

PLANNING FOR  
SEA LEVEL RISE VULNERABILITY  
IN NORTH CAROLINA

by  
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## **Abstract**

Global sea level rise and local subsidence may result in relative sea level rise (SLR) in North Carolina of approximately 20 to 106 centimeters (approximately 8 to 42 inches) or more by 2100. The project on which this paper is based aimed to examine the State's vulnerability to SLR and possible policy responses, as well as to develop a framework for presenting associated information to stakeholders that takes into account sound risk communication theories and practices. SLR will intensify erosion, flooding, property damage, and wetland destruction; and it will also redefine the boundaries of floodplains. While shoreline change can be modeled, limited conclusions can be drawn from such models because of uncertainty about the natural forces and human decisions that affect the shoreline. This paper argues that those interested in the future of the North Carolina coast should start, as soon as possible, to educate the public about the potential implications of SLR and the risks to coastal residents and properties. Planning ahead for SLR and its consequences will give communities more options and reduce costs. Hurdles to educating policy-makers and the public about North Carolina's vulnerability to SLR and to fostering discussion of potential responses should be surmountable if appropriate entities take the lead and necessary financial and technical resources are provided. This paper recommends a framework that could serve as a useful starting point for this endeavor. Among other things, the author recommends that strategies for communicating about North Carolina's vulnerability to SLR be crafted in advance, with care, and in a manner that involves physical and social scientists, risk communication experts, coastal managers, and representatives of different target audiences.



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## LIST OF ACRONYMS

**AEC** – Area of Environmental Concern

**CAMA** – Coastal Area Management Act

**CFM** – Coastal Flooding Model

**CHPP** – Coastal Habitat Protection Plan

**CRC** – Coastal Resources Commission

**CRS** – Community Rating System

**CZMA** – Coastal Zone Management Act

**EPA** – United States Environmental Protection Agency

**ETJ** – Extraterritorial Jurisdiction

**FEMA** – Federal Emergency Management Administration

**GIS** – Geographic Information System

**IPCC** – Intergovernmental Panel on Climate Change

**LIDAR** – Light Detection and Ranging

**NCAC** – North Carolina Administrative Code

**NC DEM** – North Carolina Division of Emergency Management

**NC DCM** – North Carolina Division of Coastal Management

**NFIP** – National Flood Insurance Program

**NOAA** – National Oceanographic and Atmospheric Administration

**NOAA CO-OPS** – National Oceanographic and Atmospheric Administration Center for Operational Oceanographic Products and Services

**NOAA CSCOR** – National Oceanographic and Atmospheric Administration Center for Sponsored Coastal Ocean Research

**NOAA OCRM** – National Oceanographic and Atmospheric Administration Office of Ocean and Coastal Resource Management

**NSF** – National Science Foundation

**SAV** – Submerged Aquatic Vegetation

**SLR** – Sea Level Rise

**USACE** – United States Army Corp of Engineers

**USGS** – United States Geological Survey



## Chapter 1

### Introduction

There is unequivocal evidence that global temperatures are increasing and sea levels are rising. Between 1906 and 2005, global average temperatures rose by 0.74°C. The best estimates scientists at the Intergovernmental Panel on Climate Change (IPCC) can agree upon indicate that, by 2100, global average temperatures will increase by another 1.8°C to 4.0°C. Most of the warming in at least the past 50 years is very likely due to the increase in greenhouse gas (i.e., any gas that contributes to global warming) concentrations contributed by human activities. Greenhouse gas emissions are expected to continue, probably at a higher rate than current emissions (IPCC 2007).

Based on those tide gauges that have recorded data for more than 150 years, it appears that sea level rose 0.025 to 0.076 meters (m) (2.5 to 7.6 centimeters) more in the 20<sup>th</sup> century than the 19<sup>th</sup> century (EPA 2006a, citing IPCC 2001). Over the entire 20<sup>th</sup> century, global average sea level rose an average of 0.17 m (an average of 0.17 centimeters per year [cm/yr]). Between 1961 and 2003, the rate of SLR increased to an average of 0.18 cm/yr; the rate was higher, an average of 0.31 cm/yr, for the last 10 years studied (1993 to 2003). These data suggest that the rate of sea level rise (SLR) may be accelerating (IPCC 2007).

In early 2007, the IPCC released estimates of potential future SLR. Its models indicate that, by 2090 to 2099, global average sea level will be 0.18 m to 0.59 m higher than levels in 1980-1999 (for simplicity, described hereafter as SLR by 2100, compared to the level in 2000). These estimates assume that ice sheets in Greenland and Antarctica will continue to melt at the rates observed over approximately the past 10 years. If the rate of melting increases at the same rate as global temperatures increase, then SLR might be 0.1 to

0.2 m greater than these projections. However, “[l]arger values [for SLR] cannot be excluded, but understanding of these effects [e.g., unexpectedly rapid melting of the ice sheets] is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise” (IPCC 2007).

This paper argues that coastal managers should start, as soon as possible, to educate the public about the potential implications of SLR and the risks to coastal residents and properties. Some social scientists have urged that society’s response to global climate change comprises the largest uncertainty associated with its repercussions (Moser 2005). Whether, when, and how those who care most about the effects of SLR begin educating others about these issues will affect not only how decision-making about possible responses is approached, but will also influence the timing and quality of dialogue about these concerns.

Chapter 2 of this paper explores the complexities associated with predicting the effects of global climate change and SLR on the oceans and coasts. The chapter then outlines the potential threats posed by SLR, such as increased flooding, erosion, and wetlands loss. Next, it describes specific strategies coastal communities affected by SLR could adopt. Public education about these alternatives, including their costs and benefits, would permit more informed decision-making and engender support for and public participation in planning for the future.

Because of the planning requirements associated with many of the options for responding to SLR, the chapter suggests that it would be desirable to begin to plan for SLR as soon as possible. For example, considerable long-term cost savings could result from making decisions about infrastructure construction and maintenance that anticipate future

SLR. Further, not acting now could foreclose future response options. This chapter also suggests that involving the public in selecting strategies for responding to rising waters would likely lead to greater community acceptance of whatever decisions are made.

Communities can make the most intelligent decisions about how to respond to SLR, given anticipated costs and benefits, the author believes, only if they fully understand the implications of SLR and possible responses to it.

Primarily in Chapter 3, the paper addresses how SLR might affect North Carolina's coastal zone. First, the chapter presents an outline of available data on past and potential future rates of relative SLR (i.e., global SLR plus subsidence) along different parts of North Carolina's coast. The chapter also describes various research efforts that have been conducted or are underway that address past and potential future rates of SLR, along with associated effects, focusing primarily on erosion and land loss patterns, as well as wetland behavior.

There are at least two major, federally-funded research projects focusing on future shoreline change in North Carolina that are being carried out largely by researchers at universities in North Carolina. The results of these studies should provide a more refined picture of potential future shoreline change than currently available data. In the interim, the current paper makes use of a geographic information system (GIS) dataset created by Poulter to model areas that might be inundated by SLR in North Carolina.

Chapter 3 next outlines North Carolina's coastal zone management policies that are relevant to planning for and adjusting to SLR. These include regulations associated with developing along the oceanfront, estuarine shorelines, and wetlands, as well as a requirement for local land use plans (nominally, at least) to take into account future SLR.

Two efforts to focus on how SLR will affect certain portions of North Carolina are then presented. The first, funded in part by the U.S. Environmental Protection Agency, addresses the likelihood that stakeholders will attempt to protect coastal property in certain parts of North Carolina from the effects of SLR (e.g., using seawalls, fill, and/or beach nourishment), and in which areas protection efforts are unlikely. The second is a GIS analysis the author performed, using Poulter's currently-available flooding model, to determine which parts of Morehead City and the surrounding area over which the City has zoning jurisdiction could be inundated by SLR. In particular, this analysis focuses on the amount of land area potentially flooded, including the types of land use that will be affected, to give the City information about potential reductions in property values, streets that will need to be shored up or repaired, etc. The author suggests, in addition, that Morehead City would be an excellent location for risk communication about the local effects of SLR to begin because several stakeholders that might potentially become involved in this type of outreach are already located in Morehead City or nearby.

There is no doubt that risk communication about SLR is inherently challenging. This topic, among others, is addressed in Chapter 4, particularly in the context of coastal North Carolina's vulnerability to SLR. Risk is everywhere, though the types, immediacy, and seriousness of different risks vary. Because of the heterogeneity of different sectors of our society, people interpret risks, risk messages, and appropriate responses to risks differently. Chapter 4 discusses these issues and describes important principles associated with the process of communicating about SLR vulnerability.

Scientific debate about SLR may have led the public to misunderstand the fact that risks from SLR are certain. While they might seem imprecise, indefinite, or imperceptible to

some, the author suggests that the general contours of the risks should not necessarily be difficult to understand if they are explained carefully. Appropriate responses to SLR for different communities are, nevertheless, potentially quite controversial, in part because of their social and economic effects, which favor some sectors of society and some interests over others.

Chapter 4 includes an outline of general principles of designing and implementing effective public outreach and risk communication programs. Among other things, the author recommends that communication strategies be crafted in advance, with care, and in a manner that involves physical and social scientists, risk communication experts, coastal managers, and representatives of the different target audiences. Any communications strategy should also cover who the communicators and audiences will be, what messages and how much information will be communicated, what media will be used, where and how information dissemination will occur, and how often it will occur. Among other things, this paper urges that risk messages be clear, focused, targeted, and come from multiple sources; be communicated repeatedly over time; and take advantage of different media to maximize the number of people reached effectively.

Chapter 5 very briefly synthesizes the information presented and reiterates the paper's most important conclusions and recommendations.



## Chapter 2

### Global Climate Change, SLR, and Their Effects on the Coasts

#### 2.1 Background: On Predicting the Effects of Global Climate Change on the Seas

There are considerable uncertainties associated with estimating global SLR, even aside from the question of how much warming will occur to drive SLR (IPCC 2007; Rahmstorf 2007). Some scientists have argued that IPCC estimates described at the beginning of Chapter 1 are too conservative, especially their estimates associated with the contributions from glaciers and ice sheets. Some of these scientists have pointed out that the glaciers draining ice from the ice sheets in Greenland and Antarctica have been moving away from the ice sheets to warmer water at increasing rates, some of them doubling in speed in the last 5 to 10 years (Kerr et al. 2007). The volume of water in the ice sheets is vast, and total melting of the ice sheets would raise sea level around the world by 65-70 m (Cazenave 2006; Rahmstorf 2007). Melting of the Greenland ice sheet alone would cause sea level to rise by approximately 7 m (23 ft) (IPCC 2007); some research has estimated that this ice sheet could fully melt within the next millennium (Overpeck et al. 2006).

Beyond IPCC reports, a variety of studies have been published that project potential future SLR. For example, a scientist at the Potsdam Institute for Climate Impact Research recently published a study pointing out that the rates of SLR for recent decades predicted by existing models generally underestimate actual rates. This scientist created a different model to interpret the potential consequences of the IPCC's six warming scenarios, which produced a best estimate of potential SLR from 0.55 to 1.25 m by 2100; including the statistical error for the model produces a range of 0.5 to 1.4 m of SLR (Rahmstorf 2007). Another recent study projected, based on evidence from the last interglacial period, that the rate at which the

ice sheets might melt will be more rapid than many have estimated, leading to “many meters of sea level rise” “well before the end of this century” (Overpeck et al. 2006). Some SLR will occur even if greenhouse gas emissions were stabilized in 2030. If that were to occur, the IPCC predicted (in 1990) that sea level would rise by 0.18 m by 2030 and a total of 0.41 m by 2100 (IPCC 1990).<sup>1</sup>

Several factors cause sea level to rise. Currently, the primary factor is thermal expansion of the oceans as a result of increases in the temperature of ocean waters (IPCC 2007). (The ocean is thought to have absorbed, over approximately the past 50 years, more than 80% of the heat added to the climate system [IPCC 2007].) The temperature of the oceans determines the density and volume of their waters (Barth and Titus 1984). The second most important factor contributing to SLR is the melting of glaciers and ice caps, which adds additional water to the oceans. Finally, melting ice sheets in Greenland and Antarctica have a substantial impact on raising global average sea level (IPCC 2007). In many areas, SLR is compounded by coastal subsidence, which can be caused by tectonic forces and sediment compaction, as well as humans draining land or withdrawing fluid from it, among other factors (USGS 2004). The United States Geological Survey (USGS) reports that in southern Louisiana, land is subsiding at a rate on the order of 1 cm/yr,<sup>2</sup> and that the highest observed subsidence rates on the Gulf Coast are in Port Neches, TX, where land subsided at a rate of 3 cm/yr over a 22-year period (USGS 2002).

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<sup>1</sup> In the 1980s, some studies indicated that global average temperatures might rise by as much as 9°C by 2100, a significantly higher estimate than current projections. Past sea level rise projections were also considerably higher than current projections. In 2001, the IPCC had projected that the total sea level rise between 1990 and 2100 might range from 0.09 m to 0.88 m, with a central value of 0.48 m (IPCC 2001). Some U.S. Environmental Protection Agency (EPA) projections, particularly in the 1980s, evaluated increases in sea level of 0.5, 1, and 2 m by 2100 and indicated that a 1 meter increase was the most likely (Titus and Narayanan 1995).

<sup>2</sup> It should be noted that other studies report other rates. See, e.g., “Coastal Louisiana in crisis: Subsidence or sea level rise?” in *Eos*, 7 November 2006, 87(45): 493-508.

Scientists have observed an increase of intense hurricane and tropical storm activity in the North Atlantic since approximately 1970, which they indicate is associated with higher ocean temperatures. The IPCC projects that it is likely that hurricanes and tropical storms will be more intense in the future (i.e., peak wind speeds will increase, as will heavy precipitation) as a result of increasing temperatures (IPCC 2007). Increases in hurricane intensity would likely cause increased storm damage to coastal communities, including erosion damage.

Global climate change could have numerous other effects on the oceans. For example, it is expected to affect their salinity and acidity (IPCC 2007). Levels of primary productivity in the upper layers of the ocean are thought to be linked to temperature, light intensity, and ocean circulation, among other factors. Productivity could decline as a result of higher water temperatures and lower light levels reaching some areas (because of higher sea level). However, the relationship between climate change and productivity is complex, and it is still being studied (Lange, Burke, and Berger 1989).

## **2.2 Potential Consequences of SLR**

SLR is projected to increase erosion rates, which will be variable across different parts of the shoreline. In addition, SLR is expected to inundate low-lying areas, subject larger areas to flooding, and increase tidal ranges. These effects translate into increased property damage to coastal residents and taxpayers, as well as potential adverse effects on coastal recreational opportunities. Other potential effects of SLR include destroying wetlands, increasing the salinity of estuaries, causing saltwater intrusion into aquifers, and decreasing the amount of light reaching the sea floor. Additional information about these threats is provided in this section.

*Erosion.* Coastal erosion caused by SLR, storms, and other factors will exacerbate the effects of global climate change on coastal communities. Erosion can lead to property damage, as well as loss of valuable coastal real estate, recreational opportunities, and tourism. Already approximately 70% of the sandy coasts around the world are experiencing net erosion, some of which can be attributed to SLR (Vellinga and Leatherman 1989). Further erosion would cause the land lost from a 1-meter increase in sea level to be greater than that suggested by looking at maps of lands that are lower than 1-meter in elevation, for example.

Erosion occurs as waves pass over beaches, pick up sand or sediment, and carry it, in suspension, back out to sea, or across the beach, further inland. Large waves formed during storms cause increased erosion by picking up sand and other materials from parts of beaches and dunes that are above the usual reach of the waves. SLR will allow the waves to reach further inland. However, when conditions are calm, much of the sand carried offshore is gradually returned to the portion of beaches that the waves reach. In this way, erosion and accretion at a single location can alternate. Because major erosion tends to occur only after storms and the behavior of storms is variable over time, erosion rates at a single location frequently vary over time (Riggs 2001).

Some research suggests that as sea level rises, the shoreface retains an equilibrium shape. The shoreface is defined as the portion of the beach affected by wave-driven transport, ranging from the most landward point sand is washed up to during storms to the most seaward point, underwater, where waves still pick up significant bottom sand and sediment. As a result, when the sea level rises, this model suggests that some of the eroded sand will fall to the base of the shoreface so that it maintains its original shape, shifted

upward and landward, except along barrier islands (Zhang, Douglas, and Leatherman 2004; A.B. Murray, Duke University personal communication, March 14, 2007). Some scientists have disputed this model, however. They have pointed out, for example, that the composition of the sediments and rocks underlying the shoreface can affect the patterns of coastal erosion and deposition, as can lateral transport along the shoreline, over barrier islands, etc. These critics have also argued that an equilibrium profile might never be maintained (see, e.g., Pilkey et al. 1998).

Changes to the coastlines are further complicated by the fact that waves washing some sand onto land (by a process called overwash), particularly during storms, can increase the elevation of the coast, as overwash repeatedly piles sand from the nearshore environment on top of itself on the beach. Overwash is a particularly important force in barrier island systems, as noted below. Overwash can cause more rapid erosion (NRC 1988). In addition, sand is transported along the coast (this is termed alongshore transport). Alongshore transport is affected by the shape of the coastline and the angle at which waves encounter the shore, among other factors. Therefore, alongshore transport will also affect the future shape of the coastline. The amount of erosion caused by SLR, wave action, and tides will also differ depending on shoreline type (e.g., rocky or sandy, made up of barrier beaches, cliffs, or marshes) and sand supply (e.g., whether there are offshore shoals) (Riggs 2001; U.S. Global Change Research Program 2003). Finally, the activities of and structures built by humans (e.g., shoreline stabilization efforts and roads) affect the behavior of waves, sediment supplies, the transport of sand, and the durability of the coastline.

*Flooding, Higher Storm Surge, and Higher Tidal Ranges.* Future SLR will cause some coastal lowland areas to be flooded most or all of the time, and others to be flooded

only when tides are at the high end of their range. The more gradual the slope of the coastline, the further inland the shoreline will migrate due to SLR alone (before factoring in additional erosion) (Zhang, Douglas, and Leatherman 2004). Wave size could also change in areas where the water depth is sufficiently shallow that it limits wave heights (Titus 1990b). Irregular flooding due to storm surge will also be increased as a result of SLR, because this surge will start from a higher base than it does currently and hence could reach further inland (Gornitz 1991; Titus 2003). (Storm surge refers to the difference between the maximum water height observed during a storm and the expected height due to normal tidal activity [NC DEM 2004a].) Thus, it seems likely that storm damage will increase due to global climate change regardless of whether storms occur more frequently or with greater intensity than they have in the past. This means that disaster relief costs will probably also increase (Barth and Titus 1984). Low-lying island nations are particularly at risk from flooding.

Flooding will threaten infrastructure and property, possibly causing property values to decline. SLR threatens numerous coastal roads, some of which already become flooded during the highest high tides. The drainage ditches that drain some coastal roads also might become less effective due to SLR. This too may increase flooding, particularly if precipitation intensity or levels increase (both possible effects of global warming because warmer sea water fuels more intense tropical storms and warmer air can hold more water vapor) (Titus 2003). Roads affected by severe erosion or flooding, if not raised or otherwise protected, could cut off routes into and out of communities (Titus 2003). There will also be impacts on navigation. For example, bridges that large boats pass through now with little clearance may not longer be usable by these same boats as a result of higher sea level.

Furthermore, SLR will also mean that the areas (e.g., portions of rivers) that are tidally-influenced will change (Titus 1990b).

A 1989 study estimated that the total value of all property in the United States threatened by inundation from a 0.5 m rise in sea level was \$138 billion (in 1990 dollars). Property that could be inundated by a 1 m rise in sea level was valued at an estimated \$321 billion (in 1990 dollars) (Yohe 1989). Flooding also poses a threat to farming in low-lying coastal areas, as well as to low-lying hazardous waste disposal sites (Barth and Titus 1984). It could also reduce coastal recreational opportunities (e.g., because of shrunken beaches or reduced fish populations dependent on coastal wetlands, a risk noted below) and decrease tourism, a major industry in many coastal areas (U.S. Global Change Research Program 2003).

*Increases in Salinity and Saltwater Intrusion.* A larger tidal range will likely result in saltwater reaching further inland and upstream than it does currently. SLR could also cause higher salt levels, which some species cannot tolerate, in estuaries and other water bodies (Titus 1990b). When salinity changes appreciably, species composition could change. For example, some scientists have argued that increases in salinity in Chesapeake and Delaware Bays are among the reasons oyster harvests have been reduced in these water bodies (Ramsar 2002; Hull and Titus 1986). Furthermore, saltwater is toxic to some freshwater plants (Riggs 2001). If droughts became less frequent, increased rainfall might prevent or offset salinity increases in some water bodies (Hull and Titus 1986).

Another potential effect of SLR is saltwater intrusion into aquifers. In many coastal areas, there is an underground freshwater lens over top of saltwater. One model indicates that because saltwater is 1.025 times denser than the freshwater, this lens would be expected

to be 40 times thicker than the elevation of the water table above mean sea level. As a result, every centimeter that sea level rises reduces the thickness of the freshwater lens by 40 cm. In other words, the capacity of freshwater lenses overlaying saltwater can be reduced by 40 times the amount of SLR (Gornitz 1991). This model may not apply to aquifers that are strongly influenced by groundwater pumping or that have complex geometries (Sorensen, Weisman, and Lennon 1984). Even in the absence of SLR, groundwater is already sometimes pumped at a higher rate than the rate of fresh water recharge, leading to saltwater intrusion in coastal areas (Universities Council on Water Resources 2006).

Saltwater intrusion into rivers could also threaten drinking water supplies. In some areas (e.g., New York City), communities draw their water from parts of rivers just upstream from the part that is salty during droughts. SLR has the potential to move the freshwater-saltwater interface upstream, which could mean that some existing water intakes might pump saltwater or brackish water they are not equipped to process during droughts. Furthermore, some aquifers that hold groundwater used by communities are recharged by rivers that might become salty in the future (EPA 2006a). There are, it should be noted, a variety of techniques that could be used to prevent or reduce saltwater intrusion into aquifers. These range from augmentation of stream flow during droughts (to maintain a freshwater flow that helps keep saltwater from migrating upstream), to creation of physical barriers to saltwater intrusion, to injection of freshwater into the aquifer to raise water levels and counteract saltwater intrusion, to extraction of saltwater before it reaches freshwater, to changes in pumping patterns (Sorensen, Weisman, and Lennon 1984). Alternatively, communities could build desalinization plants, but these are particularly expensive (Barth and Titus 1984).

Finally, saltwater intrusion can affect agricultural fields, making them no longer productive. In some locations, drainage ditches were installed in the past to drain wetlands for agriculture, silviculture, and mosquito control. These ditches can contribute to inland flooding, saltwater intrusion, and wetland degradation (Poulter 2005). When saltwater reaches peat (in wetlands), it can trigger a chemical reaction (sulfate reduction) that dissolves the peat, causing rapid elimination of wetland ecosystems (S. Riggs, East Carolina University, personal communication, February 22, 2007). Therefore, in some areas, organizations have been taking steps to prevent saltwater from backing up into drainage ditch networks (Poulter 2005).

*Impacts on Barrier Islands.* Barrier islands are islands with the sea (ocean, gulf, or similar waterbody, hereafter ocean) on one side and a bay or sound on the other. The term comes from the fact that the island serves as a barrier between the ocean and the bay or sound. On the ocean side of barrier islands, one often finds beaches and sometimes dunes behind them. Most of the marshes are found on the bay side, because it is difficult for them to form and persist in high-energy environments with strong waves (Mitsch and Gosselink 2000). As sea level rises, the waves tend to wash sand from the ocean side of a barrier island to the bay side, particularly during storms. This overwash process causes barrier islands to “roll over” or “migrate” towards the bay side. New land can therefore be built on the bay side from the sediment removed from the ocean side (Pilkey et al. 1998). Equally importantly, the sediment washed to the middle of the island tends to increase the total height of the island, helping the island survive SLR. Not all barrier islands have survived SLR; some have disintegrated, such as the Chandeleur Islands, which had reached more than 6 m

in elevation in places during the first half of 2005, before Hurricane Katrina (Sallenger et al. 2006).

Where barrier islands are developed, humans tend to interrupt natural overwash processes. Sand overwashed onto roads or private property tends to be bulldozed back to where it came from, usually to form or reinforce the dunes on the ocean side of an island. In other words, after a storm, dunes may be restored, but the sand scoured from beaches may not be returned to them, and there is no growth of the barrier island on the back (bay) side. As one can imagine, this is not sustainable indefinitely. Because new sand is not added to compensate for the loss of all sand in areas affected by scour or inundation, including on the bay side, barrier islands will tend to narrow. In addition, because most land surfaces are already covered with pavement or buildings and property owners typically do not want sand on their lawns, the overall height of barrier islands does not grow from overwash, making them more vulnerable to SLR. While most states have programs to place sand back on their ocean-side beaches to counteract erosion, only Delaware, Mississippi, and New Jersey routinely add sand to even some of their bay-side beaches (Titus 2000). SLR could increase sediment transport and deposition in some areas, removing sand from others at higher rates than those presently observed (Riggs 2001).

*Changes to Deltas, Banks, and Channels.* The changes to hydrologic regimes that might result from SLR could affect sediment distribution. This includes the quantity of sand deposited into deltas, the locations of channels, and the location of offshore banks. Deltas are built from sediment transported by rivers and the sea and often require additional sediment input to keep from sinking. If levees are built along the banks of rivers, they deprive the floodplains of sediment that might help the floodplains keep pace with SLR and

counteract any natural subsidence. Dams also deprive the deltas themselves of sediment and can exacerbate subsidence due to sediment compaction (IPCC 1990).

*Effects on Submerged Aquatic Vegetation.* Submerged aquatic vegetation (SAV) stabilizes shorelines via several mechanisms, including by trapping and binding sediment, as well as baffling waves. In addition, SAV serves as important habitat; some fish and shellfish depend even more on SAV than they do on wetlands. SAV growth and distribution is linked to water depth, light levels that penetrate down to the plants, salinity, waves and currents (especially those driven by storms), biological disturbances, and other factors. Given that SLR will affect water depth, light levels, and fresh water inflow, at a minimum, SAV will undoubtedly be affected (Auer 2004).

