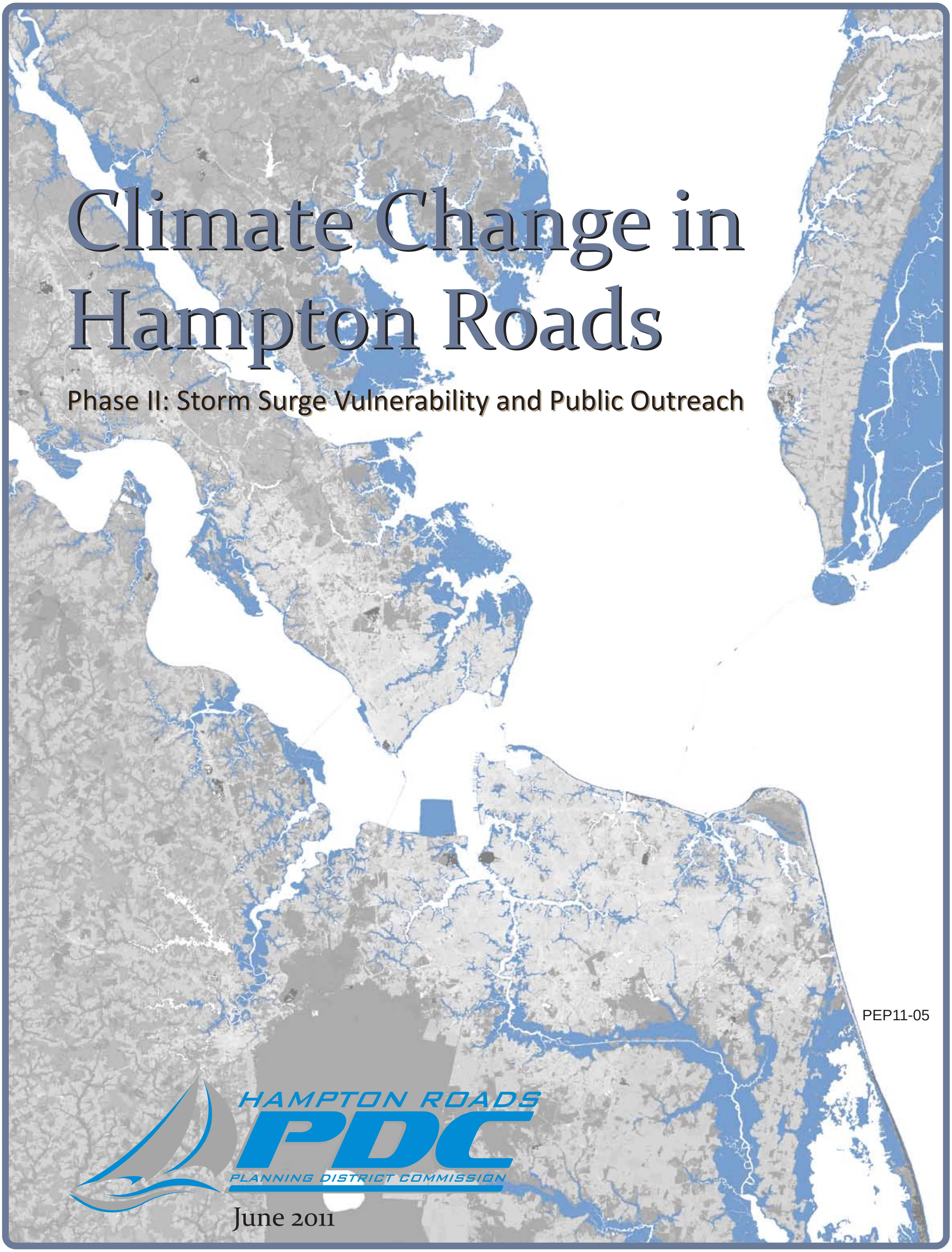

Climate Change in Hampton Roads

Phase II: Storm Surge Vulnerability and Public Outreach

PEP11-05

HAMPTON ROADS PDC PLANNING DISTRICT COMMISSION

June 2011

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CLIMATE CHANGE IN HAMPTON ROADS
PHASE II: STORM SURGE VULNERABILITY AND PUBLIC OUTREACH

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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 a summary of the second year of the Hampton Roads Planning District Commission's Climate Change Adaptation project. The report contains eight major sections. The first section describes sea level rise in Hampton Roads. The second section describes several sea level rise and flooding vulnerability analysis case studies. The third section describes the various datasets used in this analysis. The fourth section describes the methodology used for the analysis. The fifth section provides a brief summary of the results. The sixth section describes the public outreach efforts HRPDC staff participated in or coordinated during this grant period. The seventh section describes some adaptation options available for responding to sea level rise, as well as some planning frameworks that could be used locally and regionally to address climate change in Hampton Roads. The eighth section summarizes the project and offers some next steps.

ACKNOWLEDGEMENTS
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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. Land cover data from the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (C-CAP) is shown in grayscale. Areas in blue are tidal wetlands or are within one meter of elevation of spring high tide (Titus and Wang 2008).

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Executive Summary

The Hampton Roads Planning District Commission is currently engaged in a three-year focal area grant project from the Virginia Coastal Zone Management Program on Climate Change Adaptation. This report represents the work from the second year of that project. The first year focused on researching the types of impacts that the Hampton Roads region could potentially experience from climate change and on engaging and educating local government staffs about those impacts. The focus during the second year shifted to assessing the extent of those impacts with a focus on sea level rise and flooding, along with engaging the public through a variety of means on those issues. HRPDC staff presented to several governmental and non-governmental organizations and groups over the course of the grant period, including formal presentations, informal discussions, and panels.

The geographic analysis in this report attempted to estimate the region's exposure to flooding and sea level rise by collecting and using data for storm surge zones, population, critical facilities, transportation infrastructure, and businesses. The results indicate that Hampton Roads is significantly vulnerable to flooding during storms as well as sea level rise, with the Cities of Chesapeake, Hampton, Norfolk, Poquoson, Portsmouth, Virginia Beach and Gloucester and York Counties being particularly vulnerable. This vulnerability to existing hazards reinforces the perception that sea level rise is a potential threat to the region. Educating and engaging the public, incorporating sea level rise into current planning efforts, and developing a regional plan for considering adaptation options are three important steps Hampton Roads should take in the near future to meet this challenge.

