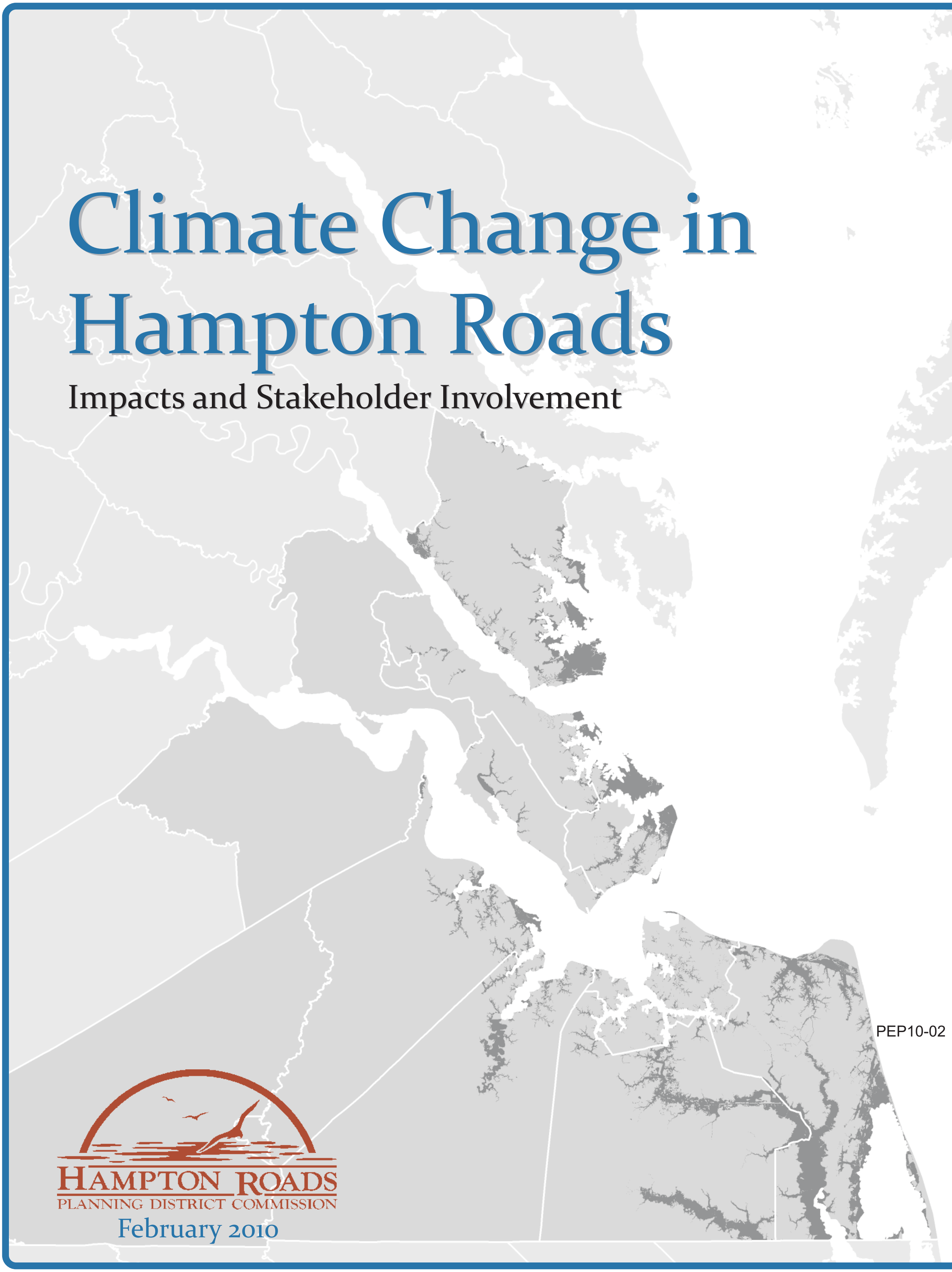
Climate Change in Hampton Roads

Impacts and Stakeholder Involvement



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HAMPTON ROADS
PLANNING DISTRICT COMMISSION

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HAMPTON ROADS PLANNING DISTRICT COMMISSION

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CLIMATE CHANGE IN HAMPTON ROADS: IMPACTS AND STAKEHOLDER INVOLVEMENT

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The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S Department of Commerce, NOAA or any of its subagencies.

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Prepared by the staff of the Hampton Roads Planning District Commission

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ABSTRACT
This report provides an overview of the potential impacts of climate change on the Hampton Roads region and describes various mitigation and adaptation strategies that can be taken to reduce and prevent damage from climate change impacts. The report contains seven major sections. The first two sections introduce climate change and describe its impacts. The third section provides a brief analysis of the impacts of climate change on Hampton Roads' natural resources. The fourth section describes various strategies for mitigating and adapting to the impacts of climate change. The fifth section describes the efforts of other regions and cities to develop climate change strategies. The sixth section describes HRPDC efforts to involve local stakeholders, including developing a regional cooperative framework for addressing climate change. The final section describes lessons learned and next steps.

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Virginia Coastal Zone MANAGEMENT PROGRAM

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About the cover: The front cover image was created using ESRI ArcMap and CorelDraw. It shows member localities of the Hampton Roads Planning District Commission in medium gray and the surrounding counties and cities from Maryland, North Carolina, and Virginia in light gray. The dark gray areas are Category 1 storm surge areas within the planning district.

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Introduction

Climate change has become one of the dominant news stories of the last decade. Projections of temperature increases and rising sea levels are made by scientific organizations and researchers. Nations' representatives met in Copenhagen in December 2009 to discuss what could be done to mitigate climate change (Zeller, 2009). These talks resulted in an accord that was seen as "a modest step" toward addressing climate change, but that did not contain firm targets for reductions of greenhouse gas emissions. (Revkin & Broder, 2009) The agreement included commitments to reduce emissions, help developing nations reduce emissions through clean energy, and provide aid to vulnerable countries for climate change adaptation. Organizations such as the National Wildlife Foundation, the Pew Environmental Group, and the National Science Foundation have added to the research by governmental organizations such as the Intergovernmental Panel on Climate Change and the U.S. Climate Change Science Program. Their findings show that our climate is changing. The earth is warming at an increasing rate, and it is primarily due to human activities such as the burning of fossil fuels and the clearing of forests (Karl, Melillo, & Peterson, 2009). Observations have shown a significant increase in global average temperature over the last century. In addition, global average sea level has increased. Other significant observed changes include decreases in snow and icepacks, altered precipitation patterns, and a decrease in the frequency of cold days along with an increase in the frequency of hot days. Changes to local climates have occurred and are occurring across the globe.

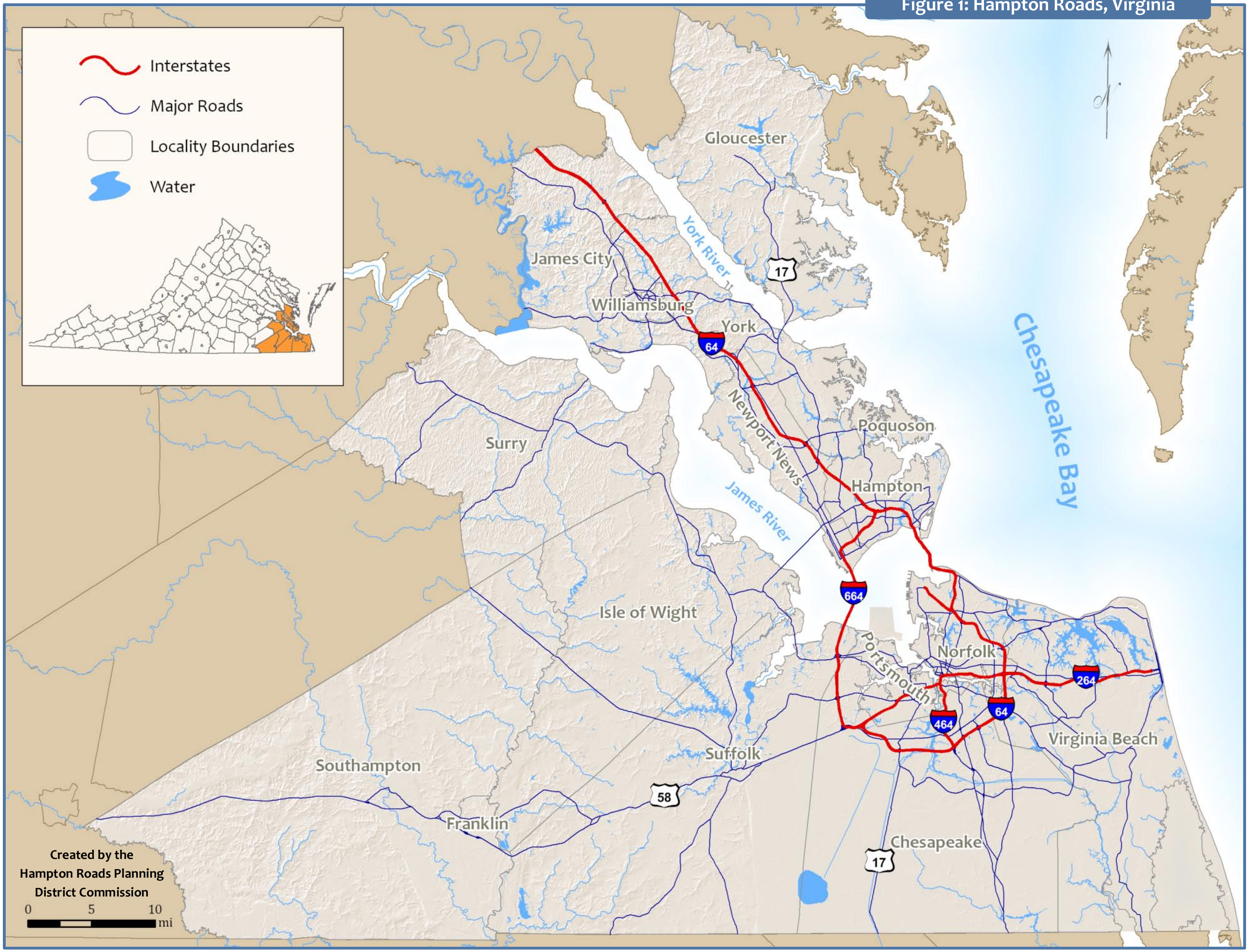
Climate change will likely result in several significant adverse impacts on Hampton Roads including inundation and flooding of both developed and natural areas due to sea level rise, increased impacts from severe weather events and associated storm surge, and ecological damage to coastal and marine ecosystems due to temperature increase and loss of wetlands habitat. Many of these impacts are already occurring, and they will continue to increase over the next century. Rising sea levels are of principle concern to the region (Fahrenthold, 2008). The full extent of these impacts will not be realized for several decades at least; however, the root causes of climate change and the long lead times required to enact policy change or construct infrastructure demand a planning response in the present. "While it is unlikely Virginia will see drastic changes in the next few years, advance planning is recommended, given the scale of many adaptation efforts and the risks associated with being unprepared for key impacts," (Governor's Commission on Climate Change, 2008). Planning for climate change now may help mitigate its impacts while also reducing the costs of any necessary adaptation. The focus of this document is on identifying what the impacts of climate change are likely to be for the Hampton Roads region, and developing a framework for responding to climate change through regional cooperation.

Planning for climate change now may help mitigate its impacts while also reducing the costs of any necessary adaptation.

Climate change will be one of the greatest challenges for Hampton Roads, the United States, and the world to deal with over the next century. Climate change is already occurring and will continue to have large impacts on populations around the world. Responding to these impacts and their threatened increase will require both mitigation and adaptation. However, despite the possible dangers of climate change it also presents an opportunity for positive change and development. Wind energy development represents one such as yet untapped opportunity for Hampton Roads, while the expansion of existing modeling and simulation capabilities to climate change impacts is an opportunity where the capacity and ability already exist.

The report contains seven major sections. The first section describes climate change in general terms. The second section describes the impacts of climate change on the Hampton Roads region and to specific sectors. The third section provides a basic analysis of the impacts of climate change on a specific sector, natural resources. The fourth section describes various strategies for mitigating and adapting to the impacts of climate change. The fifth section describes the attempts of other regions and cities to develop climate change strategies. The sixth section describes efforts undertaken by HRPDC to involve local stakeholders in planning for climate change. The final section describes future steps for the project and for regional action.

Figure 1: Hampton Roads, Virginia



What is Climate Change?

"Climate is the weather of a particular region, averaged over a long period of time." - National Science Foundation

To understand how climate change impacts human society requires an understanding of what climate is and how it affects people and environments. "Climate is the weather of a particular region, averaged over a long period of time," and includes things such as the temperature, precipitation, and wind (National Science Foundation, 2009). Weather varies from day to day, month to month, and year to year. Climate averages the weather over many years to describe the general character of a region. Knowing these past trends guides understanding of when seasons occur and how warm or cold they are. A region's climate has broad impacts on many of the human and natural activities that occur within its boundaries. Plant and animal species can survive only in a specific range for which they have adapted over many years. As climate changes those species will either have to move to a more suitable climate or become extinct. The greenhouse effect is one of the main drivers of life on earth – it allows for life to exist in its present form. It is caused by the presence of various heat-trapping gases such as carbon dioxide and water vapor in the atmosphere. These gases are naturally present in the atmosphere, but their quantities have significantly increased since the mid-1700s, mainly due to human activity. This increase in greenhouse (or heat-trapping) gases will change Earth's climate more quickly and to a greater extent than would otherwise occur (Karl, Melillo, & Peterson, 2009).

Different organizations use different definitions of climate change. The IPCC defines climate change as "any change in climate over time, whether due to natural variability or as a result of human activity," (IPCC, 2007). While natural factors influence climate most of the focus has been on human influences and how they have increasingly affected climate over the last half-century. The increase in emissions of greenhouse gases into the atmosphere through human activities such as the burning of fossil fuels, agriculture, and industrial processes has been documented (Karl, Melillo, & Peterson, 2009). The main greenhouse gases climate scientists analyze are carbon dioxide, methane, nitrous oxide, halocarbons, ozone, and water vapor. Carbon dioxide is considered to be the major contributor because of its sheer quantity, even though other greenhouse gases have a larger per-unit effect on atmospheric temperature. Water vapor is recognized as the most potent greenhouse gas, but human activities do not cause much of an increase. Instead, temperature increases resulting from other greenhouse gas emissions result in more water vapor because warmer air holds more moisture, creating a warming "feedback loop," (Karl, Melillo, & Peterson, 2009). Other human influences on climate include the use of aerosols and changes in land cover to urban development and agriculture. Other natural influences on climate include the change of the Earth's orbit around the Sun and volcanic eruptions.

The impacts of global warming will depend on its extent. This extent will be determined by the quantity of greenhouse gases emitted and how long those emissions are continued. Warming will increase global average sea level due to a combination of thermal expansion, melting glaciers, and melting ice sheets. Precipitation patterns will change. The distribution of rainfall throughout the year will also change; rainfall will be more concentrated as heavy storm events are punctuated by periods of drought. Average temperature will increase, but so will the number and temperature of extremely hot days. Changes in temperature, water availability, and water salinity will also force changes in terrestrial and aquatic ecosystems.

Climate change will have effects that will occur in the short, medium, and long timeframes. Changes may be gradual early on and more stark later. In addition, impacts may not necessarily be observed in a linear fashion; some impacts of climate change may grow significantly more intense as thresholds are crossed. The main effect of greenhouse gas emissions will be to increase global average temperatures. This temperature increase will in turn lead to secondary effects such as altered precipitation patterns and sea level rise. Another effect of climate change may be more intense storms, including tropical storms. Storm surge will increase as well due to a combination of sea level rise and stronger storms (Karl, Melillo, & Peterson, 2009). Some of these effects may be blunted by reducing greenhouse gas emissions and thus mitigating some climate change, but most will still be felt to some extent. Many of the impacts of climate change will not be felt for some time; these effects will lag behind their causes. Additionally, many effects will persist for years even if their causes are eliminated. Even though some climate change can still be mitigated, some adaptation will be required at some point.