*Wetland Destruction.* Wetlands, including mangrove swamps, and other nearshore vegetation, including SAV, can also buffer communities from the effects of storms because they increase friction and can slow waves. They also trap sand and slow down erosion (Riggs 2001; Titus 1990b). Therefore, the destruction of coastal wetlands can increase coastal flooding and storm damage. An oft-quoted statistic is that every 2.7 miles of coastal wetlands can reduce storm surge by 1 foot, on average (see, e.g., LA DNR n.d.), but this can be widely variable.<sup>3</sup> Some types of wetlands are more crucial for buffering purposes than others, and this depends on a variety of factors (EPA 2006b). Salt marshes and mangroves are particularly effective at buffering coastal storms (Mitsch and Gosselink 2000).<sup>4</sup>

Wetlands also serve many important functions within ecosystems and for human communities. For example, wetlands are among the most productive ecosystems in the

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<sup>3</sup> However, some scientists have questioned the research supporting this statistic, which was conducted in 1963 (J. Pahl, Duke University, personal communication, November 21, 2006).

<sup>4</sup> While coastal wetlands tend to slow down waves due to friction, it must be recognized that flooding adjacent to wetlands can be greater, in some cases, than it would be were there deeper, open water (A.B. Murray, Duke University, personal communication, August 25, 2006).

world. They provide important habitat for a variety of species, important feeding grounds for many migratory birds, and nurseries for many types of fish. Wetlands also improve water quality by absorbing nutrients and pollutants from water. In addition, wetlands can absorb stormwater and release it gradually, thereby reduce flooding. More than 95% of commercially-harvested fish are dependent on wetlands, typically as nursery and feeding areas (Mitsch and Gosselink 2000). Therefore, wetland loss can have economic impacts on the seafood industry. Because many wetlands store large amounts of carbon, their destruction could exacerbate global climate change over the long term (Ramsar 2002; Mitsch and Gosselink 2000). Scientists are in the process of studying wetland response to SLR, as well as the potential future effects of SLR on coastal wetlands (e.g., Kirwan and Murray 2007, as well as NOAA CSCOR 2006b).

Wetlands can potentially survive SLR in two different ways. First, in some areas, peat and sediment will be able to accrete on top of existing wetland areas at a sufficient rate to keep up with SLR. In many areas, wetlands accretion has been able to keep pace with SLR thus far, although this is not true in coastal Louisiana, for example. Whether this will continue depends on the rate of SLR, type of vegetation present, and concentration of suspended sediment. Changes to any of these factors could disrupt the current equilibrium (Kirwan and Murray 2007). Depending on the rate of future SLR, it may be that only a minority of coastal wetlands can keep up with it. Second, some newly-flooded areas adjacent to wetlands that were formerly uplands have the potential to become wetlands, offsetting the expected loss in coastal wetlands. Also, some coastal wetlands can migrate inland. This cannot occur in areas where the slope is too steep, however (USGS 1997). In most places, it appears that the area available for wetland creation in the region inland from and at slightly

higher elevations than current wetlands is much smaller than the size of the wetlands expected to be lost. Developed land is unavailable for conversion to wetlands, as are areas behind seawalls, bulkheads, levees, and similar structures that are intended to keep the land behind them dry. In some densely developed areas, there may be virtually no undeveloped land that could be converted to wetlands in the future (Titus 1988).

Existing studies of the potential effects of SLR indicate that it could destroy large areas of coastal wetlands by drowning them or causing them to become saltier more quickly than they can adjust to. One study, cited by the IPCC in 2001, reported that a 0.38 m increase in relative sea level could convert from 6% to 22% of coastal wetlands across the world to open water, and a 1 m increase could destroy 25% to 26% of coastal wetlands (IPCC 2001; Nicholls et al. 1999). A 1991 study estimated that if communities try to protect residential and commercial areas from the effects of SLR (e.g., by constructing seawalls), a 0.5-m increase in sea level would cause 20% to 45% of all coastal wetlands to be lost in the U.S., and a 1-m increase in sea level would cause 29% to 69% of U.S. coastal wetlands to be lost. Even if communities did nothing to try to protect developed areas, almost as high a percentage of coastal wetlands in the United States might be lost (from 17% to 43% for a 0.5-m increase and from 26% to 66% for a 1-m increase SLR). The change in the area of wetlands across the U.S. from a 1-m SLR scenario includes a projected 22,500 square kilometers (km) of existing wetlands lost and 6,700 square km of wetlands created from the inundation of areas that were formerly dry land (Titus et al. 1991; Titus 2000).

*Ongoing Research.* Numerous studies of the potential effects of SLR are ongoing across the world. A listing of national and international studies is beyond the scope of this paper, but studies that address effects on North Carolina are described in the next chapter. It

should be noted that for more than a decade, there has been a national effort to study the effects of climate change on the U.S., called the U.S. Global Change Research Program. Recently, the U.S. Climate Change Science Program has been supplementing the work of the Global Change Research Program. The former is currently working on a study of coastal elevations and SLR, which will synthesize information from independent mapping projects by a variety of organizations that address the implications of SLR. The study will focus on the Atlantic coast, from New York to North Carolina. It will address which lands could be inundated, how erosion and coastal processes might affect future shoreline shape, at what rate wetlands can possibly accrete, what lands would be expected to require future protection, and what lands could be available for wetland migration. The products of this project will include quantitative data on coastal elevations, shoreline erosion, wetland accretion, and areas where the shore is likely to be protected. Qualitative case studies about the impacts of SLR on communities will also be presented. Finally, the report's authors will propose a plan for additional SLR research to answer questions that appear to be most urgent in the short-term, so policy makers can make informed decisions (U.S. Climate Change Science Program 2006). Within its Climate Change Division, EPA has a small team assigned to an ongoing SLR project, the mission of which is to "accelerate the process by which the U.S. coastal zone prepares for the long-term consequences of rising sea level" (Titus 2003). The staff assigned to this project also coordinates a variety of studies associated with SLR.

### **2.3 Possible Responses to SLR**

The above discussion of the effects of SLR on coastal wetlands alludes to the fact that the effects of SLR will vary depending on how humans respond. There are a variety of ways in which humans might choose to respond to the effects of SLR. First, communities can

attempt to adapt to SLR, while protecting existing development. To do so, they can either: (1) hold back the sea using seawalls, bulkheads, and similar structures and/or adding sand to their beaches, or (2) elevate structures and perhaps try to elevate wetlands and beaches, as well. Second, communities can “allow nature to take its course” and attempt to retreat from the shoreline (Titus 2003). The discussion below addresses these potential responses.<sup>5</sup>

Many would argue that it would behoove communities to decide how they are going to respond now, rather than allowing residents to act *ad hoc*, and before the effects of SLR become severe. At a minimum, communities might want to avoid actions that increase their vulnerability to SLR. Many of the possible planning measures would be easier to implement proactively now, rather than reactively later, or can only be implemented proactively, such as prohibiting bulkheads or requiring that homes be built in such a way that they are moveable. Sometimes design considerations can take into account the likelihood of future SLR. For example, seawalls can be built in a fashion that allows for relatively inexpensive future modification (e.g., increasing their height) (IPCC 1990). Similarly, construction or maintenance of other types of infrastructure that takes into account future SLR also could result in future cost savings. If a community decides that it is not going to protect a certain area, the government might invest less money on infrastructure or plan for it to have a shorter lifespan than infrastructure in areas that will be protected.

Due to a variety of factors such as these, planning for SLR now generally would be expected to be significantly less expensive than responding to it in the future, and decisions made both in the past and today will influence future costs (IPCC 2001). However, if a

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<sup>5</sup> It should be noted that there is an additional set of possible responses, which includes all actions that can be taken to minimize sea level rise by mitigating the factors that cause global climate change, to the extent this is possible. These strategies primarily involve reducing emissions of greenhouse gases and are not included in this discussion.

desired response to future water levels can be delayed at no cost, it probably should be. Generally, it is usually engineering solutions that can be postponed, not land use decisions, because once development has occurred, it is unlikely to be abandoned—unless that was a part of the original plan (Titus 2000). In some cases, legal structures might have to be changed to accommodate some of the responses under consideration, another reason to begin planning early (IPCC 1990).

Coastal managers may find themselves having to balance economic concerns and the desires of private property owners, which tend to encourage unbridled development, with protecting people's interests and ecosystems in the long term by discouraging development that will have to be defended in areas susceptible to inundation and by taking steps to protect the long-term functioning of natural systems. These competing interests may lead to developing different plans for existing development and new development. Most importantly, managers might want to begin to educate the public about the potential effects of SLR so that private property owners understand the risks of owning, living on, or working on coastal property and so that communities appreciate the potential implications of SLR. Public education would allow coastal managers to begin to engender broad support for and public participation in planning for the future. Affected communities should be involved in selecting strategies for responding to rising waters, which should lead to greater community acceptance of the decisions that are made. Communities can make the most intelligent decisions that appropriately weigh costs and benefits only if they fully understand the implications of SLR and possible responses to it (IPCC 1990).

The Coastal Zone Management Subgroup of the IPCC argues, "It will take 10 years to implement plans, in view of the time required for the necessary analyses, training the

people, developing the plans and mobilizing the public and political awareness and support. Therefore, the process should begin today.” Moreover, “adaptive strategies may require lead times in the order of 50 to 100 years, to tailor them to the unique physical, social, economic, environmental and cultural considerations of a particular coastal area” (IPCC 1990).

*Protection.* Of the possible responses to SLR and erosion, protecting resources and societal investments via shoreline stabilization often appears to have the most *gross* economic benefits, at least in the short term (e.g., preventing property damage, loss of income from renters and tourists, and reductions in property value), but it may not necessarily have the most *net* long-term economic benefits because of associated capital, operation and maintenance, environmental, and social costs, depending on how the environmental and social costs are monetized. It is natural for people to want to protect beaches threatened by erosion, sea level rise, storms, or other factors. Beaches are highly valued for the recreational opportunities they provide. They also provide important habitat to a variety of species and protect other habitats, such as maritime forests, from direct exposure to ocean waves (Frankenburg 2006). They also afford some protection to coastal structures from damage inflicted by waves and storms.

To foster the longevity of beaches and reduce erosion hazards, shoreline engineering has been conducted, is underway, or is under discussion in many coastal communities (NRC 1990, 1995). Designing and implementing effective shoreline protection projects can be challenging, however. For a variety of reasons associated with their costs, benefits, design, effects, and effectiveness, shoreline stabilization efforts tend to be controversial (NRC 1995). Some detractors have emphasized that many “shoreline stabilization” projects, particularly hard stabilization approaches and bulldozing sand from the lower part of beaches to the upper

part, actually hasten erosion in front of them, sometimes rendering projects counterproductive. However, the apparent success of shoreline stabilization projects, at least in the short-term, often encourages additional coastal development (Pilkey et al. 1981).

In most coastal states, the U.S. Army Corps of Engineers is working with towns to place additional sand (often dredged from off-shore areas) on their beaches to offset the effects of erosion and SLR. These efforts to add fill to beaches, often called beach nourishment projects, maintain and widen recreational beaches and protect structures, including private homes. Some nourishment projects are conducted to protect infrastructure, such as bridges and roads. Beach nourishment is the only shoreline engineering strategy that addresses the sand budget, which is a major factor controlling the amount of erosion that occurs in some areas (NRC 1995). One disadvantage of this approach is that, in most places, the beach nourishment has to be repeated because the sand washes away, often as frequently as every 3 to 10 years (Pilkey et al. 1981). The supply of sand that fits the criteria for beach nourishment projects, in suitable locations to be mined, is limited. Therefore, future costs associated with obtaining and transporting sand, as well as beach nourishment projects as a whole, could rise considerably in the future (Pilkey and Coburn 2006). Most beach nourishment projects are funded partially by the federal government; typically, the federal government has covered 65% of their cost (USACE 2004b).

Beach nourishment projects can also have negative effects on the species that live in or on the sand (e.g., mole crabs) and the communities that depend on these organisms. These effects can be exacerbated when the sediment added to the beach is of a different type or grain size than the sand that had been there previously (Peterson, Hickerson, and Johnson 2000). Finally, beach nourishment disrupts habitats in the areas from which the sand is

mined, not only by scooping up animals and their habitats while dredging, but also by increasing turbidity. Constructing or rebuilding dunes is another method of using sand to stabilize the shoreline and protect property (IPCC 1990).

Other methods of enhancing resilience to waves include constructing wetlands, planting salt-tolerant species (e.g., bald cypress and sabal palm) to reforest inundated areas, planting seagrass, and creating artificial reefs, as well as controlling pollution, development, and other anthropogenic activities that degrade natural wetlands, cypress and mangrove swamps, seagrass beds, and reefs (IPCC 1990).

An alternate shoreline management strategy is to place hardened structures, such as seawalls, dikes, floodwalls, revetments, bulkheads, or similar structures between property and the waves. These have the benefit of being longer-lasting. However, the sand on the ocean-side of the hardened structures tends to get washed away, typically more rapidly than it would if the hardened structures were not present. This ultimately leads to the destruction of the beach in front of them (Pilkey et al. 1981). The National Research Council has indicated, “There are many examples of properly planned, designed, constructed, and maintained seawalls and revetments that have prevented further retreat of the shoreline, but beaches sometimes have been lost as a result” (NRC 1990, p.11). Not only do areas in front of hardened structures lose sediment, but areas adjacent to them also tend to erode because of the depleted sediment supply (Riggs 2001). As the NRC continues:

There are examples of properly planned, designed, constructed, and maintained detached breakwaters and groin fields that have been effective in the local control of coastal erosion; however, impacts on downdrift beaches must be considered. Beach nourishment is now the method of choice for beach preservation in many coastal communities (NRC 1990, p. 11).

Another issue that has been raised is that, if there are wetlands seaward of hardened structures, the wetlands will be unable to migrate inland as sea level rises. As a result, the wetlands can get “squeezed out” between open water and hardened structures. In other words, these structures tend to lead to the disappearance of beaches, wetlands, and other intertidal habitats, as well as public access to the beach, in some cases. If fishing were affected, there would also be economic impacts on fishermen (Titus 1990a, 2003).

Seawalls that are built to keep seawater out also can keep rainwater in, thereby increasing flooding after storms, an effect some areas have installed pumping systems to combat. These systems can be quite expensive (Titus 2003; Titus 1990a). Another problem with hardened structures is that many find beaches lined with seawalls and similar structures less attractive than those that are maintained via beach nourishment. Other structural stabilization techniques include levees built along river banks to protect adjacent property from being flooded when a river overflows and floodgates that are usually left open, but can be closed to prevent upstream flooding during storms (IPCC 1990).

EPA and the U.S. Army Corps of Engineers have issued nationwide permits and general permits that apply to most bulkheads (Titus 2000). However, recognizing their effect on beaches, some states have banned most or all hardened structures on ocean-side lots, including North Carolina, which passed such a rule in 1985. At least some of these states allow giant sandbags to be placed in front of property in imminent danger of being affected by oncoming waves (NOAA CSC 2000). These sandbags, which can be up to 7 tons in size, function in a similar fashion to hardened structures, except they are temporary, at least in theory. North Carolina’s rules require that sandbags be removed within 2 years, but the state has not been able to enforce this requirement (Pilkey and Stutz 2000). Some homes have had

to be moved or have fallen into the ocean despite attempts to use sandbags for protection. Many states have beach nourishment programs that tend to reduce the necessity of building seawalls, bulkheads, and similar structures. However, most state prohibitions against hardened structures do not apply to bay shorelines, and there are few nourishment programs for bays. Further, it is cheaper to build effective hardened structures on the bay side than it is on the ocean side. As a result, total loss of beaches and wetlands along the bay side is expected to be much greater in most states than loss of beaches on the ocean side. Some states have removed subsidies they offered property owners who built hardened structures (Titus 2000).

The federal government has long paid 65% of the cost of beach nourishment projects; the other 35% is paid by a project “sponsor,” such as the state or local government. Since there is no dedicated funding for beach nourishment in some states, including North Carolina, the local share is often sizable. However, the federal government has tried to reduce the percentage of the cost of beach nourishment projects that the U.S. government bears, and it may continue to do so. In 2003, the federal government began to cover only 50%, not 65%, of projects that are periodically renourished (but it still covers 65% of the initial nourishment) (NOAA CSC 2006). President George W. Bush has expressed support for a proposal made by President Clinton that the federal share be reduced to 35% (Associated Press 2002). Some might argue that trying to do so is wise in light of the fact that SLR will increase the amount of sand (and nourishment projects) required to protect homes and beaches.

A 1989 study estimated the cost of protecting all land developed in the United States (at the time) threatened by future SLR using beach nourishment and property elevation on the

open ocean and dikes on sheltered shorelines. It concluded that protecting existing development would cost \$55-\$123 billion for a 0.5-m rise in sea level and \$143-\$305 billion for a 1-m rise in sea level (Titus et al. 1991).

*Accommodation.* In some cases, planners and residents may decide to try to elevate structures, infrastructure (roads, bridges, pipelines, etc.) and even landscape features to preserve them in the face of SLR. The National Flood Insurance Program requires insured structures that sustain damage equal to more than 50% of their value to be elevated (Neumann et al. 2000). In addition, communities might institute strict building codes. There might be floor height requirements, minimum piling depths, and modified drainage requirements associated with new development (IPCC 1990).

Whether wetlands survive may depend on the rate of SLR and whether government or communities take any measures to foster wetland survival (Titus 2000, 2003). Artificially elevating wetlands (which would presumably then have to be replanted) tends to be expensive and has rarely occurred (Titus 2000). Communities already bearing the cost of elevating structures and associated infrastructure, where property values may have declined because of SLR, might be unlikely to take on the added cost of elevating or otherwise protecting wetlands. Alternatively, communities could set aside undeveloped land at an appropriate slope and elevation where wetlands could be naturally established as sea level rises. One author asserts that, “existing federal landholdings seem likely to facilitate wetland migration, even though no one considered rising sea level when the land was acquired. By contrast, the [Clean Water Act and the federal wetlands regulatory program do] not encourage activities to ensure that wetlands survive rising sea level . . .” (Titus 2000).

How long beaches survive may depend on a variety of factors, including rates of erosion and SLR, but unless more sand is added to them, many beaches will ultimately be inundated. If communities undertake both elevation and beach nourishment, they may be able to preserve both coastal property and the amenities of natural coastal shorelines (Titus 2000). However, this would require considerably more sand than simply protecting communities via beach nourishment (Titus 1990a).

Besides elevation, building code restrictions, and taking measures to ensure that there will continue to be viable coastal wetlands, there are a variety of other measures government can take to adjust to SLR. For example, local government could require additional flood proofing and restrict the uses permitted on the ground floor of existing buildings. Government agencies and utilities could also implement some of the previously-described methods for counteracting saltwater intrusion. Some agricultural lands could be converted to yield salt-tolerant crops, and some areas might become suitable for aquaculture. Importantly, various practices that exacerbate the adverse effects of SLR could also be prohibited. Finally, officials could expand existing storm warning and emergency preparedness plans that apply to coastal communities (IPCC 1990).

Flood insurance can be an important factor in areas that have selected a strategy of adaptation. It can cover some of the economic losses that accrue to landowners after damaging storms. However, some insurance companies are pulling out of coastal areas (Associated Press 2006). If insurance becomes difficult to obtain or considerably more expensive, this may encourage landowners to take whatever measures are necessary to make their properties less vulnerable, in order to qualify them for insurance. In this way, insurance requirements could affect people's behavior.

If they wanted to, insurance companies could make requirements to qualify for insurance more stringent. Indeed, many have argued that it is imperative to make changes to the National Flood Insurance Program (NFIP), which provides insurance to many coastal property owners. In some cases, these property owners might not otherwise be able to purchase insurance, because private insurers would not want to take on such a high risk property. Some of the shortcomings of the NFIP that have been identified include that it encourages building in high-risk areas, that it provides insurance at rates lower than the free market would dictate, and that it allows property owners to make repeated claims over time and repeatedly rebuild in flood-prone areas (Feldman 2006a). Congress noted, in 2004, that there were approximately 10,000 insured properties that had received four or more claim payments exceeding \$1,000 or for which multiple claims have totaled more than the property's assessed value. As of the late 1980s, approximately half of the properties with multiple claims were in coastal areas (Bunning-Bereuter-Blumenauer Flood Insurance Reform Act 2004).

*Retreat.* Communities can adopt a variety of strategies encouraging or requiring retreat from the shoreline. Very lightly developed areas may not require a planned retreat strategy, but a strategy may be needed in moderately to densely developed areas that have decided to retreat (Titus 2003). If governments do nothing else, they might remove subsidies and incentives for coastal construction, access, and insurance (IPCC 1990). Beyond that, planning to retreat might first involve forbidding development of undeveloped coastal lots or requiring construction setbacks (i.e., set back behind a certain line) based on elevation, past erosion rates, or even projected future erosion. Nine states (including North Carolina)

require new buildings to be set back from the shoreline by a distance equal to the amount of erosion expected over the next 30 to 60 years (Neumann et al. 2000).

To encourage retreat, rebuilding could also be curtailed. State or local government agencies could institute guidelines restricting rebuilding certain shorefront homes after they are destroyed by flooding or storms. Communities often oppose this type of restriction, which reportedly has rarely been implemented (Titus 1990a). Since 1988, South Carolina has required that buildings that sustain damages equal to more than two-thirds of their value not be rebuilt. However, most properties damaged extensively by Hurricane Hugo in 1989 were rebuilt anyway (Neumann et al 2000). One of the disadvantages of retreat is that it can compress inland populations (Van Arsdol et al. 2001).

One approach that facilitates retreat would be to establish construction guidelines that require that new homes be constructed in such a way that they are moveable. Some states have taken this further and implemented a policy of “presumed mobility,” sometimes described as a “rolling easements.” This type of policy allows property owners to build near the shoreline, on the condition that they (1) not build any shoreline stabilization structures and (2) move and remove any structure they have built if erosion or the encroaching shoreline makes continued use of it unsafe (Titus 1990b, 1998). In theory, this policy operates on the same principle as a conditional lease that allows occupation of a parcel up until sea level reaches a certain point. It gives property owners advance notice that they will have to vacate structures threatened by SLR. For example, communities might require structures to be moved once they are seaward of the first line of vegetation on the beach, a policy that has been adopted in Texas, which prohibits construction seaward of that line (Titus 1990a). Maine, South Carolina, and Rhode Island have also adopted some version of

rolling easements under some circumstances (EPA 2006a). These policies are based on the public trust doctrine, which holds, among other things, that navigable waters are owned by state, for the benefit of the public. In most states, public trust lands extend landward as far as the high water mark, although in some states it only extends as far as the mean low water mark (Kalo et al. 2002). For hundreds of years, courts have consistently found that the “law of accretion and reliction” holds that the boundary between public and private land migrates inland as the shore erodes (Titus 1998).

Rolling easements can be adopted in two different ways, one requiring property owners to be compensated for them, and the other at no cost to the state. In the latter case, states could simply clarify that one implication of public ownership of oceans and beaches up to the mean high water line (or mean low water line, whichever is state policy) is that people must remove privately-held structures once they begin to fall on public property. In other states, the state government may decide that it, the federal government (e.g., the U.S. Fish and Wildlife Service), or a non-profit organizations would need to purchase all rolling easements. But since these entities would be purchasing the right to the property at some point fairly far into the future (after the house is no longer safe to occupy, in some cases), one might argue that the cost of the easement should be discounted in the same way that economists typically discount future benefits, making the cost of a rolling easement fairly low. For example, the present value of \$1 million at a discount rate of 5% is \$750 (Titus 1998, 2000). One representative of the Nature Conservancy indicated that the Nature Conservancy tried for years to find a property owner interested in selling a rolling easement in North Carolina, but never located one (S. Pearsall, The Nature Conservancy, personal communication, January 31, 2007).

Some communities have chosen a more comprehensive approach to moving back from the shoreline, which might be called “managed retreat.” This planning decision for addressing high-risk areas may involve government or non-profit organizations buying threatened coastal properties so that they are no longer occupied. (Sometimes undeveloped parcels can be purchased to prevent development, but in densely occupied areas, undeveloped parcels may be rare.) Alternatively, managed retreat may entail communities setting thresholds that trigger requirements to demolish or move structures threatened by the sea and by continued erosion. Sometimes relocation assistance or buy-back programs for affected landowners accompany these requirements (NOAA OCRM 2006).

Retreat tends to have fewer negative environmental impacts than other responses to SLR, particularly shoreline stabilization. Preventing or removing development tends to conserve shorelines in their natural state. However, retreat probably has the greatest impact on communities (Titus 2003). For example, if people move far, neighborhoods, families, and traditions could be disrupted. In some cases, people might not feel welcome in the areas to which they have relocated (IPCC 1990). On the other hand, the level of anxiety created by moving might be less than would be experienced by people staying in their homes and finding the waves lapping up practically to their doorsteps.

It is understandably unpopular to abandon vulnerable areas, given how much people value living on the beach or having a view of it. In some areas, there may not be enough available land to allow all those who have to move to resettle in the same community or to continue to have direct beach access (IPCC 1990). At least one author has recommended that sand be added to the bay side of barrier islands (imitating natural overwash processes) to make up for the land lost by retreat from the ocean side, perhaps allowing some homes to be

moved to the newly-created land on the bay (Titus 1990a). Since this would cause bayfront property owners to lose the benefits of being adjacent to the bay, it seems unlikely that this option will be selected in many areas.

Retreat can also have significant economic costs. These include the costs of moving buildings and their contents, acquiring land to move coastal structures to, and the cost of acquiring new buildings for people and businesses to move to. In addition, communities potentially face declining property values and the cost of rebuilding infrastructure. On the other hand, the cost of storm damage might go down significantly if structures are moved away from the shoreline. There would also need to be significant institutional effort involved in formulating a retreat strategy, educating people about it, and implementing it (IPCC 1990)

Studies estimating the costs of retreating from the current shoreline, per se, seem to be limited. One 1996 study reports a variety of data that begin to create a picture of potential retreat costs. Specifically, given a 33-cm increase in sea level, the authors derived “annuitized estimates for the average cost of protection and abandonment run[nin]g from \$19 to \$26 million per year, and transient costs for 2065 [undiscounted protection costs and lost property values, respectively, expected in that year for] both [approaches that] round off to \$55 million” (Yohe et al. 1996, p. 403). This same study estimates the following costs associated with protection or retreat in response a 1-m increase in sea level: protection—\$160 million amortized; \$36.1 billion cumulative; and \$330 million in 2065; and retreat—\$190 million amortized; \$45.4 billion cumulative; and \$380 million in 2065 (Yohe et al. 1996).

Even retreat probably cannot prevent a large net loss due to SLR in the total area of coastal wetlands. This is because the area available to be converted to wetlands is probably

smaller than the area of wetlands at risk (IPCC 1990). Some would argue that this makes it all the more important for governments to identify areas that will be allowed to be converted to wetlands as sea level rises. Furthermore, given that they have not had decades or centuries to adapt to wetland conditions, newly inundated areas that become wetlands will not, at least initially, necessarily provide as good a habitat for organisms that live in or feed in wetlands.

