees free public access to beaches on the Texas coast, extending from the mean low tide to the first line of stable vegetation. While litigation is pending to clarify the effects of the Act on beachfront property owners, the Act results in the public easement "rolling" with the vegetation line as long as its movement is gradual/natural and not caused by an event like a hurricane (Texas General Land Office, 2014).

Potential Implementation Mechanisms: The EPA Climate Ready Estuaries Program encourages the use of rolling easements and may be used to provide broad policy guidance. The North Carolina Coastal Area Management Act's rules associated with development seaward of the Mean High Water Line can be used to undergird leverage such a policy.

Strategy 2.2: Allow wetland habitats to move based on changes in SLR.

Description: According to the DENR, habitat corridors such as wetland marshes are essential components of the State's Wildlife Action Plan. In North Carolina, more than 70 percent of the species listed as endangered, threatened, or of special concern depend on wetlands for survival. Thus, a policy that acquires and protect lands for wetland habitat migration as coastal ecologies change as a result of SLR could have significant benefits to State flora and fauna. These benefits include advancing existing State wildlife science and policy; and maintaining key nurseries that support important seafood, hunting, and recreational interests in the State.

Feasibility Considerations: While it is not hard to imagine this policy boosting coastal economies through tourism and ecosystem services, these benefits likely will prove difficult to quantify. The processes required (e.g., land and property acquisition) to accomplish this aim will likely prove very expensive. A clear prioritization strategy to acquire land would need to be developed in order to most effectively use the financial resources available. In addition, an outreach strategy to identify willing sellers (assuming a voluntary program) would need to be implemented.

Potential Implementation Mechanisms: At the Federal level, the Coastal Wetlands Conservation Grant Program; Coastal Wetlands Initiative, which identifies and disseminates tools to protect and restore wetland resources; and the Wetlands Reserve Program, which offers landowners the opportunity to protect, restore, and enhance wetlands on their property, could be used to allow wetland migration in North Carolina. At the State level, both the Wetlands Conservation and Coastal Habitat Protection Plans could help implement this strategy.

5.1.3 Agricultural Receptor

Strategy 3.1: Adopt property tax reductions to incentivize the elevation or relocation of agricultural structures located within the .02%-annual-chance coastal floodplain.

Description: The protection of agricultural lands serves multiple benefits, including the preservation of the State's agricultural heritage, the preservation of open space, the containment of urban sprawl, and the limitation of future flood and SLR-related losses. Farms, including their buildings and infrastructure, are often located in floodplains because of the nutrient-rich soils and relatively flat topography. Working to protect vulnerable structures and infrastructure from flood-related losses can help to reduce the likelihood that a flood disaster will further stress those whose economic survival is often tenuous. Maintaining working farms in the floodplain is often preferable to more intensive uses like subdivisions and shopping centers that can significantly affect the natural function of the floodplain due to the addition of impervious surfaces and the physical alteration of the area's hydrological carrying capacity.

Feasibility Considerations: The North Carolina Department of Revenue (DOR) already offers a tax deferment program, by which taxpayers who use their land for agriculture, horticulture, or timber production are taxed at the lower value of these present uses, rather than their higher true market value as developable land. Expanding a well-established statewide program to include the means to incentivize flood hazard risk reduction initiatives for farmers may prove politically acceptable while requiring limited administrative changes.

Potential Implementation Mechanisms: Amending the DOR's present use value tax program to compensate qualified agricultural property owners who elevate or relocate agricultural structures and infrastructure appears to be the optimal way to implement this strategy.

Strategy 3.2: Incentivize the transition to crops, varietals, and other agricultural/aquacultural products that are more resilient to an increase in the salinity of groundwater and surface water and/or more frequent flooding as a result of SLR.

Description: As soil composition changes due to SLR, it is unlikely that North Carolina's farmers will be as able to rely on certain varietals and crops as they have in the past. Accordingly, an incentives policy that encourages transitioning to crops, varietals, and other agricultural/aquacultural products that are more resilient to soil and water composition changes could help maintain agriculture as an economically viable job sector while preserving an important cultural legacy in North Carolina. The protection of farmland offers an important alternative to more intensive development in floodprone areas in the coastal plain.

Feasibility Considerations: The transition of crops, varietals, and other agricultural/aquacultural products will likely be slow, as issues of technical feasibility (e.g., the identification of resilient varietals and species) and administrative feasibility (e.g., the promotion and acceptance of alternatives by farmers) may be significant. Transitioning may require considerable investment to retrain workers and purchase new types of equipment. This may be particularly difficult for smaller farming operations.

Potential Implementation Mechanisms: Though there are few domestic case studies of this type of agricultural adaptation, the U.S. Agency for International Development has been active in supporting transitions to more resilient crops in Central America. Their small grant program, perhaps in conjunction with the technical services section of the North Carolina Department of Agriculture and Consumer Services, could be instructive in overcoming the economic and technical hurdles of this strategy. In addition, the North Carolina Cooperative Extension Service could provide information to farmers tied to crops that are able to thrive in varied conditions, including changes in average winter and summer temperatures, variations in the timing and amount of precipitation, and increasing levels of salinity in groundwater and surface water.

Strategy 3.3: Provide new job training for people in the agricultural industry whose livelihoods are threatened by SLR.

Description: In some cases, the agricultural community may be able to adjust practices over time, such as the planting of new crop varietals and the adoption of new storm water management techniques in order to maintain a viable operation despite changes in sea level. In other cases, new crop varietals and changes in agricultural practices will not be enough to stave off the effects of SLR. In response, new job training might be provided for people in the agricultural industry whose livelihoods are threatened by SLR. Such training would better prepare residents to face a job market with unfamiliar options.

The approach to retraining could take several forms. Training programs or other incentives could be developed to promote new skills in areas of agriculture that are likely to be more resilient to SLR. This would ensure that agriculture continues to be an important economic engine in the State. Alternatively, the State could provide for non-agriculturally oriented retraining programs or other educational incentives geared toward retraining displaced agricultural workers for entirely new careers. The goals of the two approaches are very different. One strives to maintain the level of agricultural employment while also providing skills that are in demand in the industry, while the other approach concedes some loss of agricultural employment and focuses on maintaining overall employment in the State. Given the relatively gradual nature of SLR, the State's strong university and community college systems have some lead time to develop or alter the curricula necessary to help implement this strategy.

Feasibility Considerations: The State Department of Labor (DOL) Trade Adjustment Program, which retrains workers who have lost their jobs due to international competition, has recently been used by fishermen who have lost their jobs to changing environmental conditions, and similar programs could be used as a form of economic development in poorer areas in the State. This assumes, however, that farmers and fishermen would be interested in such retraining, and that sufficient job opportunities for retrained agriculture and aquacultural workers exist near communities threatened by SLR. Issues of social and economic feasibility will have to be resolved to successfully implement this strategy.