Rising Temperatures

Greenhouse gas emissions are causing global temperatures to rise. Higher temperatures have already been observed, and the rate of increase is expected to grow. Since 1900 global average temperature has increased by approximately 1.5°F, but by 2100 it is projected to increase by an additional 2 to 11.5°F (Karl, Melillo, & Peterson, 2009). The United States Global Change Research Program estimates that temperatures in the Northeastern United States will increase by 2.5 to 4.5°F in winter and 1.5 to 3.5°F in summer, while **Southeastern states will see increases of 4.5 to 9°F (Karl, Melillo, & Peterson, 2009).** Average temperature increases will result in stress placed on ecosystems and a variety of impacts on human health and the built environment. In addition to average increases, increases in maximum observed temperatures are also expected. Heat waves are also likely to be more frequent and to last longer. The Governor's Commission on Climate Change projected an average temperature increase of 3.1°C (5.6°F) for Virginia during the 21st century (Governor's Commission on Climate Change, 2008).

Changing Precipitation Patterns

Rising temperatures have the potential to radically alter historic precipitation patterns, affecting human settlements and the natural environment at all scales (global, national, and local). **Droughts are likely to increase in frequency, intensity, and duration (Karl, Melillo, & Peterson, 2009). At the same time, storm events are expected to increase in intensity, bringing larger quantities of rainfall with the same or fewer storm events.** Stronger storms that bring more rain will also have the potential to cause more damage due to winds and flooding. More intense hurricanes and nor'easters will bring higher wind speeds, more rainfall, and increased storm surge, all of which will be exacerbated by sea level rise. In addition, larger rainfall events will result in more runoff and its resulting impacts on waterways. More rainfall will have both benefits and costs for the region, depending on how its frequency is altered. The Governor's Commission on Climate Change, using the same scenario as for temperature increases, projected for Virginia an overall precipitation increase of 11% by 2100 (Governor's Commission on Climate Change, 2008).

Sea Level Rise

Global sea level rises due to increases in the volume and quantity (or mass) of water in the world's oceans. Rising temperatures cause

Even though some climate change can still be mitigated, some adaptation will be required.

water to increase in volume due to thermal expansion (CCSP, 2009). Sea level rise caused by an increase in volume is referred to as steric sea level rise. Rising temperatures also cause more ice and snow to melt, adding to the total amount of liquid water in the oceans; this is referred to as a eustatic increase. Both steric and eustatic sea level rise are global phenomena. Sea level rise can be affected locally by other factors such as land subsidence. Subsidence can be caused by sediment compaction or extraction of subsurface liquids like water or oil. Because of this local variation scientists refer to both global and relative sea level rise. **Global sea level rise includes both steric and eustatic factors. Relative sea level rise adds regional factors such as land elevation changes, winds, and currents.** Global sea level rise is now projected to be between 3 and 4 feet by 2100, under higher emissions scenarios (Karl, Melillo, & Peterson, 2009). This is greater than the level stated by the IPCC, which was 8 inches to 2 feet, for two reasons: more is now known about ice sheet dynamics (which were not factored into the IPCC's calculations at the time), and observed emissions have been higher than predicted by the IPCC.

Land subsidence is a significant factor in the rate of sea level rise in Hampton Roads (CCSP, 2009). Several factors contribute to land subsidence within the region. First, Hampton Roads is located on a passive continental margin, the trailing edge of a tectonic plate that is creating gradual subsidence of the land (Boon, Sea Coast and Sea Level Trends, 2004). In addition, several isostatic processes are at work. The second factor is isostatic rebound, which is the result of the retreat of glaciers following the end of the last ice age. In the northern hemisphere this phenomenon has caused land areas in northern latitudes that were once covered in ice to rise in elevation as the ice has melted. To the south of the previously ice-covered areas, land that was once bowed upward by the weight of the ice to the north is now gradually subsiding as the bowing in the earth's crust is relieved. A third factor is the removal of groundwater from aquifers under the region. As the water is removed for drinking water and other uses the aquifers compress slightly, further contributing to subsidence. The rate of subsidence varies across the Hampton Roads region. **In general, land subsidence accounts for between one-third and one-half of the observed sea level rise in the region.** The

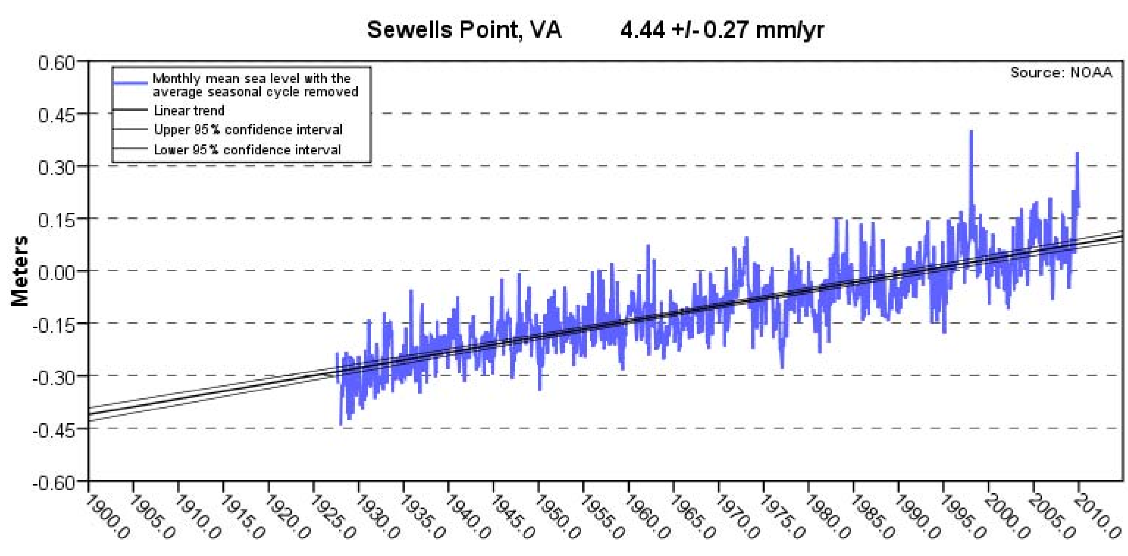


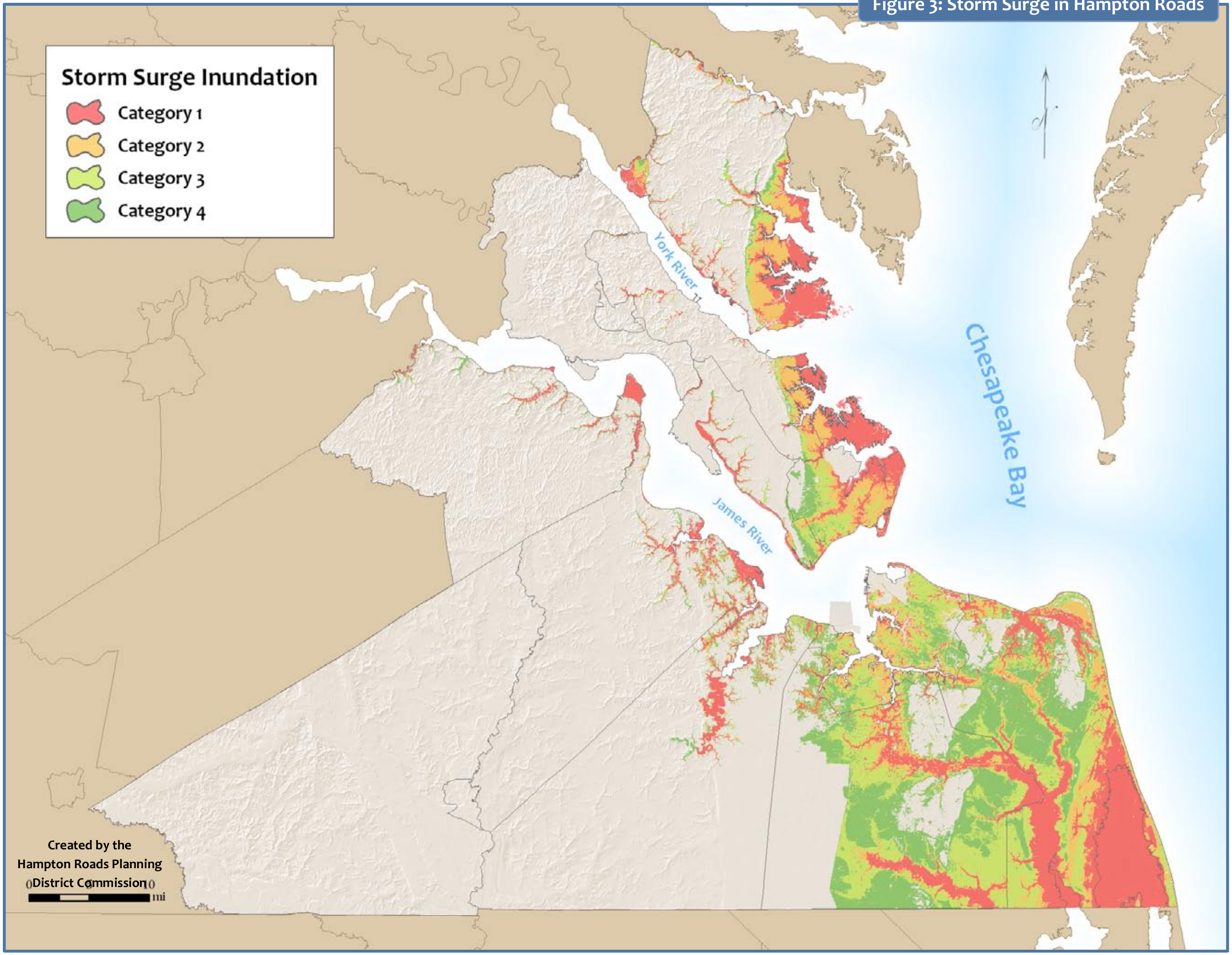
Figure 2: Historic Sea Level Rise at Sewell's Point, Virginia, 1927-2006
Source: (NOAA, 2008)

remaining component in sea level rise in the region is the result of a combination of the global phenomenon of thermal expansion of sea water and polar ice melt associated with climate change.

Hampton Roads experienced sea level rise of 4.44 mm per year (+/- 0.27 mm/yr) for the period from 1927 to 2006 (Figure 2). This translates to 1.46 feet of sea level rise over 100 years (NOAA, 2008). This measure is based on the Sewell's Point tide gauge at the mouth of the Elizabeth River. This change has made the region more vulnerable to storm surge flooding over time. Accurate prediction of future sea level rise rates is problematic, a fact that is openly acknowledged within the scientific community. Several factors contribute to this difficulty including unknown future greenhouse gas emission rates, incomplete understanding of ice melt dynamics and possible future changes in ocean circulation patterns. To deal with this uncertainty most predictions of future sea level rise are given as ranges. As an example the 2009 report titled Global Climate Change Impacts in the United States references sea level rise ranges associated with three different IPCC emission scenarios and more recent estimates of global sea level rise that substantially exceed the IPCC estimates (Karl, Melillo, & Peterson, 2009). At the low end of the scale, the IPCC lower emission scenario predicts between 0.6 and 1.3 feet of global sea level rise by 2100. At the high end of the scale are more recent estimates that suggest between 3 and 4 feet of global sea level rise by 2100. Regardless of which projected trend is most accurate, for Hampton Roads the effects of global sea level rise will be exacerbated by local land subsidence.

Sea level rise and the increased frequency of intense storms will have serious impacts on Hampton Roads' built and natural environments. **The combined impacts of sea level rise and increased storm strength are arguably the most threatening effects of climate change to the Hampton Roads region.** The region is already vulnerable to hurricanes and other serious weather events (Figure 3). Higher sea level will result in more areas being vulnerable to storm surges. Flooding may increase in frequency and severity. Regional infrastructure such as roads and utilities will be at risk of damage or temporary incapacitation due to storm events, and permanent incapacitation due to sea level rise induced flooding. Flood zones may increase in size, putting more buildings and infrastructure at risk. Industries that rely on access to the water or infrastructure in coastal areas may also be harmed. Climate change may hold particular risks for military infrastructure, since a good portion of the region's military facilities are on or near the coast at lower elevations. These risks to the built environment will have to be accounted for in future planning efforts.

Figure 3: Storm Surge in Hampton Roads



Storm surge data obtained from the Virginia Department of Emergency Management

Climate Change Impacts

The last section focused on the causes of climate change and its predicted effects. This section will look more closely at the impacts of climate change, with a focus on Hampton Roads. Impacts will be the result of interactions between effects such as higher temperatures and sea level rise on various sectors of the human and natural environments such as built infrastructure, human health, and ecological systems.

The Chesapeake Bay is a sensitive environmental system that will experience significant changes due to climate change, including increases in temperature and salinity. More intense storms and greater stream flow will increase erosion of coastal land formations. Increases in water temperature and salinity will affect species composition and populations, causing important Bay species to decline or disappear. Wetlands, marshes, and other ecologically significant ecosystems will also be severely affected by climate change; rising sea level combined with urban development may result in the destruction of these areas if they cannot migrate to higher elevations. Climate change may also "exacerbate threats already faced by Virginia ecosystems, such as invasive species, pathogens, and pollution," (Governor's Commission on Climate Change, 2008). Infrastructure and populations in Hampton Roads are also at risk from the effects of climate change. Large populations live in areas already subject to flooding during storm events; those areas will be even more vulnerable as climate change occurs. Similarly, many important or critical facilities or infrastructures are in areas that will be increasingly subject to flooding or inundation.

Vulnerability and Risk

The impacts of climate change will not be felt uniformly across the world. Determining what the likely impacts will be is one of the first steps in successfully adapting to climate change (Snover, et al., 2007). The impacts of climate change will depend on several interrelated, local characteristics, including risk, sensitivity, and vulnerability.

Risk is a combination of an event's likelihood and its consequence (Deltacommissie, 2008). Consequence in this case refers to the impacts or effects of an occurrence (i.e. what could happen or how much damage could result). Reducing either factor reduces total risk; alternately, increasing either increases risk. An example of reducing the probability of an event is the construction of a levee to prevent flooding. Reducing the consequences of that flooding could involve moving buildings out of the flood zone.

Sensitivity is the degree to which a community is affected by an occurrence (Snover, et al., 2007). A low-lying community is sensitive to sea level rise because that could result in flooding or inundation of important areas. Climate change will likely increase the region's sensitivity to storm events.

Vulnerability is a combination of sensitivity and adaptive capacity (Snover, et al., 2007). These combined with risk provide an assessment of how a natural hazard might affect a community. Adaptive capacity refers to an area's ability to adapt to changing circumstances. It can also refer to a community's resilience, or ability to recover quickly with minimal lasting damage from an event. Areas where hazards occur more often that have high sensitivity and low adaptive capacity are consequently more vulnerable to those hazards.

Climate change may "exacerbate threats already faced by Virginia ecosystems." - Governor's Commission on Climate Change

Using these terms to describe Hampton Roads provides a good general analysis of why the region needs to address the threats of climate change. Climate change increases the probability of flooding or strong storms, while existing development patterns increase the consequences of those events. The region lies near sea level and depends on the ocean for much of its economy, resulting in a high degree of sensitivity. Currently the region is also very vulnerable to climate change because of its infrastructure and building patterns. This region will be sensitive to weather and flooding because of its geography. Responding to climate change should involve addressing potential impacts through the reduction of risk and vulnerability.