## **2.4 Summary**

Global climate change, fueled by greenhouse gases in the atmosphere, is projected to have significant effects on coastal areas. Storm intensity is projected to increase, and sea level will continue to rise throughout the world. The IPCC projects that global average sea level will rise 0.18 to 0.59 m or more by 2100 (IPCC 2007). SLR and storms will continue to fuel erosion in coastal areas. Higher sea levels will also increase flooding, the reach of storm surge, tidal ranges, salinity in estuaries and rivers, saltwater intrusion, and the rate of wetland loss. SLR threatens barrier islands, particularly when natural overwash is interrupted or prevented.

Potential strategies for responding to SLR fall into three categories: protection (of development), accommodation (i.e., making changes to adjust to SLR), and retreat (i.e., moving back from the shoreline). This chapter discusses a variety of specific options for responding to SLR that fall within these three strategies. These options range from adding sand to beaches, to building bulkheads, to changing incentives associated with development, to mandating setbacks, to elevating structures, to preventing development in some areas, to curtailing rebuilding after damaging storms, to offering buyouts, to requiring people to move structures once they reach a certain proximity to the water's edge. Table 1 highlights the fact that decisions associated with planning and infrastructure in areas vulnerable to sea level rise

might vary depending on whether a community selects protection, accommodation, or retreat. The desirability of identifying areas wetlands will be able to migrate to and assisting wetlands with gaining elevation is also highlighted in this chapter.

**Table 1. Changes to Planning Activities Depending on SLR Response Strategy Selected**

Activity	Fundamental Response Strategy		
	Dike or Seawall	Elevate Land	No Protection Wetland Migration
Rebuilding drainage systems	Checkvalves, holding tanks room for pumps	No change needed	Install larger pipes, larger rights of way for ditches
Replace septic with public sewer	Extending sewer helps improve drainage	Mounds systems elevate septic system; extending sewer also okay	Extending sewer undermines policy; mounds system ok
Rebuild roads	Keep roads at same elevation; owners will not have to elevate lots	Rebuild road higher, motivates property owners to elevate lots	Elevate roads to facilitate evacuation
Location of roads	Shore-parallel road needed for dike maintenance	No change needed	Shore parallel road will be lost; all must have access to shore-perpendicular road
Setbacks/subdivision	Setback from shore to leave room for dike	No change needed	Erosion-based setbacks
Easements	Easement or option to purchase land for dike	No change needed	Rolling easements to ensure that wetlands and beaches migrate

Source: Titus 2005

Many factors associated with selecting response options to SLR suggest that it would be desirable to begin to plan for SLR as soon as possible. Acting now could result in considerable cost savings in the future, and not acting now could foreclose future options. Some have argued that, “It is urgent for coastal nations to begin the process of adapting to

SLR not because there is an impending catastrophe, but because there are opportunities to avoid adverse impacts by acting now, opportunities that may be lost if the process is delayed” (IPCC 1990). At a minimum, communities might want to avoid acting in ways that increase their vulnerability to SLR. Efforts to educate the public about the potential effects of SLR are needed to help stakeholders appreciate the risks. These efforts will also allow the public to participate in deliberations about how to prepare for and respond to SLR. Planning for SLR involves public discussion of the costs and benefits of potential responses, as well as the potential consequences of actions (and inaction). If all stakeholders are able to provide input before decisions about how to respond are made, this may increase the public acceptance of the decisions.



## Chapter 3

### Consequences of and Potential Responses to SLR in North Carolina

#### 3.1 Introduction

North Carolina has more than 500 km (300 miles [mi]) of coastline on the open ocean, as well as a total of approximately 6,400 km (4,000 mi) of estuarine shoreline (NC DCM 2001a, 2003a). The majority of North Carolina's estuaries are together known as the Albemarle-Pamlico Estuary System (APES), shown in Figure 1. The system includes the Albemarle, Currituck, Croatan, Roanoke, Pamlico, Core, Bogue, and Back Sounds, as well as five major river basins (the Chowan, Roanoke, Pasquotank, Tar-Pamlico, and Neuse) and many tributaries that enter the Sounds. The Neuse has a sufficiently large estuary that sometimes the Neuse Estuary is described separately from APES. APES is the second largest estuary in the eastern United States, with approximately 4,800 km (3,000 mi) of shoreline (Riggs 2001). A small portion of APES falls within southeastern Virginia.

Twenty counties in North Carolina are adjacent to the Atlantic Ocean, North Carolina's estuaries, or both. Most of these twenty counties are shown in Figure 1. Nearly 900,000 people, approximately 10 percent of the state's population, live in these counties (U.S. Census Bureau 2007). Coastal tourism contributes approximately \$2.8 billion/yr to the North Carolina economy (NC DCM 2004a). Property taxes in coastal counties provide a very important source of revenue to the counties.

**Figure 1. Albemarle-Pamlico Estuary System and Vicinity**



Source: Clay, Orr, and Stuart 1975

A significant proportion of North Carolina’s Outer Banks is publicly owned. Perhaps most well known is Cape Hatteras National Seashore, which includes portions of Bodie Island, Hatteras Island, and Ocracoke Island, extending from Nags Head to Ocracoke Inlet. The National Seashore does not include eight villages on these islands. Pea Island National Wildlife Refuge, on Hatteras Island, is managed separately from the National Seashore, by the U.S. Fish and Wildlife Service (National Park Service 2000). Cape Hatteras National

Seashore extends approximately 115 km (70 mi) (Pendleton, Thieler, and Williams 2005). Immediately to its south is the Cape Lookout National Seashore, which includes the southern 90 km (56 mi) of the Outer Banks. This includes the undeveloped islands of North Core Banks, South Core Banks, and Shackleford Banks, as well as Cape Lookout itself and its famous lighthouse (National Park Service 2005).

Considerable research is ongoing about the potential effects of future SLR on North Carolina. Some of this research simply documents past or projects future rates of SLR. Other research discusses the question of whether SLR might cause permanent breaches in the Outer Banks, as well as under what conditions and where these breaches might occur. Several studies focus on erosion, including research that extrapolates potential future erosion rates and patterns (based on a variety of factors, such as past erosion, lithography and other features of the shoreline, projected SLR, and future coastal storms). Finally, some studies have focused on the effects of SLR on North Carolina's wetlands.

The next section of this chapter presents many of these studies and summarizes their implications, in order to give readers a better idea of how SLR might affect the state. Section 3.3 provides background information about relevant coastal zone management policies in North Carolina. Section 3.4 presents information about the National Flood Insurance Program and selected funding sources for hazard mitigation. Next, section 3.5 provides some comments about a preliminary effort to assess potential responses to SLR in North Carolina. In section 3.6, examples of the types of resources at risk from SLR in one community are presented. Finally, section 3.7 summarizes this chapter.

### 3.2 How SLR Might Affect North Carolina

According to the U.S. Global Change Research Program, mean annual temperatures in the southeastern United States are projected to increase by 4 to 10°F by 2100, according to two different climate models (U.S. Global Change Research Program 2003).<sup>6</sup> North Carolina is already experiencing some of the highest rates of relative SLR observed in the continental United States (Poulter 2005). In August 2005, North Carolina passed the “North Carolina Global Warming Act” (Session Law 2005-442), creating the Legislative Commission on Global Climate Change, which was established to study and report on the potential causes of global climate change, its effects on North Carolina, the costs and benefits of potential actions that could be taken to address global climate change, and the possibility of recommending a state global warming pollutant reduction goal, among other issues.<sup>7</sup> In February 2007, the Commission endorsed recommending to the General Assembly a number of positive steps to develop legislated programs, databases, management strategies, and plans for public education and involvement. These recommendations, which have been approved for inclusion in the Commission’s interim report to the legislature in the coming weeks, include the following (S. Riggs, East Carolina University, personal communication, February 23, 2007):

- Create a Blue Ribbon Commission on Adaptation to Climate Change to develop a comprehensive State Climate Change Adaptation Plan
- Create a Coastal Adaptation Program to purchase land or conservation easements in “at risk” portions of the low-lying coastal zone

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<sup>6</sup> A large portion of the difference between the two estimates results from differences in the future amounts of precipitation the two models project. One model forecasts a decline in annual precipitation, while the other forecasts a significant increase (on the order of 25% more than current precipitation levels) (U.S. Global Change Research Program 2003).

<sup>7</sup> Session Law 2005-442 is available online at:  
<http://www.ncga.state.nc.us/Sessions/2005/Bills/Senate/HTML/S1134v7.html>.

- Establish a framework for mapping and inventorying the State’s coastal and riverine resources including the land areas within the coastal zone, the ocean and estuarine shore zones, etc.
- Set up permanent monitoring systems within the State’s coastal zone, including oceanic, estuarine, and riverine stations to measure absolute changes in SLR
- Develop policies such as hardening shorelines, managing or retreating from barrier islands and high-hazard ocean and inlet shorelines, maintaining or moving roads, bridges, water lines, power lines and other infrastructure associated with the barrier islands, etc.
- Define a set of short-term (5-10 year), mid-term (25-50 year), and long-term (50-100 year) environmental change targets and mitigation measures that should be required if specific effects of climate change reach projected magnitudes
- Require sellers of coastal properties to disclose potential hazards to buyers
- Provide for public education and outreach

#### *Rates of SLR*

To calculate relative (i.e., apparent) SLR experienced by a coastal community, it is necessary to add local subsidence to global eustatic SLR. The term eustatic refers to the uniform, worldwide change in sea level, i.e., due to volume changes in the ocean. Reported subsidence rates for the North Carolina coast range from 0.08 cm/yr (an estimate based on 1920-1983 data from a tide gauge in Wilmington, NC<sup>8</sup> [NRC 1988]), to 0.09 cm/yr at Sandy Point (Edenton), NC, which is on the Albemarle Sound (B. Horton, University of Pennsylvania, personal communication, February 22, 2007), to 0.19 cm/yr in Nags Head, NC (Daniels 1996), to 0.23 cm/yr in northeastern North Carolina (Poulter 2005), to 0.32 cm/yr along the sound side of the Outer Banks (based on microfossil records from 5 marshes,

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<sup>8</sup> Some geologists have pointed out that while the Wilmington, NC, tide gauge data is widely used as a source of information on sea level rise—since it is the longest-operating tide gauge in North Carolina—it is questionable whether its records are representative of other parts of the North Carolina coast. There are several reasons for this, including the fact that the Wilmington tide gauge is located 40 km from the coast, in an area regularly affected by dredging (B. Horton, University of Pennsylvania, personal communication, February 22, 2007; NOAA CO-OPS 2004).

showing 0.6 cm/yr of total SLR since 1940 reported by Kemp et al. (2006), then subtracting 0.18 cm/yr of eustatic SLR), to a statewide average of 0.36 cm/yr (Munger and Shore 2005). This range of estimates translates to a total of approximately 7.4 cm to 33 cm of subsidence alone by 2100.

One reason these estimates vary is because the rate of subsidence is not constant across the North Carolina coast (S. Riggs, East Carolina University, personal communication, February 22, 2007). Wilmington and vicinity are thought to be affected by long-term tectonic uplift of the “Cape Fear arch.” On the other hand, from Cape Hatteras north to at least the Chesapeake Bay, there is land surface or crustal subsidence, causing above-average recent subsidence rates (Fenster and Dolan 1993; Gornitz and Seeber 1990).

The barrier islands north of Cape Lookout project seaward, and they experience higher wave energy than is common south of Cape Lookout (Riggs and Ames 2003). This could affect erosion rates. In addition, it should be noted that the average slope of land in the coastal zone is also not consistent throughout the entire North Carolina coastline. The average land slope north of Cape Lookout is very gentle, approximately 0.04 m/km (0.2 feet [ft]/mi) or 1:26,000. South of Cape Lookout, the average land slope is considerably steeper, 0.6 m/km (3 ft/mi) or 1:1,800 (Riggs 2001). This means that any given increase in sea level would likely flood more land in northeastern North Carolina than southeastern North Carolina, in general. These figures suggest that if there were no other factors affecting the rate of shoreline retreat, a 1 cm increase in sea level could cause the shoreline to move inland (retreat) by 18 to 260 meters. Similar estimates, accompanied by the caveats about the other factors that can affect shoreline change, have also been published by other scientists (Pilkey and Cooper 2004). Available data, some of which is presented in section 3.2, does not reveal

retreat rates that are as high as the top end of these estimated retreat rates (see, e.g., Moore et al. 2006).

To project potential future scenarios, one could also examine relative SLR data from North Carolina and how it compares to global SLR to date. Table 2 shows tide gauge data from 5 locations along the North Carolina coast and the long-term average rates of SLR at each location. These rates range from 0.20 cm/yr to 0.43 cm/yr. The tide gauge data suggest that rates of relative SLR steadily increase going from Southport up the coastline to Duck, suggesting a possible gradient in subsidence rates (NOAA CO-OPS 2004). However, some scientists have questioned the reliability of the rates of relative sea level reported at Wilmington and Beaufort because these tide gauges are not on the Atlantic coastline directly and are affected by regular dredging of navigational channels (B. Horton, University of Pennsylvania, personal communication, February 22, 2007).

The rate of eustatic SLR has averaged 0.18 cm/yr during approximately the same timeframe (1963-2001), according to the IPCC (2007). This suggests relative SLR experienced along the North Carolina coast could be approximately 0.02 to 0.25 cm/yr greater than eustatic SLR. Table 2 also shows the implications of these two sets of estimates, taken together. They suggest that, if subsidence rates stay constant, subsidence plus eustatic sea level could yield an increase in relative sea level in the northern part of North Carolina coast of up to 0.84 m (between 2000 and 2100) and in the southern part of North Carolina of up to 0.73 m. The IPCC's estimates assume ice flow from Greenland and Antarctica will continue at the rates observed from 1993 to 2003. Total SLR could be higher if the rates at which the ice sheets melt are higher, for example (IPCC 2007).

**Table 2. Rates of Relative SLR at NC Tide Gauges and Potential Implications**

Location	Years for Tide Gauge Data <sup>1</sup>	Average Relative SLR <sup>1</sup>	Subsidence Rate Suggested*	Potential Total SLR from 2000 to 2100**
Duck, NC	1978-2002	0.43 cm/yr	0.25 cm/yr	43 – 84 cm
Cape Hatteras, NC	1978-2002	0.35 cm/yr	0.17 cm/yr	35 – 76 cm
Beaufort, NC***	1973-2002	0.32 cm/yr	0.14 cm/yr	32 – 73 cm
Wilmington, NC***	1935-2002	0.21 cm/yr	0.03 cm/yr	21 – 62 cm
Southport, NC	1933-1954, 1976-1988	0.20 cm/yr	0.02 cm/yr	20 – 61 cm

Notes:

<sup>1</sup> NOAA CO-OPS 2004

<sup>2</sup> IPCC 2007 reports total eustatic SLR might be 18 to 59 cm by 2100, if rates of ice flow from Greenland and Antarctica continue at rates observed for 1993 to 2003. If rates of ice flow grow linearly with global average temperature increases, total SLR could be another 10 to 20 cm greater by 2100.

\* Calculated by subtracting the rate of average eustatic SLR (IPCC 2007) from the rate of relative SLR indicated by the tide gauge (NOAA CO-OPS 2004).

\*\* Calculated by adding total subsidence that would occur over 100 years, as suggested by NOAA CO-OPS data, to IPCC estimates of total eustatic SLR by 2100.

\*\*\* Tide gauge in location affected by periodic dredging, which could affect the data (B. Horton, University of Pennsylvania, personal communication, February 22, 2007).

The preceding discussion describes one way to develop potential future SLR scenarios. Other researchers have used different methods to derive SLR estimates. For example, three recent articles (Church 2006, Cabanes et al. 2001, and Brahic 2007) estimate that the current rate of global SLR is in the 0.31 to 0.33 cm/yr range, the same range reported by the IPCC in 2007. Some researchers might say, therefore, that in regions with no tectonic uplift, SLR between 2000 and 2100 would be expected to amount to at least 31 cm. Some scientists also use a maximum (high-end) amount of sea level rise of more than 1 m by 2100. For example, some scientists have used a projected maximum SLR by 2100 of 1.06 m. The 1.06 m projection was developed from the IPCC's 2001 projections, along with a total of 0.20 m of subsidence in NC, then adjusting the baseline year from 1990 to 2000 to reach 1.06 m (Poulter et al. in prep.).

### *Breaches of the Outer Banks*

How barrier islands respond to SLR can be affected by topography and morphology of the island, subsurface geologic layers, sediment availability, coastal storms, rate of SLR, and anthropogenic modifications to the coastline, such as bulldozing sand back onto the beach after storms (Moore et al. 2006). There is some concern that increased storm activity and SLR might cause breaches (i.e., new inlets) in parts of the Outer Banks (Daniels 1996; Dixon 2004; Riggs 2001; Riggs and Ames 2003). Inundation and sediment overwash can contribute to breaching (USACE 2004a).

In September 2003, as a result of Hurricane Isabel, a new inlet was punched in Hatteras Island. It was approximately 600 meters wide and 5 meters deep. Shortly thereafter, the U.S. Army Corps of Engineers and North Carolina Department of Transportation closed the inlet by dumping sand into it and reconstructed damaged U.S. Highway 12 (Pendleton, Thieler, and Williams 2004; Roach 2003). The inlet that was formed in 2003 was in almost the same location as an inlet that formed after a 1933 storm (Wamsley and Hathaway 2004). While there are currently only 4 inlets along the Outer Banks from the Atlantic Ocean to the Albemarle-Pamlico Sound Estuarine System, historical records indicate that there have been as many as 11 open inlets into the Sound in the past, which have opened and closed naturally over time (Stick 1990). There currently are also 18 inlets to the west of Cape Lookout (Riggs 2001).

One study indicates that if sea level rises by 1.4 to 1.9 m by 2100, the barrier island system off North Carolina would be susceptible to collapse (Oberlin College News Service 2007). If the Outer Banks were permanently breached, the Albemarle-Pamlico Sound would be converted into a bay, and its salinity would increase (Auer 2004). Currents and tidal

regimes would also change, and inundation from SLR would be expected to reach further inland than it would were the Outer Banks to remain intact. Another model suggests that if sea level were to rise 0.69 m and there were extensive breaching of the barrier islands, tidal amplitude would increase by 0.56 m, causing an effective SLR in the Albemarle-Pamlico Sound of 1.25 m (Poulter 2005).

#### *Erosion Rates and Land Loss – Atlantic Coast*

In the mid-1990s, the North Carolina government calculated long-term average erosion and accretion rates by comparing the location of the shoreline in 1992 with the oldest available shoreline data, mostly from the 1940s. As of 1992, these rates ranged from approximately 24 m/yr (80 ft/yr) of erosion (just west of Ocracoke Inlet), to approximately 7 m/yr (23 ft/yr) of erosion (at the southernmost point on Bald Head Island and west of Oregon Inlet), to much lower rates of erosion, to low rates of accretion, to approximately 9 m/yr (30 ft/yr) of accretion (at the South Carolina line and slightly west of Hatteras Inlet), to more than 24 m/yr (80 ft/yr) of accretion (just west of Cape Lookout, on the western edge of the peninsula upon which the cape sits) (NC DCM 2004). North Carolina later recalculated long-term erosion rates by comparing 1998 shorelines with the oldest available shoreline data. This analysis indicated that approximately 18 percent of the coast adjacent to the ocean had long-term erosion rates that were greater than 1.5 m/yr (5 ft/yr), approximately 20 percent of the ocean coastline had long-term erosion rates between 0.6 m/yr (2 ft/yr) and 1.5 m/yr (5 ft/yr), and approximately 30 percent had long-term erosion rates between 0 m/yr (0 ft/yr) and 0.6 m/yr (2 ft/yr). Approximately 32 percent of the coastline was accreting. The

maximum erosion rate shown on the 1998 large-scale maps was 30 ft, just west of Drum Inlet (NC DCM 2003b).<sup>9</sup>

A few studies have reported past erosion rates along the Atlantic coast of North Carolina. For example, Leatherman, Zhang, and Douglas reported average long-term (over more than 100 years) erosion rates for the entire North Carolina coastline. They analyzed data three separate ways: (1) average erosion rates for all of the coastline, except for erosion events caused by large storms (which tend to cause large amounts of erosion, followed by years of beach recovery); (2) average erosion not influenced by large storms, inlets (where there is typically a high erosion rate), or coastal engineering structures; and (3) average erosion for those areas included in the second data set that were eroding (i.e., with areas where the beach is stable or accreting removed from consideration). See Table 3 for the results of these calculations, along with the results of other studies of erosion rates and potential land loss. Leatherman, Zhang, and Douglas estimated that the average future erosion caused by a 1 m rise in sea level would be 88 m if they included areas in the second dataset and 139 m if they included areas in the third dataset (Leatherman, Zhang, and Douglas 2000a). It should be noted that other authors have contended that the study by Leatherman, Zhang, and Douglas might have overestimated *or* underestimated actual erosion rates associated with SLR, if they demonstrated an association between SLR and the magnitude of shoreline change at all (Galvin 2000; Pilkey, Young, and Bush 2000; Sallenger et al. 2000; see also Leatherman, Zhang, and Douglas 2000b).

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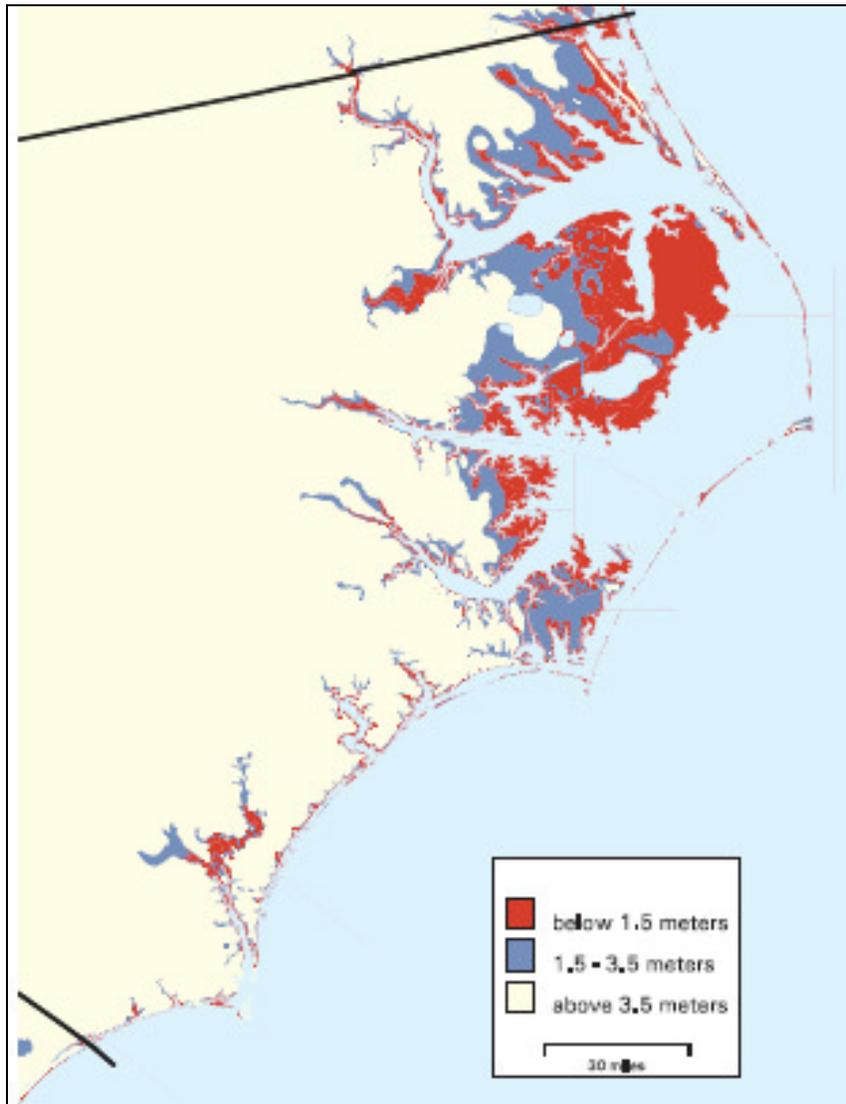
<sup>9</sup> Detailed long-term average annual shoreline change rate maps from the state of North Carolina are available on the Internet at <http://dcm2.enr.state.nc.us/Maps/erosion.htm> and [http://dcm2.enr.state.nc.us/Maps/ER\\_1998/SB\\_Factor.htm](http://dcm2.enr.state.nc.us/Maps/ER_1998/SB_Factor.htm). Also, the U.S. Minerals Management Service reports that the average erosion rate from Cape Hatteras to the Virginia line was 1.4 m/yr (4.7 ft/yr), but does not report the source of this estimate (U.S. Minerals Management Service 2007).

**Table 3. Summary of Studies on Erosion and Land Loss on NC's Atlantic Coast**

Variable reported	Amount of SLR	Results	Citation
Past long-term erosion rates for individual parts of NC's ocean coast	Variable in different parts of the state	Ranging from ~80 m/yr of erosion – ~80 m/yr of accretion (as of 1992). 18% of NC's ocean coast eroding at an average (avg.) rate > 1.5 m/yr, 20% eroding at > 0.6 m/yr and < 1.5 m/yr, 30% eroding at $\geq 0$ m/yr and $\leq 0.6$ m/yr, and 32% accreting (averages reported as of 1998).	NC DCM 2004
Past long-term erosion rate, all of NC's ocean coast	Variable in different parts of the state	Avg. of 870 m/yr, excluding the effects of large storms. Avg. of 320 m/yr excluding large storms, inlet areas, & engineering structures. Avg. of 500 m/yr excluding large storms, inlet areas, engineering structures, & stable or accreting areas.	Leatherman, Zhang, and Douglas 2000a
Future erosion rate, all of NC's ocean coast	1 m	Total of 88 m (on avg.), excluding storms & areas with inlets or engineering structures. Total of 139 m (on avg.), excluding storms, inlets, engineering structures, and stable or accreting areas.	Leatherman, Zhang, and Douglas 2000a
Future erosion and land loss in Nags Head	0.52 m; 1.31 m	33–43 m, leading to 0.40 square km of land loss; 60–79 m, leading to 17 square km of land loss. Land loss estimates assume wetlands accrete at 0.45 cm/yr. Also, past erosion rates of 0.55 to 0.72 m/yr have been reported in this area.	Daniels 1996
Potential future inundation of NC coast	0.52 m; 1.06 m (above 2000 levels)	3,500 square km of land (total); 5,320 square km of land (total).	Poulter et al. in prep.
Future barrier island migration, from Rodanthe to Cape Hatteras	0.09 m; 0.48 m; 0.88 m	Migration 185 m (at an avg. rate of 2 m/yr); Migration 555 m (at an avg. rate of 6 m/yr); Migration 925 m (at an avg. rate of 10 m/yr).	Moore et al. 2006

Several models have been developed or are being created to represent the potential future effects of SLR on North Carolina. (See Table 3 for model results.) The simplest way to model lands that would potentially be affected is to determine the areas that are at lower elevations than predicted SLR and assume that they all will be inundated. Several studies conducted by EPA used this approach (e.g., Titus 2000 and Titus et al. 1991). A map of potential SLR vulnerability in North Carolina based on this approach is included as Figure 2. Because it fails to take into account a variety of factors that will affect which lands ultimately are inundated, including erosion and the ability of wetlands to accrete, most scientists have attempted to refine this approach.