Potential Implementation Mechanisms: A collaboratively partnering between the DOL, the North Carolina Cooperative Extension Service (NCCES), and the State's university and community college system would need to occur to help refine and implement this strategy.

5.1.4 Critical Infrastructure Receptor

Strategy 4.1: Elevate existing and proposed critical facilities located in coastal flood hazard areas (e.g., the 1%-annual-chance-year floodplain) 1, 2 or 3 feet above the base flood (1%-annual-chance flood) elevation to account for differing SLR scenarios.

Description: Many coastal structures are sited in a manner that enables them to be close to and easily accessible by the public, their employees, or the assets that they service. Accordingly, relocating critical facilities elsewhere may result in a loss of efficiency. Elevating critical facilities located in coastal flood hazard areas (e.g., the 1%-annual-chance, or 100-year, floodplain) 1, 2, or 3 feet above the BFE will help to ensure that they can function during floods without having to sacrifice their optimal locations. It is important to note that some communities in the State, especially active participants in the Community Rating System program, may have these types of provisions in place for new facilities.

Feasibility Considerations: The adoption of a "freeboard" requirement (i.e., establishing a given height above which a structure must be elevated) has significant up-front costs. This strategy also relies on flood maps being updated frequently enough to account for changes to BFE so that new critical facility buildings are constructed based on the most up-to-date data. This too carries technical, administrative, and economic costs. The State of North Carolina benefits from the high technical and administrative capacity of the NCFMP, which is responsible for mapping and updating the FIRMs over time. In addition, the digital mapping of projected SLR, which will be made available to communities as requested, allows for the dual assessment of projected changes in coastal FIRMs and SLR. It should be noted that the State of North Carolina currently requires a 1-foot freeboard on new and improved structures in designated floodplains.

Potential Implementation Mechanisms: This strategy will require both the identification of existing and proposed at-risk structures and the funding needed to pay for the construction of new facilities or retrofitting of existing structures. Existing critical facilities at the local level are often found in a jurisdiction's HMP, while State-owned facilities are addressed in the State HMP. Post-disaster funds that could be used to implement this strategy include the Public Assistance (PA) 406 Program and the HMGP.

Strategy 4.2: Elevate existing roads, prioritizing roadways that connect critical facilities or serve as evacuation routes, and that are located in the 1%-annual-chance floodplain and/or subject to SLR inundation.

Description: Considering the extreme costs associated with this strategy, it makes sense to develop a prioritization plan to elevate selected road segments. One option to consider is to first elevate those roads that connect critical facilities and evacuation routes located in r coastal floodplains that are at risk of SLR inundation. Another option is to prioritize primary versus secondary roadways.

Feasibility Considerations: Though less expensive than a more comprehensive elevation policy that encompasses all roads in the same mapped hazard area, this remains an expensive way to manage flood-related impacts. Technically, the strategy is rather complex and involves not only elevating the roadway, but also expanding culverts and modifying supporting infrastructure. Moreover, the service loss that would accompany this strategy is likely to generate local concern, impacting this strategy's feasibility. Such a strategy would require coordinating closely with businesses and citizens in the vicinity of chosen roadways in order to determine the best course of action (e.g., identifying alternate routes for traffic, including those to be used during hurricane season when evacuations may be necessary; and coordinating the number, location, and timing of projects to be retrofitted) in order to minimize interruptions and financial impacts to the local economy. In the long term, more frequent flooding or permanent inundation might make some of these routes inappropriate to maintain, particularly if the areas served are no longer inhabited.

Potential Implementation Mechanisms: The mechanisms would likely be the same as those used in the previous strategy. Close attention should be placed on the approach taken to repair and retrofit NC Route 12 along the Outer Banks over time, as this roadway represents one of the State's most vulnerable to more intense storms and SLR. NC 12 also connects critical facilities and serves as an important evacuation route.

Strategy 4.3: Relocate critical facilities outside the 1%-annual-chance coastal floodplain.

Description: A highly expensive and beneficial approach (from a risk reduction/adaptation standpoint) would be to relocate critical facilities outside the 100-year coastal floodplain. This strategy would drastically reduce flood-related damages and associated facility downtime, improving the consistent functionality of critical facilities. The relocation of critical facilities to less vulnerable locations has the potential to also influence future development patterns in those areas, thereby further reducing long-term exposure to coastal flood hazards. This strategy would build on the direction of Federal Executive Order 11988, which states that Federally funded structures must be located outside the .02%-annual-chance, or 500-year, floodplain.

Feasibility Considerations: The relocation of critical facilities outside of floodprone areas has been undertaken in eastern North Carolina following Hurricanes Fran, Floyd, and Irene. This technique, while highly effective in reducing future flood-related losses, requires a significant commitment of financial resources, technical acumen to manage a project of this nature, and political support from elected officials and the general public. In addition to being costly, the relocation of critical facilities must include the identification of suitable sites and an analysis of how changes will influence service needs (e.g., wastewater and water management, provision of protective services, educational and/or sheltering needs) and influence future growth patterns.

Potential Implementation Mechanisms: The mechanisms would likely be the same as those used in the previous strategy. An assessment of examples drawn from Hurricanes Fran and Floyd may prove instructive as to the process used to make these projects viable, including conducting eligibility determinations, procuring available funding, and engendering public support.

Strategy 4.4: Develop standard operating procedures for the relocation and retrofit of at-risk infrastructure and critical facilities located in coastal flood hazard.

Description: To help communities avoid having to develop infrastructure and critical facilities relocation procedures amidst the confusion and disorder that often follows disasters, the development of an integrated State-level strategy in the pre-disaster environment would allow North Carolina communities to proactively address these issues while pre-positioning themselves to take advantage of post-disaster hazard mitigation and disaster recovery funding. In using Federal funds for post-disaster recovery, consideration of Federal Executive Order 11988 is necessary. It states that any action in the flood hazard area should be modified to “minimize potential harm to or within the floodplain.” A well-constructed State strategy should include:

1) Efforts to better coordinate the expenditure of hazard mitigation and public assistance grant programs following federally declared disasters,

2) The development of an education and training program for State and local officials regarding grant eligibility and implementation, and

3) The development of an infrastructure and critical facilities relocation guide for local governments that can supplement Federal disaster recovery planning guidance that is emerging under the National Disaster Recovery Framework (NDRF).

Feasibility Considerations: The pre-event development of a State infrastructure and critical facilities relocation strategy is not an expensive proposition. Developing such as strategy will, however, require the involvement of a number of State and local officials to devise an effective education and training program and associated guidance materials. Encouraging local officials to consider adopting a more proactive approach associated with preparing for the relocation of infrastructure investments and critical facilities in advance of a disaster may prove more challenging. These efforts should be linked to the evolving Federal guidance tied to the development of local disaster recovery plans under the NDRF and existing local HMPs developed in accordance with the Disaster Mitigation Act of 2000.