Built Environment

Climate change will have significant effects on the built environment. Stronger storms with higher wind speeds will cause greater amounts of damage to structures. Storms already pose significant risks to Hampton Roads' private property and public infrastructure, and climate change will likely only increase that risk (Karl, Melillo, & Peterson, 2009). Recent storm events have only confirmed how vulnerable the region is to flooding. One potential consequence of more intense storms combined with sea level rise is that future storms could cause greater damage without being as strong, or that stronger storms could cause substantially more damage. Hurricane Isabel, as an example, caused a similar level of flooding as the August 1933, which was the region's "storm of the century," (Boon, The Three Faces of Isabel: Storm Surge, Storm Tide, and Sea Level Rise, 2003). That risk will increase both in consequence and in frequency. Though sea level rise is not the only contributor to a hurricane or other storm's surge (when a storm occurs during lunar and astronomic tidal cycles is another significant factor), a higher sea level means that the potential for devastating flooding will be higher. Increased risk of flooding will also have an impact on property owners through the insurance industry, as premiums rise or availability declines (Governor's Commission on Climate Change, 2008).

Rising waters may inundate or periodically flood both property and infrastructure, causing its loss and requiring its removal. The Hampton Roads region is particularly vulnerable because of its highly dense population pattern near the shore (CCSP, 2009). The Virginia Beach-Norfolk Metropolitan Statistical Area is one of the most vulnerable areas in the world; it is the 10th largest coastal metropolitan area in terms of assets exposed (Governor's Commission on Climate Change, 2008). Specific areas of the region at risk due to sea level rise or flooding from storms include the eastern part of the Peninsula and the Elizabeth River and North Landing River watersheds. The number of nationally, regionally, or locally important structures, facilities, and systems at risk is large. Critical infrastructure such as roadways, railways, and utilities are in vulnerable areas. A study by the U.S. Department of Transportation analyzed the impacts of sea level rise on transportation infrastructure due to inundation and storm surge flooding (Wright & Hogan, 2008). Important transportation infrastructure in Hampton Roads that is vulnerable to sea level rise includes the Interstate 64 Hampton Roads Bridge Tunnel. A number of military installations, including Naval Station Norfolk, Joint Expeditionary Base Little Creek – Fort Story, Joint Base Langley-Eustis, Fort Monroe, Naval Weapons Station Yorktown, Naval Shipyard Norfolk, and others are also in vulnerable areas (Governor's Commission on Climate Change, 2008).

Natural Environment

Climate change will have a number of impacts on the natural environment. These impacts can be divided into those that affect plant and animal species and those that affect landforms.

Plants and animals will be threatened by climate change's impacts of increased temperatures as well as the changes in environments it causes. Many species are highly sensitive to climate conditions such as temperature, salinity, and CO_2 concentrations, and changes to those conditions could alter population balances in the Bay. While increased CO_2 in the atmosphere may encourage plant growth, heat stress may cause it to decline. Wetlands plants will be drowned due to floodwaters or sea level rise. CO_2 deposition will result in ocean acidification, which can reduce the ability of corals and oysters to survive (Karl, Melillo, & Peterson, 2009). Additionally, higher temperatures will lead to lower levels of dissolved oxygen, which will reduce the capacity of aquatic environments to support life. This could have a significant effect on several important species in the Chesapeake Bay, including blue crabs, eel grass, and oysters, causing species shift or potentially extinction (Governor's Commission on Climate Change, 2008). Water quality will be negatively affected by climate change. Increased stream flow from more intense rainfall events will increase concentrations of sediments and nutrient pollutants in the Chesapeake Bay and its contributing waterways (Pyke, et al., 2008). In addition, climate change could deprive some species of nursery or nesting habitats; wetlands that are important for migrating waterfowl could also disappear, negatively affecting those species (Jasinski & Claggett, 2009). Climate change could also encourage the spread of marine diseases and invasive species.

Negative impacts on the environment will result in the loss or transition of important landforms and ecosystems. Sea level rise will inundate some wetlands, resulting in marsh drowning and the transition of those areas to open water (Jasinski & Claggett, 2009). Sea level rise and stronger storms will result in significant shoreline erosion, further resulting in the drowning of wetlands (Karl, Melillo, & Peterson, 2009). In some cases ecological thresholds will be crossed as triggering events such as storms breach barrier islands. Such events would cause rapid ecosystem change and loss of coastal landforms. Large storm events could, with sea level rise, have greater potential to change the coast by destroying already fragile barrier islands or other sensitive coastal landforms. Where possible landforms such as coastal wetlands may migrate inland if change is gradual enough; however, in more urban areas like much of Hampton Roads that migration is prevented by development or infrastructure. This will result in further destruction of wetlands (Pyke, et al., 2008). Climate change will thus exacerbate many of the negative impacts already affecting important ecological areas.

Climate change will exacerbate many of the negative impacts already affecting important ecological areas.

Water Supply

Climate change will have significant effects on water resources in Hampton Roads and around the world. Warming weather will cause changes in the frequency and volume of precipitation, the frequency and length of droughts, changes in the timing of spring snow melt, higher rates of evaporation, and increases in water temperatures (Karl, Melillo, & Peterson, 2009). Exactly how the regional water supply of Hampton Roads will be affected is unclear. Higher temperatures will likely lead to greater evaporation of surface water sources, including shallow reservoirs, leading to reduced supplies. While annual precipitation will likely increase in the region, it will likely occur in more concentrated bursts, with longer periods of

Climate change may change conditions to the extent that water resources planning can no longer use data from the past as a guide to the future availability of water.

drought in between large storm events (Karl, Melillo, & Peterson, 2009). Greater concentration of preciptation during storm events will cause increases in stream flow, while longer dry periods between storms may result in reduced stream flow. Greater demand for water for irrigation may also result from higher temperatures and longer periods of drought. Increased demand for air conditioning will also stress water supplies, as power plants use more water for cooling. Longer periods without rainfall will stress water resources. Larger rainfall events may also stress water storage capacity with potential consequences for water supply infrastructure such as dams and reservoirs. Climate change may change conditions to the extent that water resources planning can no longer use data from the past as a guide to the future availability of water (Karl, Melillo, & Peterson, 2009).

Climate Change will also have water quality impacts. Greater precipitation intensity will likely increase runoff, which will decrease surface water quality. More runoff will carry more pollution to the Chesapeake Bay, leading to algae blooms and higher bacteria populations (Karl, Melillo, & Peterson, 2009). Greater periods of drought will reduce the quality of drinking water supplies. Sea level rise will also increase the reach of salt water into freshwater surface waters as well as coastal aquifers, due to increasing evaporation and plant water loss rates (Karl, Melillo, & Peterson, 2009). This may force localities to use desalination in more instances.

Economy

The Hampton Roads regional economy is heavily dependent on several industries related to the ocean. These include tourism, the military, and the Port of Virginia. Tourism along the oceanfront is a large factor in the Virginia Beach economy that affects the rest of the region. The military has several installations that will be more vulnerable to sea level rise and are already vulnerable to storm surge flooding. Loss of these installations and the transfer of their personnel to other areas of the country would result in the loss of many jobs and supporting industries in the area. The Port of Virginia and related industries will also be affected by climate change. Port and shipbuilding infrastructure may be inundated or periodically flooded, resulting in work stoppages or the removal of these facilities entirely. Replacement costs for any of these facilities would be very high. Additionally, increases in storm occurrences may result in higher insurance costs for infrastructure, homes, and businesses, potentially leading to lower rates of economic development and growth.

While climate change will pose many serious challenges for the region, mitigating and adapting to climate change will offer Hampton Roads several opportunities for economic development. Hampton Roads is well suited for two such opportunities in particular. The development of wind energy will be important to reducing greenhouse gases and offshore wind will be a significant resource to develop. An area with category 5 and 6 (high potential for wind energy) winds lies offshore of Virginia Beach. In addition to being an ideal location for wind energy generation, Hampton Roads has some assets that could serve to make the region a hub of logistical support, including a deep water port and developed industrial capacity, which could help the region take advantage of offshore wind energy development elsewhere along the Atlantic coast. Hampton Roads also has a developing modeling and simulation industry with institutions such as the Virginia Modeling, Analysis and Simulation Center in Suffolk (part of Old Dominion University in Norfolk) and the Virginia Institute of Marine

Science in Gloucester. VIMS is already working on modeling the impacts of climate change, and VMASC could apply some of its capabilities in that direction.

Human Health and Society

Climate change may have negative effects on human health in the region; however, these effects will probably be slow to occur and will thus afford the region the chance to effectively plan and respond. More intense storms will have the potential to cause injury and death to Hampton Roads residents, as well as property damage. Storms could also interfere with food and water supplies. Warmer weather may lead to more diseases in the region that are currently found in more southern areas. Illnesses and deaths due to hotter weather may also increase, though some of this will be offset by a decrease in injuries and deaths due to cold weather (Karl, Melillo, & Peterson, 2009). Diseases associated with air pollution may also increase as the result of climate change. In addition to those effects, many populations in Hampton Roads will be particularly vulnerable to climate change. Lower-income individuals may not have the resources to prepare themselves in advance for these changes or to respond when storms or warmer weather occur. Racial and ethnic minorities, children, and the elderly are all more vulnerable. Populations living in coastal areas and floodplains, of which there are many in the Hampton Roads region, will also be much more vulnerable to sea level rise, storm events, and some diseases than others. Changes in weather patterns, particularly the increase in heavy rainfall events, may cause an increase in waterborne diseases (Karl, Melillo, & Peterson, 2009).

Climate change will also impact humans culturally, socially, and economically. Climate change will change the quality of life for people in Hampton Roads. Though the research in this area of climate change impacts is not as developed as that for the weather and environmental effects, it is likely that human communities will be affected by climate change. Those affected by climate change could potentially include watermen, farmers, shoreline property owners, coastal governments, residents, and tourists. Possible effects of climate change include: damage to coastal infrastructure, increased risk of disease from insects, changes to renewable and sustainable resources, loss of cultural resources and values, and changes in species abundance and spread. The costs of climate change could include greater funding of flood control measures, losses to agricultural production, reduced water supplies (or shifting reliance to more expensive sources), impacts to forestry operations, greater seasonal energy usage, lost recreational opportunities, and reduced fisheries stocks. Reduced availability of insurance in areas exposed to storms and flooding will be one consequence of climate change that will affect some Hampton Roads residents (Karl, Melillo, & Peterson, 2009). Possible responses to these impacts could include stormwater management, urban stream restoration, fishery management, and incorporating climate assumptions into building and planning practices (Pyke, et al., 2008).

Sea level rise and the increased storm surge that accompanies it will have a profound effect on the region's natural resources.

Analysis: Natural Resources Impacts in Hampton Roads

The previous two sections discussed the effects of climate change and what impacts they will have on various sectors. Once the types of impacts are identified it is important to assess the quantity and quality of those impacts. This sort of analysis requires information on both the extent of impacts as well as the affected sector(s). For Hampton Roads much of this data is unavailable at this time, but considerable work has been done cataloging the region's natural resources through a series of regional green infrastructure assessments and plans. A basic analysis has been conducted using the available data to begin the process of analyzing the impacts of climate change on the region. Information on these impacts has also been collected from other sources to complement the analysis.

Natural resources provide a wealth of benefits, including ecological services such as water quality enhancement and wildlife habitat, as well as recreational value. Protecting, preserving, and enhancing the natural resources of Hampton Roads is vital to sustaining its natural environment as well as its quality of life. To this end, several regional efforts have aimed to identify those areas that should be protected and to develop policies that achieve that goal. These efforts have included the Southern Watershed Area Management Program and the Hampton Roads Conservation Corridor Study (HRPDC, 2007). Through these projects a regional green infrastructure network was identified. **This green infrastructure consists of areas that are valuable for natural habitat, water quality, or both that are linked together through a network of corridors.** The most recent version of the regional green infrastructure network includes over 500,000 acres of green infrastructure in all three categories.

However, natural resources such as the regional green infrastructure network are increasingly coming under threat from climate change. Temperature increases, sea level rise, and stronger storm behavior all negatively affect valuable natural resources. In addition, climate change will exacerbate other stressors such as land development, fertilizer use, and increases in human population (Jasinski & Claggett, 2009). In addition, the Chesapeake Bay region is more vulnerable to sea level rise than most places because of a combination of flat topography and extensive development (Glick, Clough, & Nunley, 2008). In some areas of the Bay, including Hampton Roads, land subsidence further increases vulnerability to sea level rise. Since much of Hampton Roads' green infrastructure lies along the coast, sea level rise and the increased storm surge that accompanies it will have a profound effect on the region's natural resources and its ability to maintain and preserve those resources into the future.

Research by organizations such as the U.S. Global Change Research Program and the National Wildlife Federation (NWF) has described the potential impacts of climate change on natural resources. Expected changes include reduced populations of plant and animal species, shifts in species habitats, inundation of low-lying areas, increased turbidity and nutrient content of water bodies, and erosion of coastal and riparian areas (CCSP, 2009). Inundation of wetlands increases the salinity of the ecosystem and can also infiltrate groundwater aquifers, which can reduce species diversity (Glick, Clough, & Nunley, 2008). Sea level rise will also increase the vulnerability of coastal areas to storm surge.

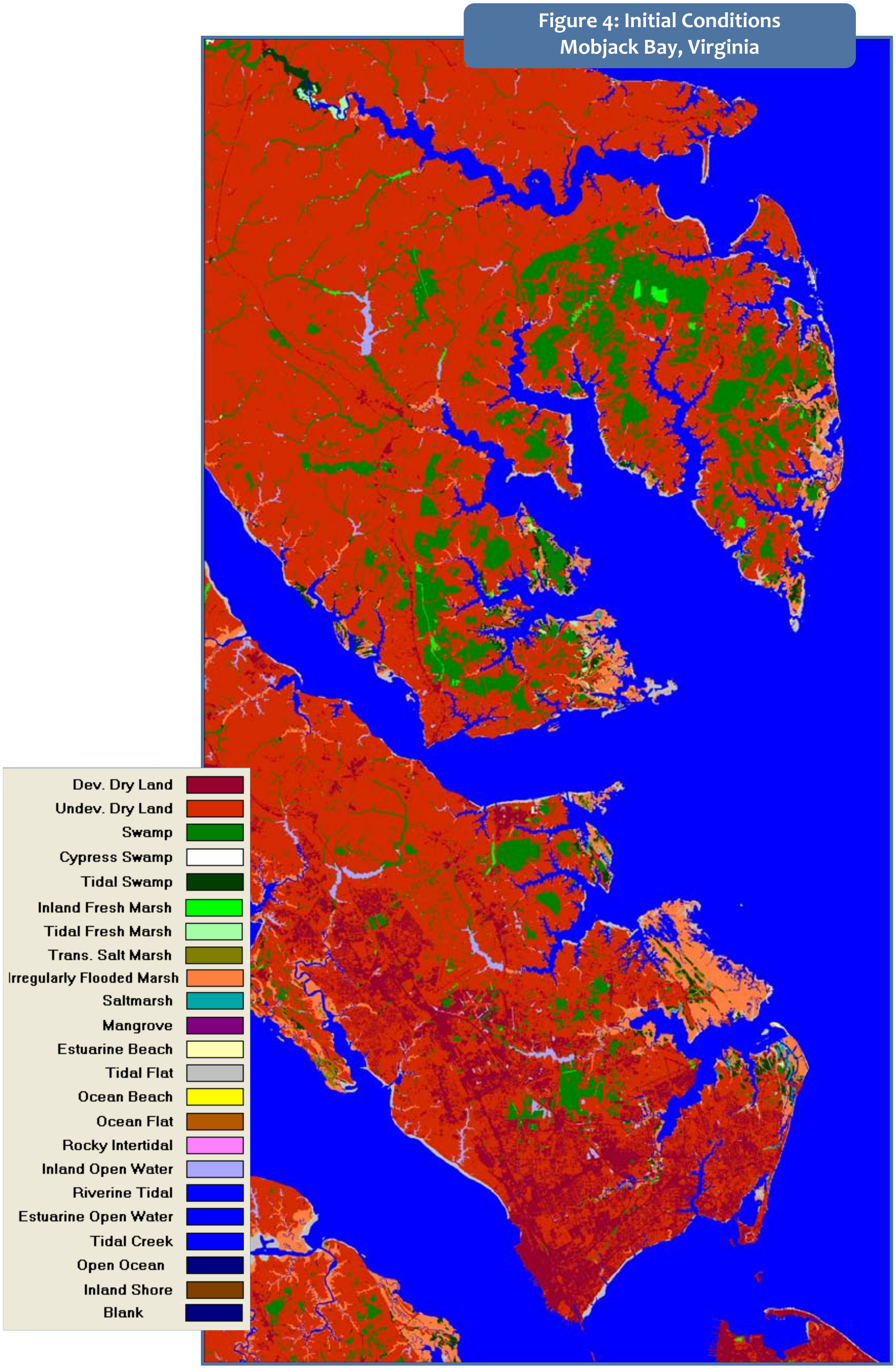
In some cases wetland migration inland will occur as a natural response to sea level rise, but often this will be prevented by development or hard flood protection systems. Protecting upland buffers from development can reduce wetlands loss further down the road (Glick, Clough, & Nunley, 2008). In some cases new wetlands may also be created through accretion as sea level rises and inundates low-lying coastal areas.