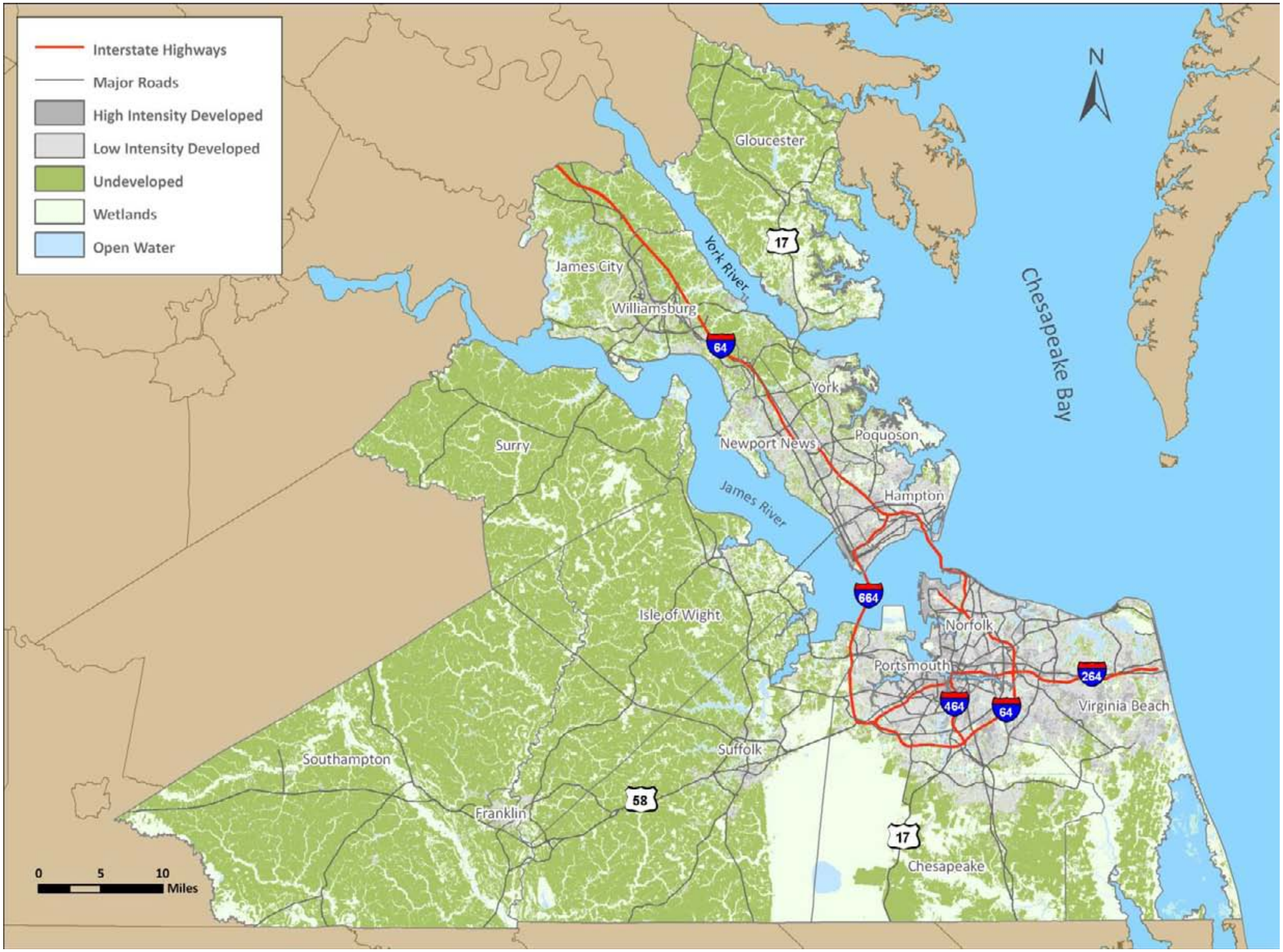
INTRODUCTION

The Hampton Roads Planning District Commission has been working on a three-year Sustainable Coastal Communities Focal Area Grant from Virginia's Coastal Zone Management Program (VCZMP) focused on Climate Change Adaptation. The VCZMP identifies focal areas to focus multiple years of funding to help develop long-term programs. The first year of the HRPDC's Climate Change Adaptation project focused on identifying the broad impacts the region potentially faced as a result of climate change and engaging local governments in identifying vulnerabilities and adaptation options. Through that process as well as cooperative efforts with other researchers and stakeholders, sea level rise and storm surge flooding were identified as two of the most pressing concerns related to climate change. The Hampton Roads region is already particularly vulnerable to storm surges from hurricanes and nor'easters as a result of its intensive coastal development and relatively flat topography. While its location along the Mid-Atlantic coast protects it from the brunt of many tropical storms, when storms strike the area the effects can be quite damaging and incapacitating. Sea level rise will increase the threat from storm-induced flooding in addition to permanently inundating some areas. Accelerated rates of sea level rise due to climate change pose an even greater threat to the region.

Given that storm surges and sea level rise pose significant threats to both the natural and built environments in Hampton Roads, it is important to quantify the extent of those threats to create effective tools for mitigating those threats or adapting to them. Understanding how much of a threat sea level rise and storm surge are can also help decision makers calculate the potential costs of those hazards in terms of losses, while also determining the benefits of various mitigation and adaptation measures relative to their costs. The goal of this phase of the project was to develop a way to quantify the regional impacts of sea level rise, to the economy as well as the built and natural environments. Developing a geographic information systems (GIS) tool to measure impacts from sea level rise that could be replicated by individual localities in Hampton Roads was a primary consideration. The outputs from this tool development and use would then be used to inform research and discussion concerning adaptation and mitigation policies. At the same time, work would continue on the development of a regional framework for climate change adaptation.

The creation of a tool to estimate the impacts of sea level rise is an important step in developing effective polices that cope with climate change. One outcome of using such a tool is the creation of vulnerability or exposure maps that assess infrastructure, population, or other important conditions within areas at risk from flooding or inundation. Identifying which areas are threatened and how much is affected can allow for the effective distribution of resources to various adaptation measures. These maps and data summaries, using high-resolution elevation, land use/land cover, demographic, and economic data, are useful for both short-term and long-term land-use, infrastructure, and hazard mitigation planning efforts (Gesch, Gutierrez and Gill 2009). The availability of more precise data and advanced geographic information systems capabilities allows for extensive spatial analysis and modeling of these impacts. Estimates of adaptation costs and the scale of political decisions required when selecting appropriate adaptation measures make accurate assessments of vulnerability critical. Some measures, such as current hazard mitigation planning, are "win-win" or "no regrets" decisions – they provide benefits now for current issues while also providing some mitigation or adaption benefits for sea level rise (NOAA Coastal Services Center 2010). Other measures, such as seawalls or dikes, can be very expensive (Koch 2010). Given the uncertainties involved in planning for sea level rise, the following analysis should be taken as a first-take general estimate of the region's current vulnerability to storm-surge and potential vulnerability to sea level rise. This report should be seen as part of the process of discussing what options are appropriate and cost-effective for adapting Hampton Roads to climate change and sea level rise.