**Figure 2. Model of Land in North Carolina Vulnerable to Sea Level Rise, Based on Elevation Alone**



*This map is based on modeled elevations, not actual surveys or the precise data necessary to estimate elevations at specific locations. The map is a fair graphical representation of the total amount of land below the 1.5- and 3.5-meter contours; but the elevations indicated at particular locations may be wrong. Those interested in the elevations of specific locations should consult a topographic map. Although the map illustrates elevations, it does not necessarily show the location of future shorelines. Coastal protection efforts may prevent some low-lying areas from being flooded as sea level rises; and shoreline erosion and the accretion of sediment may cause the actual shoreline to differ from what one would expect based solely on the inundation of low land. This map illustrates the land within 1.5 and 3.5 meters of the National Geodetic Vertical Datum of 1929, a benchmark that was roughly mean sea level in the year 1929 but approximately 20 cm below today's sea level. [In other words, t]he 1.5-meter contour depicted is currently about 1.3-meters above mean sea level, and is typically 90 cm . . . above mean high tide. Parts of the area depicted in red will be above mean sea level for at least 100 years and probably 200 years (use local estimates if possible). The 3.5-meter contour illustrates the area that might be flooded over a period of several centuries.*

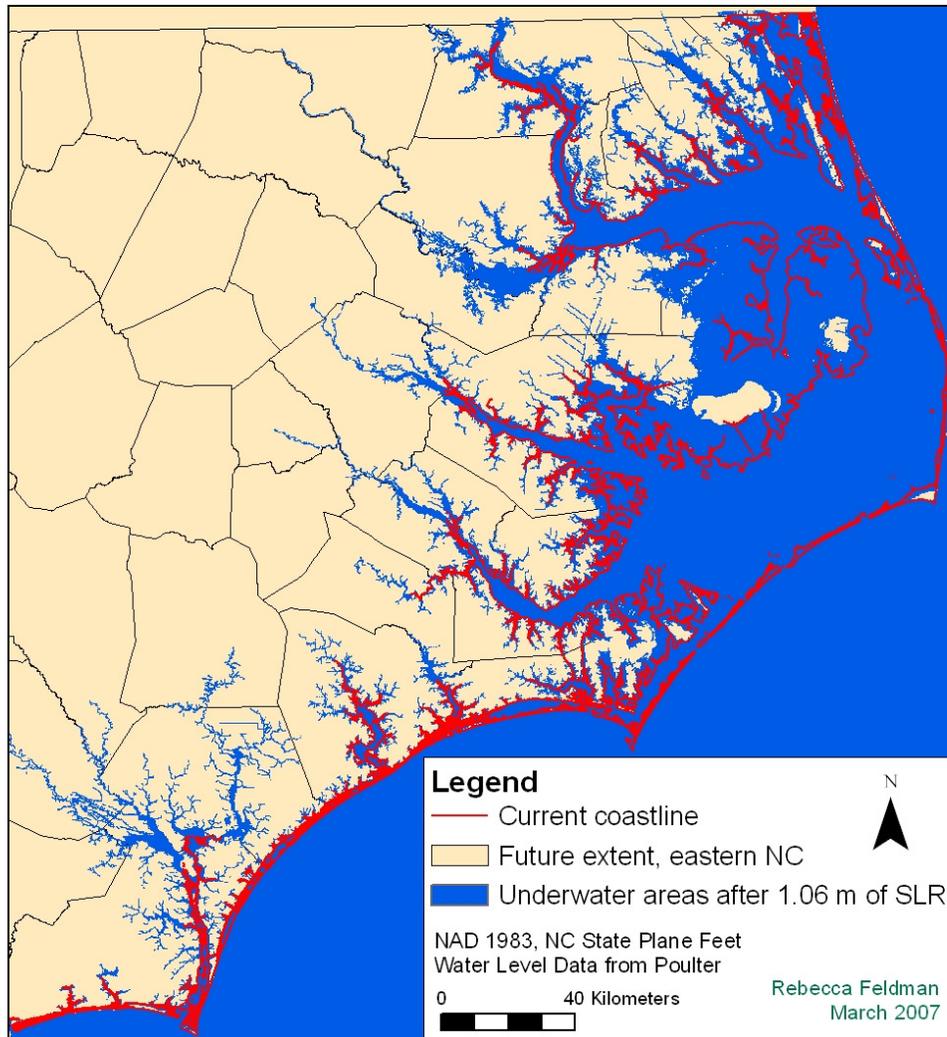
—Caveats recommended by EPA  
(Source: Titus and Richman 2001)

To improve on available information of the type shown in Figure 2 about potential areas affected by sea level rise map in North Carolina, one researcher, using hi-resolution LIDAR (light detection and ranging) elevation data released by the North Carolina Floodplain Mapping Program in 2002, constructed a model that assumes that any 23.2 square meter (250 square ft) grid cell drawn on the landscape would only be flooded if an adjacent cell were flooded. This creates a model that allows, for example, dikes to protect the areas landward of them (B. Poulter, Potsdam Institute for Climate Impact Research, personal communication, March 16, 2007; Poulter 2005). The elevation data used for this study had a vertical accuracy of 0.25 m. This approach predicts that an SLR of approximately 0.52 m by 2100 would inundate 3,500 sq km (1,350 sq mi) of low-lying land in North Carolina and an SLR of 1.06 m would inundate approximately 5,320 sq km (2,050 sq mi), an area approximately the size of Delaware. As is shown by Figure 3, in the latter case, land loss would be primarily on the Albemarle-Pamlico peninsula. Approximately 30 percent of this peninsula is at an elevation below 1 m, and more than 5,000 sq km (1,930 sq mi) of the peninsula is at an elevation of less than 1.25 m. Some of the inundated land would also be in river valleys on other parts of the coast and on the Outer Banks. However, these data may be overestimates of future land loss because they do not take into account erosion or the ability of wetlands to accrete (Poulter 2005; Poulter et al. in prep.), among other possible factors.

The notion that erosion causes the shoreface profile to migrate landward and upward as sea level rises, described above, was first proposed by Bruun in 1954 and discussed in later papers by Bruun and others (Zhang, Douglas, and Leatherman 2004). As noted above, Bruun's model indicates that sand eroded due to SLR is deposited along the shoreface, which maintains a consistent profile shape (except where sand is overwashed onto barrier islands).

The model assumes that there is a depth at which the waves no longer pick up sand from the bottom. It does not take into account alongshore transport of sand or sediment. As also noted above, some have questioned these assumptions (see, e.g., Thieler et al. 2000 and Pilkey et al. 1998), and others have elaborated on Bruun's model.

**Figure 3. Areas Projected to be Under Water After SLR of 1.06 m**



One recent analysis combined the Bruun model, a modified version of it, and an inundation model. This analysis predicted that, in Nags Head, NC, if sea level rises 0.52 m (by 2050), the shoreline would retreat between 33 and 43 m, and if sea level rises 1.31 m (by 2100), the shoreline would retreat 60 to 79 m. These estimates assume humans do not

attempt to stabilize shorelines (whereas, in fact, humans are likely to try to stabilize the shoreline wherever they can obtain permits to do so). For reference, past erosion rates of 0.55 m/yr and 0.72 m/yr have been reported for Nags Head. This study produced estimates of potential future land loss in Nags Head, assuming that wetlands could accrete at a rate of 0.45 cm/yr and that no inlets were created in Nags Head. These estimates indicate that, if humans do not endeavor to stabilize shorelines, net land loss in Nags Head might be on the order of 0.4 square km (0.15 sq mi or 100 acres) for a 0.52-m SLR and 17 sq km (6.6 sq mi or 4,200 acres) for a 1.31-m SLR. If the ocean shoreline were stabilized, this area would narrow from the landward side, and the ability of wetlands to accrete would be compromised (Daniels 1996).

In contrast, another study predicted shoreline migration rates approximately 10 times higher for a 25-km stretch of the North Carolina coast slightly to the south (from Rodanthe to Cape Hatteras) (Moore et al. 2006). This study used a model called GEOMBEST, which is based on the Bruun model, along with added parameters, such as factors representing composition and erodability of the eroding geologic layers, instead of assuming there is an infinite supply of sand (Stolper, List, and Thieler 2005). Model results indicated that if sea level rises by 0.09 m by 2100, the barrier island would migrate 185 m (at an average rate of 2 m/yr), if sea level rises by 0.48 m by 2100, the barrier island would migrate 555 m by 2100 (at an average rate of 6 m/yr), and if sea level rises by 0.88 m by 2100, the barrier island would migrate 925 m by 2100 (at an average rate of 10 m/yr). It should be noted that these rates are higher than observed modern long-term erosion rates along this portion of the North Carolina shoreline, which could be considered a proxy for island migration rates (Moore et al. 2006).

“The primary challenge in predicting shoreline response to SLR is identifying and quantifying the important variables that contribute to coastal evolution in a given area,” a USGS study noted (Pendleton, Thieler, and Williams 2004). USGS identified six variables that affect coastal evolution, including geomorphology (which affects resistance to erosion and other factors); historic shoreline change rate; regional coastal slope (which reflects a region’s risk of flooding); rate of relative SLR; mean tidal range; and mean significant wave height (which, squared, is directly proportional to mean wave energy).<sup>10</sup> USGS assessed the Cape Hatteras National Seashore’s vulnerability to SLR using these six criteria. Its model does not integrate such factors as alongshore transport, which has a heterogeneous effect on the shoreline and is dependent on the shape of adjacent coastline. The model indicates that 27 percent of the National Seashore is very highly vulnerable, another 27 percent is highly vulnerable, 30 percent is moderately vulnerable, and 16 percent is at low vulnerability to SLR (Pendleton, Thieler, and Williams 2004). The coastal vulnerability assessment methodology is one component of USGS’ National Assessment of Coastal Change Hazards, an effort to determine vulnerability along the U.S. coast based on past shoreline change, coastline type, and exposure to storms (USGS 2006). Researchers associated with USGS are also studying wetland accretion in areas affected by subsidence and SLR (USGS 2007), as well as conducting other modeling efforts to simulate large-scale changes in coastal morphology as a result of SLR (see, for example, USGS 2005).

#### *Erosion Rates and Land Loss – Estuarine Shorelines*

An excellent summary of estuarine dynamics is presented in *Shoreline Erosion in North Carolina Estuaries*, written by Stanley Riggs of East Carolina University and

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<sup>10</sup> Other researchers have identified additional criteria, such as nearshore sediment volume and shallow nearshore stratigraphy (i.e., geologic layers) (Miselis and McNinch 2006).

published in 2001 by North Carolina Sea Grant. This volume contains extensive information about different shoreline types, associated rates of erosion along different sections of North Carolina's estuaries, and related topics. The major shoreline types it identifies are sediment-bank, organic (found along marshes and swamp forests), combination, and back-barrier. Different shoreline types tend to have different erosion rates and types of beaches, among other differences. The book indicates that erosion rates may be related to the following characteristics: shoreline stabilization efforts and whether dredging occurs, fetch (i.e., the distance waves travel over open water, from their origin to where they break), exposure to wind and waves from storms, shoreline profile, shoreline orientation, offshore bottom characteristics, water depth, shoreline bank height and composition, size of beach, vegetation onshore and offshore, the presence of boat wakes, and the behavior of storms, tides, currents, and waves (Riggs 2001).

The following data are presented in Riggs (2001).<sup>11</sup>

- Conservative estimates based on land loss along 2,564 km (1,593 mi) of estuarine shoreline between around 1975 and 2000 suggest that along the *entire* estuarine coastline, approximately 109 sq km (42 sq mi) of land eroded. This translates to approximately 4.4 sq km/yr (1.7 sq mi/yr) of land lost. Of this, the majority (61 percent) was marsh. Another 5 percent was swamp forest, 28 percent was low sediment bank, 5 percent was high sediment bank, and 1 percent was along bluffs.
- Figures from the same dataset as above, covering approximately half of the estuarine shoreline, suggest that, on average, marshes erode at a rate of 0.94 m/yr (3.1 ft/yr). The average erosion rate along low banks was 0.79 m/yr (2.6 ft/yr), along high banks was 0.58 m/yr (1.9 ft/yr), along bluffs was 0.64 m/yr (2.1 ft/yr), and along swamp forests was also 0.64 m/yr (2.1 ft/yr).
- Generalized countywide average estuarine erosion rates for 15 individual coastal counties calculated by the U.S. Soil Conservation Service in 1975 (based on shoreline sections ranging from a total of 42 to 238 km [26 to 148 mi] in each county) were from 0.3 to 1.4 m/yr (0.9 to 4.5 ft/yr). Riggs cautions that methods used to conduct this study yield only "extremely" general data. This study did not include the bay side of North Carolina's barrier islands.

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<sup>11</sup>For more information, readers may wish to consult the book directly.

- Riggs reevaluated a 1974 comparison of aerial photographs for different portions of the North Carolina mainland adjacent to the Pamlico Sound, documenting shoreline change over 9-33 years. He found maximum annual erosion rates up to 14 m/yr (45 ft/yr) in most places, except one where the maximum was 48 m/yr (156 ft/yr). Average annual erosion rates in the areas studied ranged from 0.3 m/yr (1 foot/yr) to 11 m/yr (36 ft/yr).
- A 1983 study examining erosion along the back of North Carolina's barrier islands found that, overall, most areas were eroding between 1852 and 1980. The average erosion rate on shorelines from the Virginia border to Cape Hatteras was 1 m/yr (0.3 ft/yr), whereas along the ocean shoreline along these same islands, the average erosion rate was 0.8 m/yr (2.6 ft/yr). West and south of Cape Hatteras, the average erosion rate was approximately 1.2 m/yr (4 ft/yr).
- When Riggs and his colleagues studied shoreline change in the mid-1970s, they found that approximately 95% of the 778 km (483 mi) of estuarine shoreline studied in three counties along the Pamlico estuarine system was eroding. Along the Albemarle estuarine system, an average of 90% of the 701 km (436 mi) evaluated across nine counties was "significantly" eroding. In individual counties adjacent to this estuary, 73% to 98% of the portion of the shoreline studied was significantly eroding. Using the same methods to study 727 km (452 mi) along the Neuse estuarine system in three counties, Riggs and his colleagues found that 90% of the shoreline experienced significant erosion. In Carteret County, along Core, Back, and Bogue Sounds, 357 km (222 mi) of shoreline was studied. Of this, 90% was significantly eroding.
- Finally, in 1977, two researchers (Hartness and Pearson) studied 261 km (162 mi) of the shoreline along the Intracoastal Waterway (in Pender, New Hanover, and Brunswick Counties). They found that 23% of the shoreline was significantly eroding. In southeastern North Carolina, the shorelines most susceptible to erosion were along the Intracoastal Waterway, other navigational channels, and the Cape River and New River estuaries (Riggs 2001).

#### *Major Ongoing Efforts to Model Shoreline Change*

The National Oceanic and Atmospheric Administration (NOAA) has recently undertaken two efforts to facilitate SLR modeling in North Carolina. First, it created a software tool (called VDatum) that correlates tidal datums, which are relative to mean sea level, with various datums used for topographic data on land. This tool is invaluable because comparing datasets from different sources on elevations (i.e., both heights and depths) that use different datums required referencing the datasets to the same vertical datum (NOAA

OCS 2006). Second, NOAA developed a Coastal Flooding Model (CFM) for a portion of coastal North Carolina (Pamlico and Bogue Sounds, as well as the Neuse River) that uses the continuous topography and bathymetry data from VDatum, as well as NOAA's customized model of the tidal system in a portion of the estuarine and coastal waters of North Carolina. The CFM is a high-resolution hydrodynamic model that takes into account changes to tides and circulation patterns due to SLR, winds, and storms to predict what areas would be flooded under different scenarios, including scenarios that involve inlet modification. Predicted shoreline migration can also be determined from the CFM (Auer 2004; NOAA CSCOR 2007).

The CFM was developed in part to support three studies NOAA is funding under its Ecological Effects of Sea Level Rise research program. NOAA points out that studies of shoreline change resulting from SLR would be incomplete without considering ecological processes, such as erosion, changes to wetlands, productivity, and human activities. An important purpose of the funded studies is to provide managers with better data about vulnerable locations, habitats, and species upon which to base decisions that affect land use in the coastal zone. These studies are scheduled to be completed in late 2008 (NOAA CSCOR 2006a, b).

The first of the Ecological Effects of Sea Level Rise studies models potential ecological responses of NC estuarine habitats to higher water levels. More specifically, it forecasts how variable water levels, wave energy, and shoreline stabilization methods would affect productivity and the ecological services provided by sub-tidal, inter-tidal flat, oyster reef, submerged aquatic vegetation, and wetland areas. The second study models changes in plant community composition, sediment accretion, and morphology of coastal wetlands—and

how these features interact—in response to tidal forcing and SLR. This study includes various field experiments, including on the relationship between productivity, relative elevation, and tidal forces, as well as on sedimentation rates and elevation changes. The third study focuses on future changes to the shore zone (from shallow estuarine waters to the edge of coastal wetlands) based on physical factors, including cover type, geomorphology, substrate, hydrodynamics, incoming waves, structures built by humans, and storms. The results of all three studies, once completed, will be available to coastal managers. The studies will, ideally, produce models and maps that allow managers to adjust inputs to reflect different management options, and then to predict the potential results across the environment. These ecological forecasts are intended to help focus further research and monitoring and will assist managers in understanding potential future conditions (NOAA CSCOR 2006b; Auer 2004).

A variety of other efforts to model the potential impacts of SLR on all or parts of the North Carolina coast are underway. For example, researchers at Duke University have received funding from the National Science Foundation (NSF) to developing a model of large-scale (over tens to hundreds of kilometers), long-term coastline change caused by wave-driven sediment transport. Their calculations indicate that the shape of the shoreline will be determined considerably more by alongshore transport than by cross-shore transport resulting from SLR. These researchers are developing an approach that takes into account human manipulations of the coastline, such as decisions to undertake beach nourishment projects, efforts to protect coastal roads, economics, and policy constraints. In particular, the NSF-funded study will suggest which areas might experience the greatest erosion and accretion, whether large portions of the barrier islands might disappear, and how quickly

shoreline change might occur (A.B. Murray, Duke University, personal communication, October 18, 2005; NSF 2006). Duke researchers are also conducting other modeling of potential shoreline change. For example, they have predicted that it will be affected by variability in the composition of the sediment along different parts of the shoreline, as well as wave climates and alongshore transport, yielding heterogeneous shoreline change along different parts of the coastline (see, for example, Murray et al. 2007).

#### *Effects on Wetlands and SAV*

Some studies have focused on the effects of SLR on wetlands. (It should be noted, of course, that a variety of other causes also contribute to wetland loss in North Carolina's coastal zone [see, for example, Street et al. 2005].) Some studies of the potential effects of SLR on wetlands have not been quantitative. Moorhead and Brinson (1995), among others, argue that, if the rate of SLR accelerates, it is unlikely that marshes in the Albemarle-Pamlico Sound will be able to accrete at a rate that would allow them to keep up. In other words, they predict extensive portions of the wetlands in this region will become submerged. However, they do not predict how large the area of wetlands lost might be, on the basis that rates of shoreline erosion and wetland accretion under a scenario of more rapid SLR are unknown (Moorhead and Brinson 1995).

Riggs and Ames (2003) studied 21 wetland field sites to assess current rates of wetland loss; from their findings, they extrapolated that approximately 3.2 sq km (1.25 sq mi) of wetlands along North Carolina's estuarine shoreline, mostly in brackish marshes, are destroyed each year due to SLR and shoreline hardening. For reference, the North Carolina Division of Coastal Management (DCM) estimates that there are more than 11,450 sq km (4,420 sq mi) of coastal wetlands in North Carolina's 20 coastal counties (including wetlands

not directly adjacent to the coast) (Sutter 1999). Of these, approximately 3,060 sq km (1,180 sq mi) of wetlands are within 1 mile of the shoreline (NC DCM 2003c; Feldman 2006b). Hackney and Cleary (1987, as reported in Street et al. 2005) reported that wetlands in southeastern North Carolina can accrete at a rate of 0.12 cm/yr.<sup>12</sup> A major driver of coastal wetland accretion in some areas is the tides and the sediment they transport. However, there are no astronomical tides in the Albemarle-Pamlico estuary, which means that wetland accretion rates there might be different from rates elsewhere (Auer 2004).

One fairly intricate model (called SLAMM2) that has been used to model wetland response to SLR takes into account exposure to the open ocean, wave climate, substrate type, existing development, potential wetland accretion (at rates equal to current rates), and other factors to predict how land cover would change. A study using this model projected that efforts to protect developed areas from SLR (e.g., with bulkheads) would cause 38% of wetlands along the South Atlantic coast (from North Carolina to southern Florida) to be lost if sea level rises 0.5 m and 44% of wetlands along the South Atlantic to be lost if sea level rises 1 m. If no efforts were made to protected developed areas, 34% of wetlands in the region were predicted to be lost from a 0.5 m rise in sea level and 40% of wetlands would be predicted to be lost from a 1 m rise in sea level (Park et al. 1989). In this model, loss of wetlands in the South Atlantic was largely driven by the assumption that wetland accretion would not keep pace with SLR (Moorhead and Brinson 1995). It should also be noted that this model used fairly coarse resolution elevation data (Park et al. 1989).

No major studies have been conducted on the potential effects of SLR in North Carolina on SAV. It has been estimated that there are approximately 800 sq km (300 sq mi) of estuarine SAV in North Carolina, which is comparable to the area of salt marsh in the

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<sup>12</sup> Note this value is less than a third the rate of accretion assumed in Daniels 1996.

estuarine system. This means that SAV covers about 8.5% of the estuary. How shoreline change will affect SAV types and distribution is not well understood, because a variety of factors related to how SAV is affected by environmental changes have not been fully studied (Auer 2004). More research directed towards reducing some of these uncertainties would give managers better information about potential changes to SAV, fish populations, and the added mitigation potentially provided by SAV of the effects of storms on the coast.

### **3.3 Relevant Coastal Zone Policies in North Carolina**

#### *Background*

A series of North Carolina laws and policies are designed to protect and manage coastal resources, both public and private. In North Carolina, the State's jurisdiction extends over the land and water in the ocean below the mean high tide line, as well as all other navigable waters and the land beneath them, among other areas. The State holds these waterways and the beach up to the high water mark in trust for the public's use and enjoyment (NC Gen. Stats. § 77-20, 2006).

State legislation that addresses coastal management includes the Coastal Area Management Act (CAMA) and the Dredge and Fill Law; North Carolina has also adopted other policies adopted in keeping with the federal Coastal Zone Management Act. The North Carolina Coastal Resources Commission (CRC) establishes rules and policies for implementing these laws, including by designating Areas of Environmental Concern in the coastal zone, regulating development within these areas, and approving land use plans for communities within the 20 coastal counties. The Governor appoints the 15 members of the CRC, who have expertise in a range of issues. DCM, within the Department of Environment and Natural Resources, is responsible for carrying out CRC rules through a variety of

planning, permitting, enforcement, research, and education programs. DCM is also responsible for implementing the North Carolina Coastal Reserve Program (NC DCM 2005). The jurisdiction of CRC and DCM under CAMA is limited to the 20 coastal counties (see Figure 1), as well as adjacent estuarine and oceanic waters (NC DCM 2001b).

DCM considers and approves major permit applications for coastal zone development in CAMA-defined Areas of Environmental Concern (including permits related to post-storm redevelopment). These permits must be consistent with local land use plans approved by DCM, as well as DCM regulations associated with development in Areas of Environmental Concern. Land use planning allows counties (and, in some cases, municipalities) to determine—in advance—how they will manage future development. CRC determines whether the local land uses plans submitted for its approval have met its requirements, which mainly relate to required elements in each plan (i.e., which issues the plans must address) (15A NCAC 07B .0702). DCM provides technical assistance and grants to local government for local planning efforts (NC DEM 2004b).

#### *Land Use Plans*

Land use plans are all supposed to include population characteristics, areas subject to natural hazards, maps of natural features and protected areas, current land use, lands suitable for future development, capacity of infrastructure, plans and policies for future land use (including conservation) and development, as well as the benefits and disadvantages of these policies, among other issues (15A NCAC 07B .0702). The regulations for land use plans mention SLR in this context: “Planning objective: Develop policies that minimize threats to life, property, and natural resources resulting from development located in or adjacent to hazard areas, such as those subject to erosion, high winds, storm surge, flooding, or sea level

rise” (15A NCAC 07B .0702 (d) (3) (D) (ii)). The rules go on to indicate that these policies should set criteria for the location, density, and intensity of development in natural hazard areas and correlate development with evacuation infrastructure (15A NCAC 07B .0702 (d) (3) (D) (iii)). Despite these requirements, most local land use plans from coastal jurisdictions reportedly mention SLR only briefly or in passing, do not describe policies specifically tailored to areas threatened by SLR, and/or indicate that communities are looking to the state to take action on SLR (J. Titus, U.S. Environmental Protection Agency, personal communication, March 19, 2007).<sup>13</sup>

*Requirements for Areas of Environmental Concern (AECs)*

The AECs defined by the State include, among others: ocean hazard areas; natural and cultural resource areas; estuarine waters; coastal wetlands; and estuarine and public trust shorelines (15A NCAC 07H). Different requirements apply to new development and redevelopment in the various types of AECs. Setbacks in the ocean hazard AEC, for example, are measured from the location of the first line of vegetation<sup>14</sup> and are based on long-term annual erosion rates. Specifically, the ocean hazard area setback is equal to 30 times the long-term annual erosion rate in a particular location, except where this rate is less than 2 ft/yr, in which case the setback is 60 ft behind the vegetation line. These requirements

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<sup>13</sup> The first section of the federal Coastal Zone Management Act (CZMA) states, “Because global warming may result in a substantial sea level rise with serious adverse effects in the coastal zone, coastal states must anticipate and plan for such an occurrence” (16 U.S.C. 33 § 1451). The fact that North Carolina’s regulations mention sea level rise may stem from requirements of the CZMA, as amended, that approved state coastal zone management programs address sea level rise. Specifically, approved programs must “study and [develop], in any case in which the Secretary considers it to be appropriate, . . . plans for addressing the adverse effects upon the coastal zone of land subsidence and of sea level rise” (16 U.S.C. 33 § 1452). To support these types of efforts, the National Oceanic and Atmospheric Administration can award coastal zone enhancement grants to states for projects aimed at “anticipating and managing the effects of potential sea level rise . . . ,” among other purposes (16 U.S.C. 33 § 1456b).