The National Wildlife Federation performed a sea level rise impact analysis of the Chesapeake Bay region and Delaware Bay in 2008. The model used, the Sea Level Affecting Marshes Model (SLAMM), considered five processes caused by sea level rise: inundation, erosion, overwash, saturation, and salinity (Glick, Clough, & Nunley, 2008). Scenarios used were taken from or based on those designed by the IPCC. Additional scenarios were run based on sea level rise of 1 meter, 1.5 meters, and 2 meters. In this case sea level rise refers to eustatic global sea level rise. Two scenarios are of particular use here. The Governor's Commission on Climate Change referenced the A1B scenario (0.39m of sea level rise) in its description of climate change impacts on the Commonwealth. The model showed significant impacts across the entire study area. In the A1B-Maximum scenario (0.69m of sea level rise), tidal marsh area declines by 36%. 57% of the Chesapeake Bay region's tidal swamps also disappear by 2100. In addition, 4%, or over 400,000 acres, of coastal land is also lost through inundation or erosion. These losses and others through sea level rise and climate change have the potential to form a "completely different Chesapeake Bay region," with different land forms, flora, and fauna (Glick, Clough, & Nunley, 2008).

NWF also ran the model for several subareas of the Chesapeake Bay region, including two in Hampton Roads: Mobjack Bay between Gloucester County and the Peninsula (Figure 4) and South Hampton Roads (Figure 8). The model predicts different impacts for these areas. In the Mobjack Bay area, undeveloped dry land declines by 13% under the A1B-Mean scenario (Figure 5), and by 19% under 1 meter of sea level rise (Figure 6), with much of this occurring in Eastern Hampton and Gloucester (Glick, Clough, & Nunley, 2008). Other impacts predicted for the area include soil saturation, conversion of brackish marsh to salt marsh, and conversion of dry land to transitional marsh. The study assumed that developed lands would be protected from sea level rise for this scenario. The scenario does not predict or account for any increase in developed land.

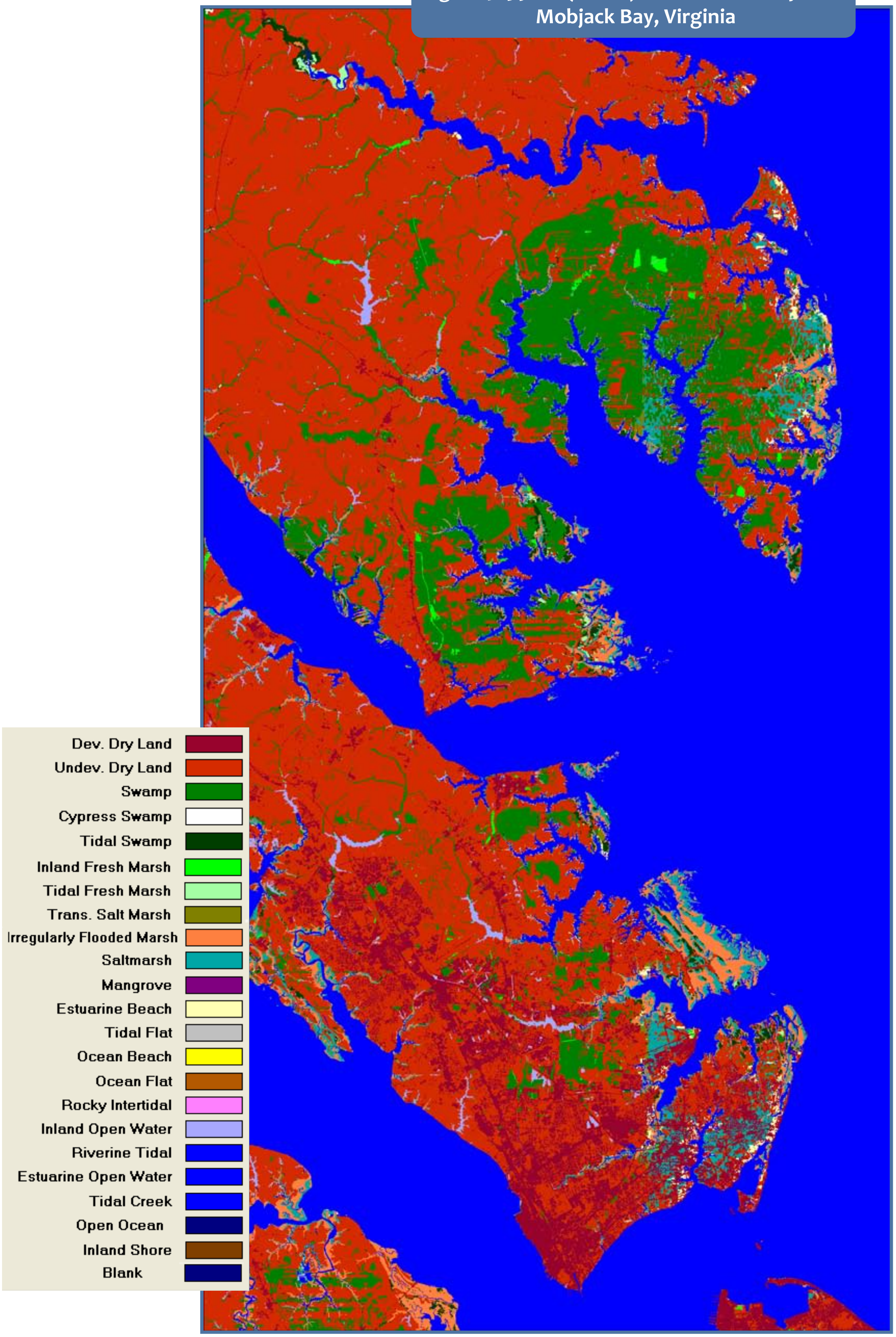
The South Hampton Roads coastal area is similarly affected. In both cases a significant part of the area is already developed. (The same assumptions concerning developed land are maintained for this analysis as well.) Undeveloped dry lands are predicted to decrease by 16% under the A1B-Mean scenario (Figure 9) and by 22% under a 1-meter rise in sea level (Figure 10). Tidal flats and tidal swamps are also predicted to experience significant losses in the area. Some environments such as saltmarshes are expected to experience significant increases. Ocean beach is expected to decline significantly, though the analysis does not allow for artificial beach re-nourishment (Glick, Clough, & Nunley, 2008). A significant inland area of Virginia Beach will be threatened because of the reach of the North Landing River, which will be subject to increased tidal flooding (lower right area of Figures 9 and 10).

In order to assess the potential impact of sea level rise on ecologically important areas of the region a GIS analysis was performed on the regional green infrastructure network. The green infrastructure network consists of



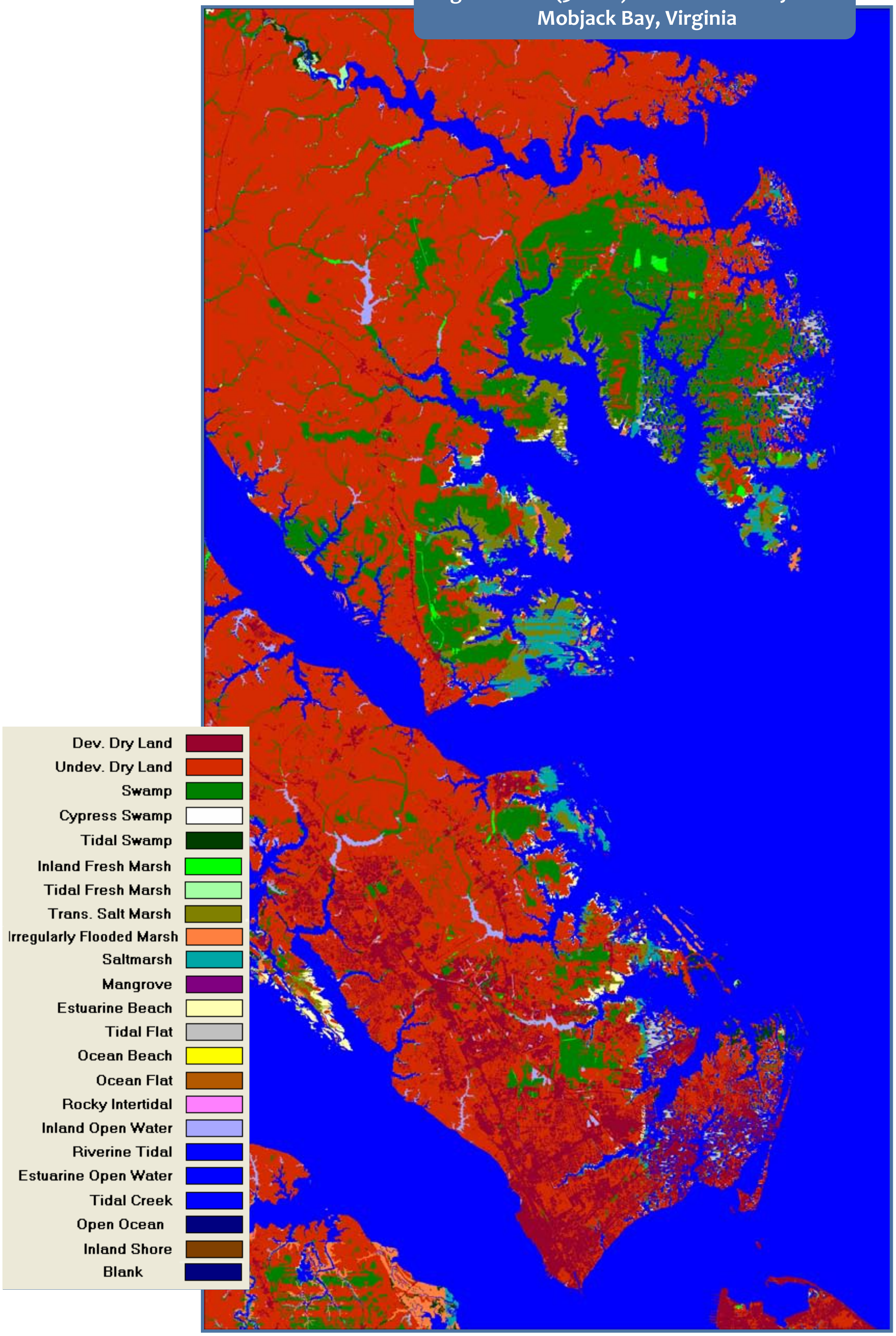
(Glick, Clough, & Nunley, 2008)

Figure 5: 39-cm (1.28 ft) Sea Level Rise by 2100
Mobjack Bay, Virginia



(Glick, Clough, & Nunley, 2008)

Figure 6: 1-m (3.28 ft) Sea Level Rise by 2100
Mobjack Bay, Virginia

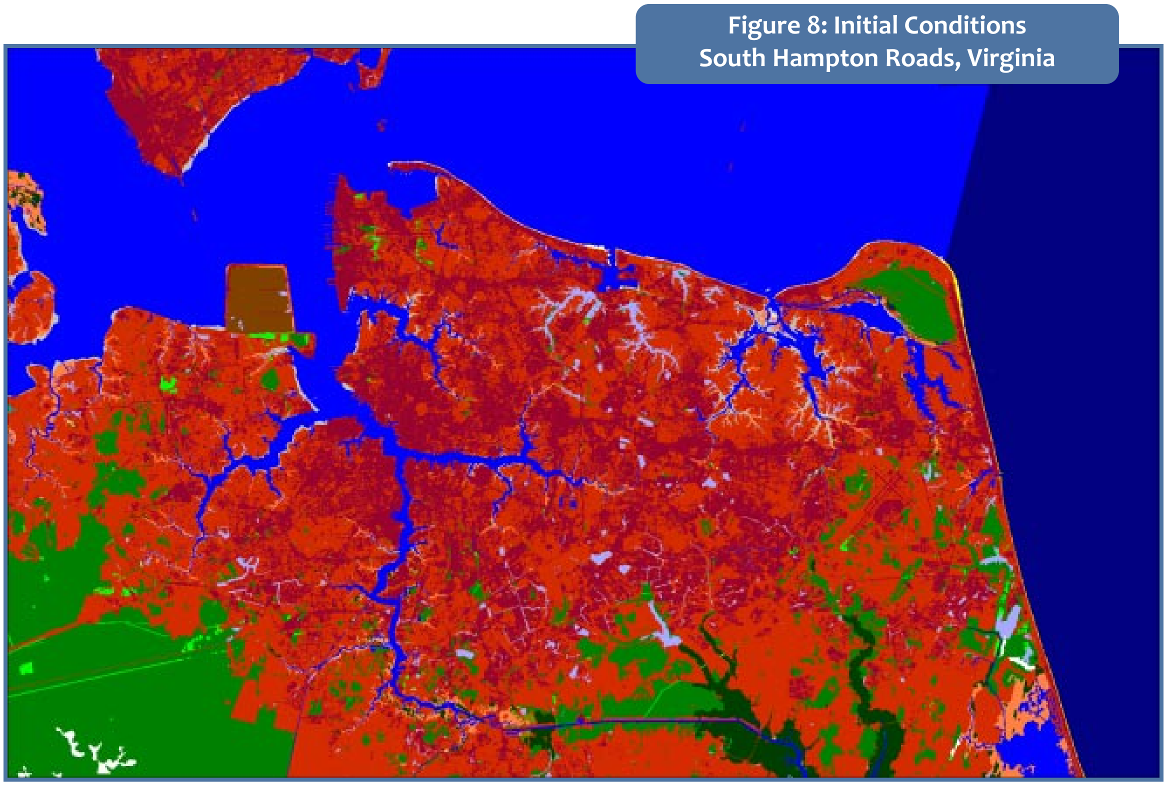


(Glick, Clough, & Nunley, 2008)