This report consists of eight sections as well as appendices containing supporting documents. The first section describes sea level rise in Hampton Roads. The second section describes several case studies of vulnerability analyses conducted by others that measure the threats of storm-surge flooding and/or sea level rise. The third section describes the various datasets used in this analysis. The fourth section describes the methodology used in the analysis. The fifth section gives an overview of the results, including tables and maps. The sixth section describes this grant period's public outreach efforts and partnerships with other organizations. The seventh section describes various policy options that have been identified for adapting the region to sea level rise and storm surge. The final section provides an overview of the planned steps to be taken during the final year of this focal area project.



Map 1: Hampton Roads, Virginia

SEA LEVEL RISE IN HAMPTON ROADS

Global sea level is determined by the volume and mass of water in the world's oceans. Sea level rise occurs when the oceans warm or ice melts, bringing more water into the oceans. Sea level rise caused by warming water or thermal expansion is referred to as steric sea level rise, while sea level rise caused by melting snow and ice is called eustatic sea level rise. The combination of steric and eustatic sea level rise is referred to as absolute sea level rise. Absolute sea level rise does not include local land movements. Additionally, while it is often represented as a global average, absolute sea level rise varies from place to place as a result of differences in wind patterns, ocean currents, and gravitational forces. This variation is shown in the figure below.

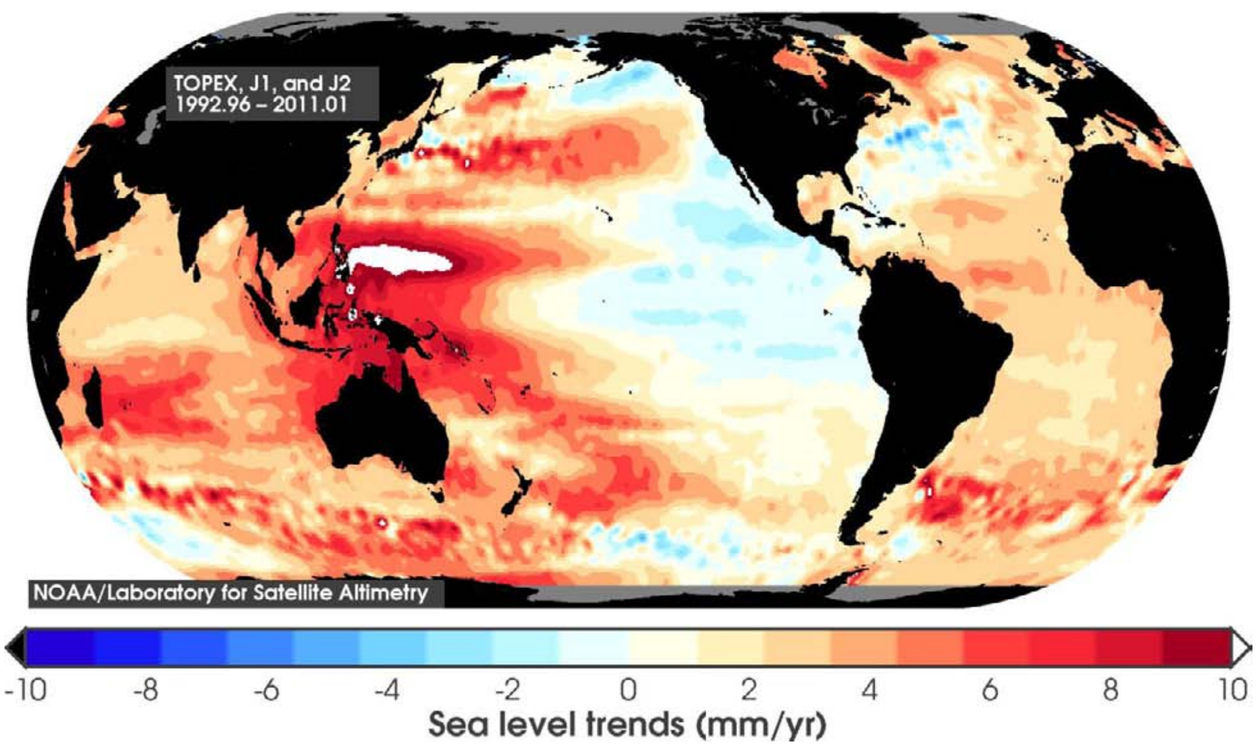
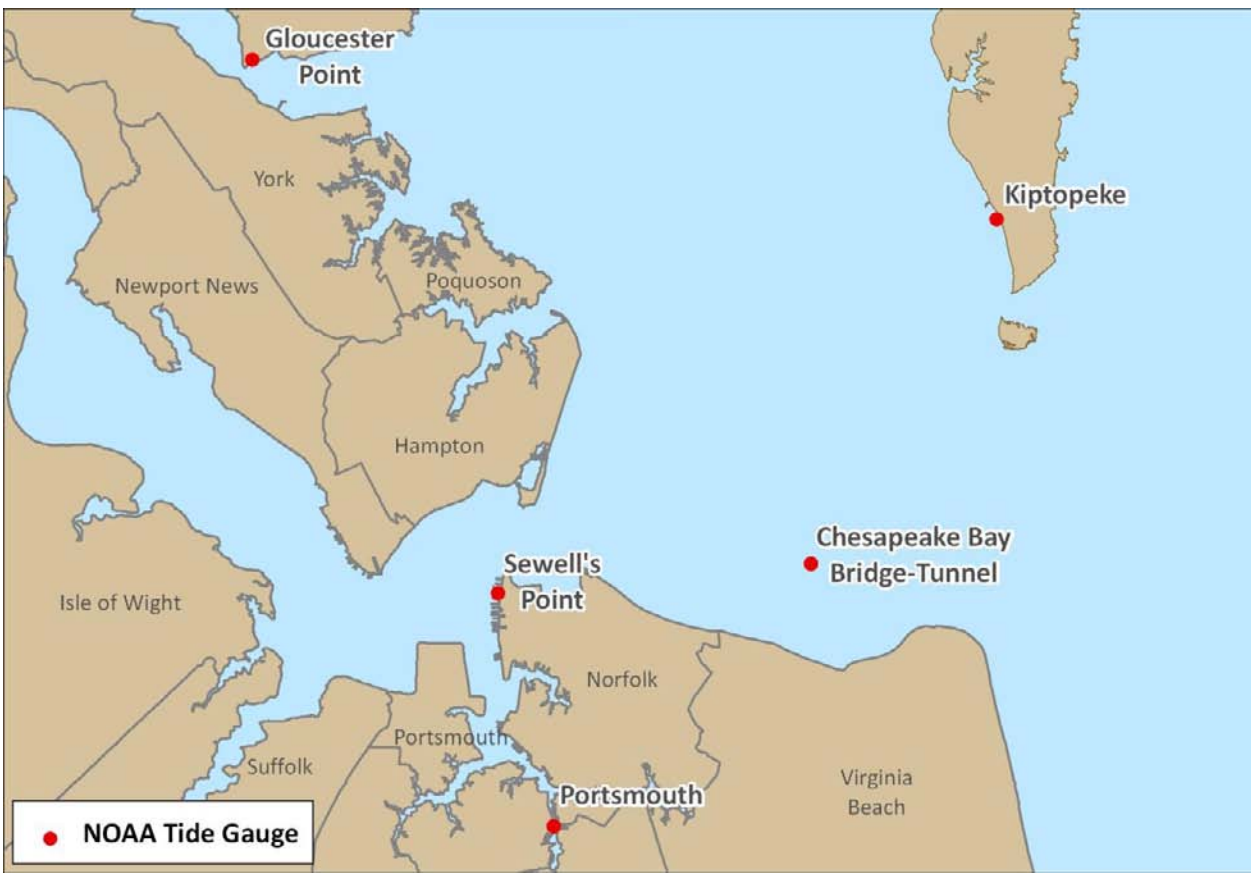