Potential Implementation Mechanisms: A State infrastructure and critical facilities relocation strategy could be developed as part of the North Carolina Department of EM’s Public Assistance Administrative Plan and the Hazard Mitigation Section’s HMGP Administrative Plan and the State HMP. The writing of State guidance and the implementation of a training program could be achieved through existing training program funds, while the implementation of actual projects may be funded through the PA 406 Program and the HMGP.

Strategy 4.5: Protect ports, ferries, bridges, and docks to allow current modes and paths of water dependent transportation and access.

Description: In many cases, due to the functionality of water-dependent infrastructure and the cost-prohibitive nature of relocation, a strategy to protect coastal North Carolina’s water-based infrastructure from the effects of SLR could include the selective armoring or strengthening of ports, ferries, bridges, and docks. In other cases, it may be possible to facilitate the relocation of transportation infrastructure as sea levels rise.

Feasibility Considerations: In addition to its economic feasibility, armoring raises significant social and environmental issues. While this strategy may be one way to protect water-dependent critical facilities in their present condition and location, caution would need to be exercised in enabling new development in vulnerable areas of the coast, thus increasing exposure over time. In addition, consideration should be given to developing protective measures that account for both risks facing coastal development today as well as SLR impacting coastal infrastructure in the future. Any strategy that involves armoring could potentially pose negative environmental impacts by preventing the natural migration of habitats as sea levels rise. The North Carolina Ports Authority recently conducted the

North Carolina Maritime Study, in which SLR information from the NCFMP was used to inform how future conditions will impact existing and planned port facilities and infrastructure. The North Carolina Department of Transportation (NCDOT) is largely responsible for bridge and ferry infrastructure in the State. While NCDOT has yet to develop an overarching policy regarding SLR, anticipated changes have been taken into consideration on a project-specific basis.

Potential Implementation Mechanisms: Given the high costs of protecting North Carolina's water-dependent uses, the development of an implementation strategy will require the input and resources drawn from a range of stakeholders. Funding options might include State and Federal grants as well as private sector and quasi-governmental contributions from water-dependent industries and organizations.

5.1.5 Buildings Receptor

Strategy 5.1: Expand the acquisition of severe repetitive loss (SRL) properties, emphasizing those located in coastal floodplains and subject to SLR inundation.

Description: The State of North Carolina, like most other States, has in place a SRL strategy. An SRL property is defined as a residential property that is covered under an NFIP flood insurance policy and that: a) has at least four NFIP claim payments (including building and contents) over $5,000 each, and the cumulative amount of such claims payments exceeds $20,000; b) for which at least two separate claims payments (building payments only) have been made with the cumulative amount of the building portion of such claims exceeding the market value of the building. For both a) and b), at least two of the referenced claims must have occurred within any 10-year period, and must be greater than 10 days apart. Expanding the program to include residential properties particularly vulnerable to SRL could be written into the State's repetitive loss strategy as an additional and/or tie-breaking criteria in the selection process of eligible applicants. Designating areas prone to SLR (drawn from the NC SLRIS) and repetitive flood loss (drawn from existing NFIP flood loss data) could be geo-referenced using GIS. This information could be used to identify and prioritize applicants and link potential repetitive loss acquisitions with other property acquisition programs, thereby encouraging the purchase of contiguous properties when possible.

Feasibility Considerations: FEMA's FMA program, like many Federal grants, requires a non-Federal match. A key administrative challenge includes identifying willing sellers of coastal property. The proposed program could be implemented with minor alteration to an existing applicant scoring system.

Potential Implementation Mechanisms: FEMA's FMA, program coupled with the HMGP and other property acquisition programs, could be instrumental in implementing this strategy. A potential mechanism may be to expand North Carolina Senate Bill 300, which amends the EM laws to include a mitigation fund focused on the acquisition of coastal repetitive loss properties. The implementation of the program and its coordination with other complementary grants could be facilitated through the digitizing of eligible properties and analyzing these properties using GIS. Moreover, FEMA announced in December 2013 that it would begin to consider SLR in evaluating cost-effective hazard mitigation projects. By calculating benefits from mitigating to higher elevations, projects in coastal North Carolina are more likely to achieve favorable status.

Strategy 5.2: Continuation of freeboard requirements for all new buildings within the 1%-annual-chance coastal floodplain.

Description: Requiring a freeboard for all new buildings within the 1% annual-chance is among the most widely accepted best practices to reduce structural damages due to rising floodwaters. This approach also stands to help communities as they consider additional, more comprehensive strategies to address coastal flooding and rising sea levels. The adoption of a freeboard requirement can be applied to both new construction and properties located in the 1%-annual-chance floodplain that are substantially damaged following disaster events. This approach is not foolproof, however, since the design standards of elevated structures may still be exceeded with a change in the intensity of rainfall events, coastal storms and associated storm surge, and rising sea levels.

Feasibility Considerations: The adoption of a freeboard requirement can be viewed as a lower cost alternative to property acquisition. The availability of the analytical data (including depth damage curves, cost of construction/elevation, etc.), coupled with the widespread application of this strategy, make it one of the more technically and administratively feasible FIMS. As of March 1, 2012, the North Carolina Residential Building Code requires a 1-foot freeboard. As a result, the lowest finished floor in new buildings and structures located in designated floodplains shall be elevated to or above the BFE plus 1 foot (International Code Council (ICC) R322.1). Additionally, the ICC has introduced a Coastal A Zone as a flood hazard area that has been delineated as subject to wave heights between 1.5 and 3.0 feet (ICC R322.2). However, it remains unclear if the 2012 NC Residential Code requires V Zone construction standards in the Coastal A Zone (NC Association of Floodplain Managers). The adoption of a 2- or 3-foot freeboard could be accomplished through a change in the building code or adopted and incorporated into a community's local flood damage prevention ordinance (FDPO).

Potential Implementation Mechanisms: The current 1-foot freeboard requirement strategy could be continued or a higher freeboard requirement implemented through the adoption of a State building code for floodplain development and tied to the local FDPO found in communities that participate in the NFIP.

5.1.6 Societal Receptor

Strategy 6.1: Retrofit historic and culturally significant buildings to better withstand coastal flooding and SLR.

Description: While it is possible to use building codes and permitting to require that new construction be resilient to coastal hazards, these tools do not always apply to older buildings, particularly historic buildings that were designed and constructed years ago. The National Center for Preservation Technology and Training identifies SLR as a major threat to historic buildings in coastal areas. Though the benefits may be difficult to quantify, retrofitting historic or otherwise culturally significant buildings enables North Carolina to preserve the integrity of vulnerable, culturally significant, economically valuable resources.