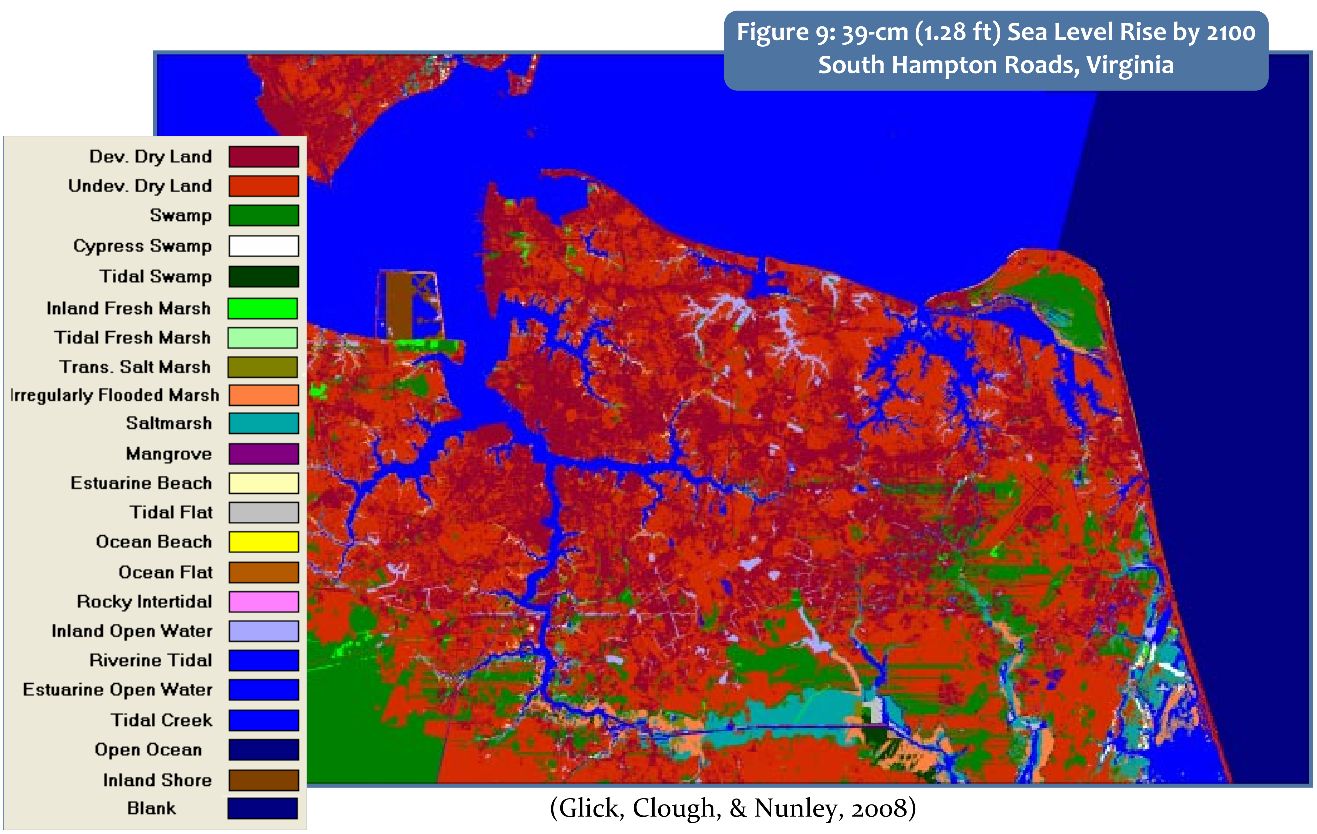
Figure 7: Land Cover Loss and Change due to Sea Level Rise (SLR), Mobjack Bay, Virginia

Terrain	% of Initial Cond.	Initial Cond. (acres)	39-cm (1.28 ft) SLR (acres)	39-cm (1.28 ft) SLR % Change	1-m (3.28 ft) SLR % Change
Dry Land	39.8%	266,182	232,393	-13%	-19%
Developed	5.1%	33,893	33,893	0%	0%
Swamp	5.5%	37,019	54,902	48%	26%
Cypress Swamp	0.0%	17	17	0%	0%
Inland Fresh Marsh	0.2%	1,562	1,569	0%	-6%
Tidal Fresh Marsh	0.1%	709	724	2%	-13%
Transitional Marsh	0.2%	1,028	3,257	217%	1,015%
Irregularly Flooded Marsh	3.5%	23,747	16,502	-31%	-80%
Saltmarsh	0.1%	487	14,466	2,872%	1,621%
Estuarine Beach	0.1%	655	2,399	266%	479%
Tidal Flat	0.9%	6,296	336	-95%	-74%
Ocean Beach	0.0%	0	0	N/A	N/A
Inland Open Water	0.6%	3,788	3,872	2%	1%
Estuarine Open Water	43.0%	287,962	300,253	4%	17%
Open Ocean	0.0%	0	0	N/A	N/A
Inland Shore	0.0%	5	5	0%	-8%
Tidal Swamp	0.8%	5,582	4,389	-21%	-67%
Rocky Intertidal	0.0%	0	0	N/A	N/A
Riverine Tidal	0.0%	225	175	-22%	-41%
Tidal Creek	0.0%	0	0	N/A	N/A

(Glick, Clough, & Nunley, 2008)

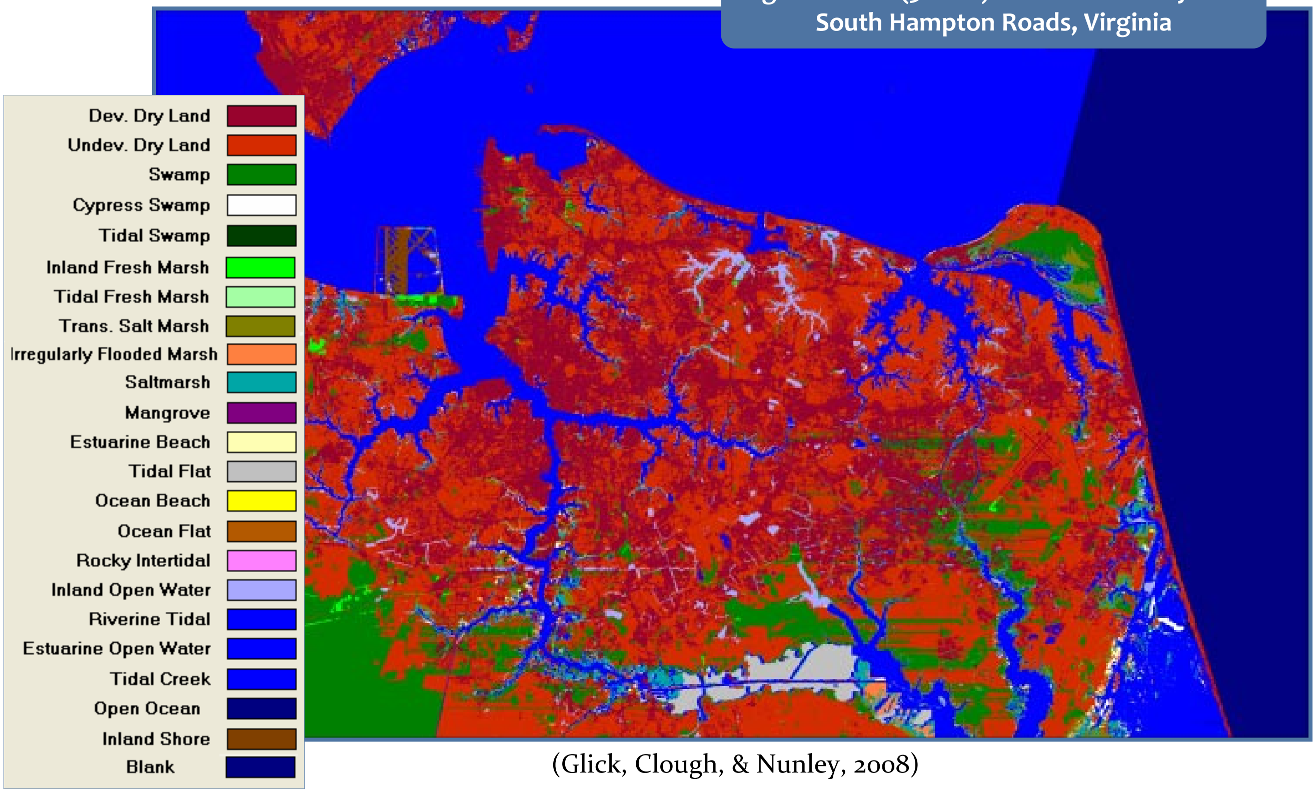


(Glick, Clough, & Nunley, 2008)



(Glick, Clough, & Nunley, 2008)

Figure 10: 1-m (3.28 ft) Sea Level Rise by 2100
South Hampton Roads, Virginia



(Glick, Clough, & Nunley, 2008)

Figure 11: Land Cover Loss and Change due to Sea Level Rise (SLR), South Hampton Roads, Virginia

Terrain	% of Initial Cond.	Initial Cond. (acres)	39-cm (1.28 ft) SLR (acres)	39-cm (1.28 ft) SLR % Change	1-m (3.28 ft) SLR % Change
Dry Land	29.5%	143,373	120,578	-16%	-22%
Developed	15.1%	73,373	73,373	0%	0%
Swamp	9.5%	46,028	51,818	13%	10%
Cypress Swamp	0.1%	546	544	0%	0%
Inland Fresh Marsh	0.3%	1,554	1,621	4%	-5%
Tidal Fresh Marsh	0.0%	111	82	-27%	-52%
Transitional Marsh	0.0%	217	3,603	1,557%	1,882%
Irregularly Flooded Marsh	1.5%	7,497	8,335	11%	-54%
Saltmarsh	0.0%	40	9,232	23,250%	16,560%
Estuarine Beach	0.1%	408	1,530	275%	396%
Tidal Flat	0.6%	2,745	539	-80%	32%
Ocean Beach	0.1%	274	77	-72%	-96%
Inland Open Water	1.1%	5,132	4,861	-5%	-7%
Estuarine Open Water	26.1%	126,745	133,037	5%	16%
Open Ocean	14.1%	68,335	73,660	8%	8%
Inland Shore	0.5%	2,204	1,275	-42%	-57%
Tidal Swamp	1.4%	6,798	1,601	-76%	-97%
Rocky Intertidal	0.0%	5	0	-100%	-100%
Riverine Tidal	0.1%	697	324	-54%	-62%
Tidal Creek	0.0%	0	0	N/A	N/A

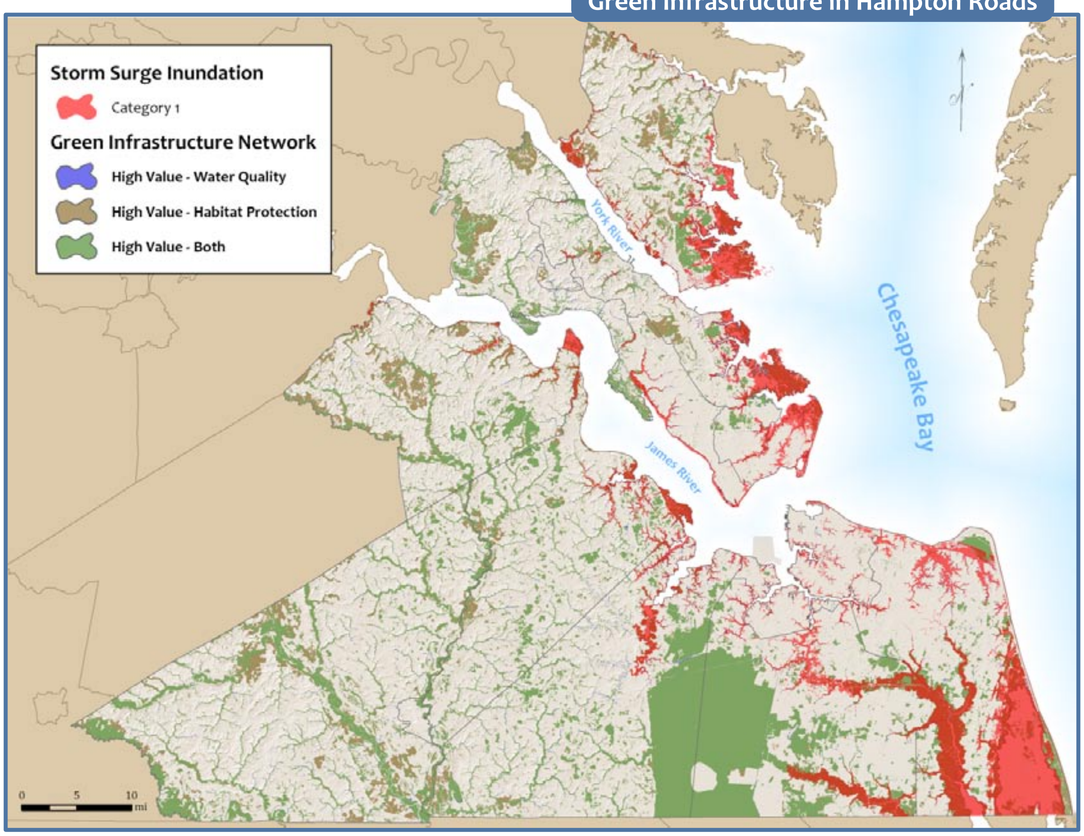
(Glick, Clough, & Nunley, 2008)

areas in the region that are ecologically valuable for water quality purposes, habitat, or both (HRPDC, 2010). The plan provides an inventory of existing natural resources and valuable areas as well as a guide for preservation and protection efforts. Incorporating sea level rise projections allows for the prioritization of areas that should be preserved to allow for upland migration in coastal and riparian areas. The latest update to the regional plan identified over 500,000 acres of high value areas, including over 12,000 acres of land of high value for water quality, over 96,000 acres of land of high value for habitat, and over 400,000 acres of high value for both.

Long-term viability of the green infrastructure network will be in part affected by sea level rise as areas are inundated or subject to more frequent flooding. Climate change may result in the permanent loss of green infrastructure or significant change in some areas. Accurately assessing the impacts of sea level rise on green infrastructure requires consistent high-resolution elevation data. In the absence of such data an analysis was done using Category 1 storm surge (approximately four to five feet above normal sea level) as a proxy for projected impacts from the combination of sea level rise and increased storm surge. However, better elevation data is needed for more reliable analysis of these impacts. Using storm surge data reveals areas that are at risk both due to inundation and to increased flooding from storms. To analyze the impacts of sea level rise on the regional green infrastructure network storm surge data was overlaid on the network using GIS (Figure 12). The analysis showed that over 84,000 acres or 16.5% of the region's green infrastructure network will be at risk of inundation or more frequent flooding due to climate change. This includes approximately 3,900 acres of area valuable for water quality, 1,500 acres of area valuable for habitat, and nearly 79,000 acres valuable for

Over 84,000 acres or 16.5% of the region's green infrastructure network will be at risk of inundation or more frequent flooding due to climate change.

Figure 12: Storm Surge Inundation of Green Infrastructure in Hampton Roads



both. In addition, this analysis does not account for how climate change will exacerbate many of the other stressors already affecting the region's green infrastructure, such as non-surge riverine flooding, nutrient pollution from development and agriculture, and increased salinity in waterways and aquifers.

A similar analysis was conducted by staff at the Virginia Institute of Marine Science, the Chesapeake Bay Observation System, and Noblis. This analysis used some high-resolution elevation data and storm surge models to analyze the impact of a major storm event when modified by sea level rise (Stamey, Wang, & Smith, 2010). For their analysis the researchers used Hurricane Isabel as their test case, and modified it using set intervals of sea level rise between 0.5m and 2.0m (Figures 13-19). One of the focus areas of the analysis was centered on Lynnhaven Bay in Virginia Beach. The Hampton Roads Conservation Corridor (HRPDC, 2006) system was used to show regional vulnerability to a large storm event that is modified by sea level rise. The analysis shows that the study area will be greatly affected by storms because of sea level rise, and that the conservation corridor system is extremely vulnerable to flooding. Additionally, that vulnerability will increase over time as sea level continues to rise. Hurricane Isabel showed that parts of the region and the conservation corridor system are already vulnerable, but a similar storm fifty to a hundred years from now could devastate the area. A catastrophic storm event, symbolized by the Hurricane Isabel +2m scenario (Figure 18), has the potential to not only inundate much of the system, but also significantly alter the coastline. Such a result could occur if a barrier island or coastal dune system were breached by a storm, which could then cause severe erosion.