Figure 1: Absolute Sea Level Trends from Satellite Radar Altimeters, 1992-2011
(NOAA Laboratory for Satellite Altimetry 2011)

Sea level rise experienced at the local level is referred to as relative sea level rise, since it is measured relative to a fixed point on land, usually by a tide gauge (Boon, Brubaker and Forrest 2010). Measuring sea level rise in this manner incorporates any vertical change in land, either subsidence (sinking) or uplift (rising).

Hampton Roads is more vulnerable to sea level rise than most regions because it is subsiding due to a combination of geological processes, such as isostatic rebound, faulting and consolidation of sediments in fill structures such as the Chesapeake Bay Impact Crater, and sediment compression caused by groundwater withdrawals (Boon, Brubaker and Forrest 2010). However, the relative impact of these individual processes on the region's rate of subsidence is not well understood. The overall effect of these processes is that the region is sinking at the same time the sea is rising, so even in the absence of any global sea level rise, Hampton Roads would still be experiencing rising sea levels. In 2010, the Virginia Institute of Marine Science and U.S. Army Corps of Engineers published a study on sea level trends in the Chesapeake Bay, with a focus on identifying the amounts of absolute and relative sea level rise occurring in the region (Boon, Brubaker and Forrest 2010). This study analyzed sea level trends for ten tide gauges in the Chesapeake Bay from Maryland to Virginia, using linear regression to remove seasonal and decadal patterns to determine long-term trends. This analysis found that absolute sea level rise (sea level rise caused by an increase in water volume and mass) in the Chesapeake Bay from 1976 to 2007 was approximately 1.8mm/year, and that subsidence rates ranged from 1.3mm/year to 4.0mm/year at different sites around the Bay. On average, the study concluded that subsidence accounts for 53% of the relative sea level rise measured in the Chesapeake Bay. The report did not identify any acceleration in sea level rise in the Chesapeake Bay. However, subsidence makes the areas surrounding the Chesapeake Bay particularly vulnerable to any absolute sea level rise, so continued research and monitoring is recommended.

Long-term sea level trend data for the Hampton Roads region are available from five National Oceanic and Atmospheric Administration (NOAA) tide gauges, three of which remain active. These gauges are located at the Chesapeake Bay Bridge-Tunnel, Gloucester Point, Kiptopeke, Portsmouth along the Southern Branch Elizabeth River, and Sewell's Point in Norfolk. These locations are shown on Map 2 (page 7). Continuous NOAA tide measurements in Hampton Roads began in 1927 at the Sewell's Point station, with additional stations established in 1935 (Portsmouth), 1950 (Gloucester Point), 1951 (Kiptopeke), and 1975 (Chesapeake Bay Bridge-Tunnel). Longer observation periods provide clearer signals of sea level trends because regular seasonal, annual, and decadal variations can be identified and removed. Observed sea level trends (with a 95% confidence interval) at these stations range from 3.48 ± 0.42 mm/year at the Kiptopeke station to 6.06 ± 1.14 mm/year at the Chesapeake Bay Bridge-Tunnel. These ranges represent local or relative sea level rise rates, which include both absolute sea level rise and subsidence. The Chesapeake Bay Bridge-Tunnel, Kiptopeke, and Sewell's Point trends are through 2006. The Gloucester Point and Portsmouth stations were deactivated in 2003 and 1987, respectively. Long-term trends for these stations are shown in the following figures from NOAA's Tides & Currents website (National Oceanic and Atmospheric Administration 2011).



Map 2: NOAA Tide Gauges in Hampton Roads that Measure Sea Level Trends
(National Oceanic and Atmospheric Administration 2011)

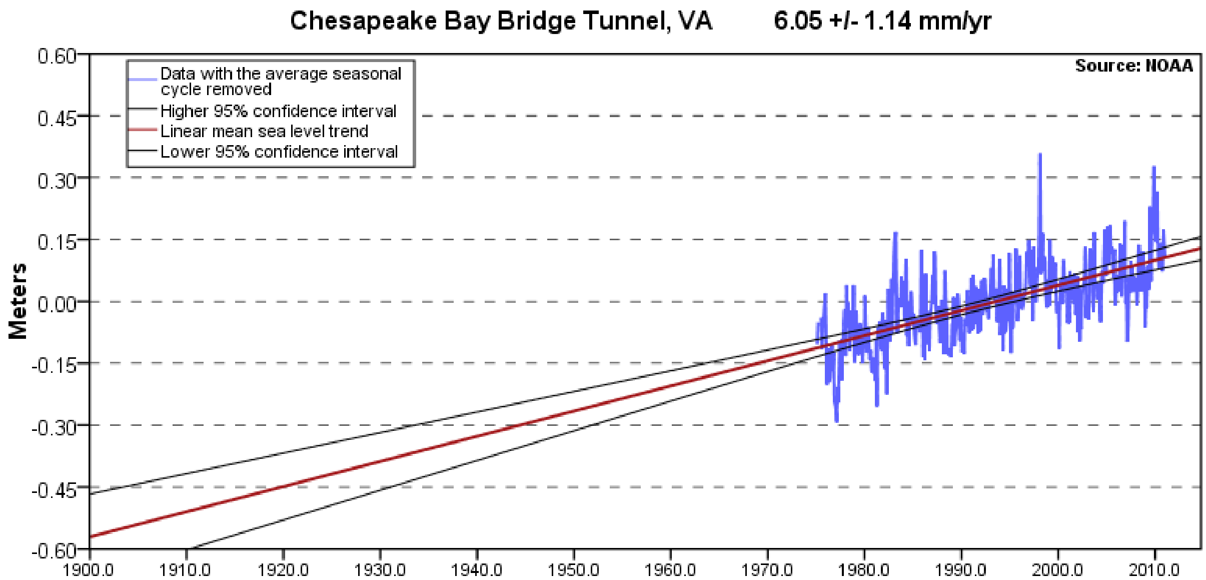


Figure 2: Mean Sea Level Trend, Chesapeake Bay Bridge-Tunnel Station (1975 – 2006)

The long-term mean sea level trend at the Chesapeake Bay Bridge-Tunnel tide gauge from 1975 to 2006 was 6.06 ± 1.14 mm/yr. The observed rate equals a rate of 1.98 feet over 100 years (National Oceanic and Atmospheric Administration 2011).