Feasibility Considerations: Given the interest that many North Carolinians have in the State's history, a strategy that promotes historic preservation is likely to be socially and politically feasible. However, the costs associated with the retrofitting of historic structures can complicate the evaluation of this strategy statewide, and may hinder its administrative feasibility. It is also difficult to determine in a quantitative manner the benefits of protecting these types of structures or sites. Historical or sentimental value is difficult to assess and may be greater than the benefits associated with damages avoided through the retrofitting of such structures.

A quantitative assessment of these structures can be accomplished. First historic and culturally significant structures located in areas subject to coastal flooding and SLR inundation should be identified and prioritized in order of their importance and/or need to be protected. Next, an assessment of these properties should be conducted to determine the best retrofit strategy and its associated costs. Once structures are identified the data from the IHRM program can be used to determine the location of historic and culturally significant structures in the coastal floodplain and assess first-floor elevations, square footage, and other relevant features needed to assist in the cost estimation of varied strategies.

Potential Implementation Mechanisms: The Coastal and Estuarine Land Conservation program, housed in NOAA, and FEMA's Environmental Planning and Historic Preservation program could be used to help implement this strategy. In addition, the HMGP and PDM Program may be used to retrofit at-risk historic properties. Through the State HMP and regular interactions as part of acquisition and elevation projects across the State, the State Hazard Mitigation Officer (SHMO and State Historic Preservation Officer (SHPO) should to work together to implement this proposed strategy.

Strategy 6.2: Protect site-specific cultural resources from the effects of coastal flooding and SLR in order to maintain their economic and social vitality.

Description: In addition to their often quantifiable economic benefits, iconic historical sites are culturally and historically significant to coastal communities and the State overall. A number of strategies may exist to preserve cultural resources such as lighthouses or Coast Guard stations in the face of coastal erosion and SLR, including relocating or retrofitting structures or adopting protective measures through nourishment or hardened structures such as groins or sea walls.

Feasibility Considerations: The implementation of this strategy at the project level is dependent upon the location and type of structure and the financial and technical feasibility of the protective measure proposed. Typically, hard structures such as sea walls or revetments are expensive, must be maintained over time, and often require accompanying nourishment projects to protect the beach in front of them. The relocation of structures, on the other hand, allows for the natural migration of the coastline, but requires the potential acquisition of public landholdings for the new location if in fact the culturally significant site can or should be relocated. (Some sites are culturally significant due to their physical location.) The relocation of the Cape Hatteras Light Station 2,900 feet from the spot on which it was built in 1870 due to high rates of coastal erosion provides a prominent example of this FIMS. Since the 1930s, efforts had been made to protect the lighthouse from the encroaching sea, with a series of groins and nourishment projects implemented to counteract erosion.

Potential Implementation Mechanisms: At the State level, the North Carolina Department of Cultural Resources maintains 27 historic sites in addition to other archeological sites. The North Carolina Division of Parks and Recreation, within the Department of Environment and Natural Resources, manages a number of culturally significant parks, including the Fort Fisher State Recreation Area, Carolina Beach State Park, Hammocks Beach State Park, Fort Macon State Park, and Jockey's Ridge State Park. Neither the *Systemwide Plan for NC State Parks* (2009) nor the *General Management Plan for Carolina Beach State Park (*January 2007) address increased storminess or SLR. The National Park Service, as described in the capability assessment of the North Carolina SLRIS, conducted an assessment of the relative coastal vulnerability of the National Park units to SLR. This study quantifies the likelihood that physical changes to Parks Service assets will occur. Like in the previous FIMS, an assessment of existing structures should be considered to determine whether protective measures should be undertaken.

Strategy 6.3: Flood proof existing coastal health care facilities.

Description: Given the central role that hospitals play in addressing the impacts to public health following flood-related events, it may make sense to consider these facilities separately from other critical infrastructures. Not only are more resilient health care facilities better able to care for patients before an event, but they are also better able to treat those injured during floods. By floodproofing existing coastal health care facilities, such as the coastal area's primary hospital in New Hanover County, the State can improve the immediate and long-term wellness of coastal residents.

Feasibility Considerations: Though floodproofing standards will likely vary depending on the location and type of construction, this figures to be a costly strategy. Depending on the extent of the floodproofing required, some retrofits could cause temporary interruptions in service at certain facilities, impacting its ability to provide high quality health care.

Potential Implementation Mechanisms: In the past, FEMA PDM grants have been used to flood proof hospitals elsewhere in the southeast, including Charleston, South Carolina. This program could be similarly applied in North Carolina. Additional programs include HMGP and the PA 406 Program, which provides funds to incorporate hazard mitigation into the repair of public facilities like hospitals.

Strategy 6.4: Remediate coastal Superfund brownfield sites in order to prevent increased contamination due to run-off.

Description: North Carolina's coastal counties contain seven brownfields designated as Superfund sites, which EPA identifies as housing hazardous substances that may endanger public health. During floods, the hazardous substances from these contaminated sites can run off into coastal waterways, presenting significant risks to recreational and drinking water sources. By targeting these brownfields sites for remediation, North Carolina can address this threat to public health. North Carolina has a history of addressing water pollution caused by surface water runoff. After Hurricane Floyd, the Clean Water Management Trust Fund initiated a voluntary buyout of swine farms in the 1%-annual-chance floodplain to limit the amount of agricultural pollutants entering State rivers. Similarly, the DENR acquired junkyards in the floodplain after Hurricane Floyd. While administrative lessons can be applied from these post-disaster initiatives, this strategy proposes taking a more proactive pre-disaster approach, focusing on Superfund sites that are likely to be inundated in the future due to SLR.

Feasibility Considerations: Though brownfield remediation is a costly strategy, sites that receive Superfund designations are eligible for funding from EPA and, in some cases, the Department of Defense. The availability of Federal funding could greatly enhance the economic, as well as administrative and legal, feasibility of this strategy.

Potential Implementation Mechanisms: The DENR Superfund Section, which investigates uncontrolled and unregulated hazardous waste sites, provides a strong organizational implementation mechanism.

Strategy 6.5: Identify and support industries that could experience growth as a result of changing coastal hazards.

Description: SLR, increased coastal flooding, and erosion are likely to increase disaster related losses in the coastal zone of North Carolina. In some cases, these changes in coastal conditions can also offer enhanced economic opportunities for those organizations that offer goods and services that will be needed by coastal communities, businesses, and individuals. The Alaska Adaptation Strategy, for example, features a section on evaluating the potential expansion of arctic economic activities, including increased shipping and fishing in areas formerly occupied by large ice floes. Similarly, North Carolina could identify industries that might experience growth as a result of changing conditions, such as eco-tourism, outdoor recreation, and certain types of fishing. Construction firms that provide expertise in structural elevation as well as engineering and planning firms may see an increase in business as communities and businesses attempt to protect at-risk properties and infrastructure as part of a larger climate change adaptation /risk reduction strategy. Similarly, communities, businesses, and individuals may be forced to confront SLR impacts and the potential occurrence of coastal storms resulting in additional work tied to disaster recovery and reconstruction activities.