<sup>14</sup> The first line of vegetation is above the mean high tide line and is described as “the boundary between the normal dry-sand beach, which is subject to constant flux due to waves, tides, storms and wind, and the more stable upland areas” at 15A NCAC 7H .0305 (f).

are doubled for non-residential or multi-family residential structures that have more than 5,000 sq ft of total floor area. The regulations also specify when structures must be placed behind dunes and under what circumstances this requirement supersedes the erosion setback line. Further, a variety of circumstances that warrant exceptions to the rules are specified in the regulations (15A NCAC 7H .0306). It should be noted that if high water lines and vegetation lines move up and landward due to SLR, both setbacks and the boundary between private land and public trust land would also move an equal amount.

North Carolina's regulations explicitly recognize the potential negative effects of building along the ocean coast. They note, for example:

Because large structures located immediately along the Atlantic Ocean present increased risk of loss of life and property, increased potential for eventual loss or damage to the public beach area and other important natural features along the oceanfront, increased potential for higher public costs for federal flood insurance, erosion control, storm protection, disaster relief and provision of public services such as water and sewer, and increased difficulty and expense of relocation in the event of future shoreline loss, a greater oceanfront setback is required for these structures than is the case with smaller structures (15A NCAC 7H .0306 (a) (4)).

The regulations also state:

(c) In order to avoid public expenditures for maintaining public safety, construction or placement of growth-inducing public facilities to be supported by public funds shall be permitted in the ocean hazard area only when such facilities:

- (1) are of public benefit,
- (2) shall not increase existing hazards or damage natural buffers,
- (3) shall be safe from flood and erosion-related damage,
- (4) shall not promote growth and development in ocean hazard areas.

Such growth inducing facilities include sewers, waterlines, roads, and bridges (15A NCAC 7H .0306 (c)).

North Carolina explicitly accepts that some structures must be moved or removed due to erosion: “Permits shall include the condition that any structure shall be relocated or dismantled [within two years of] when it becomes imminently threatened by changes in shoreline configuration” unless something changes and it becomes no longer imminently threatened (15A NCAC 7H .0306 (l)). As noted previously, North Carolina allows beach nourishment and installation of “temporary” sandbags to protect property, but most hardened structures are not allowed on the oceanfront (15A NCAC 07H .0308). The only instances in which hardened structures are permitted on the oceanfront when certain conditions are met: (1) to protect an imminently threatened bridge that serves the only road to a barrier island, (2) to protect an imminently threatened historic site of national significance, and (3) to maintain a commercially-used navigation channel “of regional significance” (15A NCAC 07H .0308 (a) (1)).

Bulkheads and other hardened structures in areas that are eroding are permitted along estuarine shorelines and the shores of other public trust waters, e.g., rivers. These hardened structures must be built landward of wetlands (15A NCAC 07H .0208 (b) (7)). Beach nourishment along non-oceanfront shorelines is also permitted, as long as it meets certain requirements, including (at least theoretically) that it should not occur in areas where there are “high erosion rates [and] where frequent maintenance will be necessary” (15A NCAC 07H .0208 (b) (8)).

Since 2000, development along estuarine shorelines and shorelines of other public trust waters has been required to be set back 30 ft from the water line, unless one of several exemptions applies. There are also a number of additional restrictions associated with building within 75 ft of estuarine and other public trust waterbodies (15A NCAC 07H .0209).

Only water-dependent uses are permitted within Estuarine AECs (the estuaries themselves), Public Trust AECs (i.e., other public trust waters), or Coastal Wetland AECs (i.e., wetlands containing at least one of 10 plant species typically found in North Carolina marshes). Development is to be directed from these AECs, whenever possible (15A NCAC 07H .0208).

#### *Other Relevant Policies*

North Carolina has also legally adopted a series of “policy statements” that address its policies associated with, for example, public access to the state’s shorelines, controlling and addressing shoreline erosion, and avoidance or mitigation of activities that have adverse effects on coastal water quality. These policies also indicate that DCM and CRC shall coordinate with NC DEM on matters relating to disaster warning, response, and relief; CRC shall establish requirements for local governments to develop disaster reconstruction plans meeting certain criteria; and CRC shall encourage buyouts of properties where structures have been destroyed, “rather than continuing to fund rebuilding in high hazard areas” (15A NCAC 07M .0503). It is not clear that any of the policy statements are binding, however. For that matter, the local ordinances in the counties governed by CAMA are not required to be in line with county land use plans, except in the AECs, which might lead one to question how binding the local land use plans are on the majority of the land in the counties (J. Titus, U.S. Environmental Protection Agency, personal communication, March 19, 2007).

North Carolina’s Coastal Habitat Protection Plan (CHPP) describes threats to coastal habitats from natural forces and human activities and makes a number of management recommendations, which the State had formally adopted (after receiving and considering numerous public comments). The CHPP recommends that:

Buyers and owners of coastal property should be aware of SLR and the potential for loss of wetlands and property. Updated and accurate coast-wide

estuarine erosion rates are needed for the CRC and EMC [Environmental Management Commission] to determine adequate development guidelines and rules along the coast (DCM 2002 [an unpublished report]). Priorities for coastal wetland protection should also acknowledge SLR, and protect gently sloping areas upland of coastal wetlands to allow for landward migration of coastal wetlands with SLR (Street et al. 2005).

The extent to which these recommendations are being implemented is unknown.

A variety of North Carolina requirements related to hazard mitigation apply to coastal areas. The State's Flood Hazard Prevention Act of 2000 authorizes local governments to prohibit landfills, hazardous waste management facilities, junkyards, and chemical storage facilities in the 100-year floodplain. This legislation may have been triggered, in part, by severe flooding in 1999 from Hurricane Floyd. Since November 2004, North Carolina has also required local governments, in order to receive state funding after disasters, to adopt a locally-developed, state-approved hazard mitigation plan. Since 2004, the State has also had a policy of only providing public assistance funding in response to flood damage to those communities that participate in the NFIP. The North Carolina Department of Emergency Management (NC DEM) promotes the development of local hazard mitigation plans by providing technical assistance, funding, guidance, and hazard data to local governments. Some of the funding originates from the Federal Emergency Management Agency (FEMA). NC DEM was also instrumental in the development of a state-wide hazard mitigation plan (NC DEM 2004b).

### **3.4 The National Flood Insurance Program and Disaster Mitigation Funding**

The NFIP was created in 1968 to reduce the costs to the nation of disaster relief associated with flooding by making federally-subsidized flood insurance available to individuals in communities that joined the program (by adopting floodplain management and flood hazard mitigation policies). Although participation in the program is optional across

the nation, there are strong incentives for community participation, especially in North Carolina. To receive loans insured by the federal government or loans from federally-insured banks, homeowners must have flood insurance (42 U.S.C. § 4001, et seq.). To be eligible for any flood insurance, the property insured must be in an area covered by the NFIP. As noted above, North Carolina will now only give out disaster assistance grants to participating communities. Hazard mitigation planning grants are also only available to areas that take part in or plan to apply to the NFIP (NC DEM 2004b).

While a review of the mitigation measures required by the NFIP and associated standards is outside the scope of this paper, a few provisions bear mention. New or reconstructed buildings in the floodplain must be elevated to or above the 100-year flood level (i.e., the level that floodwaters have only a 1 in 100 chance of reaching in any given year). Also, the NFIP's Community Rating System (CRS) provides incentives for communities to adopt enhanced flood mitigation policies by offering discounts on flood insurance premiums for communities that exceed NFIP minimum requirements (FEMA 2005). Many have criticized the NFIP, arguing, for example, that it encourages and provides inappropriate subsidies for unwise coastal development, that properties that have suffered repeated losses have drained the NFIP disproportionately, and that NFIP premiums will be unable to cover past and future claims (Feldman 2006a).

Between 1987 and 1994, the NFIP allowed homeowners to use up to 40 percent of the value of their insurance to relocate their threatened homes. In 1994, when the NFIP was amended, this component of the program was redefined and folded into the Flood Mitigation Assistance program, which provides grants to mitigate long-term flood risks in communities that participate in the NFIP and have flood mitigation plans. These grants can be used to

help fund elevating, purchasing, relocating, or demolishing certain insured buildings, as well as flood proofing sewers, installing floodgates, constructing retention ponds, modifying culverts, and nourishing beaches. In some cases, technical and financial assistance to states and local governments for mitigation projects can also be obtained from the National Pre-Disaster Mitigation Fund (NC DEM 2004b).

Besides removing the provision that allowed use of NFIP funds to relocate threatened buildings, the National Flood Insurance Reform Act of 1994 (folded into the larger Riegle Community Development and Regulatory Improvement Act of 1994, Public Law 103-325) made several other changes to the NFIP. Not all of the changes that were originally proposed made it into the final version of this legislation, however. One proposal that was eliminated would have curtailed flood insurance in coastal erosion hazard zones (defined as areas where erosion was likely to damage or destroy buildings and infrastructure within a set period of time). Specifically, this provision would have prohibited FEMA from issuing new flood insurance policies within delineated 30-year erosion hazard areas and set conditions for the issuance of new policies in delineated 60-year erosion hazard zones. Instead, the version of the legislation that passed required FEMA to study and map erosion hazard areas and fund an economic impact analysis of the costs and benefits of mapping, regulating, and insuring these zones (Spann 1994; Whiteman 1997).

Communities with comprehensive disaster mitigation plans, approved by the NC Department of Emergency Management (NC DEM), are eligible for funding through the federal Hazard Mitigation Grant Program. Most communities have submitted disaster plans, consistent with this requirement. After Hurricanes Fran and Floyd (in 1996 and 1999, respectively), NC DEM conducted a large buyout program, using HMGP funds and funds

earmarked by Congress for acquisition of properties damaged by the latter hurricane. The State has facilitated buyouts of approximately 6,000 properties or more that have repeatedly sustained flood damage, especially damage from these two hurricanes. The State has also provided additional funding to affected homeowners to purchase similar housing outside the floodplain. Federal funding has also enabled property owners to elevate approximately 1,000 structures or more in the last ten years, facilitated “flood-proofing” public facilities, and supported public outreach (NC DEM 2004b).

A FEMA-funded study of North Carolina’s flood hazard mitigation initiatives, conducted following Hurricane Floyd, found that residents of communities that participated in the NFIP were more aware of potential flood risks and implemented more flood hazard mitigation strategies than residents of communities that did not participate in the NFIP. Furthermore, the homeowners surveyed who had implemented flood damage prevention measures saved, on average, \$9,900 in damages from Hurricane Floyd. The study concluded, however, that the “Acquisition and relocation of floodprone buildings is more effective at reducing flood losses than any other approach” (Hazard Mitigation Technical Assistance Partnership 2000, at iv). Designating floodprone areas as open space and preventing their development also saved millions of dollars. In one area studied, within 3 years, the cost of relocation was covered by the cost of damages foregone had the structures remained in place (Hazard Mitigation Technical Assistance Partnership 2000).

Another federal law that affects development in North Carolina’s coastal zone is the Coastal Barrier Resources Act of 1982. Designed to discourage development on vulnerable, undeveloped portions of barrier islands, this legislation forbid any new federal subsidies (including for flood insurance and roads) on undeveloped portions of barrier islands depicted

on maps of the Coastal Barrier Resources System, originally drawn in 1981 (16 U.S.C. §§ 3501-10). Portions of the Coastal Barrier Resources System fall in the following North Carolina counties: Brunswick (including parts of Bald Head Island and Sunset Beach), Carteret (including part of Pine Knoll Shores), Currituck, Dare (including parts of Kill Devil Hills and Nags Head), Hyde, New Hanover (including parts of Carolina Beach, Kure Beach, Wilmington, and Wrightsville Beach), Onslow (including parts of North Topsail Beach and Swansboro), and Pender. Much of the land in the Coastal Barrier Resources System is in unincorporated parts of these counties (FEMA 2006).

### **3.5 Beginning to Assess Potential Responses to SLR in North Carolina**

Nationwide, it has been predicted that:

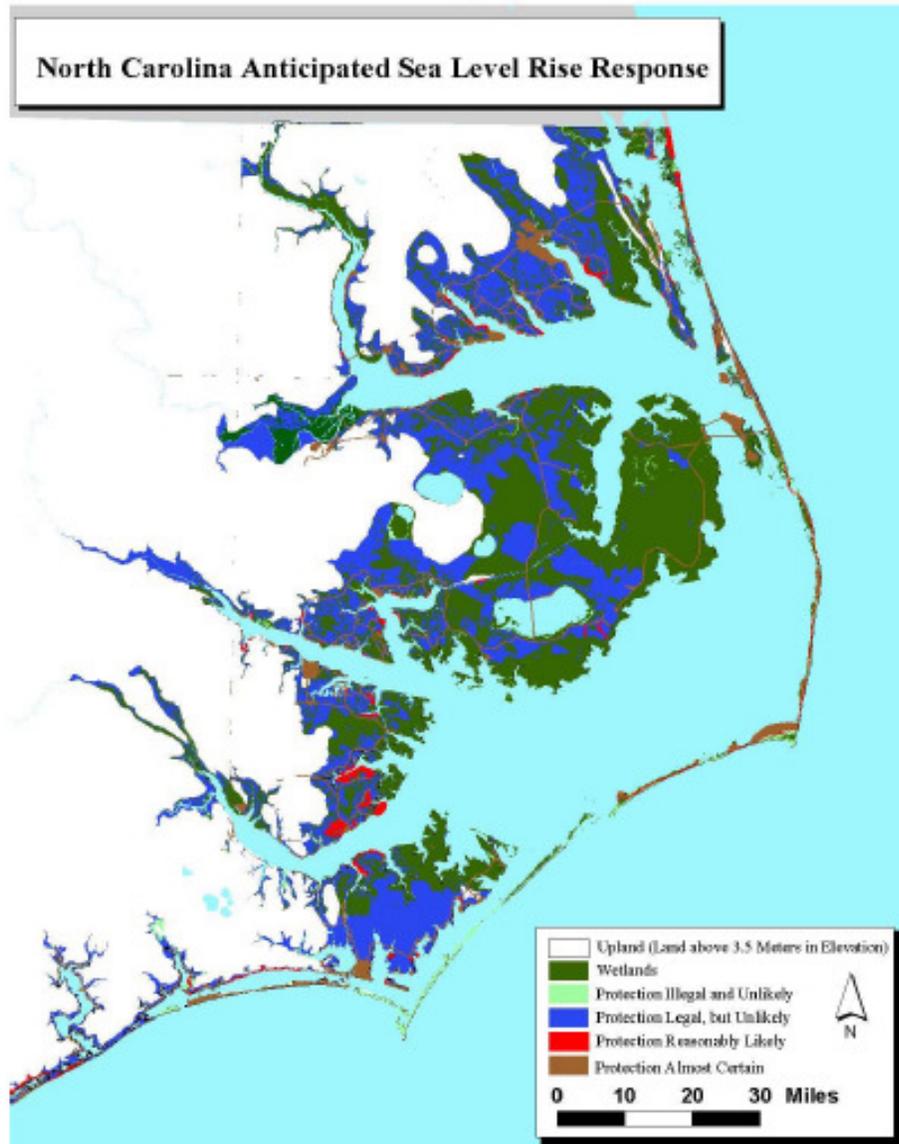
[C]ities and other heavily developed areas will be protected because the value of land and structures is many times the cost of constructing the necessary dikes and pumping systems; lightly developed residential areas, as well as forests and farmland, on the other hand, will probably not be protected because the cost of doing so would be greater than the market value of the land. . . . The debate in the United States centers on moderately developed lowlands and on areas that are already vulnerable to storms (Titus 1990b).

In North Carolina, the Outer Banks—particularly the parts north of the Cape Hatteras National Seashore and the Cape Lookout National Seashore—contain many popular, highly developed, and highly desirable beach resorts. Some of these areas are more vulnerable to complete inundation than other areas, particularly some of the low-lying parts of the Albemarle-Pamlico Peninsula (Poulter 2005). According to one study, a number of coastal planners expect that some parts of the Outer Banks will be protected from inundation. This would also entail protecting the routes between the Outer Banks and the mainland, such as NC-64 and NC-264. Some of the roads connecting the towns on the Outer Banks with the mainland and with one another will likely eventually have to be converted to causeways, and

more bridges will become necessary. Maintaining these roads may encourage communities to protect immediately adjacent properties (Titus 2003). It is well known that the locations of roads have a substantial impact on development patterns.

Researchers at North Carolina Sea Grant (a research and educational organization funded by NOAA and the North Carolina General Assembly) conducted initial interviews with representatives of North Carolina's Department of Environment and Natural Resources about which coastal areas they anticipated would be defended from the effects of SLR and which areas they expected might not be protected (e.g., using beach nourishment or hardened structures). The intent was to distinguish between areas where shore protection is projected to be almost certain, probable, possible (but unlikely), and very unlikely because it is currently illegal. Figure 4 is a published version of a map showing the preliminary results of that study. The caption beneath Figure 4, which appears in the original article, explains the meaning of the different colors used on the map. Table 4 presents additional information about how judgments about the likelihood of protecting coastal areas were derived. Also, it should be noted that the entire area shown in color in Figure 4 is at an elevation of 3.5 meters or less above mean sea level (Titus 2003).

**Figure 4. The Likelihood of Adopting Future Shoreline Protection Strategies in Specific Parts of the North Carolina Coastal Zone**



*Draft maps illustrating the areas where . . . state coastal planners expect people to hold back the sea. Areas depicted in brown are almost certain to be protected with beach nourishment, fill, or some form of structure. Areas in blue represent privately owned land that the state planners do not expect to be protected. Areas in red represent land that probably will be protected, but where protection is less likely than the areas in brown. For example, along the barrier islands north of Corolla, the Coastal Barrier Resources Act prohibits federal assistance. Although property values may be sufficient to justify beach nourishment to hold back the sea, the absence of federal funding makes such projects less likely than in similar areas that are eligible for federal funding. These maps are being revised to reflect the local expertise of county governments, who generally expect more areas to be protected. Source: Walter Clark, North Carolina Seagrant.*

—Original caption  
(Source: Titus 2003)

**Table 4. EPA/NC Sea Grant Approach to Coding Likelihood of Shore Protection**

Likelihood of Protection	Land-Use Category
Shore Protection Almost Certain (brown)	Existing developed land (commercial, industrial, residential, governmental) within extensively developed areas or designated growth areas (including areas with central water and sewer)
	Extensively used state parks operated for purposes other than conservation, in areas that are certain to be protected, and have current shore protection.
	Future development within extensively developed areas and/or designated growth areas
	Publicly owned developed (e.g., historical landmarks) and military lands
	Military lands in urban areas where land would be protected even if base closed
	Existing development within less densely developed areas or outside of growth areas (in the majority of counties)
Shore Protection Likely (red)	Existing development within less densely developed areas or outside of growth areas (in a minority of counties)
	Lightly developed areas with no central water or sewer—or mobile homes—in areas not expected to gentrify
	Projected future development outside of growth areas
	Moderately used parks operated for purposes other than conservation in areas likely to be protected, or shorefront parks with no current protection in areas certain to be protected
	Military lands in areas where protection is not certain
	Moderately developed oceanfront lands ineligible for federal subsidies, or surrounded by areas that will not be protected
	Conservation easements in some areas where shore protection would be certain even if land remained as farmland
Shore Protection Unlikely (blue)	Undeveloped privately owned land in areas expected to remain sparsely developed (i.e., not in a designated growth area and not expected to be developed)
	Lightly developed unbridged or roadless barrier islands ineligible for federal subsidies
	Resource conservation areas (Critical Areas Act)
	County-owned lands
	Conservation easements in most locations
No Shore Protection (light green)	Private lands owned by conservation groups, and some conservation easements
	Publicly owned natural lands
	Developed areas where environmental regulations prohibit shore protection

Source: Titus 2005

As noted in the caption for Figure 4, the researchers involved with the preliminary study in 2003 planned to enhance and expand upon their research after the above-referenced article was published. In fact, after the above draft of the map was published, EPA representatives met with county officials throughout North Carolina and were informed that many more areas along the shoreline would probably be protected than indicated on the original draft of the map. This effort to create very detailed, accurate maps, which is still ongoing, is part of a national effort undertaken by EPA to encourage long-term planning associated with SLR vulnerability by evaluating potential responses to SLR in each coastal state. As part of completing this study, EPA and others intend to research policies and regulations in North Carolina, consult county and local land use plans, and interview state and local coastal planners in individual counties to produce detailed maps of where in each county developed areas are likely to be protected (via beach nourishment, hardened structures, or elevation) and where natural forces will be allowed to operate. In other words, the type of map shown in Figure 4 will be produced on a county-by-county basis and provided to appropriate stakeholders for their review prior to publication in a report covering the entire state of North Carolina. This forthcoming report will be titled, “The Likelihood of Shore Protection in North Carolina” (J. Titus, U.S. Environmental Protection Agency, personal communications, March 18 and April 26, 2007).

### **3.6 SLR Vulnerability in the Morehead City Area**

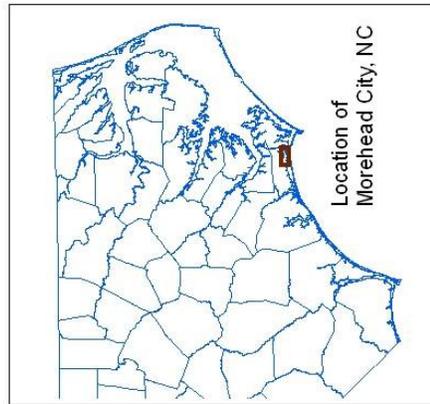
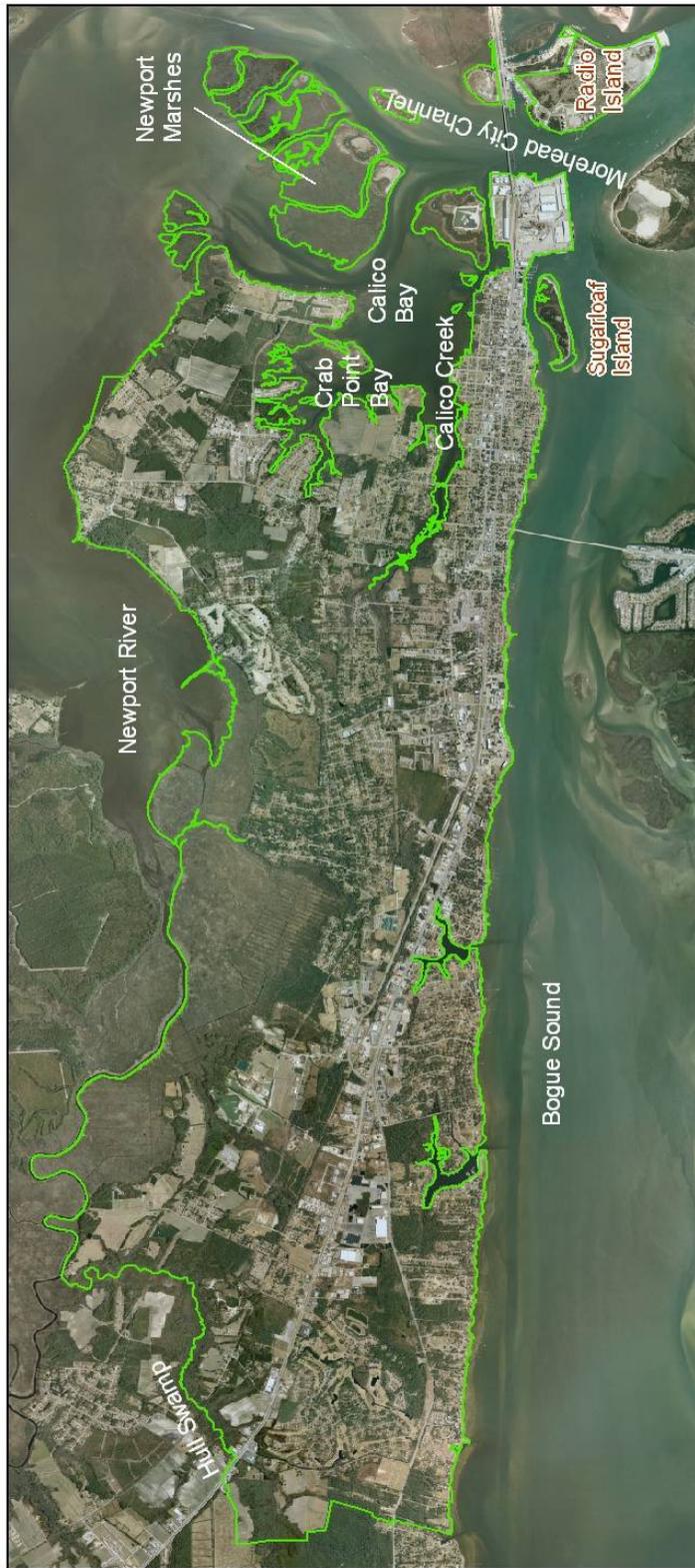
#### *Morehead City and Vicinity Study Area*

To estimate the effects of SLR at a smaller scale than North Carolina as a whole, this study also includes a geographic information system analysis using one available model of the effects of SLR. Morehead City, together with and the immediately adjacent area over

which it has zoning authority (called its extraterritorial jurisdiction or ETJ), was selected to serve as a case study. Morehead City is less than 15 miles northwest of Cape Lookout, along the north side of Bogue Sound, and is shown in Figure 5. The Newport River (and a part of the Atlantic Intracoastal Waterway that runs through it), Calico Bay, Calico Creek, and Crab Point Bay extend along the east side and northeast side of Morehead City and its ETJ (hereafter called the study area). Along much of the northern boundary of the study area are floodplains associated with the Newport River and Hull Swamp. The location of Morehead City, therefore, allows for the study of flooding due to SLR in one region, along estuarine shorelines, riparian zones, and floodplains.

The study area also might serve as a good location for risk communication about the local effects of SLR to begin because several stakeholders that might potentially become involved in this type of outreach are already located in Morehead City or nearby. Specifically, the North Carolina Divisions of Coastal Management and Marine Fisheries both have regional offices in Morehead City. One might argue that the former is the state agency that would most appropriately become involved in encouraging coastal counties to prepare for SLR. The University of North Carolina–Chapel Hill’s Institute of Marine Sciences is in Morehead City and Duke University’s Marine Lab is in adjacent Beaufort, and researchers at both institutions are studying SLR in the State. Finally, the North Carolina Coastal Federation, a non-profit organization, has its headquarters in nearby Ocean, North Carolina.