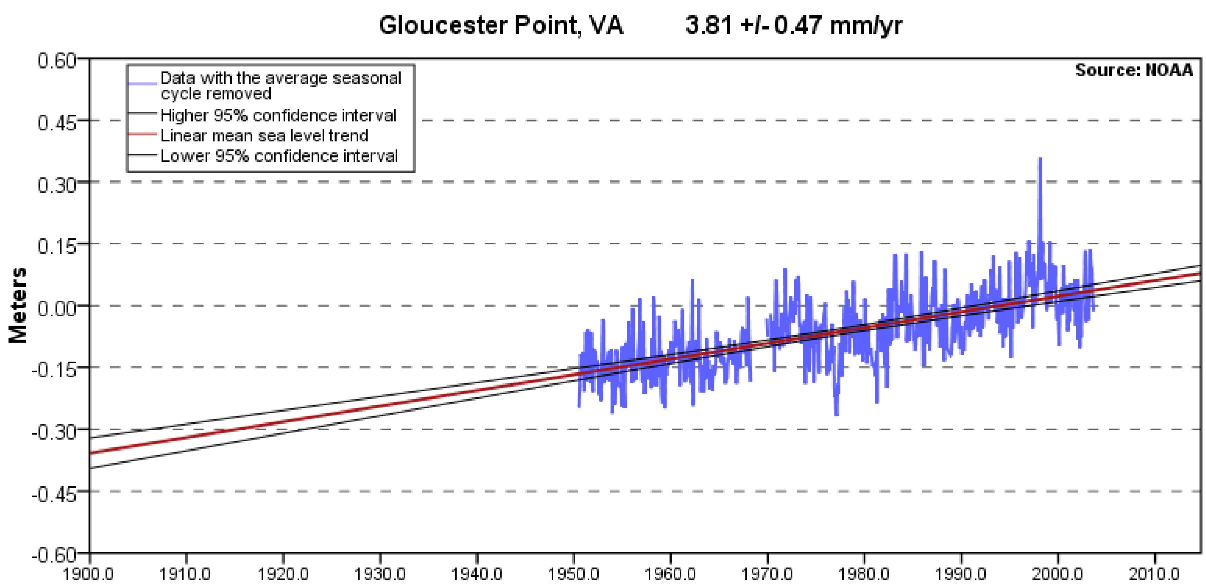


Figure 3: Mean Sea Level Trend, Gloucester Point Station (1950– 2003)

The long-term mean sea level trend at the Gloucester Point tide gauge from 1950 to 2003 was 3.81 ± 0.47 mm/yr. The observed rate equals a rate of 1.25 feet over 100 years (National Oceanic and Atmospheric Administration 2011).

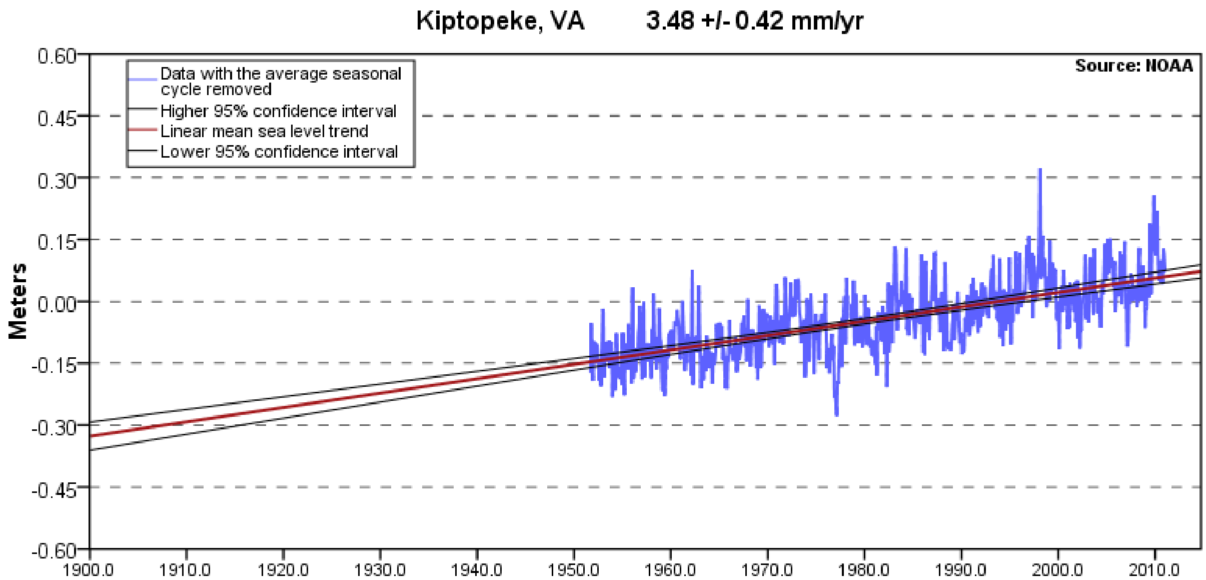


Figure 4: Mean Sea Level Trend, Kiptopeke Station (1951 – 2006)

The long-term mean sea level trend at the Kiptopeke tide gauge from 1951 to 2006 was 3.48 ± 0.42 mm/yr. The observed rate equals a rate of 1.14 feet over 100 years (National Oceanic and Atmospheric Administration 2011).