Figure 13: Initial Conditions, Virginia Beach, Virginia

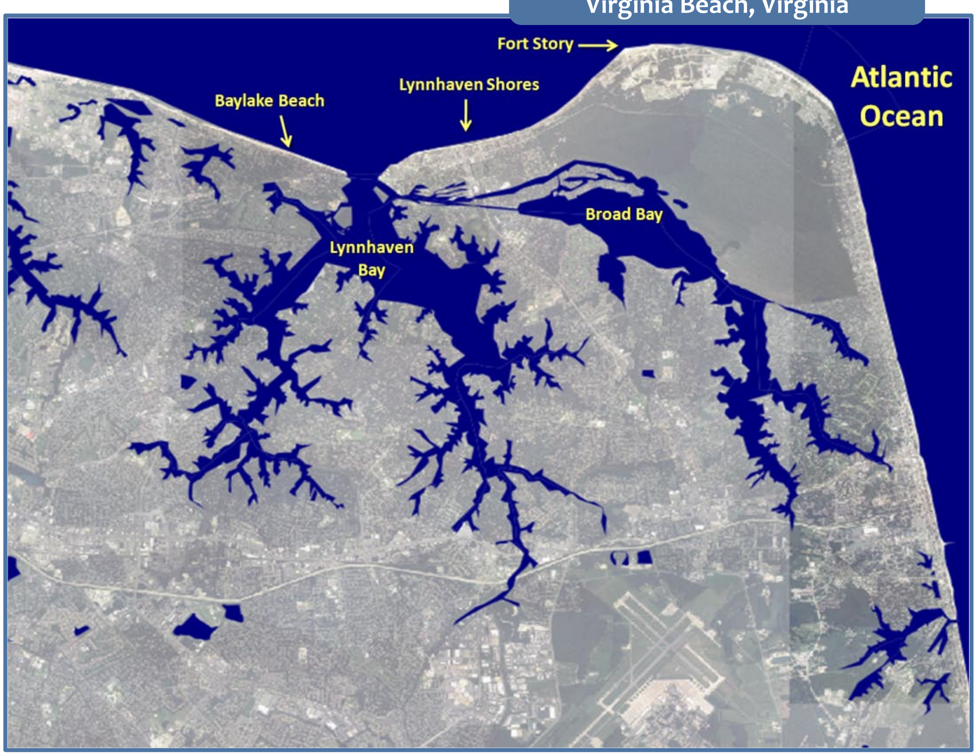


Image from (Stamey, Wang, & Smith, 2010)

Figure 14: Conservation Corridors, Virginia Beach, Virginia

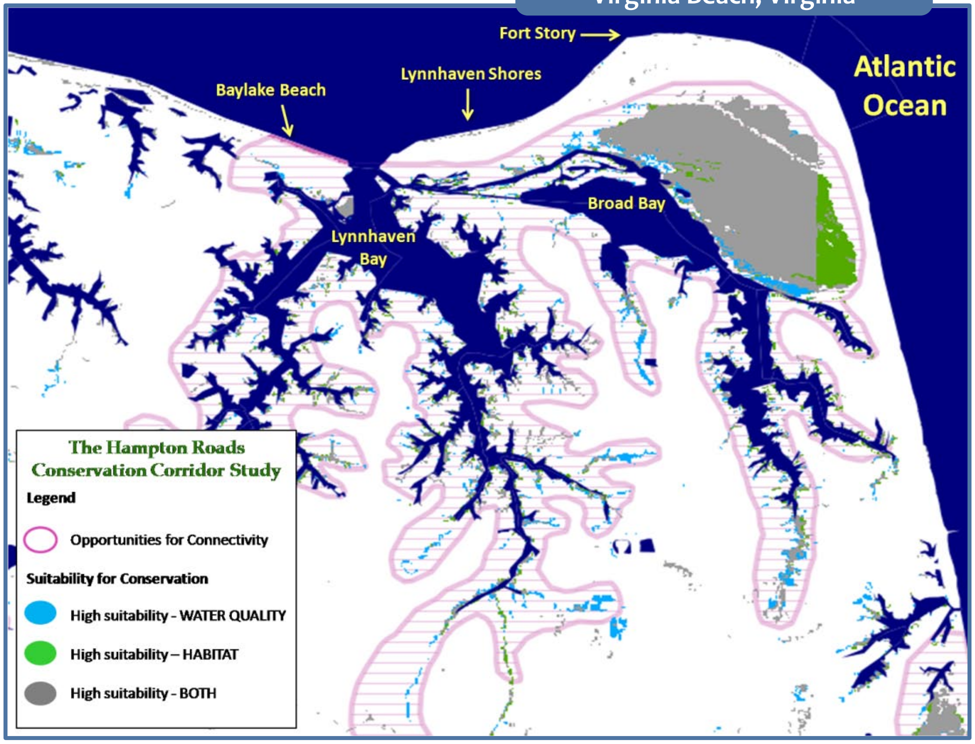
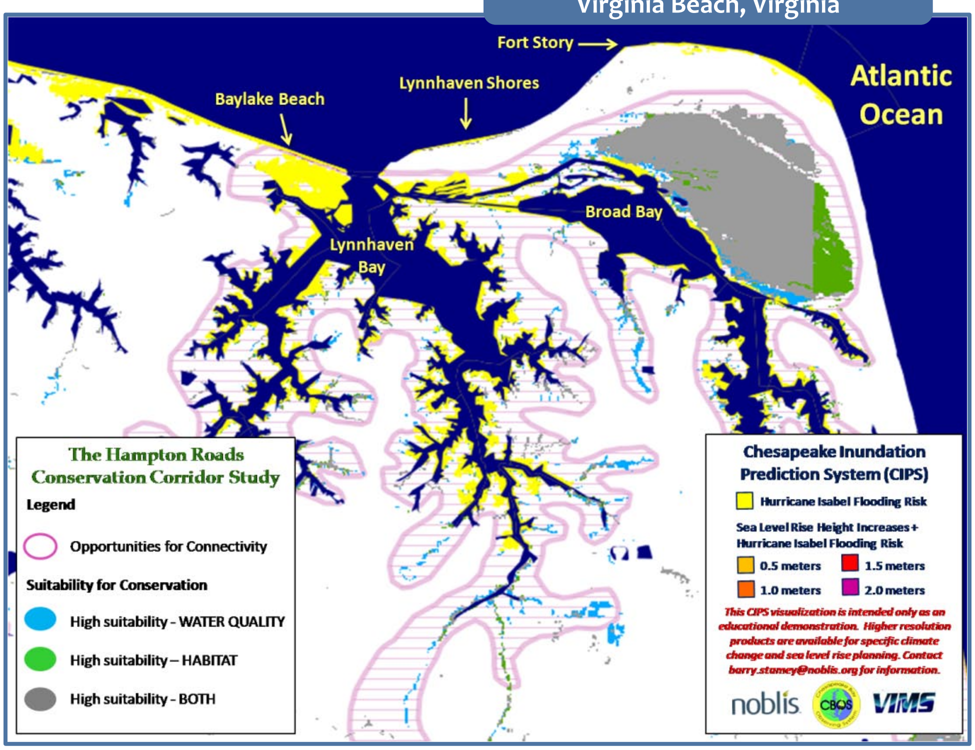


Figure 15: Hurricane Isabel flood risk, Virginia Beach, Virginia



Images from (Stamey, Wang, & Smith, 2010)

This series of maps is a demonstration of the capability of running high resolution inundation models using hypothetical conditions developed by NOBLIS and VIMS as part of the Chesapeake Bay Inundation System (CIPS). The sea level rise increments depicted are not a prediction of future sea level rise. NOBLIS and VIMS reserve copyright and permission must be obtained from them prior to any use of the images.

Figure 16: Hurricane Isabel flood risk +0.5m SLR, Virginia Beach, Virginia

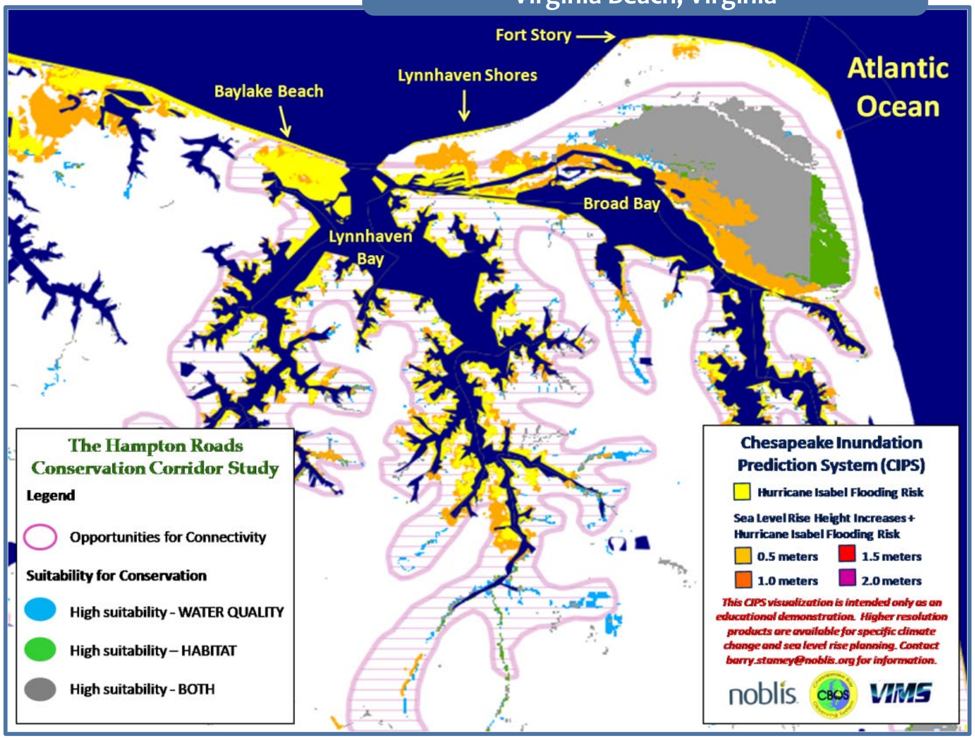
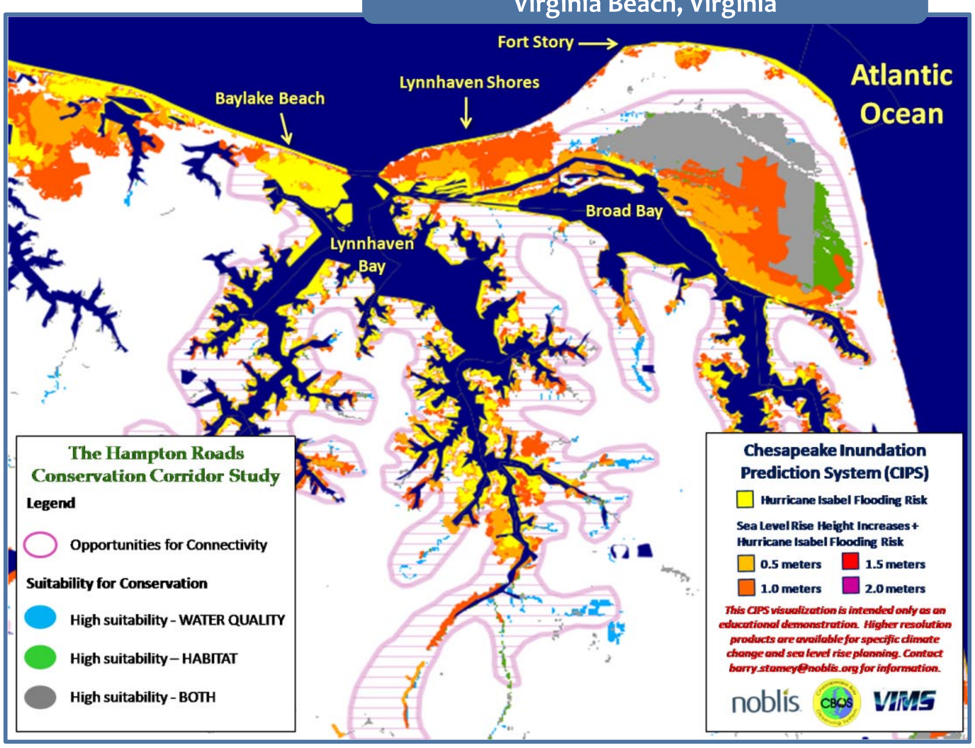


Figure 17: Hurricane Isabel flood risk +1.0m SLR, Virginia Beach, Virginia



Images from (Stamey, Wang, & Smith, 2010)

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Figure 18: Hurricane Isabel flood risk +1.5m SLR, Virginia Beach, Virginia

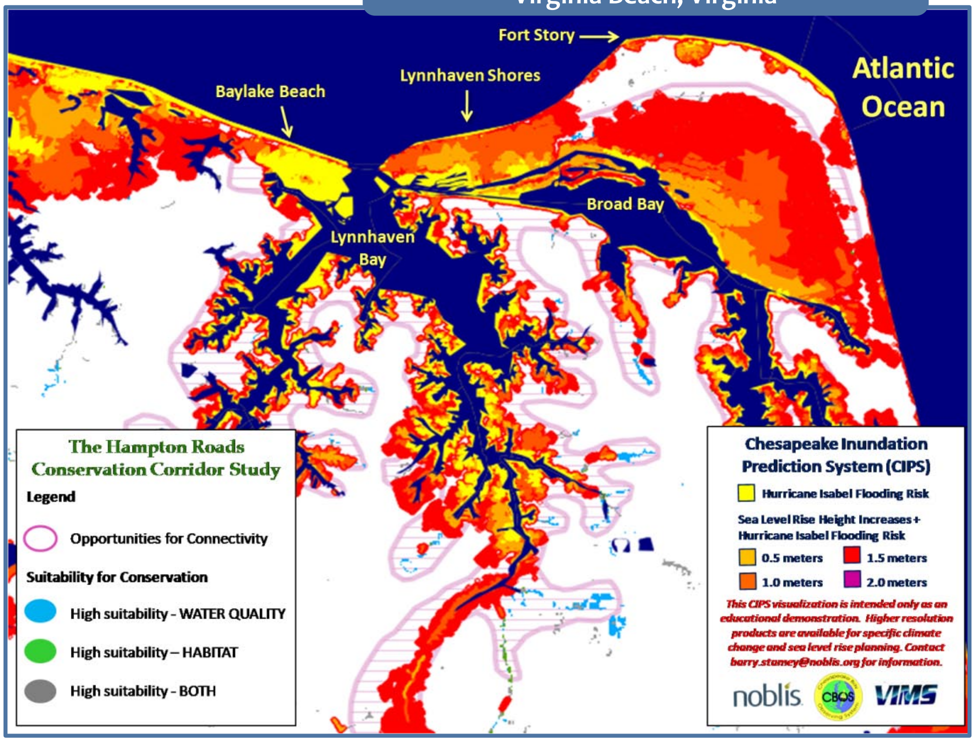
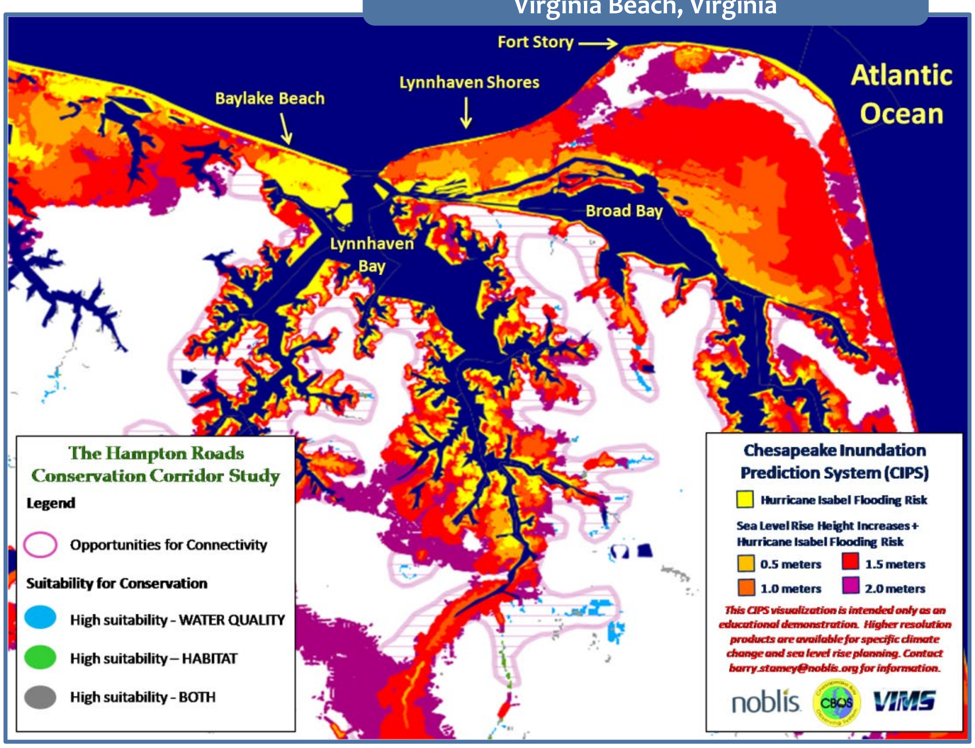


Figure 19: Hurricane Isabel flood risk +2.0m SLR, Virginia Beach, Virginia



Images from (Stamey, Wang, & Smith, 2010)

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Given current levels of atmospheric greenhouse gases, global temperatures will continue to rise over the next century, making adaptation a necessity.