Feasibility Considerations: The growth of support industries is likely to be a somewhat organic process, developing as opportunities are identified over time. Creating or expanding existing North Carolina Department of Commerce Job Development Investment Grant and One NC Fund programs used to attract businesses in the State might be explored relative to what may become an emerging niche market in a State particularly vulnerable to SLR and coastal storms.

Potential Implementation Mechanisms: The North Carolina Division of Emergency Management is the primary organization involved in the mitigation planning process. The State might consider requiring local governments to include SLR in their HMPs. If this approach is undertaken, the State should commit the resources needed to assist local governments assess their vulnerability and develop appropriate projects designed to reduce their exposure / impact to this hazard. The data developed as part of this study would provide a good source of how coastal hazards may evolve. The University of North Carolina Chapel Hill Coastal Hazards Center's development of the Climate Change Handbook for Local Governments identifies potential mitigation strategies that might be considered. Training, education and outreach efforts may be used to increase local capacity to address potential SLR and increased storminess in their HMPs, including the formation of strong implementation measures.

Strategy 6.6: Require communities to incorporate an assessment of sea level rise impact and the formulation of SLR impact strategies into local hazard mitigation plans.

Description: The 2010 update of the North Carolina Statewide HMP covers long-term hazards, including SLR and climate change. However, few local HMPs in the State assess the impact associated with SLR or include strategies to reduce flood vulnerability associated with changes in sea levels. This finding is consistent with a national study of State and local coastal hazard mitigation plans that found few local plans include climate change adaptation measures (UNC, Chapel Hill).

Feasibility Consideration: Local communities have the authority to include SLR in their HMPs and develop mitigation strategies to reduce coastal flood impacts. FEMA recently developed a climate change policy memo and the FEMA Hazard Mitigation Planning Handbook encourages communities to consider climate change in their assessment of impact and development of mitigation projects.

Potential Implementation Mechanisms: The North Carolina DEM is the primary organization involved in the mitigation planning process. The State might consider requiring local governments to include SLR in their HMPs. If this approach is undertaken, the State should commit the resources needed to assist local governments assess their vulnerability and develop appropriate projects designed to reduce their exposure / impact to this hazard. The data developed as part of this study would provide a good source of how coastal hazards may evolve. The University of North Carolina Chapel Hill Coastal Hazards Center's development of the *Climate Change Handbook for Local Governments* also represents a positive step. The guide should be supplemented by training, education, and outreach efforts focused on building an increased local capacity to address SLR and increased storminess in their HMPs, including the formulation of strong implementation measures.

5.2 What Strategies Perform Best?

A sub-set of the strategies was defined in Section 5.1 and were analyzed further by attempting to quantify potential costs and benefits associated with implementation. SLR, a non-stationary hazard, presents many challenges in assessing the costs and benefits of any particular strategy. Calculations were simplified to the extent possible due to data limitations, and a number of assumptions were necessary to sufficiently narrow the analysis to fit within the scope of this study. These strategies were assessed as if they were implemented today at the time of the analysis (2010) and as if implementation was deferred to year 2025. In order to perform an analysis of costs and benefits, it was necessary to interpolate between the study's modeled annualized flood losses over two distinct SLR "curves." The figures that follow depict the curves chosen for this analysis. The present value of the benefits (generally the losses avoided) was calculated using a discount rate of 7%. Costs and benefits are in 2009 dollars and were not inflated prior to applying present value. The authors acknowledge the limitations of the applicability of the results of the analysis performed. In practice, assessing the costs and benefits of particular adaptation strategies should necessarily involve the gathering of the most robust and up-to-date data at the highest resolution possible and input from a variety of stakeholders to garner the most complete accounting of all costs and benefits.

TABLE 23. PROJECTED INCREASE IN SEA LEVEL BASED ON HISTORICAL AVERAGE AND HISTORICAL HIGH SLR RATES IN NC.

Modeled Year	Historical Average (cm)	Historical High (cm)
2010	0	0
2025	3	10
2050	9	20
2075	15	30
2100	20	40

Of the strategies evaluated quantitatively, two strategies emerged as yielding large benefit to cost ratios: the strategy to relocate critical facilities outside the 100-year coastal floodplain and the strategy to elevate existing and proposed critical facilities located in the 100-year coastal floodplain. It is clear that this would be an expensive proposition in the case of existing facilities; the large benefits that would accrue from this strategy underscore the value in applying it for proposed critical facilities.

5.2.1 Strategy: Acquire property subject to coastal flood inundation and maintain the property as open space in perpetuity.

Assessing Benefits and Costs: The study team narrowed its quantitative analysis of this strategy to assessing the costs and benefits associated with acquiring property within the 4%-annual-chance floodplain (25-year floodplain) and maintaining the land as open space in perpetuity. To do this, the team determined from the project database which structures were within the specified floodplain. Table 24 indicates benefits, costs, and an estimated benefit-cost ratio (BCR) for both historical average and the historical high SLR curves. The methodology applied mimics the FEMA module, though the calculations were done outside the module. A cost-beneficial effective strategy requires the BCR to be greater than 1.

TABLE 24. BENEFITS AND COSTS FOR ACQUIRE PROPERTY STRATEGY IMPLEMENTED IN 2010 AND 2025*

Strategy implemented year 2010			
Scenario	Benefits (present value)	Mitigation Project Costs	BCR
Historical Average	2,885,529,000	2,424,197,000	1.2
Historical High	3,112,960,000	2,417,708,000	1.3
Strategy implemented year 2025			
Historical Average	1,112,165,000	2,423,849,000	0.5
Historical High	1,310,411,000	2,423,849,000	0.5

*Values rounded to nearest thousand

Assumptions:

1. Mitigation costs (the costs assumed for acquiring the impacted properties), include only the replacement values of the impacted structures. These were assumed to be a reasonable representation of fair market value. Land parcel maintenance (mowing, etc.) was not considered within the costs.

2. Land value data was not available and was not incorporated into the mitigation cost values shown in the tables above. In order to remain cost beneficial, total land value for the structures evaluated here would need to be 19% of the structure replacement value or lower.

3. Benefits for the strategy were flood losses avoided (building losses, building contents losses, indirect losses) by removing the structures.

4. To simplify calculation, the useful life of the strategy was considered to span from the year implemented until year 2100.