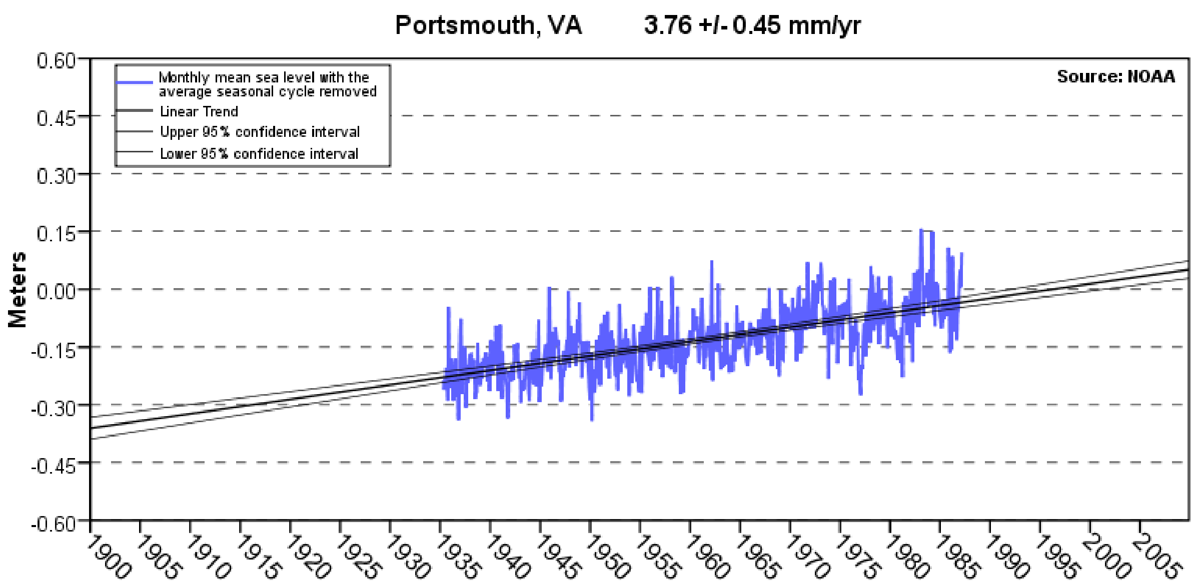


Figure 5: Mean Sea Level Trend, Portsmouth Station (1935 – 1987)

The long-term mean sea level trend at the Portsmouth tide gauge from 1935 to 1987 was 3.76 ± 0.45 mm/yr. The observed rate equals a rate of 1.23 feet over 100 years (National Oceanic and Atmospheric Administration 2011).

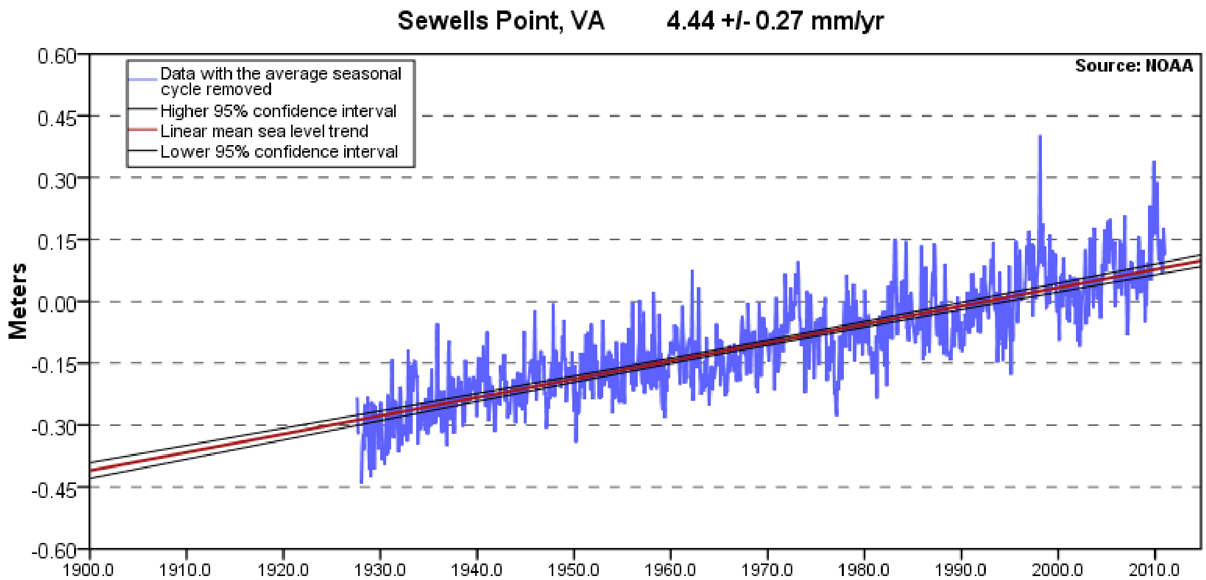


Figure 6: Mean Sea Level Trend, Sewell's Point Station (1927 – 2006)

The long-term mean sea level trend at the Sewell's Point tide gauge from 1927 to 2006 was 4.44 ± 0.27 mm/yr. The observed rate equals a rate of 1.46 feet over 100 years (National Oceanic and Atmospheric Administration 2011).

Unfortunately, while historical trends of sea level rise over the 20th century in the Chesapeake Bay are documented by actual observations, planning for sea level rise over the next century involves a great deal more uncertainty, for both absolute sea level rise and relative or local sea level rise. In this respect, the uncertainty concerns the extent of sea level rise, not whether or not it is occurring. This uncertainty results from several factors.

First, projecting absolute future sea level rise involves making a number of assumptions. For global sea level rise, scenarios of different greenhouse gas emissions levels (which include assumptions about population growth and distribution, technology use, economic growth, and other components) are used as inputs to models that then calculate changes to sea level, global average temperatures, precipitation levels, and others. Instead of interpreting these as predictions, it is more appropriate to understand them as projections of possible futures. In this way, the models can be used to test different behaviors, trends, or policies and their effects on the global environment. Scenario planning is used in many different fields, including planning and business, and is very useful when future actions are likely to have a great impact on future developments. In the cases of climate change and sea level rise, the United Nations Intergovernmental Panel on Climate Change (IPCC) and others have noted that while some degree of climate change is inevitable, the full extent will depend on choices made and actions taken in the future (Intergovernmental Panel on Climate Change 2007).

Second, climate change and sea level rise projections rely on the use of models that have varying degrees of precision and understanding of the processes being modeled. Some things, such as thermal expansion of water, are relatively well understood, while others, such as ice flow processes, are less so. For this reason, many projections of climate change and its impacts are given as both best estimates and as ranges for each scenario. These ranges account for the uncertainties both in data and in modeling long-range processes. However, they are still projections that rely on assumptions concerning future behavior. In addition, the IPCC's projected levels of sea level rise, shown in Figure 6 below, only account for global average sea level rise, which does not account for local variations in sea level rise resulting from winds, vertical shifts in land, or ocean currents.