It should also be noted that the Morehead City government seems to be highly aware of flooding risks. For approximately 15 to 20 years, the City has reportedly required new homes to be elevated 1 foot higher than the Federal Emergency Management Agency’s base



**Legend**

- Morehead City and Its ETJ
- NC County Boundaries

0 1 2 Kilometers

N

North American Datum (NAD) 1983  
 NC State Plane Coordinate System  
 Aerial Photograph from Sept. 2006

Rebecca Feldman      April 2007

Figure 5. Location of Morehead City and Its Extraterritorial Jurisdiction (ETJ)

flood elevations. The current draft of the City's revised Land Use Plan indicates, "The main resource protection issues discussed during the development of the 1999 plan and reflected in the adopted policy statements include . . . the implication of anticipated sea level rise" (Wooten Company 2006). However, when asked what the City is doing to prepare for SLR, the City's Planning Director indicated that the City is not currently doing anything other than enforcing its requirement that structures be elevated an extra foot. As discussed later in this section, the Planning Director seems to be receptive to receiving more information about the potential effects of SLR in the City's jurisdiction (L. Staab, Morehead City Planning Department, personal communication, April 19, 2007).

#### *Data Sources*

The first data source used for this study was information on locations defined by grid cells that might be flooded by different increments of SLR provided by Benjamin Poulter, formerly at Duke University and now at the Potsdam Institute for Climate Impact Research. He provided a raster grid representing whether any given 50-foot by 50-foot square cell would be either below water or above water under modeled increases in the relative height of sea level amounting to 0.32 m, 0.72 m, and 1.06 m, respectively. The first projection is considered to be a low-end estimate and was influenced by several sources, including long-term tide gauge data from North Carolina and vicinity, as well as recent articles by Church (2006), Cabanes et al. (2001), and Brahic (2007) that report current rates of global SLR in the 0.31 to 0.33 cm/year range, consistent with IPCC (2007) estimates (B. Poulter, Potsdam Institute for Climate Impact Research, personal communication, March 31, 2007). SLR of 0.72 m by 2100 is one possible mid- or mid- to high-range projection for the North Carolina area. The 1.06 m projection was developed from the IPCC's 2001 projections (IPCC 2001),

which had predicted a maximum of 0.88 m of SLR from 1990 to 2000, adding a total of 0.20 m of subsidence in NC, then adjusting the baseline year from 1990 to 2000 to reach 1.06 m (Poulter et al. in prep.). The raster grid was developed based on gridded LIDAR data from the North Carolina Floodplain Mapping Program, which detected the average elevation of each grid cell from LIDAR data acquired during 2001 (from flights over the North Carolina coast). The elevation data used for this study had a vertical accuracy of 0.25 m (Poulter 2005).

Poulter's model, mentioned in Section 2.2, predicts areas that would be flooded based on whether their elevation is higher or lower than that of the predicted future sea level, with one modification. Specifically, a grid cell is only projected to be flooded if an adjacent cell in any of eight directions (north, northeast, northwest, west, east, southwest, southeast, or south, looking at a cell from the view of someone in an airplane) is also flooded (sometimes called an 8-sided model). This approach prevents pits from appearing as if they will be inundated if they are surrounded on all sides by walls or bulges that are sufficiently high that they would prevent flooding from SLR (Poulter 2005). It should be noted that this model does not take into account erosion or accretion of wetlands or shorelines, alongshore transport, changes to tidal regimes, the effects of storms, new shoreline protection strategies (seawalls or beach nourishment), or many other factors that could affect which areas actually become inundated in the future. The LIDAR elevation data do not necessarily accurately capture seawalls, since they use the average elevation detected within a grid cell, so some seawalls may be missing from the dataset, potentially suggesting that some coastal properties will be vulnerable to SLR that are actually protected, at least partially.

The second dataset used for this study was land use data from the Morehead City Planning Department, which provided electronic data it received from its consultant, the Wooten Company, as part of the City's efforts to update its Land Use Plan over the past few years. The City Planning Director was not sure when exactly she received these GIS Land Use data from the Wooten Company or exactly how up to date the data were, but she estimated they reflect land use as of 2003 or 2004. This Land Use dataset covered both the City and the ETJ. Its positional accuracy was not available from the town, but since it was used with zoning data meant for tax purposes, the accuracy was probably intended to be quite high. The dataset included information about both zoning, which reflects what future land uses may be allowed, and current land use, which provides better information about how land was being used at the time the dataset was last updated (L. Staab, Morehead City Planning Department, personal communication, April 19, 2007). Morehead City has more than 20 types of zoning districts, which can fall into these land use types: commercial, industrial, institutional, residential, floodplain, planned development, and street. One limitation of the data is there no land use type (or zoning district) is included that defines land temporarily or permanently being used for open space or farming. Such a category might provide more insight into current or planned uses for some parcels.

### *Methods*

The basic approach to this GIS analysis was to overlay parcels in the Land Use dataset with the datalayers representing inundated lands under each of the SLR scenarios to determine where they overlapped. As is often the case with GIS analyses, many more steps were required to output this analysis than might be suggested by this summary.<sup>15</sup> Of note for

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<sup>15</sup> More complex analyses were also considered and investigated, but they proved to be so unwieldy that they had to be postponed for a future research project. For example, an effort was made to

present purposes are several ways in which the Land Use dataset for Morehead City and its ETJ had to be modified for this analysis that might make the results less precise than one might think.

Several imperfections with the Land Use dataset from the City Planning Department were identified. Specifically, there were many places where parcel boundaries did not quite match up to adjacent parcels. For the most part, the problem seemed to be that the outlines of many roads were digitized and included in the GIS data, but in other large portions of the town, there were what amounted to holes where there should have been roads. However, there was no clear pattern to which roads were included or excluded, which suggests this may have been an error. This might have been easy to remedy had a source of highly-accurate GIS data for the boundaries of the City and its ETJ been identifiable. However, various GIS datasets purporting to cover the boundaries of the City and, sometimes, its ETJ appeared to be much rougher (i.e., less precise) than the Land Use dataset. This was a particularly important problem to address in the many locations where roads dead-ended at the shoreline. In these locations, the outlines of the City and its ETJ were discontinuous, and a method was needed to outline the end of the street.

The selected approach to overcome this challenge associated with the missing data was to connect one corner of one coastal parcel to the nearest corner of the coastal parcel across the street. Although there were clearly inaccuracies associated with this method (based on viewing a digital version of an aerial photograph underneath the parcel boundaries)

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identify the specific, discontinuous locations of seawalls in Morehead City and in its ETJ, including along the docks on Bogue Sound, near Evans Street, and on private property. However, it turned out that most of the seawalls were along Bogue Sound, the creeks that empty into it on the south side of the ETJ, and the Morehead City Channel, whereas most flooding due to sea level rise was along the Newport River and vicinity, along the northern edge of the ETJ. Therefore, the option of recording in a GIS the precise locations of the seawalls in Morehead City to see how that would change inundation patterns was determined not to be very useful and was not completed.

and greater accuracy might have been obtained by tracing what appeared to be the shoreline in an aerial photograph, the latter approach was rejected for at least two reasons. First, the approach adopted was consistent across the study area. Second, it was difficult to tell where wetlands and beaches ended and where the water began from the aerial photographs in some cases, especially where there was exposed vegetation near the shoreline. Either the exact time the aerial photograph was taken or other specific information about tidal conditions (e.g., whether it was high tide, low tide, or somewhere in between) would also probably have been needed to try to determine where the mean high water line was (which delineates what is considered private property from what is considered public trust beach). In the absence of this information, drawing straight lines from one parcel to the next was judged a better approach than tracing apparent shoreline boundaries from a digital aerial photograph.

Creating one continuous outline of Morehead City and its ETJ facilitated identification of where there were missing portions of roads, missing parcels, or other holes in the Land Use data, so they could be filled in before calculating the size of areas in different land use categories that might be inundated by SLR. For reference, it should be noted that the Land Use dataset originally contained approximately 43.1 sq km (16.7 sq mi or 10,660 acres), including some roads. The data cleaning performed for this study resulted in adding approximately 2.6 sq km (1.0 sq mi or 650 acres) to the entire study region, bringing the total estimated area for Morehead City and its ETJ to approximately 45.7 sq km (17.7 sq mi or 11,310 acres). In other words, had this data cleaning not been performed, almost 6% of the area on land within the study area would have been erroneously excluded.

All of the land added in this fashion was assigned, for the purposes of this analysis, a zoning of NA (not available) and a land use of “mostly streets.” While practically all the

land added using this method seemed to actually represent streets, there were two or three obvious exceptions. First, one partial parcel on Bogue Sound that was added manually traced the boundary of a promontory reinforced with a seawall and was adjacent to a parcel showing planned development as its land use, suggesting that the added portion of the parcel might also appropriately be characterized as planned development. The second exception was one residential parcel that appeared to be a hole in the Land Use dataset, which had a residential property on either side. The land use coded for this polygon was also left as “mostly streets” (for consistency). Keeping all the added parcels coded in that manner allows for easy differentiation between the streets and other original parcels in the Land Use dataset from the polygons added for this analysis, which viewers might have less confidence in the accuracy of. This method of data cleaning may have added other minute polygons between valid polygons from the Land Use data. This is the third type of potential exception to the fact that the majority of polygons added to the dataset represented streets.

To draw conclusions from overlaying one dataset containing polygons and another dataset containing grid cells, it is necessary to convert the polygons to cells or the cells to polygons. For this analysis, it appeared that converting the cells from the inundation grids to polygons would result in loss of considerable fine detail, so the revised Land Use data were converted from polygon to grid format instead. While the cells in the inundation datasets were 50 feet (approximately 15 m) on each side, converting the revised Land Use parcel data at that resolution also would have resulted in considerable loss of detail. Instead, the revised Land Use data were converted to cells that were 12.5 feet (3.8 m) on each side, creating sixteen cells in the rasterized revised Land Use dataset for every one cell in the inundation dataset. It should be emphasized that this technique takes fairly precise parcel data and

converts it to a more generalized grid, in which each cell is assigned the land use type found in the majority of the 156 sq ft (14.5 sq m) cell.

*Results*

Converting the revised Land Use data for Morehead City and its ETJ into a 12.5-ft raster grid results in a grid that covers a total of approximately 45.7 sq km (17.7 sq mi), as shown in Table 5. This represents the total area within Morehead City’s jurisdiction, including uninhabited floodplains such as the Newport Marshes, as well as islands such as Sugarloaf Island (also uninhabited), Radio Island (used for industrial and residential purposes), and an island created from dredge spoil. This data suggests that, when islands are included, the study area is approximately 55% residential, 11% floodplain, 9% streets, 6% planned development, and the rest is a mix of institutional, industrial, and commercial land uses. Like the source datasets, the Land Use grid does not specifically identify any land used for agriculture or open space.

**Table 5. Land Use Estimates in Morehead City’s Jurisdiction**

Land Use	Sq Km	Acres	Sq Mi	Percentage
Floodplain	5.24	1294	2.02	11.4%
Residential	24.92	6157	9.62	54.5%
Institutional	1.93	477	0.75	4.2%
Industrial	3.35	827	1.29	7.3%
Commercial	3.51	867	1.36	7.7%
Planned development	2.57	634	0.99	5.6%
Street	1.63	403	0.63	3.6%
Mostly streets	2.61	645	1.01	5.7%
Total	45.75	11306	17.67	100.0%

Tables 6, 7, and 8 show the land uses that would be affected by the three modeled SLR projections. In all three cases, roughly half of the land affected is projected to be within

floodplains, most of which are undeveloped. The model also estimates that there may be between 0.1 sq km and 0.3 sq km of flooding of residential properties in Morehead City’s ETJ. The relatively large percentage of industrial flooding, as compared to flooding affecting other land use categories, probably comes from the projected flooding of the “island” just north of the Morehead City side of the bridge to Radio Island, which is composed of dredge spoil (i.e., material dredged during channel maintenance) (H. Scott, Morehead City recreational boater, personal communication, April 17, 2007). This analysis also predicts some street flooding, including flooding in several places across Highway 70 and Highway 24, both of which are evacuation routes. See the three tables that follow for detailed estimates of types of land potentially flooded by SLR, broken down by land use category. These data are also depicted in Figures 6, 7, and 8, which show vividly that most of the flooding would occur in the floodplains and along low areas near current or past streambeds or wetlands, with less flooding along the estuarine shore than one might expect.

**Table 6. Land in Morehead City’s Jurisdiction Affected by 0.32 m of SLR**

Land Use	Sq Km	Acres	Sq Mi	Percentage
Floodplain	0.21	51.83	0.08	58.7%
Residential	0.11	26.45	0.04	30.0%
Institutional	0.005	1.17	0.002	1.3%
Industrial	0.03	8.01	0.01	9.1%
Commercial	0.003	0.84	0.001	1.0%
Planned development	0.001	0.31	0.0005	0.4%
Street	0.001	0.32	0.001	0.4%
Mostly streets	0.002	0.58	0.001	0.7%
Total	0.357	88.30	0.138	100.0%

**Table 7. Land in Morehead City’s Jurisdiction Affected by 0.72 m of SLR**

Land Use	Sq Km	Acres	Sq Mi	Percentage
Floodplain	0.32	79.48	0.12	52.8%
Residential	0.24	58.12	0.09	38.6%
Institutional	0.01	2.06	0.003	1.4%
Industrial	0.03	8.48	0.01	5.6%
Commercial	0.004	1.07	0.002	0.7%
Planned development	0.004	0.92	0.001	0.6%
Street	0.002	0.41	0.001	0.3%
Mostly streets	0.003	0.82	0.001	0.5%
Total	0.61	150.53	0.235	100.0%

**Table 8. Land in Morehead City’s Jurisdiction Affected by 1.06 m of SLR**

Land Use	Sq Km	Acres	Sq Mi	Percentage
Floodplain	0.33	80.78	0.13	45.8%
Residential	0.33	81.22	0.13	46.0%
Institutional	0.01	2.67	0.004	1.5%
Industrial	0.04	10.01	0.02	5.7%
Commercial	0.01	1.71	0.003	1.0%
Planned development	0.02	4.76	0.01	2.7%
Street	0.003	0.64	0.001	0.4%
Mostly streets	0.01	2.28	0.004	1.3%
Total	0.71	176.39	0.276	100.0%

Table 9 summarizes the amount and percentage of land currently assigned to each land use category that might be inundated by the three SLR scenarios. This table shows that approximately 1 to 2 percent of the entire area over which Morehead City has jurisdiction, including 4 to 6 percent of the associated floodplains, could be inundated by SLR, were this model to reflect actual future conditions (which it cannot due to the limitations cited above, among others). In addition, these analyses suggest that approximately 1 percent of residential and industrial property could be flooded in the future, and this could have negative effects on the tax base of Morehead City.

**Table 9. Summary of Estimated Area in Each Land Use Category within Morehead City's Jurisdiction Potentially Inundated by SLR**

Land Use	Sq Km, Total, in City's Jurisdiction	Modeled 0.32 m Rise		Modeled 0.72 m Rise		Modeled 1.06 m Rise	
		Sq Km Flooded	Percent (%) of Total	Sq Km Flooded	% of Total	Sq Km Flooded	% of Total
Floodplain	5.24	0.21	4.0%	0.32	6.1%	0.33	6.2%
Residential	24.92	0.11	0.4%	0.24	0.9%	0.33	1.3%
Institutional	1.93	0.005	0.2%	0.01	0.4%	0.01	0.6%
Industrial	3.35	0.03	1.0%	0.03	1.0%	0.04	1.2%
Commercial	3.51	0.003	0.1%	0.004	0.1%	0.01	0.2%
Planned development	2.57	0.001	0.0%	0.004	0.1%	0.02	0.8%
Street	1.63	0.001	0.1%	0.002	0.1%	0.003	0.2%
Mostly streets	2.61	0.002	0.1%	0.003	0.1%	0.01	0.4%
<b>Total</b>	<b>45.75</b>	<b>0.36</b>	<b>0.8%</b>	<b>0.61</b>	<b>1.3%</b>	<b>0.71</b>	<b>1.6%</b>



**Figure 6. Land in Morehead City's Jurisdiction Affected by Projected Sea Level Rise of 0.32 m**

**Legend**

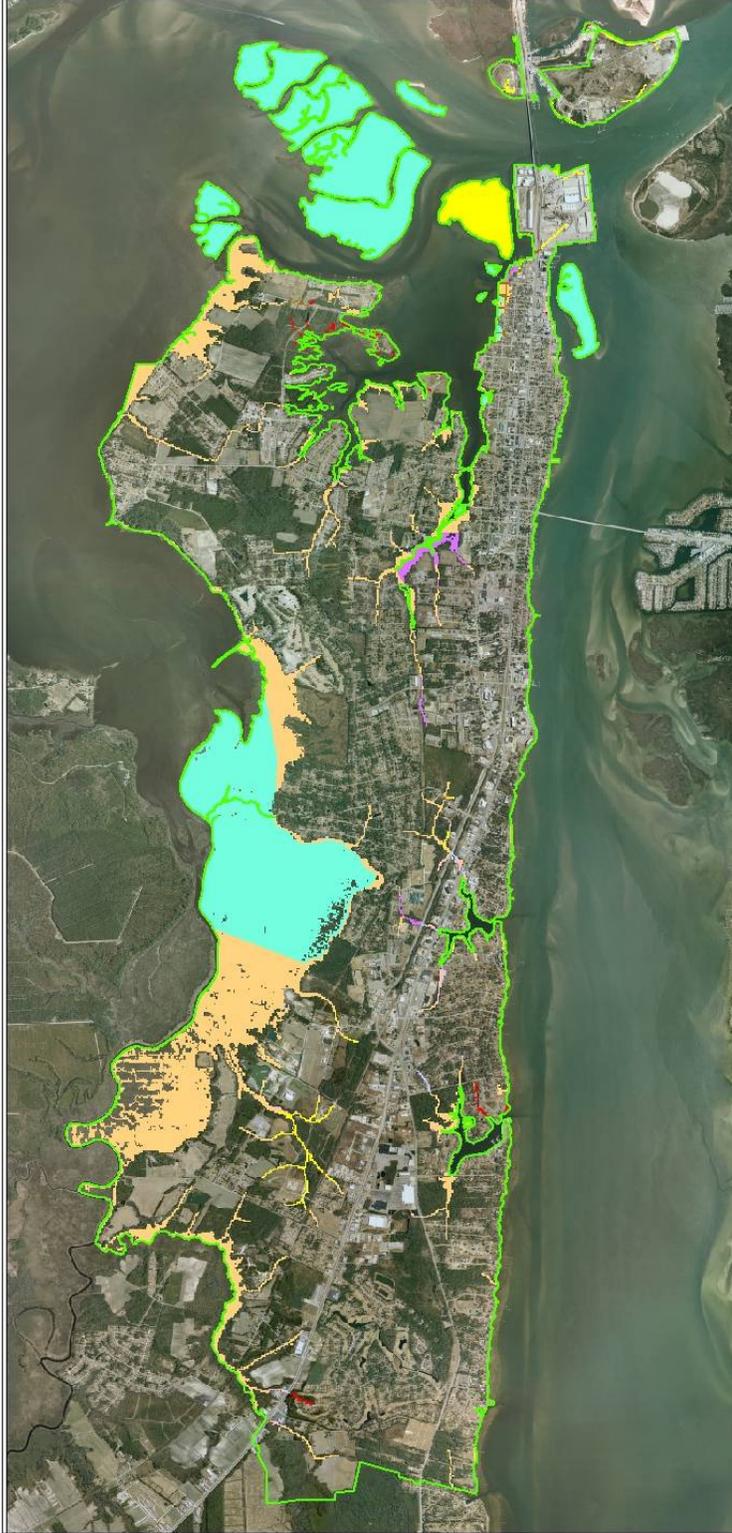
- █ Morehead City and its ETJ
- █ Land Inundated by 0.32 m of SLR
- █ Mostly streets
- █ Floodplain
- █ Residential
- █ Institutional
- █ Planned development
- █ Street
- █ Industrial
- █ Commercial

NAD 1983, NC State Plane Feet  
Water Level Data from Poulter

Rebecca Feldman April 2007

0 0.5 1 1.5 2 Kilometers

*Aerial photograph from September 2006 shown as backdrop. If aerial photograph is visible, land is not projected to be inundated.*



**Figure 7. Land in Morehead City's Jurisdiction Affected by Projected Sea Level Rise of 0.72 m**

*Aerial photograph from September 2006 shown as backdrop. If aerial photograph is visible, land is not projected to be inundated.*

**Legend**

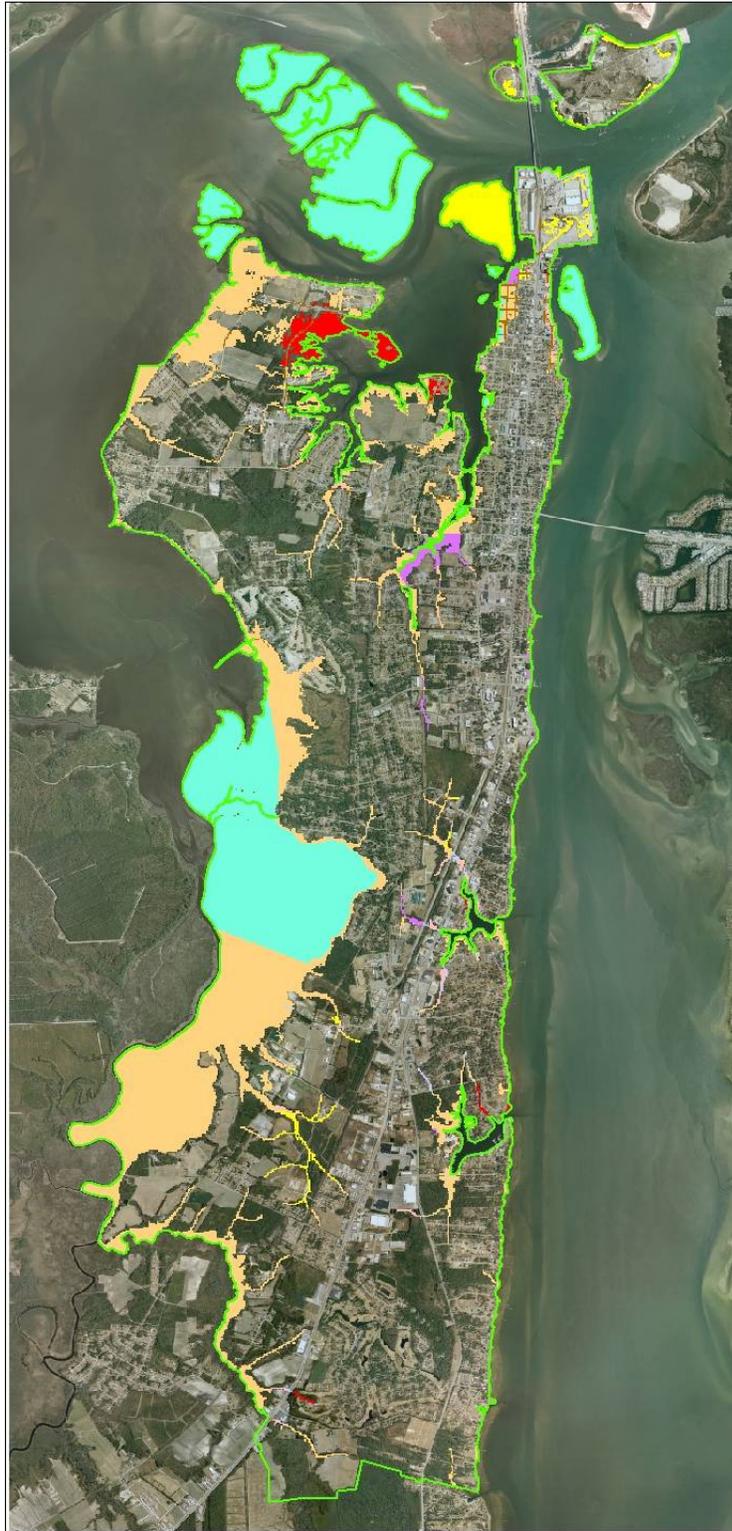
- Morehead City and its ETJ
- Land Inundated by 0.72 m of SLR
- Mostly streets
- Floodplain
- Residential
- Institutional
- Planned development
- Street
- Industrial
- Commercial



NAD 1983, NC State Plane Feet  
Water Level Data from Poulter

Rebecca Feldman April 2007





**Figure 8. Land in Morehead City's Jurisdiction Affected by Projected Sea Level Rise of 1.06 m**

**Legend**

- █ Morehead City and Its ETJ
- █ Land Inundated by 1.06 m of SLR
- █ Mostly streets
- █ Floodplain
- █ Residential
- █ Institutional
- █ Planned development
- █ Street
- █ Industrial
- █ Commercial



NAD 1983, NC State Plane Feet  
Water Level Data from Poulter

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0 0.5 1 2 Kilometers

*Aerial photograph from September 2006 shown as backdrop. If aerial photograph is visible, land is not projected to be inundated.*

### *Discussion*

The inundation scenarios used for this analysis provide a useful starting point for Morehead City to begin to consider how to respond to SLR vulnerability. For example, perhaps City officials think it might be appropriate to target lands for acquisition that appear as if they will be flooded in the future (L. Staab, Morehead City Planning Department, personal communication, April 21, 2007). It may surprise some people that elevation data suggest that much of the flooding from SLR would be along the Newport River, near Hull Swamp, and in associated wetlands, where there are no seawalls. Most seawalls are probably along Bogue Sound, the Morehead City Channel, and along the state port and military facilities that are along this channel and to the northwest of it (south of the dredge spoil island) (H. Scott, Morehead City recreational boater, personal communication, April 17, 2007). It appears that little flooding from SLR alone would affect properties along Bogue Sound, however.

Finally, it should be noted that these data and maps showing potential inundation patterns are not intended for land use decision-making because many factors are not incorporated into the model used. Because of these limitations, care should be used when showing any maps depicting potential future inundation maps to stakeholders, in order to avoid causing them undue concern or worry, for example, that they might need to sell their property. Future datasets that authors and users have higher confidence in might not need to be accompanied with caveats that are as strong. Nevertheless, interested parties should always ask about the confidence experts have in the accuracy of the models they outline, along with associated limitations, before assuming that any model will accurately predict future conditions.

Given the variability in how people react to information about potential risks and in the different political climates in different locales, it seemed useful to find out from Linda Staab, the Director of Planning for Morehead City, about possible reactions to the types of maps shown in Figures 6-8. When asked how she personally would react to maps that attempt to pinpoint which properties might be flooded by SLR in the future, she said, “I think that would be interesting.” As for how people in the City might respond, she said, “I think there would be alarmists and skeptics, as with anything.”