Responding to Climate Change

An effective response to climate change impacts will require both mitigation and adaptation. **Mitigation actions are intended to reduce the extent and rate of acceleration of climate change by reducing greenhouse gas emissions. Adaptation actions are intended to minimize the adverse impacts of climate change on built and natural systems.** Given current atmospheric greenhouse gas levels, global temperatures will continue to rise over the next century, making adaptation a necessity regardless of mitigation strategies. The reverse is also true; without mitigation climate change will at some point exceed cost-effective adaptive capacity. The long-term rate of climate change will be determined by global ability to limit the growth of and eventually reduce greenhouse gas emissions over the next 20 to 40 years. The extent and type of adaptation measures needed in Hampton Roads will largely be determined by global greenhouse gas emissions during that 20 to 40 year window. If global greenhouse gas emissions are held flat or reduced during that time period, sea level rise rates are projected to be problematic but are likely to be manageable. If greenhouse gas emissions continue to rise significantly during that period massive melting of polar ice will result and sea level rise will have a catastrophic impact on the eastern portion of Hampton Roads.

Adaptation

Adaptation to climate change will involve both changing development patterns and protecting existing development with flood control measures. Many adaptation options are available. **In general, these can be broken down into three categories: protection, accommodation, and retreat (Karl, Melillo, & Peterson, 2009)**. Protection refers to structural solutions to protect against flooding, storm surge, or inundation. Possible measures include seawalls, bulkheads, dikes, and storm surge barriers (CCSP, 2009). Accommodation refers to retrofitting or enhancing existing structures or environments. This could include elevating buildings, beach renourishment, or enhancing wetlands (Karl, Melillo, & Peterson, 2009). Retreat refers to a broad range of options that allow or encourage people and ecosystems to move away from vulnerable areas. These can include setbacks, rolling easements, and development restrictions (CCSP, 2009). Effective adaptation to sea level rise or flooding "should focus on reducing growth in areas forecasted to be" affected over the next century (Jasinski & Claggett, 2009). Using growth management to adapt to sea level rise has multiple benefits. It can protect existing ecosystems near the shore, and can provide public value by preserving those areas for recreation or public access. This ability to meet other needs such as stormwater management and habitat provision is a general hallmark of many adaptation options. They do not just help localities adapt to climate change, but can also enhance quality of life and the natural environment.

Research by the Chesapeake Bay Program describes another method of adapting to climate change. Their work differentiates between adaptation and increasing resilience. Adaptation focuses on specific targets to plan for, while resilience planning focuses on increasing the robustness of built or natural infrastructure to deal with a wide range of possible conditions (Pyke, et al., 2008). Resilient systems bend under stress but do not break, so they are able to weather storms more effectively and recover more quickly. Resilient systems are characterized by redundancy, diversity, efficiency, autonomy, strength, interdependence, adaptability, and collaborativeness (Godschalk, 2003). They are designed so that one part's failure does not cause the whole system to collapse. For cities, resilience implies distributed infrastructures that reinforce each other, while also being able to operate independently during crises (Morrish, 2008). Adaptive responses are more appropriate when future conditions are predictable, while resiliency allows for uncertainty (Pyke, et al., 2008).

Adaptation of natural systems to climate change will look radically different from adaptations in the built environment. Some possible adaptation approaches for natural systems include protecting key resources, reducing anthropogenic stress, increasing representation, replication, restoration, refugia, and relocation (CCSP, 2008). Protection focuses on identifying ecosystems or species that provide a foundation for the region's natural environment. Reducing anthopogenic stress focuses on reducing or eliminating pollution or other stressors that result from development. Adapting through representation requires identifying and protecting a diversity of species so that the ecosystem can survive and recover. Replication focuses on protecting several representative species or ecosystems so that they are not all lost during an event. Restoration focuses on bringing back damaged ecosystems. Refugia refers to identifying less sensitive areas that could provide new environments or refuges for migrating species. Relocation describes artificially moving species to less sensitive areas when that movement is prevented by development (CCSP, 2008). Unlike options designed for the built environment, these adaptation options for natural systems mostly focus on reducing impediments to these systems adapting themselves.

Mitigation

Most of the mitigation options for limiting climate change involve reducing emissions. Mitigation focuses on planning for reducing the impacts of climate change before they occur; it is "proactive rather than reactive," (Godschalk, 2003). Lower emissions rates sooner will lessen the overall magnitude of climate change and its effects. However, "no single technology can provide all the mitigation potential in any sector," so adaptation will still be required (IPCC, 2007). Emissions reductions can be achieved through greater energy efficiency or switching to lower- or non-emissions sources of energy. Reforestation is also a potential mitigation strategy. Strengthening natural systems by removing development stressors can also help mitigate some climate change impacts. Most mitigation will require changes in behavior. Several policies can be implemented to promote lower emissions; these include taxes on emissions and land-use regulations that promote more mass transit usage and less driving, or tax or other incentives that offset energy efficiency or alternative energy (IPCC, 2007).

Opportunities

Climate change has the potential to have large impacts on the Hampton Roads economy, but it may also provide some opportunities for the region. Several industries will be particularly hard hit by sea level rise and increases in storm intensity; tourism may suffer, and the military may also have difficulties with keeping its facilities accessible and functioning. Waterfront property may also be damaged, resulting in losses to both owners and to localities through decreases in property tax revenue. The impacts on physical infrastructure are hard to quantify but could potentially be high, as much of the region's critical infrastructure is located in areas that would

Climate change has the potential to have large impacts on the Hampton Roads economy, but it may also provide some opportunities.

be affected to some degree by climate change. However, mitigation and adaptation measures addressing climate change may provide some benefits to the region. A focus on alternative energy could lead to the development of wind farms off the coast and potentially to the development of a locally based industry to supply wind energy equipment and expertise to the region and the nation. Striving for energy efficiency could have a similar effect. Research into the physical adaptation responses to sea level rise could lead to the development of new infrastructures that are better suited to a more volatile climate and are more resilient to the weather patterns the region already deals with.

Parallel Efforts

Hampton Roads localities are currently working on several efforts that closely relate to the goals of climate change adaptation and mitigation. A committee has been meeting for several months to discuss coordination of Energy Efficiency and Conservation Block Grant funds spending. Non-Entitlement localities worked together to submit a regional application for lighting upgrades, while three of the region's Entitlement communities have allocated funds to a regional greenhouse gas emissions inventory. Both of these projects fall under the mitigation category. The HRPDC Elizabeth River Restoration Program Steering Committee is looking into coastal resilience planning areas around the river. One goal of this effort is to account for industrial and contaminated sites that may be inundated or flooded due to sea level rise. Planning for this is still underway. Regional emergency management personnel are engaged in two projects relating to climate change adaptation. The first is the update of the region's hazard mitigation plans, including regional plans for most of the Peninsula and Southside communities. For the first time, sea level rise will be accounted for in the plans. Also, HRPDC is in the process of developing a regional critical infrastructure/key resources plan, which will include sector plans focusing on resiliency.

Development of a Framework for Mitigation and Adaptation to Climate Change in Hampton Roads

One of the goals for the next two years of this project is to develop a regional framework for mitigating and adapting to climate change. The framework for mitigation and adaptation to climate change in Hampton Roads is intended to capture the results of the stakeholder involvement and policy formulation process and to serve as a regional guidance document for meeting the challenges of climate change. The framework is intended to be a living document that will be updated over time as knowledge about climate change improves and conditions in Hampton Roads change. Several significant difficulties exist in the development of such a framework. Those difficulties include the unknown future rate of global greenhouse gas emissions, technical difficulties in downscaling global climate models to predict regional impacts and an extremely long planning horizon. Given these challenges the framework will need to be flexible and modular so that its structure can be revised and sections can be updated easily as circumstances and scientific knowledge change.

Establishment of a specific set of goals for the framework will be accomplished through an extensive stakeholder involvement process. The following set of general goals will be used as a starting point for that process:

- Identify and implement regional and local measures that contribute to

State and National efforts to mitigate climate change;
- Structure mitigation and adaptation efforts so that they ensure the continued economic vitality and ecological integrity of Hampton Roads;
- Safety and high quality of life for citizens of Hampton Roads will be paramount in the mitigation and adaptation process;

As is the case with the goals for the process, the structure of the framework will be revised and improved through the stakeholder involvement process and subsequent research and modeling. The following structure will be used as a starting point.

Mitigation efforts will focus on completing the regional greenhouse gas emissions inventory and developing an implementable action plan. This plan will include the establishment of regional and local emissions targets, as well as the identification and implementation of greenhouse gas emission control measures.

Adaptation efforts will focus on data and information acquisition and development of strategies for both the natural and built environments. General data and information needs include consistent, high-resolution elevation data for Virginia's coastal plain; improved understanding of sea level rise rates; enhanced modeling tools for storm surge changes associated with sea level rise; and improved models for regional changes in precipitation patterns.

Information needed for natural systems adaptation includes a vulnerability assessment for at-risk ecosystems and a prioritization of adaptation options. Once these are acquired, several climate change stressors will need to be evaluated. These include sea level rise and storm surge; atmospheric temperature increase; increasing temperature, acidity, and salinity of waters; and changes in precipitation patterns. Specific environments will need to be evaluated and adaptation plans will have to be developed for each. These environments are the Chesapeake Bay and its tributaries, tributaries to the Albemarle/Pamlico Estuary, tidal wetlands, non-tidal wetlands, uplands, and barrier islands.

Information needs for built environment adaptation include a vulnerability assessment for at-risk areas and infrastructure as well as further research into adaptation options and their feasibility. Adaptation plans will be needed many sectors, including:

- Transportation infrastructure (roads, bridges, tunnels, and rails)
- Residential structures
- Commercial structures
- Stormwater systems
- Wastewater systems (including public sewers and private septic systems)
- Drinking water supply infrastructure
- Communication and mass media infrastructure
- Military facilities
- Port facilities
- Hospital and medical facilities
- Government and emergency management infrastructure and facilities

Two additional elements that will be included in the framework are a climate change educational program for the citizens of Hampton Roads and the establishment of monitoring and evaluation goals so that the regional impacts of climate change and the results of the mitigation and adaptation efforts can be measured and documented.

Case Studies

Several other localities, regions, and nations have begun the process of addressing climate change. Many of their actions have resulted in plans that outline the potential costs of climate change while also describing strategies and goals for mitigating and adapting to climate change. Most of the case studies viewed during the course of this project focused mainly on climate change mitigation in the form of greenhouse gas emissions inventories and the development of strategies to reduce those emissions. These include a report by the Metropolitan Washington Council of Governments and a greenhouse gas emissions inventory conducted by the Delaware Valley Regional Planning Commission. Others focused more on the adaptations that will be required to survive under a more hostile climate. Examples of this sort include a sea level rise impact analysis performed for California and large scale adaptation plans for the Thames River estuary and the Dutch coast.

National Capital Region

The Metropolitan Washington Council of Governments (MWCOG) is a regional organization of counties and cities in the Washington, DC area. It issued its National Capital Region Climate Change Report in 2008 (Metropolitan Washington Council of Governments, 2008). The report includes a section on climate change and its potential impacts on the Washington, DC area, a regional greenhouse gas emissions inventory, and a set of targets for reducing those emissions. Potential impacts highlighted in this report include sea level rise, higher air temperatures, higher water temperatures, changes in precipitation patterns, and human health issues. The report also includes a set of actions to be taken to reduce emissions, promote economic development, and prepare the region for climate change impacts. The report sets goals of emissions reductions of 20 percent by 2020 and 80 percent below 2005 emission levels.

The report also includes a section on the costs of meeting the various targets, as well as a discussion of the costs of inaction. The report describes strategies to mitigate emissions from energy consumption, transportation, and land use, developing a "greener" economy, preparing for climate change impacts, financing emissions reductions, and regional outreach and education. Each of these sections includes discrete recommendations that could be adopted to further the report's goals. Each recommendation is described in terms of estimated emission impacts, implementation timing, cost, and potential for other economic or social benefits. The report closes with a short section on next steps that can be taken by MWCOG to further climate change planning efforts.

Delaware Valley

The Delaware Valley Regional Planning Commission (DVRPC) is the regional planning body and metropolitan planning organization for the Philadelphia region, and includes counties in Pennsylvania and New Jersey. DVRPC has incorporated climate change into its long-range regional plan in its sections on transportation, energy efficiency, and livable communities (Delaware Valley Regional Planning Commission, 2009). In addition, DVRPC completed a greenhouse gas emissions inventory in 2009 as the first step in its Climate Change Initiatives program. The report includes a discussion of the need for an emissions inventory as well as a list of the goals the DVRPC hopes to achieve by conducting it. The DVRPC report contains a thorough description of the methodology used to calculate the region's emissions as well as the allocation process. The report establishes a baseline inventory for comparison to future assessments and projected trajectories. The allocation of the baseline inventory forms the other significant part of the report. Emissions are allocated at both the county level and at the "minor civil division" level, which refers to sub-county municipalities such as cities, townships, and boroughs. The DVRPC emissions inventory is a good example of a top-down, regional emissions inventory that is then allocated to the sub-regional entities. Because of data and modeling limitations the allocations vary in confidence, but the process "provides MCDs with an excellent starting point" for community-level emissions inventories and reduction strategies (Delaware Valley Regional Planning Commission, 2009). The report describes the allocation methodology used, and includes a set of tables cataloging the emissions allocated to each municipality.

California Coast

The California Energy Commission's Public Interest Energy Research Program sponsored a report by the Pacific Institute to look at the risk that sea level rise poses to areas on the California coast and San Francisco Bay. Using estimates of greenhouse gas emissions from the IPCC the study analyzes what may be at risk under a moderate prediction of climate change. The study looks at losses to both flooding and erosion caused by higher sea levels (California Climate Change Center, 2009).

The study includes a thorough methodology section that describes how risk, damages, and protection costs were quantified. The results of the study are divided into two sections, one on flood-related risks and the other on erosion-related risks. Both sections analyze the risk to population, critical infrastructure such as emergency facilities and roads, property, with the flood risk section also analyzing risks to wetlands. The flood risk section also includes a discussion of the costs of hard infrastructure protection measures in response to sea level rise. The report uses a series of maps to identify and quantify the value of facilities at risk of flooding by county. The report includes a significant discussion of the populations at risk due to increased flooding as well as environmental justice concerns about the effects on vulnerable populations. The report concludes with a section on recommended practices and policies for adaptation and further research.