Figure 7: IPCC Temperature and Sea Level Rise Projections by 2099

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	**Likely range (>66%)**	**Model-based range excluding future rapid dynamical changes in ice flow**
Constant year 2000 concentrations	0.6	0.3 – 0.9	Not available
B1 Scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T Scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 Scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B Scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 Scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1F1 Scenario	4.0	2.4 – 6.4	0.26 – 0.59

Source: IPCC Climate Change 2007: Synthesis Report (Intergovernmental Panel on Climate Change 2007)

More observations and research are leading to better understanding of these processes, so the accuracy of the projections should improve. The United States Global Change Research Program published a report in 2009 that included more recent research results than the IPCC report. Their summary stated that "the average estimates under higher emissions scenarios are for sea-level rise between 3 and 4 feet by the end of this century," with even higher amounts possible (Karl, Melillo and Peterson 2009). These numbers only account for absolute sea level rise. The high rate of subsidence in Hampton Roads will cause relative sea level rise to be even higher than the global average. However, there is also a great deal of uncertainty regarding the extent and rate of subsidence in the region, as its causes are poorly quantified and understood.

These measurements of past sea level rise and projections of future sea level rise have several implications for Hampton Roads localities. The long-term trend of sea level rise measured at several locations across the region provides a reasonable baseline rate of sea level rise to include while planning for the future, whether in identifying areas for future development, constructing public works and infrastructure, or land conservation and natural resources protection. Past observations of sea level rise in Hampton Roads indicate a long-term trend of approximately one to two feet of relative sea level rise every one hundred years. Studies indicate that the global rate of absolute sea level rise will increase. Therefore, local sea level rise in Hampton Roads over the next one hundred years is likely to exceed the 20th century rate. At minimum, for long-term planning purposes the region should assume historical rates of sea level rise will continue. However, the region should regularly revisit this assumption as new observations and research are made available.

CASE STUDIES

Several previous studies have analyzed how vulnerable communities are to storm surge and sea level rise. Three of these studies were used as examples for developing the methodology used in this report's analysis.

HAMPTON ROADS, VIRGINIA

The first of these studies was conducted by a team from Pennsylvania State University and focused on the Hampton Roads region. This study assessed the area's vulnerability to storms and how sea level rise would increase that vulnerability, with vulnerability defined as a function of exposure, sensitivity, and adaptive capacity (Kleinosky, Yarnal and Fisher 2007). Their research combined an assessment of the region's exposure to storm surge and sea level rise with analysis of the region's sensitivity to and ability to handle natural hazards, based on socioeconomic characteristics such as poverty and age. The study relied on previous work that identified young, old, and poor populations as having less capacity to adapt to change or respond to hazards. Exposure was measured using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, using present conditions as the baseline and adding sea level rise of 30cm (0.98ft), 60cm (1.97ft), and 90cm (2.95ft). Sensitivity and adaptive capacity were measured using data from the 2000 U.S. Census. The census blocks with the highest vulnerability to storm surge and sea level rise were located in Newport News, Norfolk, and Portsmouth, with blocks in Chesapeake, Hampton, and Virginia Beach also having significant vulnerability. The study also looked at how future population growth and movement could affect vulnerability, as well as the exposure of the region's critical infrastructure to storm surge and sea level rise. This study provides a model for HRPDC's current work as well as a baseline for comparing results.

LONG ISLAND SOUND

The Long Island Sound of Connecticut and New York was the first area studied by the Coastal Resilience Project (The Nature Conservancy 2010), an effort headed by The Nature Conservancy with the goal of studying the impacts of flooding and sea level rise in regions with significant natural and infrastructure resources at risk. The study measured the vulnerability of Long Island, New York to both sea level rise and storm surge (The Nature Conservancy 2010). The study included a focus on the vulnerability of natural resources and their usefulness as protection from flooding. This analysis used elevation data combined with sea level rise scenarios developed by Columbia University's Center for Climate Systems Research to assess which areas might be inundated from sea level rise. Ecological indicators used to measure vulnerability included tidal marshes and barrier islands, while population, infrastructure, land cover, and emergency facilities were used as socioeconomic indicators. The analysis also looked at potential economic losses from flooding using the HAZUS-MH model, developed by the Federal Emergency Management Agency to estimate vulnerability to natural hazards. The study found that the region was significantly at risk from sea level rise and storm surge flooding, including both natural resources and developed areas. In addition to the vulnerability analysis, the project also surveyed available options for adapting to sea level rise and resulted in the creation of the Future Scenarios Mapper, an interactive viewer that allows the public to compare different scenarios of sea level rise and flooding with various social, economic, infrastructure, and environmental data layers.[1] This viewer is an excellent example of making flooding and sea level rise research and analysis easily accessible to the public.

Mid-Atlantic Coast, United States

The U.S. Climate Change Science Program published a series of reports on climate change and its impacts on the United States, including one in January 2009 titled *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region* (Climate Change Science Program 2009). One of the chapters in that report, "Population, land use, and infrastructure," looked at the available data needed for a comprehensive assessment of coastal areas' vulnerability to sea level rise (Gill, et al. 2009). Utilizing geographic information systems (GIS), the authors modeled the vulnerability of Mid-Atlantic communities and watersheds to sea level rise. Their analysis encompassed population (Census data), land use/land cover (National Land Cover Dataset), and transportation infrastructure (U.S. Department of Transportation). The authors created both low and high estimates of vulnerability to reflect the uncertainty in the available elevation data, which were typically U.S. Geological Survey (USGS) Digital Elevations Models (DEMs). The analysis covered the states of Delaware, Maryland, New Jersey, New York, North Carolina, Pennsylvania, and Virginia as well as the District of Columbia. The analysis was also conducted at the watershed level and included the Albemarle Sound, Atlantic Ocean, Chesapeake Bay, Delaware Bay, Delaware River, Long Island Sound, Pamlico Sound, Peconic Bay, Potomac River, and Raritan Bay watersheds. In addition to incorporating low and high estimates resulting from elevation uncertainty, the analysis also modeled several distributions of population within census blocks, the unit at which population data was available, to account for the uncertainty in knowing where residents live within those blocks. These included a uniform distribution and other distributions excluding various

[1] http://lis.coastalresilience.org/lis.html

percentages of the lowest-lying areas within each block (e.g. the population is evenly distributed within the highest, in elevation, fifty percent of the block). This analysis builds on extensive work analyzing available elevation data (Titus and Wang 2008).