Ms. Staab indicated that she thought it nevertheless would be useful to “put the information out there” and aim for a balanced presentation of facts. Educating the public “helps them make good decisions,” she added. She also stressed the importance of presenting a variety of possible responses and alternatives when disseminating information about the risk. One such alternative she suggested might be for the City to target for acquisition properties that are susceptible to SLR. Ms. Staab added that, as with many planning efforts, the overall goal should be to aim for consensus on appropriate responses to the risks associated with SLR, including any desirable regulatory changes; but she acknowledged how hard it is to satisfy all the stakeholders.

Finally, Ms. Staab suggested that it would be important to exercise care when disseminating the information because of potential adverse economic impacts on tourism. The same might also be said for potential impacts on real estate values. In short, “presentation is important” (L. Staab, Morehead City Planning Department, personal communication, April 21, 2007). Many of the issues she raised are discussed in the chapter that follows.

### 3.7 Summary

Many studies of past and potential future SLR, erosion, and land loss in North Carolina have been conducted and are underway. During the last 30–70 years, the rate of relative SLR in North Carolina has ranged from only slightly more than the rate of global SLR to 0.25 m (10 in) more than the global, eustatic rate (NOAA CO-OPS 2004). The IPCC estimates that eustatic sea level is likely to rise by 0.18–0.59 m (7 to 23 in) by 2100, and if ice in Antarctica and Greenland melts at the same rate as temperatures warm, global sea levels could rise by another 0.1–0.2 m (4 to 8 in) by 2100 (IPCC 2007). These projections, combined with current rates of SLR and documented subsidence rates in North Carolina, suggest that, by 2100, relative sea level could rise by anywhere from 20 cm (8 in) to approximately 106 cm (42 in) along the State’s coast.

DCM published erosion rates for North Carolina’s Atlantic Ocean shorelines, as of 1998. These data indicate that, over approximately the past 50 years, 18 percent of the ocean shoreline eroded at an average rate greater than 1.5 m/yr (5 ft/yr); 20 percent eroded at a rate greater than 0.6 m/yr (2 ft/yr), but less than 1.5 m/yr (5 ft/yr); and 30 percent eroded at rates less than or equal to 0.6 m/yr (2 ft/yr) (NC DCM 2004). It is not clear how much land loss on the ocean shoreline or the estuarine shoreline future SLR might cause. Because lithography, slope, wave climate, shoreline type, and other factors vary across different coastal environments, the amount of land loss experienced in different areas will be variable.

Various published studies have estimated future erosion rates and land loss, using a variety of different assumptions, thereby making comparisons across the studies difficult. Many of these studies are summarized in Section 2.2. Additional studies of the effects of SLR on North Carolina are underway, including several being supported by a NOAA

CSCOR grant, lasting through 2008, and one funded by NSF through 2010. This (and other) ongoing research is expected to provide better information about the specific areas threatened by SLR. Some geomorphologists have warned that future SLR may cause or facilitate breaches in the barrier islands that line most of the coast. If new inlets stay open, this could substantially change the ecology of the Albemarle-Pamlico Estuary System, including by changing salinity and tidal regimes, as well as increasing the amount of land loss on the mainland (see, for example, Riggs and Ames 2003).

North Carolina's Coastal Area Management Act, as well as other legislation and rules, governs coastal development in the 20 coastal counties, which are required to prepare land use plans (although these plans are only enforced in AECs). One of the hazards these plans are supposed to take into account is SLR, but it is unclear that counties are addressing this requirement other than superficially (J. Titus, U.S. Environmental Protection Agency, personal communication, March 19, 2007). However, rules associated with CAMA do establish setbacks in certain AECs that are based on historical erosion rates, which will provide some measure of protection from SLR in the near term. A requirement for setbacks along estuarine shorelines was added to the rules relatively recently, in 2000. Finally, various other state rules and policy statements accept, in principle, the need to relocate or elevate structures on the coast that are threatened by the proximity of the shoreline, as well as the desirability of considering SLR as part of planning efforts.

NC DEM provides incentives for communities to develop hazard mitigation plans and funding (often from FEMA) for hazard planning and elevating or relocating structures that have been damaged by floods or that might be damaged by future floods. In communities participating in the NFIP, associated requirements are sometimes responsible for

considerably reducing property damage after hurricanes, the construction of buildings that are more resilient than they otherwise would be, and a greater awareness on the part of stakeholders of potential flooding risks. Parts of North Carolina's coastal zone are part of the Coastal Barrier Resources System; to discourage development in these areas, these areas are not supposed to receive any federal subsidies (including through the NFIP or the Department of Transportation for highway construction).

To tie together the information presented in this chapter about the potential risks of SLR, geographic data representing the possible extent of future SLR were compared to geographic data on the locations of land used for different purposes in Morehead City, North Carolina, and its extraterritorial jurisdiction. The results of this analysis showed that approximately 1 to 2 percent of the property in the City might be at risk. Of this property, half is already in the floodplain, 30 to 46 percent is residential, 6 to 9 percent is industrial, approximately 1 percent is commercial, approximately 1.5 percent is institutional, 1 percent is comprised of parts of roads, and 0.4 percent to 3 percent is part of parcels where future development is planned. This GIS analysis also shows that most of the flooding in the Morehead City area would be near the Newport River, Hull Swamp, and associated wetlands, where there are no seawalls. Comparatively little flooding is expected along Bogue Sound; however, most seawalls in the vicinity are probably along this sound and the Morehead City Channel, or along the state port and military facilities along the channel and to the northwest of it (south of the dredge spoil island).



## Chapter 4

### **An Effective Risk Communication Strategy for North Carolina's Vulnerability to SLR: Design and Implementation Considerations**

#### **4.1 Introduction to Risk Communication**

Risk is everywhere, and the public is bombarded on a daily basis by messages about risk, many of which are conflicting or change over time. Under these circumstances, people often do not know which messages they should pay attention to and which they should ignore, which they should believe and which they should disbelieve. Individuals also can be bewildered by both the innumerable risks they face and the variability of their immediacy, seriousness, and occurrence. Even more so, people have difficulty knowing how to respond, if at all, to risk that is less certain, less direct, less understandable, less quantifiable, and less immediate.

Some risks, for example, that certain jars of a popular brand of peanut butter have been contaminated with salmonella (Associated Press 2007) or that a number of brands of pet food have been contaminated with melamine (Goodman 2007), are immediate, definite, readily understandable, and quantifiable. These risks, which potentially affect specific individuals—those who have bought the products or who have been served them—are also typically contained easily and pass quickly. Some other risks, such as the almost certain risk, at some point, of another terrorist attack or another mass murder, are ever present but difficult or impossible for citizens to plan for adequately. This is true, in part, because key elements—the when, where, and how—of these risks will almost always be unknowable. Such events are often not easily containable and, when they do occur, may not pass quickly. Yet other risks, such as the risk of SLR in North Carolina—and elsewhere—are virtually

imperceptible, with their full and exact extent and effects perhaps not knowable for generations.<sup>16</sup> Such risks may not be easily moderated. Furthermore, the ways in which to do so may be uncertain and controversial. Different individuals may have competing interests that make it difficult to reach agreement about if and how to ameliorate these risks. It seems fair to say that the less quantifiable, more controversial, and less immediate a risk is, the more difficult it is for scientists—and even more so, for lay people—to determine, comprehend, and process the facts that are pertinent to if, when, and what responses are appropriate.

All of this underscores the importance of improving everyone’s understanding of the extent to which North Carolina is vulnerable to the effects of SLR. This will require a tailored communication process that takes account of the nature and long-term implications of the risk being conveyed, as well as the implications of (1) continuing to accept the risk or (2) acting to mitigate it.<sup>17</sup> Without effective techniques of risk communication, it is highly unlikely that the public and public policy makers will make the most intelligent decisions about if, when, and how to act in the face of the North Carolina coast’s gradually increasing vulnerability to SLR. Therefore, it is critically important for scientists and risk communicators to consider how individuals without specialized expertise take in and react to

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<sup>16</sup> One researcher has noted that sea level rise has much in common with a number of other global climate change effects: “It is slowly progressing (‘creeping’), long-term, common-place, and – by itself – rather unspectacular, and thus largely ‘invisible’ problem” (Moser 2005, p. 359).

<sup>17</sup> This is not to suggest that such communications necessarily should be shaped to influence people to act—much less to change their behavior in a particular fashion—as opposed to giving them unbiased, understandable, and useful information on which they may proceed if they believe it in their interest to do so. It is beyond the scope of this paper to take a position on the legitimate disagreement among scientists as to whether their role is to advocate the mitigation of risk or simply to educate people about risk and their options for alleviating it. For the same reason, this paper does not endeavor to convince those responsible for risk communication, either in general or in the context of North Carolina’s vulnerability to sea level rise, what position they should take in this debate.

highly technical information, as well as to improve their ability to communicate such information.

It is equally important for scientists and risk communicators to recognize that people may respond far differently to a moderate, easily understood, immediate risk they comprehend than they do to a risk that is less well understood, occurs more gradually, and is amorphous. To take an example from the former category of risk, most people who buy jars of peanut butter that may be contaminated with salmonella probably run to their cupboards to check the codes on their jars to see if they are among those recalled (even if the likelihood of many individuals becoming seriously ill is relatively small). To take an example from the latter, most people may be more or less indifferent, especially if they do not live on the North Carolina coast or in another coastal community, to acting in the face of SLR vulnerability. This may be because they perceive SLR as unlikely to have adverse effects on them in their lifetime (even if SLR is likely to have enormous consequences for millions of people, not to mention numerous governments, in the future). In other words, risk communicators need to be mindful of the special considerations that apply to their messages when “out of sight, out of mind” risks—or risks with slow time frames or that are associated with uncertainty—are involved.

#### **4.2 Risks Inherent in Risk Communication**

Messages about risk can result in confusion and contention, particularly when the messages relate to a risk that approaches so slowly as to seem all but nonexistent. Also, certain questions, such as about global warming and when it will have significant impact on sea level, are subjects of scientific uncertainty and debate. Individuals who are recognized as experts legitimately may have differing opinions about the nature, interpretation, and

conclusiveness of the available data bearing on the topic. Some experts—typically those who take the most extreme positions at either end of the spectrum—may be viewed as Doomsayers or Pollyannas who use scientific terminology, sleight of hand, or selective presentation of data to skew their messages about risk to conform to ideological predilections. At the same time, these individuals may be accused, with or without justification, of being “in the Environmentalists’ Camp” or “Corporate Hired Guns,” respectively. Even if an expert intends no bias, sometimes a risk message, to be accurate, may need to be so complex and exquisitely presented that non-experts cannot fathom it. If the message is “dumbed down,” so that it is understandable to people without technical expertise, it is quite possible that the message will communicate only partial information. When this occurs, the accuracy of the message can be disputed on the ground that it is lacking relevant information, that it is unsupportable as stated (NRC 2004 & 1989), or, even worse, that it is rife with hyperbole and designed as propaganda. These are among the criticisms leveled at Al Gore’s recent Academy Award-winning documentary, *An Inconvenient Truth* (Broad 2007). In other words, readily understood messages about complex risks such as SLR are often subject to attack as untrustworthy in one way or another.

#### **4.3 Barriers to Effective Risk Communication**

One challenge to effective risk communication has been described as follows:

[Risk] communication often goes on within contexts that pose difficult choices. . . . [C]itizens must evaluate the risks and benefits . . . for themselves, their families, and their communities. The technical experts who are the best source of such information may lose the public’s trust unless they present their expertise in a concise, comprehensible form, acknowledging scientific uncertainties and controversies (Coussens and Fischhoff 2001, p. 1).

Moreover, various settings in which risk communication takes place may present different conditions that also make effective communication more difficult. Such differences may also have a profound impact on whether or not efforts are made to mitigate SLR (Moser 2005). These circumstances include, for example, dissimilarities in education, life experiences, expertise, socio-economic status, politics, language, and culture between the communicators and the recipients of the communications. To these differences might be added the following “deep human-dimension uncertainties, which [arguably] become ever greater the further out in the future one tries to project” (Moser 2005, p. 354):

Varying degrees of problem awareness, perceptions of urgency, and understanding to the climate change (impacts) problem; differences in the value-based lenses, cognitive frames, and capacities available to analyze and interpret climate change information; and varying motivations, abilities and constraints on taking action (Ibid.).

In many instances, the individuals to whom a risk message is directed will not share a homogenous demographic profile. For example, in 2003, the median household income in North Carolina’s 20 coastal counties ranged from \$25,798, in Tyrell County (U.S. Census Bureau 2003a), to \$44,345 in Dare County (U.S. Census Bureau 2003b), where the percentages of college graduates over the age of 25 were 11% and 28%, respectively (U.S. Census Bureau 2003a, 2003b). Carteret County, in which Beaufort and Morehead City, North Carolina, are situated, placed towards the upper end of the middle of the range. Its median income in 2003 was \$33,060 and 20% of its residents over the age of 25 were college graduates (U.S. Census Bureau 2003c). If such disparities—and others that are relevant—are forgotten, those who communicate about the risk of SLR to those on the North Carolina coast will fail, at a minimum, to meet the varying informational needs of different individuals.

Other considerations are important to keep in mind. For example, in a study published by Moser (2005), she reported on the results of her analysis of three East Coast states—among them North Carolina—that were taking SLR into account in their coastal policies. As part of the study, she conducted a workshop with 10 experts in the fields of coastal science and management, uncertainty, risk assessment, and global change, who identified a number of factors that influence how people are likely to act in the face of SLR. These dynamics include the following:

[L]and-use and technology choices, location in hazard-prone areas, preparedness, vulnerability, initial and higher-order impacts (e.g., job losses, income losses, boosts for the local reconstruction industry), and societal responses to hazardous events (or anticipatory responses [to] the prospects of such events as climate change and [SLR]) (Moser 2005, p. 355).

Similarly, various risk communicators and various audiences may have divergent “world views” on issues, and it is crucial to recognize the existence of any such differing perspectives in advance of beginning to conduct an outreach effort. This is because they may be determinative of how the risk messages about SLR will be received. There may be disagreement, for example, on the relative importance of the rights of the individual as compared to the rights of society as a whole. When different perspectives are present, conflict is also likely to occur, and efforts will need to be made to keep it focused. Conflict need not be bad; rather, if people discuss an issue, instead of arguing about it, they at least can understand the views of others, even if they cannot reach agreement.

Another set of impediments to effective risk communication, in general, and effective risk communication about SLR vulnerability, in particular, is presented by so-called “noise, diversions, and filters:”

From the viewpoint of the sender of a communication, any other transmissions competing for the attention of the receiver constitute noise and

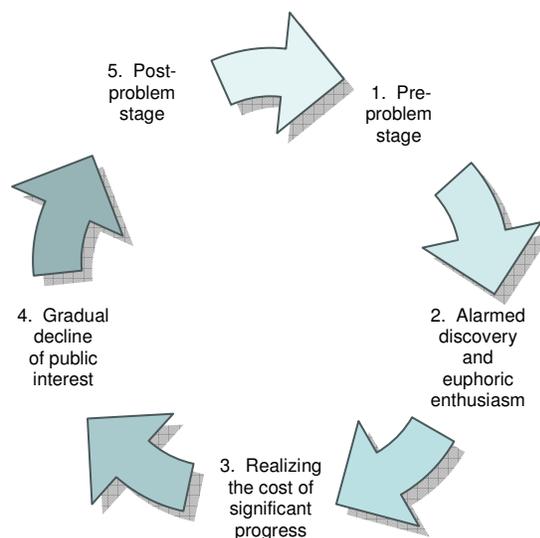
diversions. In some cases, simply because of the large number of competing transmissions beamed at the receiver, this noise may cause strong interference. . . .

The wide range of transmissions and sensory stimuli continually hitting an individual may be consciously filtered, but are also subject of a natural and sub-conscious filter which tends to eliminate reception of messages not related to the individual's personal goals (Sadler 1987, p. 3).

In other words, particularly in a world filled with messages—relating to the daily news, health concerns, etc.—it is easy for a messages to be lost that relate to risks as to which there is some degree of uncertainty and there are no immediate consequences, including SLR vulnerability in North Carolina.

An additional barrier to effective risk communication might be described as human nature. What is known as the “Issue-Attention Cycle” (Downs 1972, Foster and Sewell 1981) predicts that people's awareness of problems needing action and commitment to resolving them follow a five-stage pattern of increasing and decreasing interest. These stages are depicted in Figure 8, after Sadler 1987 (citing Foster and Sewell 1981), and they may be summarized as follows.

**Figure 8. Stages of Downs's Issue-Attention Cycle**



In the first stage, only a relatively small number of people understand the problem and what it implies, and they have to work hard to raise the consciousness of larger numbers of citizens. Difficulties may include lack of pecuniary and other resources, including sponsors and the financing, personnel, and facilities they can provide; overcoming the inherent challenge of communicating the intricacies of a complex risk; competition from other messages calling out for time and attention; and active resistance to the message. Such resistance may be due to a variety of factors. The messages communicators deliver may be too technical or otherwise lack clarity; receivers may have jumped to conclusions about the issue; message communicators may not be as open to hearing other points of view as they should be, creating a hostile environment in which messages are “tuned out;” or acting on a problem associated with the risk may conflict with powerful opposing forces.

The second stage, in which significant numbers of people finally grasp a problem and the importance of action, may only occur after disaster strikes, for example, after the devastation of Hurricane Katrina in 2005. Preferably, a risk that calls out for a solution will acquire sufficient attention before a disaster strikes if communication of the risk is clear, persistent, and comes from trusted sources. In either case, once people are focused on the existence of the problem and resolved to act (i.e., in Downs’s second stage), they often become fervent about doing whatever it takes to solve the problem and make grand commitments about what will be accomplished.

In the third stage, people realize that solutions will not be so easy and that achieving real progress will be difficult, costly, and require sacrifices. As a result, in this stage, people’s interest and commitment to action may diminish, especially in the absence of persistent efforts to keep the problem high on everyone’s agenda. At the same time,

superficial or limited improvements may be undertaken or augmented. Alternatively, other issues may come to the fore and completely overtake interest in acting to eliminate or reduce the risk.

The result is the fourth stage: gradually, the public's developed perception of the risk and motivation to respond accordingly recedes. The passage of time may also bring new problems, new scientific and other perspectives, and new risk communicators with different agendas.

As a result, stage four fades into stage five, in which the risk has been largely forgotten or – possibly because of the superficial actions taken – is perceived as having been resolved. Then, perhaps, a new catastrophe occurs, and the cycle begins anew (Sadler 1987; Foster and Sewell 1981; Downs 1972).

In short, unless risk communications about North Carolina's vulnerability to SLR are sufficiently constant, focused, targeted, powerful, compelling, and trustworthy that (1) all appropriate societal, including governmental, sectors fully understand the risk they (and future generations) face and (2) individuals, governments, and non-governmental organizations are motivated on a continuing basis to take whatever actions may be appropriate, the risk communication process will not be fully effective. The receivers of the messages will be too indifferent or distracted to stay mindful of it.

At the same time, it should be recognized that there are limits to what one can expect, even from the most carefully designed and adroitly presented risk communication messages. Neither the absence of divisive conflict nor smooth risk management decisions will necessarily result. As noted elsewhere in this paper, everyone does not have the same value system. Some management decisions, such as those related to what to do about SLR along

the coast, will be at the expense of some members of the public, particularly some property owners, over others. Often, for whatever reasons, those who are on the losing end of decision-making are those who are already more disadvantaged and less likely to be able to bear the decision's consequences. When this occurs, an odor of unfairness permeates the decision that has been made. As has also been observed:

It is also mistaken to think, as some do, that if people understood and used risk comparisons it would be easy for them to make decisions. Comparing risks can help people comprehend the unfamiliar magnitudes associated with risks, but risk comparison alone cannot establish levels of acceptable risk or ensure systematic minimization of risk. Factors other than the level of risk—such as the voluntariness of exposure to the hazard and the degree of dread associated with the consequences—must be considered in determining the acceptability of risk associated with a particular activity or phenomenon (NRC (2004 & 1989, p. 3).

Given all of the risks inherent in communication related to potential hazards and all of the impediments to communicating risk effectively, one might be pessimistic about the possibility of developing an effective strategy to communicate North Carolina's vulnerability to SLR. Nevertheless, as the sections that follow demonstrate, the task can be accomplished if a well-informed approach is taken, sufficient resources are available, and the strategy is based on sound social science research.

#### **4.4 Elements of an Effective Risk Communication Process**

While the particulars of effectively communicating complex risk will vary from case to case, these specifics tend to have much in common. One shared thread is the indispensability of plotting out a thoughtful strategy, with the assistance of risk communication experts, in advance of beginning to communicate risk messages. The more complex the risk message, perhaps, the more detailed and well conceived the strategy will need to be. If it is to succeed, every such strategy should include the five “w’s” and the “h”

that are also part of any good news story, that is, the “who,” “what,” “where,” “why,” “when,” and “how” of each and every aspect of the message that is being communicated (EPA 2002). In more general terms, a communication strategy has been defined as “a systematic, well-planned series of actions, combining different [communications] methods, techniques and tools, to achieve an intended change or objective utilising the available resources within a specific time frame” (Mefalopulos and Kamlongera 2004, p. 8). Risk communication, in particular, has been defined as follows:

[It is] a field of social science that promotes effective communication by scientists, resource managers, educators, community leaders and others . . . “to ensure accurate knowledge, attitudes, and perceptions” fundamental to “risk-wise” behaviors . . . that reduce vulnerability and respond to the impacts of [particular risks] (Scherer 2006, p. 33, quoting Ramsdell, Anderson, and Gilbert (eds.) 2005, p. 65).

However characterized, a well-conceived strategy for communicating the vulnerability of North Carolina to SLR will need to set forth, in some detail, the essential components of the process and how, when, and by whom they will be achieved.

As these elements are identified and refined, a number of considerations will come into play. The success or failure of the risk communication may hinge on the validity of the assumptions that are part of the message and about the validity of how the risk communicators perceive the intended audience. Success or failure may also depend on how limited or unlimited the contours of the message are. Furthermore, more than creativity will be required:

Communication strategies need to be based on sound social science research, audience analysis, theories of change, how audiences receive information, how social linkages influence beliefs and perceptions, the level of organizational trust, and the relevance of the information to the intended audience. Theories of change, or even assumptions of how groups, communities or individuals change as a result of information, determine the type of communication strategy developed. . . . Reducing the likelihood of

ineffective communication and improving the quality of communication require both formative and evaluative research. Formative research can prevent major communication errors, and summative research can help provide guidelines for more effective and efficient future communication (Scherer, pp. 36-37).

The pitfalls discussed above make it helpful to differentiate between a “risk message transmission”—the largely one-way communication of information about a risk, typically from experts to non-experts—and what should be a “risk communication process”—the back and forth information exchange about a risk among institutions, groups, and individuals (including experts). Approaching communication of complex risk as a multi-dimensional process can avoid or ameliorate many of the problems inherent in the one-way transmission of risk messages (NRC 2004 & 1989). This is not to suggest that one-way risk communication is always inappropriate. It certainly has its place in getting out important, easily understood messages, such as that certain jars of peanut butter may be contaminated by salmonella and their contents should not be eaten. As discussed below, one-way risk communication may, in addition, often have a role to play as part of the larger, interactive process of communicating more complex risks.

The potential elements of an effective risk communication process may be few or many, depending on, among other things, the nature of the risk, the expertise of whoever is leading the process, and the background and experience of those to whom the process is directed. The following sections describe a number of approaches that, while they have been suggested or applied in other contexts, nevertheless seem particularly useful to consider in tailoring a strategy for communicating North Carolina’s vulnerability to SLR.

#### 4.5 A Role for Social Marketing?

GreenCOM is the Environmental Education and Communication Project of the U.S. Agency for International Development. It was started in the mid-1990s in recognition of the counterintuitive “discovery” that it is not true that knowledge determines attitudes, which dictate human behavior (Hines, Hungerford, and Tomera 1987). Rather, “research shows that people who take positive environmental actions often have no better understanding of the problem than those who don’t act” (Monroe, Day, and Grieser 2000, p. 3).<sup>18</sup>

Thus, in addition to working in the areas of environmental education, environmental communication, and public participation, GreenCOM has added “social marketing”—a combination of models drawn from behavioral psychology and commercial marketing—to its strategic efforts. Basically, social marketing, which is also used by a number of other organizations trying to promote improved, more environmentally-friendly behaviors, employs behavior modification theory to identify why target audiences act as they do and to change these factors in ways that will result in more productive behavior (Smith n.d.; Kotler and Zaitman 1971).

Figure 9 depicts “The GreenCOM communication process” (as shown in GreenCOM 2002, p. 8) and “The Steps of Social Marketing for Creating Behavior Change” (also from GreenCOM, in Monroe, Day and Grieser 2000, p. 4). Of more than passing interest, perhaps, is that the steps that comprise social marketing and those are embodied in environmental risk communication, from GreenCOM’s perspective, are identical. One might wonder, then, whether there should be a role for social marketing in environmental risk communication.

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<sup>18</sup> It should be pointed out, however, that not everyone subscribes to this belief about human behavior: “If we have more knowledge about a particular environmental problem, then we will be able to make better decisions because the competition between various interests or values will give way to a rational analysis of the problem” (Sarewitz 2003, p. 136).

Figure 9. Communication Strategy Models



Graphics are from GreenCOM 2002 (left) and Monroe, Day, and Grieser 2000 (right)

The answer is highly controversial and beyond the scope of this paper. One thing that can be said is that scientists may impair their credibility when they become advocates. Another is that public officials, when they take on this mantle, especially when they speak on issues that principally affect individuals, run the same risk. Even though these officials are expected to lead, they typically are concerned about getting ahead of public opinion. And the reality is that, in general, most people prefer to be informed about a risk and options for moderating it (if the individuals so choose), rather than being told by some scientist or governmental official that a risk must be mitigated and that they should or must change their personal behavior accordingly.

#### 4.6 Risk Communication Strategy Models

A simple strategic model for risk communication is depicted in Figure 8 above. While GreenCOM clearly uses this approach in the context of social marketing, the model nevertheless has value even if the purpose of the environmental risk communication is

limited to being informative and to presenting options. The model consists of five steps: assessment, design and planning, pretesting and revision, implementation, and monitoring and evaluation.