Thames River

The Environment Agency of the United Kingdom has established a long-term flood risk management strategy for the Thames River estuary (Thames Estuary 2100, 2009). This project, Thames Estuary 2100 (TE2100), is an in-depth analysis of what impacts can be expected from climate change in the estuary and how those impacts might be reduced, negated, or adapted to. The main objectives of the plan are to reduce and minimize the risks and adverse impacts of flooding, to adapt to climate change, to promote "sustainable and resilient development in the tidal Thames floodplain," to protect the Thames River as a social cultural, and commercial resource, and to restore and enhance ecologically significant areas in the estuary (Thames Estuary 2100, 2009). The plan consists of three main parts: a flood risk management vision, an action plan and an investment program covering multiple options and avenues of adaptation, and a discussion of flexible adaptation in the context of changing knowledge of climate change and its impacts.

The TE2100 Plan is divided into three phases through the end of the 21st century: 2010-2034, 2035-2069, and 2070-2100 (Thames Estuary 2100, 2009). Adaptation options are assigned to each phase. Adaptation options are analyzed for their costs, benefits, and impacts over time. Impacts assessed are to the natural environment, the economy, human health and society, history and culture, physical infrastructure, land use, recreation and open space, and water and hydrogeomorphology (Thames Estuary 2100, 2009). The plan includes a discussion of current flood risks in the estuary and how those risks are liable to increase due to climate change. An action plan includes options for the entire estuary and for eight smaller "action zones," (Thames Estuary 2100, 2009). The estuary-wide options considered included improving existing defense, constructing tidal flood storage infrastructure, constructing a new barrier, and constructing a new barrier with locks. One of the strengths of the TE2100 Plan aside from its analysis of potential adaptation options is its focus on uncertainty and flexibility. Because the extent of climate change impacts is unknown at this time and will depend on actions into the future, the plan established a mechanism by which different options can be put into place. Ten indicators, ranging from mean sea level to erosion to development patterns are identified to establish when a change in course might be necessary to successfully adapt to climate change.

Netherlands

The Netherlands has had much experience with sea level rise and its consequences. With a significant part of the country below sea level, the kingdom is constantly at risk from the sea. To respond to the additional challenges posed by climate change, the Netherlands established the Sustainable Coastal Development Committee. This committee's work is built on that done by the Delta Committee, which was created to devise an engineered response following floods in 1953 (Deltacommissie, 2008). The goal of this new committee was to recommend adaptation options and policies that would help prevent a similar disaster in the future by preemptively responding to climate change.

The Committee's report includes twelve major recommendations for future action out to 2100. The cost of each action is projected. In addition, each recommendation is divided into specific actions for 2010-2050 and for 2050-2100. Recommendations include increasing flood protection levels, incorporating flood protection into urban development plans, and specific flood protection actions for each of several areas (Deltacommissie, 2008). The report looks at several vulnerable areas of the country, including those along the coast and some inland areas. Existing flood defenses are analyzed. The report also analyzes additional defenses that would be necessary due to climate change-induced sea level rise. Other potential impacts of climate change, such as fresh water shortages and higher temperatures, are also discussed.

The report bases its recommendations on a risk management approach (Deltacommissie, 2008). Risk management measures reduce the probability or the consequences of storm events. Acceptable levels of risk are designated for each area based on the value of the area being protected (e.g., some areas are protected to a level of a ten-thousand year water level, while some are protected to only one in 1,250 years). The report concludes with a series of recommendations on how to achieve the adaptation program.

Lessons for Hampton Roads

These case studies of climate change plans by other localities and regions provide examples of how Hampton Roads may proceed in planning for climate change. There are several lessons that can be taken from these studies and applied to the Hampton Roads region's ongoing efforts to plan for and adapt to climate change. One example is the detailed consideration of engineered and non-engineered adaptation options for expected costs and benefits, practicality, and effectiveness. Another would be explicitly considering risk in terms of impacts as well as in identifying necessary protection measures. Assessing risk would allow for more detailed adaptation needs to be considered. At this point, certain data and research deficiencies – specifically the lack of consistent high-resolution elevation data for the region as well as climate models that offer projections at the regional scale – prevent a full assessment of the region's risks and needs.

Identifying multiple adaptation pathways early on allows for flexibility in addressing impacts.

One important final lesson that can be taken from the London and Netherlands plans is that adaption plans should be reviewed and reconsidered at set intervals. Identifying multiple pathways of adaption early on in the process allows for considerable flexibility in addressing various levels of impacts while reducing the chance of unnecessary expenditures. Projecting climate change impacts is inherently uncertain, both because the science involves many complex, interrelated variables and processes and because future actions will play a pivotal role in dictating the extent of climate change. Therefore, building flexibility and multiple options into any climate change plan for the region should be seriously considered. Another lesson from the more detailed adaptation studies that consider engineered solutions is that the negative impacts of those structures on the natural environment will have to be taken into account. Constructing water barriers and other new infrastructure can cause significant changes to ecosystems. The tradeoff between engineered flood protection schemes and ecological integrity presents a major challenge in Hampton Roads, which is home to both significant development investment and important coastal natural resources.

Climate change will affect Hampton Roads communities unequally.

Stakeholder Involvement

As part of the climate change impact analysis process, staff from the Hampton Roads Planning District Commission held meetings with a variety of groups to identify and discuss potential climate change issues, concerns, and impacts on the region. Meetings were held with local government staffs, state and federal agencies, universities, private consultants, non-profit organizations, and concerned citizens.

Locality Meetings

A series of four meetings with local government staffs was held in spring 2009. Hampton Roads localities were placed into four groups based on geographic proximity and similarity. All Hampton Roads localities and cities were invited; in addition, some incorporated towns were also invited. Meetings were held in Yorktown for northwest Peninsula communities (the City of Williamsburg and Gloucester, James City, and York Counties); Newport News for southeast Peninsula communities (the Cities of Hampton, Newport News, and Poquoson); Franklin for western Tidewater communities (the Cities of Franklin and Suffolk and Isle of Wight, Southampton, and Surry Counties); and Chesapeake for Southside communities (the Cities of Chesapeake, Norfolk, Portsmouth, and Virginia Beach). Representatives from eight cities (Chesapeake, Franklin, Hampton, Newport News, Norfolk, Poquoson, Virginia Beach, and Williamsburg), four counties (Gloucester, James City, Isle of Wight, and York), and one town (Smithfield) attended the meetings.

The two Peninsula meetings were held on April 17, 2009, while the meetings for western Tidewater and Southside were held on April 29 and May 8, 2009, respectively. The climate change meetings were held concurrently with meetings for the regional green infrastructure update since the groups of localities were appropriate for both. The meetings followed a common format. HRPDC staff began the meetings by introducing the two projects, their scopes, and the goals of the meeting. Following the introduction a presentation was made on previous work done for the projects and what steps were being undertaken. After the presentation, attendees were asked for input on direction for the projects, efforts their communities were conducting concerning both projects, and the status of their comprehensive plan updates. Attendees were also given the opportunity to ask questions from HRPDC staff about the projects and their ongoing research.

Climate change will affect Hampton Roads communities unequally; some communities, such as those with ocean or river coastlines, will be more affected by sea level rise, for example. These differences were evident during the meetings, as each group had different concerns about how climate change would affect their communities and about what steps should be taken to address those vulnerabilities. Communities were also taking different steps to prepare for climate change.

The first Peninsula meeting, with staff from Hampton, Poquoson, and Newport News, focused mostly on the threat of sea level rise and possibilities for adaptation to it. These communities have low-lying areas that are already vulnerable to flooding and will be more vulnerable to more intense storms and sea level rise. These communities expressed concerns with the lack of availability of high-resolution elevation data; some of these communities have been using Category 1 Hurricane storm surge maps as proxies for areas that would be inundated by sea level rise, but this is inadequate for future planning. Sea level rise is being incorporated into Hampton's emergency management plan, and will also be addressed in the next round of Peninsula regional emergency planning efforts, although the focus will be on more immediate hazards and not long-term planning. Hampton and Newport News both have property acquisition programs that target areas in floodplains and other threatened areas when they go on the market. Hampton and Newport News are also both focusing on energy conservation and efficiency in an effort to cut costs and greenhouse gas emissions.

Identifying actions to take and policies to adopt to address climate change was one goal of the meeting. The southeastern Peninsula attendees had several suggestions for the climate change study. These included conducting a regional carbon footprint assessment, looking into federal energy grants, establishing shoreline management programs to promote living shorelines and adaptation, identifying areas to protect with infrastructure improvements and areas to allow retreat from sea level rise, raising marshes and wetlands with fill to help them keep pace with sea level rise.

The second Peninsula meeting included participants from Gloucester, James City, Williamsburg, and York. These localities are incorporating sea level rise into their plans to varying degrees. York County and Gloucester County are both working on updating their floodplain maps. James City County is including a section on climate change in the environment chapter of its comprehensive plan update; the county has also focused some efforts on reducing carbon emissions. Gloucester County is also updating its hazard mitigation plan with the rest of the Middle Peninsula.

The attendees for the second meeting also had several suggestions. Chief among these was to offer some sort of training or

education on climate change issues for planning commissions, Boards of Supervisors, and City Councils, in addition to conducting workshops for staffs. The participants also asked HRPDC to look into what other states are doing to plan for climate change.

The western Tidewater meeting included participants from Franklin, Isle of Wight, and Smithfield. These localities are for the most part not directly addressing climate change adaptation at this time. Both Franklin and Isle of Wight are participating in energy efficiency programs such as the Go Green program conducted by the Virginia Municipal League.

The Southside meeting was attended by representatives from Chesapeake, Norfolk, and Virginia Beach. These localities are all beginning to address climate change in their planning to varying degrees. Chesapeake has had internal discussions but is still researching steps to take regarding adaptation. Norfolk is focusing its efforts on energy efficiency and has participated in the Go Green program. Virginia Beach will explicitly discuss climate change and the threat posed by sea level rise in its next comprehensive plan update, which is underway. At this point they are using hurricane storm surge maps as proxies to identify which areas of the city would be inundated by sea level rise.

Suggestions from this last meeting covered physical adaptation responses, research ideas for the climate change study, and policy changes. Suggestions for adaptation possibilities included looking to existing shoreline hardening infrastructure and how to maintain or upgrade it to meet future threats and using the living shorelines approach to promote gradual adaption to sea level rise. Research suggestions for the climate change study included analyzing the environmental impacts of sea level rise and flooding as well as projected changes in precipitation and storm patterns. Identifying areas to protect with hard defenses and areas where retreat was preferable was suggested as a policy option.

Other Meetings

HRPDC staff met with faculty and staff from the Virginia Institute of Marine Science (VIMS) on April 15, 2009, to discuss current VIMS research projects related to climate change and future steps for the regional climate change study. The meeting included participants from the Center for Coastal Resources Management, the Department of Fisheries Science, and the Department of Physical Sciences. This meeting followed a similar format to the meetings with local government staffs. HRPDC staff gave a brief presentation on the regional green infrastructure update and the climate change study. VIMS staff then discussed their ongoing research projects that related to both projects.

Two research efforts by VIMS were introduced as being potentially helpful for the climate change study. The first, a shallow water habitat study looking at the impacts of sea level rise and climate change, could help identify potential or ongoing changes to the region's aquatic environments caused by climate change. The second project is a study led by Dr. Harry Wang of the Department of Physical Sciences that is analyzing the effect of sea level rise on storm surges, with the end goal of producing a high-resolution map that will detail which areas in the region are vulnerable to hurricanes and other storms as local sea level rises. Dr. Wang also offered to conduct a workshop for local planning staff on the results of his research once it is completed.

A large meeting with over thirty participants was held at HRPDC on October 29, 2009. The purpose of this meeting was to bring together local, state, and federal government staff from a variety of agencies dealing with climate change along with public and private researchers. Participants included local government planners and emergency management personnel, natural resources agency staff, representatives of concerned non-governmental organizations, and staff from private companies working on climate change research and adaptation. The meeting was divided into two parts. The first consisted of three presentations. Dr. Harry Wang of VIMS discussed storm surge and inundation modeling of the Chesapeake Bay in reference to rising sea levels. Mr. Barry Stamey of Noblis gave a presentation on the impacts of sea level rise and increased storm surge on the Hampton Roads region. Mr. Duane Apling from Northrop Grumman discussed regional climate modeling and decision aids in the context of sea level rise.

HRPDC staff also gave a brief presentation on the ongoing climate change study and projected impacts of climate change on Hampton Roads.

The meeting concluded with a discussion of how the climate change study should proceed over the next two years. The main topic of discussion was the creation and composition of a stakeholder working group that would work closely with HRPDC staff over the study's remaining timetable to consider which impacts and responses to study more closely. Attendees suggested ideas for which groups and agencies should be represented on the working group. The working group is still in the process of being formed.

The stakeholder involvement process for the climate change study continues. HRPDC staff found the meetings with local government staff and researchers to be both useful and necessary for ensuring that local government concerns and needs were being addressed, and that staff was pursuing reasonable paths of study. Working closely with researchers will help over the remaining two years of the project to maintain accuracy in projections of impacts and to keep aware of ongoing research in the field. By including local government staff in the project from the beginning and continuing their involvement through the stakeholder working group and other avenues HRPDC staff hopes to create a series of products that will be useful and practical for local governments in helping them identify, quantify, and prepare for the impacts of climate change.

Conclusions and Recommendations

Assembling and executing a long-term plan for mitigation and adaptation at the regional level will be both difficult and resource intensive.

The first year of this project has revealed how daunting a task coping with climate change will be for the region and how important it is that this effort progress rapidly. The task of assembling and executing a long-term plan for mitigation and adaptation at the regional level will be both difficult and resource intensive. Planning for climate change will have to be an interdisciplinary undertaking, combining the skills and knowledge of many fields. The Focal Area grant supplied by the Virginia Coastal Zone Management Program is a valuable first step in this process, but ultimately the effort will have to extend well beyond this initial project. Substantial additional funding is needed for data acquisition, field work and continued model development. Unfortunately additional funding sources have not yet been identified.

The initial year of work on this project has resulted in a substantial increase in the visibility of the problem of climate change within the Hampton Roads community. The Hampton Roads Planning District Commission has received two briefings on the topic and is now fully engaged in dealing with the problems of sea level rise and associated increases in flooding.

The first phase of this project has also resulted in identification of several types of information that will be needed to support future planning efforts. **One of the greatest needs is for consistent high-resolution elevation data for the entire region**; indeed, this applies to the whole Coastal Plain of Virginia. Improved elevation data is crucial to analyzing the vulnerability of the region to sea level rise and storm surge.

The application of sophisticated modeling tools will be needed to perform a detailed vulnerability analysis of the built environment and associated infrastructure in Hampton Roads. The models under development by VIMS and Noblis show great promise in their ability to replicate past storm events. Combined with the previously mentioned elevation data and appropriate funding it will be possible to assess vulnerability under a variety of sea level rise and storm scenarios and to evaluate some of the adaptation options.

In the realm of adaptation planning for the natural environment, much additional information is needed from scientists working on the question of how to best respond to the additional stresses placed on natural systems by climate change. There is general agreement within the scientific community that this will be a two step process, vulnerability analysis followed by the creation of adaptation plans. This is a relatively new area of science and the way forward is not entirely clear. General agreement exists that minimizing other stresses on natural systems such as pollution, fragmentation and encroachment by development will help to minimize damage associated with climate change. The question of the efficacy of specific interventions to assist natural systems in resiliency to climate change remains to be answered.

The Hampton Roads Planning District Commission will continue to study the regional impacts of climate change and potential responses over the next two years. There will be three areas of focus for the next year. The first will be the continued development of the regional response framework. The second will be further analysis of impacts and policy options for specific sectors such as the economy, built environment, and natural environment. The third will be continuing to work with outside agencies and groups to promote the development of tools to analyze sea level rise impacts.

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