5.2.2 Strategy: Elevate existing and proposed critical facilities located in coastal flood hazard areas above the base flood (1-percent-annual-chance flood) elevation to account for differing SLR scenarios.

Assessing Benefits and Costs: The study team narrowed its quantitative analysis of this strategy to assessing the costs and benefits associated with elevating electric power stations above the future BFE. Electric power stations represented a clearly critical facility for which good geospatial data was available for the analyses.

To do this, the team determined from its structures database which power facilities were potentially impacted by a 1%-annual-chance flood now or in the future (through the end of the century) based on the SLR curves used for this study. Table 26 indicates benefits, costs, and an estimated BCR with this strategy for each SLR curve. A cost-effective beneficial strategy requires the BCR to be greater than 1.

TABLE 25. BENEFITS AND COSTS FOR ELEVATE CRITICAL FACILITIES STATEGY IMPLEMENTED IN 2010 AND 2025*

Strategy implemented year 2010			
Scenario	Benefits (present value)	Mitigation Project Costs	BCR
Historical Average	1,415,520,000	60,708,000	23.3
Historical High	1,363,053,000	90,122,000	15.1
Strategy implemented year 2025			
Historical Average	487,348,000	55,708,000	8.7
Historical High	487,974,000	90,122,000	5.4

*Values rounded to nearest thousand

Assumptions:

1. Mitigation costs for this strategy are construction costs associated with elevating the impacted structures; 50% of the structure's replacement value was used as a rough and simplified estimate of these potential costs. In reality, the costs to elevate a building could vary considerably from structure to structure based on construction type and other site-specific factors.

2. Benefits included annualized flooding losses avoided and loss of services avoided; it is assumed that facilities are elevated to a level so as to avoid any future damage under a particular SLR curve.

3. Loss of services avoided was calculated using FEMA-approved equations for loss of electrical service. It was further assumed that the per capita per day cost for each facility ($134.26 in 2012 dollars) is computed by dividing the number of power plants in a county by that county's total population and that a particular facility could be brought back online within 6 months of an outage occurring, where:

*Loss of services = cost per capita per day * population per facility * number of damaged facilities * number of days facility (service) is out of commission*

5.2.3 Strategy: Elevate existing roads, prioritizing roadways that connect critical facilities or serve as evacuation routes, and that are located in the 100-year floodplain and/or are subject to SLR inundation.

Assessing Benefits and Costs: The study team narrowed its quantitative analysis of this strategy to assessing the costs and benefits associated with elevating two roadway segments 1 and 2 feet above their current elevation. Two 1-mile segments were arbitrarily chosen: US 76 (Oleander Drive) and Carolina Beach Avenue. Both segments are located in New Hanover County.

Approximate construction costs and construction time estimates associated with elevating roadways were provided by the NCDOT. These were developed based on rough estimates for elevating "typical" or representative 1-mile segments of U.S. and State routes. Assumptions made in developing these simplified estimates are described below. It is important to note that in practice, roadway construction costs and time may vary substantially from project to project.

Losses avoided include that of traffic delays and the associated value of lost time resulting from such delays in the event of road closure due to flooding. This considers lost wages, average traffic counts for a particular roadway, and persons per vehicle. These would only truly be loses avoided if at some point in the future a particular segment of roadway would be flooded and/or permanently inundated if elevation were not to occur. Depending on the length of time a roadway is out of commission, these losses could be quite sizeable. For this example, the authors estimated this time to be the construction time (as shown in Table 28) necessary to elevate the roadway segment.

The table below summarizes those most easily quantifiable benefits and costs. A number of other potential costs and benefits are much more difficult to value and have been omitted from our calculations. For instance, valuation of keeping a roadway or roadway segment that also acts as an

TABLE 26. ELEVATE ROADWAYS STRATEGY CONSIDERATIONS

Strategy Considerations	Value	
Person passenger	0.82	
Wage rate	28.11	
Commercial	0.18	
Persons per vehicle	2.3	
Estimated Construction Time (Per 1 Mile)	**Raise Road 1 foot**	**Raise Road 2 feet**
U.S. Routes (months)	5	7.5
NC Routes (months)	3.5	4.5
Traffic Count (daily)		
US 76 (OLEANDER DR)	25,000	
CAROLINA BEACH AVE	1,400	
Value of Lost Time Avoided (due to traffic delays/detours)		
Vehicle per hour	38.14527	
US 76 (OLEANDER DR)	$3,364,413,000	$5,046,619,000
CAROLINA BEACH AVE	$131,885,000	$169,566,000
Construction Cost (Per 1 Mile)	**Raise Road 1 foot**	**Raise Road 2 feet**
NC Routes (months)	$2,000,000	$2,300,000
U.S. Routes (months)	$4,500,000	$5,700,000
Benefit Cost Ratio	**Raise Road 1 foot**	**Raise Road 2 feet**
US 76 (OLEANDER DR)	1,682	2194
CAROLINA BEACH AVE	29	30

evacuation route open and free from flooding is a difficult undertaking. Estimating potential impacts to surrounding businesses due to construction or as a result of flooding/inundation of the roadway segment serving the businesses are important considerations, but extraordinarily complicated to analyze.

Assumptions:

1. Mitigation costs for this strategy are estimated construction costs associated with elevating "typical" or representative 1-mile roadway segments. In reality, the costs to elevate roadways could vary considerably from roadway to roadway based on any number of site-specific factors.

Additional construction cost assumptions made:

- Costs do NOT consider right-of-way cost or utility relocation
- Costs do NOT consider cost of raising existing bridges on the highway, or intersecting structures
- Assumes future-year bridges are designed to accommodate SLR (and are thus not replaced)
- Cost adds a 55% factor onto calculated costs made from quantities (accommodates drainage retrofits, intersection retrofits, and other incidentals)
- Raising by 1 foot assumes incremental "wedging" and shoulder rebuild while attempting to maintain traffic
- Raising by 2 feet assumes reconstruction with detour (either on highway or separate route)
- Construction method and cost assume that 2-foot raise is constructed at one time
    - o Existing pavement is removed prior to reconstruct
    - o Variable pavement thickness & structure depending on route classification

2. Benefits included avoidance of lost time due to detours associated with potential future flooding or inundation. These estimates were developed using FEMA equations (FEMA, 2011).

5.2.4 Strategy: Relocate critical facilities outside the 100-year coastal floodplain.

Assessing Benefits and Costs: The study team narrowed its quantitative analysis to assessing the costs and benefits associated with relocating existing electric power stations outside the 1%-annual-chance floodplain. Again, electric power stations represented a clearly critical facility that was easy to identify and analyze. To do this, the team determined from its structures database which power facilities were potentially impacted by a 1%-annual-chance flood now or in the future through the end of the century. Table 29 indicates benefits, costs and an estimated BCR with this strategy for each SLR curve. A cost-effective beneficial strategy requires the BCR to be greater than 1.