The assessment process relates not to the risk message itself, but also to finding out in advance of delivery what the audience's views, needs, and behaviors are. In addition, efforts are made to understand why people act as they do. This, in particular, suggests the potential value of focus groups or other participatory methods to ascertain this information. The results of the assessment, which should also try to identify potential funding support, are then used to design and plan the risk communication message. Among the questions to be resolved in the design and planning step are the information to be provided, who is best suited to take on communication of it, associated costs and how to meet them, appropriate audiences, communication methods, timing and sequence of messages, where communication will occur, what the indicators of success will be, and appropriate partners in the endeavor. The pretesting and revision step necessarily involves the target audience, or a subset of it, in determining the understandability and utility of the risk messages and the ways in which they will be presented. Once again, focus groups may be helpful, as well as quick surveys and structured interviews of recipients of test messages. Another component of this step is the time and effort required to make appropriate changes in light of what has been learned.

GreenCOM also recommends carrying out the implementation phase, to the extent feasible, using trusted, skilled communicators at the local level, with advice from the "technical experts" only as needed. This is because people naturally tend to have a greater affinity for those they know and trust and are often instinctively mistrustful of outsiders

(GreenCOM 2002). At the same time that implementation occurs, monitoring, evaluation, and perfecting of the process should take place. In other words, an environmental risk communication strategy should always be a work in progress:

Mid-course adjustments should be the rule, not the exception, and improve the ultimate outcome. Monitoring and evaluation permit risk communication practitioners to consult with and listen to people being affected and to refine and fine-tune approaches, messages, and materials. If people begin to change—as a result of learning new information, developing new skills, and trying new things—they will likely need new risk communication initiatives that respond to their evolving needs (GreenCOM 2002, p. 35).

EPA (2005), in the context of communicating about risks at Superfund sites, has suggested *Seven Cardinal Rules of Risk Communication*. They may be encapsulated as follows:

1. Involve the public as a partner
2. Plan efforts carefully and evaluate them
3. Listen to concerns
4. Be truthful, candid, and forthright
5. Coordinate and collaborate with other trusted sources
6. Be responsive to the needs of the media
7. Speak clearly and with understanding

When elucidated, these rules constitute an additional, albeit overlapping, strategic model for risk communication. As used in the first rule, involving the public means not only community members, but also all other interested parties with an interest in the issue.

Second, planning and evaluation consist of a series of steps, including setting objectives, determining how conclusive the risk data are, attending to group needs, training skilled

communicators on the particulars of the risk messages, rehearsing and pretesting the messages, and assessing “lessons learned.”

The rule that follows, listening to concerns, means not assuming what people think, know, or need, as well as keeping in mind that people are often more concerned about issues such as “credibility, competence, control, [and] fairness . . . than . . . quantitative risk assessments” (EPA 2005, p. 10). Fourth, part of being honest, in this context, requires providing relatively complete information and acknowledging uncertainties that exist.

The next rule, partnering and coordinating with other trusted sources, can improve and reinforce risk messages, but the absence of coordination is an invitation to disaster. A risk communication effort that includes discordant messages to the public from credible sources about material issues has a very high probability of failure. Or, as EPA (2005, p. 10) put it more gently, “Few things make risk communication more difficult than conflicts or public disagreements with such sources.”

Sixth, being responsive to the media can help get out important messages accurately. It must be remembered, in this regard, that members of the media have their own priorities, deadlines, and other constraints; and it is important to respect these. It is also important to remember that it is not the role of the media to act as an ally or advocate.

Finally, the last rule, speaking with clarity and understanding, requires explanation. EPA stresses the desirability of sensitivity to community norms, even down to small details such as speech and dress. This does not mean that risk communicators should, in their own behavior, affect these norms. What it does mean is that it is useful for risk communicators to use examples that are familiar to their audiences as a way of animating risk messages. To the extent risk recipients express apprehensions or feelings that the situation is futile, it is helpful

to acknowledge the concerns, while, at the same time, leading the dialogue back to what has and can be done. Of course, risk communicators should never trivialize a challenge or make promises they cannot keep (EPA 2005).

Yet another model is one developed to communicate greater awareness of water resources (Sadler 1987). Among its basic elements are the following:

- determining the risk communication's objectives;
- identifying the communication's audience and who would be the best risk communicators;
- deciding the level of public participation and the bases for making this determination;
- finding appropriate human and fiscal resources to undertake the process and see it through to completion;
- deciding exactly and defining clearly what the message should be;
- recognizing possible barriers to effective communication and planning ways to overcome them;
- choosing communications procedures that are well-suited to getting across the risk message and to motivating the audience to taking whatever actions, if any, that may be appropriate under the circumstances;
- finding the right terms for communicating the message to each particular audience to which it will be delivered;
- deciding when, how often, and for how long the message will be communicated;
- soliciting and taking into account feedback to determine the message's efficacy; and
- adjusting the message, as needed, based on the feedback received.

While many of the elements of the water resources communication strategy are similar to the GreenCOM and EPA models, its expanded focus on scope and scale of impact,

affected population, target audience, and timing of messages represent important additional considerations.

#### **4.7 Potential Target Audience Members**

A long list of stakeholders, including federal and state entities, local governments, non-profit organizations, business sectors, and members of the general public, will potentially be affected by or might have an interest in addressing the effects of SLR in North Carolina. These stakeholders, many of whom might be components of the appropriate audiences for risk communication about North Carolina's vulnerability to SLR, may be further subdivided, as follows:

##### *Federal entities*

- Congress
- U.S. Department of Transportation
- U.S. Department of Homeland Security (in particular, the Federal Emergency Management Administration)
- U.S. Department of the Interior (in particular, the National Park Service [which apparently is already somewhat committed to a retreat policy, e.g., the agency moved the Cape Hatteras lighthouse and has conducted a Coastal Vulnerability Assessment of the Cape Hatteras National Seashore] and the U.S. Fish and Wildlife Service)
- U.S. Department of Agriculture
- U.S. Department of Commerce (in particular, the National Oceanographic and Atmospheric Administration)
- U.S. Department of Defense (because of its coastal landholdings, as well as because one of its component parts is the U.S. Army Corps of Engineers)
- U.S. Environmental Protection Agency (in particular, its Office of Wetlands, Oceans, and Watersheds, which, among other responsibilities, administers EPA's National Estuary Program)

*State entities*

- North Carolina General Assembly (state legislature)
- North Carolina State Board of Education
- North Carolina Department of Public Instruction
- North Carolina Office of Environmental Education
- North Carolina Department of the Environment and Natural Resources (in particular, its Divisions of Water Resources, Water Quality, Soil and Water Conservation, Coastal Management, Marine Fisheries, Parks and Recreation, and Forest Resources, as well as its Environmental Management, Marine Fisheries, and Coastal Resources Commissions, Center for Geographic Information and Analysis, and Geological Survey)
- North Carolina Department of Crime Control and Public Safety (in particular, its Division of Emergency Management, Hazard Mitigation Section, and its State Hazard Mitigation Advisory Group)
- North Carolina Department of Transportation
- North Carolina Department of Agriculture and Consumer Services
- North Carolina State Ports Authority
- North Carolina Utilities Commission
- North Carolina Building Code Council
- North Carolina State Infrastructure Council

*Local government entities and representatives*

- County commissioners, town councils, and other elected and appointed county and town officials who could influence how these jurisdictions approach consideration of the potential effects of SLR
- Boards of Education and Public School Systems
- Regional Councils of Government
- Departments of Emergency Management

- Departments of Public Works
- Planning and Zoning Departments and Commissions
- Agencies responsible for building permits
- Officials who develop local hazard mitigation plans (as required by the State to receive assistance after disasters)
- Officials eligible to apply for federal pre-disaster mitigation grants or flood mitigation assistance to purchase, elevate, or relocate coastal buildings threatened by SLR, as well as public assistance or hazard mitigation grants after disasters strike
- Agencies focused on forests, parks, and conservation
- Floodplain managers

*Non-profit organizations (including academic institutions)*

- Land trusts and conservation groups, such as the North Carolina Coastal Land Trust, nature centers, etc.
- National Wildlife Federation, Trout Unlimited, and other organizations focused on protecting wildlife, fishing, or hunting waterfowl
- Relief organizations
- Researchers at research institutions, colleges, and universities who conduct studies related to SLR
- Other college and university faculty and students, who might help spread the word about SLR, particularly in planning, environmental studies, marine science, coastal zone management, engineering, and education programs

*Business interests*

- Developers in coastal areas
- Commercial property owners and renters (particularly in low-lying areas near the coast)
- Businesspeople interested in buying or renting property (particularly in the same areas)

- Realtors and local real estate boards
- Marina owners and operators and individuals engaged in other water-dependent industries
- Insurance companies
- Utilities
- Commercial fishermen
- Owners and employees of television and radio stations, newspapers, and other media outlets

#### *Individuals*

- Residential property owners and renters (particularly in low-lying areas near the coast)
- Individuals considering buying or renting property (particularly in the same areas)
- Teachers and students of all ages
- The general public

While the preceding list is indeed long, it is not necessarily all-inclusive. In determining which audiences to target for communications about the vulnerability of North Carolina to SLR, those who assume responsibility for reaching out with these messages must consider not only on which entities, groups, and individuals to focus, but also whether there are others, omitted from those listed above, who should be included. Who these outreach providers might be is considered in the next section.<sup>19</sup>

#### **4.8 Potential Risk Communicators**

There are many potential candidates to reach out and communicate about North Carolina's vulnerability to SLR. These include public and private (including religious)

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<sup>19</sup> The "Capability Assessment" associated with the North Carolina State Hazard Mitigation Plan (NC DEM 2004b) influenced the lists of stakeholders included in sections 4.7 and 4.8.

schoolteachers, school and community librarians, non-profit organizations (including academic institutions), and local, state, and federal agencies, among others. These potential risk communicators may be further detailed in the fashion that follows.

*Teachers and Librarians*

- Public schoolteachers
- Private (including religious) schoolteachers
- Community and school librarians

*Non-profit organizations (including academic institutions)*

- North Carolina Coastal Federation, which has already published articles in its newsletters about the effects of climate change, including SLR
- The Nature Conservancy, which has also published reports on the effects of and possible responses to climate change in the State
- Blue Sky Foundation of North Carolina, which encourages “hazard resistant construction” by “provid[ing] information, public education and professional training which promotes safer construction, wise land use, disaster mitigation, and sustainable development” in communities in North Carolina (Blue Sky Foundation 2003, n.p.)<sup>20</sup>
- Institute of Government at the University of North Carolina (UNC) Chapel Hill, “the largest university-based local government training, advisory, and research organization” in the country (UNC-CH 2002); however, “its potential to further the principles and practices of natural hazard mitigation remains largely untapped” (NC DEM 2004b, n.p.)
- UNC Chapel Hill Hazard Mitigation Clinic, which conducts a wide range of research, outreach, and technical assistance, and is largely supported by the North Carolina Department of Emergency Management
- Faculty at colleges and universities

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<sup>20</sup> Although it is reportedly substantially under-funded, Blue Sky is collaborating with NC DEM to pursue initiatives enumerated in North Carolina Executive Order No. 25 of 2002, which proclaims the State a “Showcase State for Natural Disaster Resistance and Resilience.” Blue Sky focuses on motivating the private sector through market-driven incentives to engage in structural and preventive mitigation strategies (NC DEM 2004b).

- North Carolina State University’s Cooperative Extension Service, which uses research-based information to develop educational programs that are designed to improve the quality of people’s lives in the State
- North Carolina Chapter of the American Planning Association
- North Carolina Association of Floodplain Managers
- North Carolina Smart Growth Alliance
- Eastern North Carolina Sustainable Development Center
- North Carolina League of Municipalities
- North Carolina Rural Development Center
- North Carolina County Commissioners Association
- Institute for Business and Home Safety
- North Carolina Homebuilders Association
- North Carolina Manufactured Housing Institute

*Local agency representatives*

- Departments of Emergency Management
- Departments of Public Works
- Planning and Zoning Departments and Commissions
- Agencies responsible for building permits
- Officials involved in local hazard mitigation planning
- Agencies focused on forests, parks, and conservation.
- Floodplain managers

*State government representatives*

- North Carolina Sea Grant

- North Carolina Department of the Environment and Natural Resources (e.g., its Divisions of Water Resources, Water Quality, Soil and Water Conservation, Environmental Health, Coastal Management, Marine Fisheries, Parks and Recreation, and Forest Resources, as well as its Environmental Management, Marine Fisheries, and Coastal Resources Commissions, Center for Geographic Information and Analysis, which could provide models of areas that will be inundated, and Geological Survey)
- North Carolina Department of Crime Control and Public Safety (particularly its Risk Assessment and Planning Branch, Floodplain Mapping Section, and Hazard Mitigation Section within the Division of Emergency Management)
- North Carolina State Ports Authority
- North Carolina Department of Commerce (specifically, its Division of Community Assistance)

*Federal agencies*

- U.S. Environmental Protection Agency (in particular, its Climate Change Division in the Office of Air and Radiation and its Office of Wetlands, Oceans, and Watersheds)
- National Oceanographic and Atmospheric Administration
- U.S. Department of Defense (in particular, the U.S. Army Corps of Engineers)
- U.S. Department of Homeland Security (in particular, the Federal Emergency Management Administration)
- U.S. Department of Agriculture (because it oversees flood risk reduction, emergency watershed protection, and watershed survey and planning programs)

These potential categories appear in the order they do because, as suggested above, the closer those who take responsibility for communicating about North Carolina's vulnerability to SLR are to their target audiences, the more likely it will be that those audiences will pay attention to these risk messages.

#### **4.9 Potential Types of Outreach**

Perhaps the best approach to communicating the risks related to SLR in North Carolina, as has been suggested above, is to start with simple, one-way messages, followed

by increasingly complex and sophisticated messages. This outreach could take many forms. Before detailing them, however, it is useful to reiterate that planning for the outreach effort should include, among other things, investigation of audience preconceptions, attitudes, existing level of knowledge, comprehension abilities, and informational needs, so that risk messages can be selected and tailored appropriately. Planning should also incorporate input from scientists and experts in risk communication, as well as audience members. It is for these reasons, that while it would be tempting to do so, it would be unwise to suggest to risk communicators, in advance, which forms of outreach they should select. Nevertheless, some or all of the following types might be used at various times during what undoubtedly will be a long-term effort:

- Creating a short, consistently used, thematic message or slogan that appears in all outreach materials, for example, “It’s Our Coast. Let’s Keep It Above Water.”
- Posters
- Public Service Announcements
- Interactive exhibits at local aquaria and museums
- Drafting middle and upper school curricula, including lesson plans, covering SLR vulnerability, particularly along the North Carolina coast<sup>21</sup>
- Fact Sheets, brochures, and flyers for various audiences (e.g., government officials, people who rely on the coast for their livelihoods, homeowners, etc.)
- Developing an Internet website providing data about SLR vulnerability in North Carolina, with links to other trustworthy websites with complementary information that the public and other stakeholders might find useful
- Setting up a Speakers Bureau to make experts available to provide briefings at conferences, meetings (including those of town and county officials), schools and other academic institutions, libraries, museums, etc.
- Training workshops and informative presentations

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<sup>21</sup> For one example, see Frankenberg 2006.

- Developing a “mitigation toolkit” for local governments
- Displays at county and state fairs and other public events
- DVD’s, slide shows, or both, for different audiences, covering scientific knowledge about SLR, its effects on public and private property, what mitigation efforts governments and citizens can make, etc.
- Providing GIS maps of areas prone to flooding or inundation

Once again, this listing is not intended to be all-encompassing; rather, it includes a number of components that, at various times, might be included in the outreach efforts.

#### **4.10 Potential Outreach Messages**

Just as it would be unwise to limit in advance the specific forms of outreach that would be appropriate to use to communicate to various audience members about the risk of SLR along the North Carolina coast, so, too, caution should be exercised in the selection of potential outreach messages. Different messages will be appropriate to the differing informational needs of diverse audiences, and some messages may be useful at some points in time during the communication effort, but not at others. Some outreach providers will undoubtedly put their own spin on risk messages, which may or may not detract from their value. In any event, somewhere along the line, it would seem to be appropriate to include some or all of the following risk messages.

- Why it is important to address SLR
- Reasons stakeholders need to understand the impacts of SLR
- What things are known and unknown about future rates of SLR, the extent of historical and predicted erosion in different locations, the effects of coastal storms, and other factors that affect the location-specific implications of SLR
- Projected impacts over time of SLR on coastal shorelines, including the extent to which it is likely that specific portions of the coast will be flooded or inundated

- Potential effects of SLR on wetlands and wildlife that depend on them
- Possible effects of SLR on local residents and the local economy, for example, some land may become uninhabitable, public infrastructure may be damaged, and public and private property may be lost
- Anticipated effects of SLR on barrier and low-lying islands
- Need to plan for SLR, to mitigate its impacts
- Potential for altering the rate and magnitude of SLR
- Benefits and consequences of employing hardened structures and beach nourishment (e.g., how frequently it may have to occur, potential costs of repeated nourishment over time, and the possibility of running out of sand suited to this purpose)
- Potential costs and benefits of retreat, as well as possible ways to implement it, if communities so choose
- Importance of ensuring that management solutions to shoreline erosion are compatible with the dynamics of the total coastal system (Riggs 2001)
- Other information about available policy responses and their characteristics

As the above messages suggest, if coastal communities begin to concentrate on how they will adapt to SLR, it may also be useful for them to focus not only on what will become of existing structures, but also on what will become of beaches and wetlands, not to mention the local economy. If communities stay focused in this way, they might decide, for example, to select areas to set aside for wetland migration or creation, even if all wetlands will not be allowed to migrate inland. And, to the extent that allowing wetlands to migrate is a matter of property rights, these rights will generally be a matter of state law, giving the State a role, if only through its courts, in these types of decisions (Titus 2000).

#### **4.11 Summary**

The quantity of daily risk messages that people hear and see can be overwhelming. Judging the quality and importance of these messages is often difficult or impossible. The

sheer number of risk messages makes it difficult to focus on any one message, and individuals may, at some point, “tune out” all but what seem to be the most urgent messages.

In a heterogeneous society, people with different backgrounds, education, politics, culture, etc. are not likely to share the same level of concern about all risks: their different perspectives will influence how they respond to risk messages about SLR and other environmental issues as compared to more immediate risks. This variability has the potential for conflict, if nothing else, about how to respond to a risk like SLR in North Carolina.

When a message relates to a risk that is slowly accreting and associated with some controversy, such as SLR, even getting the message across and helping people know how they might respond is all the more challenging. To surmount this hurdle, messages about North Carolina’s vulnerability to SLR must, at a minimum, be delivered forcefully, repeatedly, and in a targeted and completely honest fashion.

Those who design and deliver the risk messages must be mindful, however, of the limits inherent in the endeavor. It is highly unlikely that all conflict will be avoided; and making and implementing sound decisions about how to address the risk of SLR at the State and local level will undoubtedly not be a smooth process.

Even so, drawing on sound social science research and experience, there is reason for optimism. Using both scientists and risk communication experts to develop a well-thought-out strategy for communicating North Carolina’s vulnerability to SLR will be vital to success. The contours of the strategy should be shaped according to a number of factors, including how much it is determined that target audiences already know and care about SLR, their demographics and values, and how the significance of SLR to coastal North Carolina’s future can best be communicated, among other factors. In other words, there is no “one-size-

fits-all” or “off-the-shelf” strategy that will work for communicating the risk of SLR in North Carolina or anywhere else.

There is general agreement that a successful risk communication strategy, whether it be for North Carolina’s vulnerability to SLR or otherwise, must include all relevant aspects of who will perform each element, where everything will be done, why, how, and when and how often. Developing these elements may raise questions that will need to be addressed, among others, about the accuracy of both the risk messages and the communicators’ perceptions of the audiences toward whom the messages will be directed. Crucial to success will be remembering all of the lessons learned from social science research into such issues as audience analysis, theories of change, how people receive information, what influences what they believe and perceive, etc.

Most experts believe that communication of complex risks should generally be a multi-dimensional process, not simply the one-way transmission of information from experts or other authority figures to the public at large. Early participation by scientists, risk communication experts, and audience members is very likely to result in a far more effective strategy than could be created in a vacuum.

An effective strategy for communicating the vulnerability of North Carolina to SLR may, at different times, include simple and complex components, depending on a number of factors. Simple messages get attention. Following them progressively with increasingly complex ones can help sustain it. Similarly, various elements of the strategy may be executed consecutively or concurrently. The number of messages and their content should be tailored to the particular circumstances that are present, and these will vary from one coastal county to another.

There is a seemingly endless list of stakeholders who might be included in the risk communication process in one fashion or another. These include legislative and executive bodies at the local, state, and federal level; non-profit organizations (including academic institutions); a variety of business interests; and an array of individuals from property owners and renters, to individuals of all ages.

Many could usefully play a role in communicating the vulnerability of the North Carolina coast to SLR. Among these individuals and entities are teachers and librarians; professors and the academic institutions with which they are affiliated; and a long list of other non-profit organizations, for example the North Carolina Coastal Federation, The Nature Conservancy, and the Blue Sky Foundation of North Carolina. Other individuals who might participate are those with relevant expertise from numerous agencies at the local, state, and federal level. One point to keep in mind about those who might serve most effectively as risk communicators is that people instinctively are more likely to trust those they know, rather than outside authority figures.

The types of outreach that will be appropriate will vary with how limited or broad the messages are that risk communications include, the informational needs and other attributes of target audiences, the points in time during the informational campaign at which outreach occurs, the expertise of the risk communicators in creating the outreach materials, etc. Among the many forms of communication that may prove helpful over time are using a slogan in all outreach efforts, producing drafts of school curricula and lesson plans, developing facts sheets, brochures, and flyers targeting different audiences, setting up a speakers bureau, developing an Internet website, and crafting a SLR “mitigation toolkit” for local governments.

Outreach messages will likely change over time and should be tailored to a variety of circumstances. These messages may range from simple messages about the importance of mitigating the impacts of SLR on coastal North Carolina, to the likelihood that SLR will reshape the coast, to model results projecting the amount of land along the coast that will be lost to SLR at various points in time, to effects on public and private properties and local economies (as it occurs), to impacts on barrier islands, beaches, wetlands, etc. Essential components of the outreach messages should include acknowledging scientific and other uncertainties and advising audience members about what appear to be feasible and potentially meaningful policy and other responses to SLR along the North Carolina coast.

The following factors, among others, will influence the success of the endeavor: the involvement of scientists, communication experts, and audience members early in the strategy development process; how expansive or limited the goals are of the risk communications; the nature of the messages and how often they are delivered; what their scope is; how controversial they are; and finding the best people and groups to communicate the risk messages. If those who assume responsibility for communicating about the risks associated with SLR along the North Carolina coast are mindful of these imperatives, there is every reason to believe that the effort can and will be a success.

## **Chapter 5**

### **Synthesis, Conclusions, and Recommendations**

In this project, the author set about, first, to assemble the most reliable data on global SLR vulnerability and its potential consequences and, second, to present this information in a way that would have special relevance to those who care about the impacts of this phenomenon along the North Carolina coast. This was done on the premise that coastal managers and others, armed with appropriate information, could and should begin to advise potentially affected stakeholders of the real risks to residents, properties, natural resources, and ecosystems attendant to SLR. Finally, in recognition of the very high hurdles that will need to be surmounted for any such effort to succeed, the author identified a number of design and implementation considerations that should be taken into account in developing an effective risk communication strategy for North Carolina's vulnerability to SLR.

Global sea level has been rising for thousands of years, and data from recent decades suggest that the rate at which it is rising is accelerating. Associated threats are clear, such as increased flooding, erosion, wetlands loss, coastal inundation, and property and other economic damage. Nevertheless, because of the enormous complexities involved, predicting what the rate of additional SLR will be over time and how soon and to what extent the effects of this further increase will be felt in coastal North Carolina are matters imbued with uncertainty.

Coastal communities, which already have been affected by SLR or will be in the future, could adopt a number of hazard mitigation strategies. These include attempting to hold back the sea by stabilizing the shoreline; elevating structures and other geographical

features such as beaches, wetlands, bridges, and roads, to accommodate SLR; and retreating from the coast as water levels slowly rise and the shoreline moves inland.

Educating stakeholders about these alternatives, including their costs and benefits, would permit more informed decision-making and engender support for and public participation in planning for the future. Nevertheless, this is easier said than it can be done, due to a number of circumstances. First and foremost, in an age in which facts, many of them related to risk, are transmitted at the speed of light, people suffer from information overload. Given the innumerable messages about risk that people receive, it is often difficult for them to pick and choose which should be heeded and which should be ignored.

Immediate and definite risks, unless people do not know about them or they are trivial, tend to receive immediate and clear responses. Far off and indefinite risks, even when their existence is well known and they are profound, tend not to get any responses at all. There is an antidote to the latter reality, however, which is for those who care about mitigating such risks to step forward and marshal the necessary human and other resources required to give people information that will allow them to appreciate these risks fully and understand what can be done to respond sensibly to them. In the case of SLR in North Carolina, there are many organizations and other entities that might assume some or all of this responsibility.

To do so successfully, those interested in communicating about amorphous risks such as the vulnerability of the North Carolina coast to SLR need to utilize sound social science research on human behavior and risk communication. They also need to craft their strategy with great care, involving scientists, experts in risk communication, and representatives of target audiences in the planning process. In this regard, it must be remembered that all

audience members will not share identical characteristics, concerns, or perspectives; thus, messages will have to be appropriately adapted to various recipients.

Whatever strategy is adopted, it should identify who will do what, when, where, why, and how. However, while there are many models for shaping the contours of an effective risk communication program, no “cookbook” contains a recipe for communicating appropriately about North Carolina’s vulnerability to SLR. This is because each hazard has a unique set of characteristics, options for response, associated stakeholders, and individuals and entities potentially suited to participating in the risk communication process.

Adequately informing stakeholders about the risks of SLR along the North Carolina coast and what they can do about it will no more occur overnight than will the effects of this risk. Hence, those leading this communication effort must bring to it a strong commitment to stay with the endeavor over the long term.

The risk communicators must also assure that the information they deliver is clear, focused, targeted, and reliable if they hope to get people’s attention and keep it. It will also be vital to keep in mind that the risk communication process should be thought of as iterative, a work in progress that must be continually reassessed and adapted based on new information, including feedback and other insights gained over time.

Many have a stake in the future of the North Carolina coast, which will undoubtedly be shaped, in part, by SLR and what responses are selected. While the cumulative effects of SLR along the coast will not be apparent for a number of years, it is not too early to recognize the inevitable and plan for it. Indeed, in the author’s view, it is critically important for those who care about coastal North Carolina to seize the initiative today, as wise decision-making will require a far better understanding of the phenomenon of SLR, its

impacts, and the effects of potential responses than will ever occur if people wait until the consequences of SLR become acute.

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Therefore, nothing herein should be construed as representing the views of EPA.

Unless otherwise noted, the conclusions and recommendations in this paper are my own; and it is I, of course, who is responsible for any and all errors and omissions it contains.

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