TABLE 27. BENEFITS AND COSTS FOR CRITICAL FACILITIES STRATEGIES IMPLEMENTED IN 2010 AND 2025*

Strategy implemented year 2010			
Scenario	Benefits (present value)	Mitigation Project Costs	BCR
Historical Average	1,407,798,000	70,098,000	20.1
Historical High	1,407,968,000	70,098,000	20.1
Strategy implemented year 2025			
Historical Average	508,391,000	70,098,000	7.3
Historical High	497,714,000	70,098,000	7.1

*Values rounded to nearest thousand

Assumptions:
Benefits included annualized flooding losses avoided and loss of services avoided by having relocated the impacted facilities.

1. It is assumed that the facilities will be re-built outside future 1%-annual-chance floodplains.
2. Loss of services avoided was calculated using FEMA-approved equations (FEMA, 2011) for loss of electrical service. It was further assumed that the per capita per day cost for each facility ($134.26 in 2012 dollars) is computed by dividing the number of power plants in a county by that county's total population and that a particular facility could be brought back online within 6 months of a flood-related outage occurring. It should be emphasized that the value placed on loss of services for other types of critical facilities may vary substantially, where:

   *Loss of services = cost per capita per day * population per facility * number of damaged facilities * number of days facility/service is out of commission*

3. Mitigation costs are based on the replacement value of the structure. It was assumed that these costs are reasonable representations of the magnitude of those costs associated with rebuilding the facility outside of the floodplain.

5.2.5 Strategy: Continuation of freeboard requirements for all new buildings within the 100-year coastal floodplain.

Assessing Benefits and Costs: The study team narrowed its quantitative analysis of a freeboard strategy to assessing the costs and benefits associated with requiring new buildings are constructed above the future BFE at year 2100. To do this, the team determined from its structures database which “future” structures (an explanation of these can be found in Section 4.2.3) were potentially impacted by a 1%-annual-chance flood through the end of the century under the two separate SLR curves. This strategy was also evaluated with a 1-foot freeboard requirement (Table 30) and a 2-foot freeboard requirement (Table 31). Each table provides benefits, costs, and an estimated BCR with this strategy for each SLR curve. A cost-effective beneficial strategy requires the BCR to be greater than 1.

TABLE 28. BENEFITS AND COSTS FOR 1-FOOT FREEBOARD STRATEGY IMPLEMENTED IN 2010 AND 2025*

Strategy implemented year 2010			
Scenario	Benefits (present value)	Mitigation Project Costs	BCR
Historical Average	75,768,000	36,917,000	2.1
Historical High	118,281,000	48,533,000	2.4
Strategy implemented year 2025			
Historical Average	49,144,000	36,917,000	1.3
Historical High	91,658,000	48,533,000	1.9

*Values rounded to nearest thousand

TABLE 29. BENEFITS AND COSTS FOR 2-FOOT FREEBOARD STRATEGY IMPLEMENTED IN 2010 AND 2025*

Strategy implemented year 2010			
Scenario	Benefits (present value)	Mitigation Project Costs	BCR
Historical Average	156,976,000	36,917,000	4.3
Historical High	220,879,000	48,533,000	4.6
Strategy implemented year 2025			
Historical Average	99,166,000	36,917,000	2.7
Historical High	163,068,000	48,533,350	3.4

*Values rounded to nearest thousand

Assumptions:

1. Benefits included annualized flooding losses avoided; to simply calculation, it was further assumed that all impacted structures were elevated to a level so as to avoid any future damage under a particular SLR curve.
2. Costs are the increased cost of construction required for accommodating freeboard; in practice, this is expected to vary significantly from structure to structure but for analysis purposes, this was assumed as being 50% of the replacement value of the impacted structures.

5.3 How Were the FIMS Developed and Evaluated?

The FIMS were produced by developing three primary outputs. First, the team analyzed existing State-level adaptation programs, preparing case studies on Maryland, California, and Florida to see how existing management strategies could guide the formulation of FIMS for North Carolina. Next, to identify the process through which North Carolina could begin to implement an impact management strategy at the State level, research was performed to define roles, responsibilities and authority associated with SLR for State and Federal agencies.

Given the complexity of planning for SLR at the State level, it is informative to study the experiences of other States that have pursued or implemented their own statewide sea level adaptation initiatives. Of course, no two States share the same geographical, sociocultural, or political landscapes, and it is crucial to avoid applying wholesale the lessons learned in one place to another. With this in mind, the statewide planning approaches for SLR exhibited in Maryland, California, and Florida suggest a host of strategies, tools, policy options, and potential pitfalls, the knowledge of which might benefit North Carolina. This study reviewed and utilized, where appropriate, possible options that might be appropriate in North Carolina.

6 LESSONS LEARNED

Throughout the development of this study, the study team interacted with a diverse array of resources, subject matter, analytical tools, and data. Challenges were evaluated within the contextual goals of the overall effort and solved according to the resources, constraints, and objectives of the SLRIS. This section seeks to document some of the greatest challenges to future projects on similar subject matter and areas of future research.

Geomorphology Change – The SLRIS team spent significant effort into researching methodology for implementing geomorphic change, especially barrier island and shoreline evolution. This effort concluded that existing methodologies are limited, subjective, and/or founded in historical trends that may not hold for future conditions. For these reasons, barrier island and shoreline change were not addressed in a holistic manner. Future research in this subject area would assist other SLR impact studies that seek to include these processes.

Population Projection – Projecting future trends in population is a challenging topic and subject to many external dependencies that are also difficult to project. In many aspects, it is nearly impossible to predict with certainty any population increases without making sweeping assumptions about future socio-environmental conditions. Although the population projections presented have been made with careful consideration of a variety of input variables and the expert opinion of the Demographics Office of the North Carolina Office of State Budget and Management, there are still numerous questions that can be raised regarding the future makeup of the coastal population. It is recommended that future research focus on identifying, at the finest scale possible, the major drivers of population growth in coastal areas, especially with regard to land consumption and suitability.

Land Use and Development – The approach utilized in SLRIS to project future development was born out of the need to distribute a growing population over a shrinking land area with a range of suitability. More weight was given to land that was developed near existing development, causing urban areas to expand. It is debatable whether in the long term such an approach is sustainable for our urban areas, especially with concerns regarding coastal access as traffic increases and more roads are threatened by flooding. Further research is needed on these dynamics, as well as identifying with more defined certainty the types of development likely to occur with changing populations.

Database Structure and Data Management – The SLRIS leveraged a robust database structure that that housed the asset data and allowed calculation of flood impacts. An issue that was encountered was that this framework was not designed to efficiently compare results across multiple scenarios. This resulted in several instances of the database to accommodate the multiple scenarios, which in turn impeded comparison of results. We recommend that future efforts of a similar scale and complexity structure the database in a manner that incorporates the appropriate structures to efficiently manage multi-scenario data.

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APPENDIX A: HAZARD ASSESSMENT DETAILED RESULTS

A-1 Changes in Marsh Vegetation

TABLE A-1. CHANGE IN MARSH VEGATATION BY COUNTY IN UNITS OF SQ MI IN RESPONSE TO 40 CM SLR.

County	Upland	Fresh Marsh	High Marsh	Salt Marsh	Brackish Marsh	Beach	Flat	Water	Cypress Swamp	Tidal Swamp
Beaufort	-10.5	-0.1	9.1	9.8	0.0	0.0	0.7	1.2	0.0	-0.1
Bertie	-1.1	0.0	18.8	19.9	0.0	0.0	0.0	0.0	0.0	0.0
Brunswick	-1.3	-1.4	0.3	-5.4	0.0	-1.1	7.0	4.7	0.0	-0.1
Camden	-2.1	0.0	22.1	13.0	0.0	0.0	0.4	0.7	0.0	0.0
Carteret	-4.1	0.0	-0.3	-6.1	-1.0	-3.4	1.6	14.2	0.0	-0.1
Chowan	-0.9	0.0	3.4	5.9	0.0	0.0	0.0	0.0	0.0	0.0
Craven	-2.5	-0.4	5.7	7.7	0.2	0.0	0.1	0.4	0.0	-0.3
Currituck	-22.1	-0.1	24.8	11.6	1.2	-0.3	2.6	5.1	0.0	-2.4
Dare	-10.0	-2.4	54.3	13.8	-0.7	-1.4	4.6	3.7	-0.1	-0.2
Gates	-1.3	0.0	15.3	12.2	0.0	0.0	0.0	0.0	0.0	0.0
Hertford	-2.0	0.0	6.0	10.6	0.0	0.0	0.0	0.0	0.0	0.0
Hyde	-68.3	-1.4	74.1	37.6	-0.4	-0.7	5.4	3.8	-0.3	-0.1
New Hanover	-1.3	-0.7	0.7	-6.8	0.0	-0.4	6.2	3.7	0.0	-0.1
Onslow	-3.1	-0.1	0.2	1.0	-0.1	-0.9	4.0	2.5	0.0	-1.0
Pamlico	-3.4	-0.5	4.5	1.8	0.0	0.0	0.6	1.9	0.0	0.0
Pasquotank	-4.1	0.0	6.4	10.8	0.0	0.0	0.0	0.0	0.0	0.0
Pender	-1.2	0.0	1.8	-6.0	0.0	-0.4	5.4	3.3	0.0	0.0
Perquimans	-4.0	-0.1	2.6	12.7	0.0	0.0	0.0	0.0	0.0	0.0
Tyrrell	-40.0	-0.5	78.8	66.6	0.0	0.0	0.1	0.2	-0.1	-0.2
Washington	-3.0	0.0	11.8	11.4	0.0	0.0	0.0	0.0	0.0	0.0

A-2 Changes in Floodplain, by Frequency

TABLE A-2. CHANGE IN FLOOD EXTENTS FOR ALL FLOOD FREQUENCIES AS COMPARED TO TODAY'S CONDITIONS IN RESPONSE TO AN INCREASE IN SEA LEVEL OF 20 CM. UNITS IN SQ MI.

County	MHHW (Inundated)	10%	4%	2%	1%	0.2%
Beaufort	8.8	18.2	19.0	17.8	17.0	21.2
Bertie	24.8	5.0	1.8	1.8	2.2	1.8
Brunswick	4.9	2.0	2.3	2.6	2.6	2.6
Camden	8.5	6.2	4.0	4.6	6.1	11.4
Carteret	20.6	32.2	24.8	26.2	27.8	21.0
Chowan	2.4	1.3	0.9	1.2	1.4	1.4
Craven	11.2	4.8	5.4	6.5	7.2	7.8
Currituck	11.6	21.2	7.5	7.5	7.5	9.0
Dare	19.8	62.3	33.5	19.4	14.1	11.2
Gates	10.5	2.3	1.5	1.4	1.5	2.2
Hertford	7.7	1.4	1.4	1.3	1.5	1.5
Hyde	12.9	105.5	53.0	34.8	24.0	15.2
New Hanover	4.9	1.4	1.4	1.3	1.3	1.2
Onslow	9.9	3.2	3.0	3.0	3.3	3.5
Pamlico	11.8	17.8	11.7	11.3	11.5	13.7
Pasquotank	6.2	4.7	6.6	8.1	8.7	9.6
Pender	8.4	2.0	2.6	2.3	2.3	3.3
Perquimans	4.5	2.3	2.1	2.1	2.6	3.2
Tyrrell	49.3	46.2	37.2	33.4	25.6	10.6
Washington	8.3	3.5	4.3	7.6	6.6	6.5

TABLE A-2. CHANGE IN FLOOD EXTENTS FOR ALL FLOOD FREQUENCIES AS COMPARED TO TODAY'S CONDITIONS IN RESPONSE TO AN INCREASE IN SEA LEVEL OF 40 CM. UNITS IN SQ MI.

County	MHHW (Inundated)	10%	4%	2%	1%	0.2%
Beaufort	30.8	35.5	35.2	34.0	35.3	43.7
Bertie	36.7	7.3	3.8	4.0	4.1	3.6
Brunswick	8.9	5.2	5.2	5.9	5.9	6.3
Camden	34.1	10.3	8.8	11.2	16.0	24.2
Carteret	57.3	57.1	52.5	56.6	57.8	37.8
Chowan	6.4	2.3	2.2	2.6	2.6	2.9
Craven	17.4	9.9	11.8	13.4	14.9	14.7
Currituck	46.5	29.7	15.3	15.8	16.7	21.0
Dare	113.2	102.1	52.8	33.6	28.6	28.7
Gates	26.5	3.9	3.0	3.1	2.9	4.0
Hertford	13.6	2.7	2.8	2.8	3.1	3.2
Hyde	150.5	172.0	86.5	59.1	43.8	30.3
New Hanover	9.4	3.1	3.1	3.0	3.0	3.0
Onslow	16.5	5.8	5.9	6.1	6.4	7.2
Pamlico	38.2	29.9	23.6	24.2	25.1	28.6
Pasquotank	11.7	10.9	15.0	17.0	18.0	20.1
Pender	13.7	5.1	6.1	5.9	5.9	6.8
Perquimans	7.8	4.4	4.4	4.9	5.5	7.6
Tyrrell	135.8	87.9	72.3	57.4	40.0	19.6
Washington	20.5	7.1	12.0	13.6	12.6	13.4