NOAA Coastal County Snapshots

While not specifically addressing sea level rise, NOAA's Coastal County Snapshots, provided through the Coastal Services Center (CSC), provide a very quick and simple way of identifying vulnerabilities to flooding in coastal areas (NOAA Coastal Services Center n.d.). The CSC produces two types of snapshots, Flood Exposure Snapshots and Ocean and Great Lakes Jobs Snapshots. These brief reports utilize data from a number of sources, including the Federal Emergency Management Agency, the 2000 U.S. Census, and NOAA to assess the physical, natural, and economic vulnerability of communities to coastal flooding. The Flood Exposure Snapshots analyze population and critical facilities within FEMA 100-year floodplains. The reports also identify high-risk populations (the population over 65 and the population in poverty) as well as the amount of land developed within the floodplain. For example, the Flood Exposure Snapshot for Virginia Beach, Virginia identifies 19% of the total population, or 78,834 residents, living inside the floodplain, including 23% of the city's elderly population (8,086 residents) and 14% of the city's low-income population (3,933 residents) (NOAA Coastal Services Center n.d.). Approximately 4% of the city's critical facilities and 11% of its road miles are in the flood plain, and 80 acres of floodplain were converted to development between 2001 and 2006. The Ocean and Great Lakes Jobs Snapshots analyzes employment data to identify the number of employees in ocean jobs, their total wages, and the amount of goods and services they provide, as well as the total percentage of ocean jobs in the workforce and ocean-related employment trends over time. In Virginia Beach, there were 22,448 employees in ocean-related jobs making a total of $334 million in wages and providing $668 million in goods and services in 2008 (NOAA Coastal Services Center n.d.). Nearly all of these jobs are related to tourism and recreation. In Hampton Roads, both types of snapshots are available for Chesapeake, Gloucester, Hampton, Isle of Wight, Newport News, Norfolk, Poquoson, Portsmouth, Virginia Beach, and York. Ocean and Great Lakes Jobs Snapshots are also available for Franklin, James City, Suffolk, Surry, and Williamsburg.

DATA

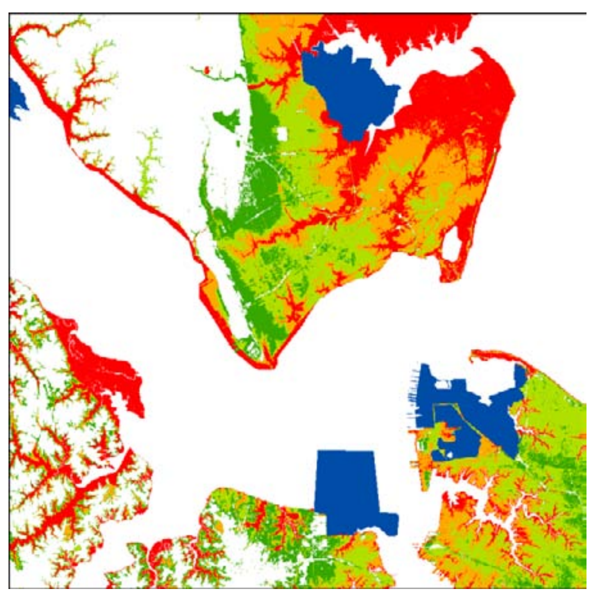
The data used in this vulnerability analysis came from multiple sources and was modified and analyzed using geographic information systems (GIS). The datasets used were selected based on need, availability, consistency, and processing capacity. The goal of this analysis, to estimate the vulnerability of the Hampton Roads region to storm surge and sea level rise, required identifying zones throughout the region that are subject to storm surge or would be subject to sea level rise, and then assessing what assets, resources, or population existed within those zones. The goal of the storm surge vulnerability analysis was to estimate the quantity of residents, employees, businesses, roads, and critical infrastructure in various storm surge zones. The goal of the next stage, a sea level rise vulnerability analysis, will be to estimate the quantity of residents, employees, businesses, roads, critical infrastructure, and natural resources in areas that could potentially be inundated by various amounts of sea level rise.

ORIGINAL DATA SOURCES

Five data categories were identified for this study: storm surge, population, business, roads, and critical infrastructure. The process for each category required identifying data sources, obtaining datasets, and extracting the necessary data from each dataset to form a working dataset. Descriptions of the various data used in this analysis are given below.

Storm Surge

Storm surge is rise in water resulting from low atmospheric pressure and high winds (J. Boon 2003). The storm surge zones used here were the result of a cooperative effort, the Virginia Hurricane Evacuation Study (VHES), between the U.S. Army Corps of Engineers, the Federal Emergency Management Agency, the Virginia Department of Emergency Management, and Hampton Roads local governments (Virginia Department of Emergency Management n.d.). Their analysis used the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model to determine the maximum storm tide elevations from Category 1, 2,



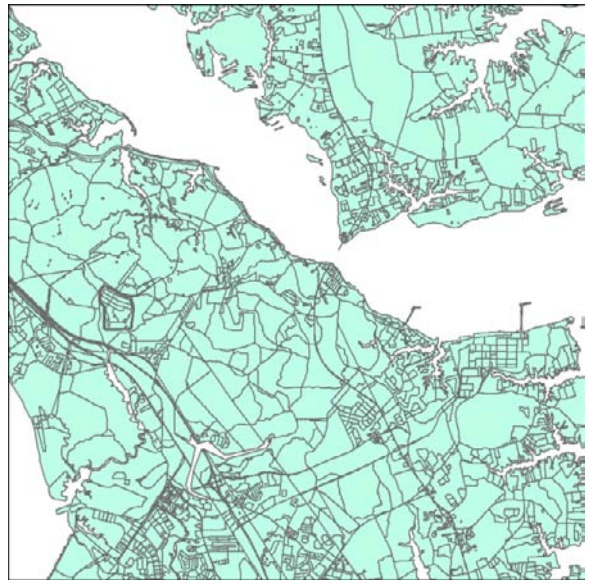
Map 3: Example Storm Surge Zones

3, and 4 hurricanes, which were then used with locality elevation data to delineate flood hazard areas. This output is the result of many different model runs, each representing a single hurricane track and wind speed, with the hazard areas representing a "maximum of the maximum," as if a given category of storm were striking the entire region all at once from every modeled angle. The model does not include precipitation, which can have a major impact on flooding. As such, these zones represent a so-called "worst case scenario" of wind-driven flooding only and are not useful for predicting the storm surge or flooding during a specific hurricane. However, the maps are useful for general planning purposes and vulnerability assessments such as this study (Federal Emergency Management Agency 2010). The elevation data used for delineation of flood hazard areas depended on the locality; several localities in Hampton Roads provided their own elevation data, while for the rest of the region the study used U.S. Geological Survey (USGS) topographic data from the National Elevation Dataset (NED). The NED topography used in the study was not as precise as the locality-provided data.

Since the goal of the Virginia Hurricane Evacuation Study was to identify vulnerable areas in coastal communities that would have to be evacuated during storm events, the Virginia Department of Emergency Management confined the study area to those communities that were deemed to be vulnerable to storm surge from hurricanes. Franklin, James City County, Southampton County, and Williamsburg were not included in the study area. Because of this, those four localities, while in the Hampton Roads Planning District, were not included in this analysis of storm surge vulnerability. While the datasets developed for the VHES appear to cover parts of those four localities that is most likely the result of slight differences in boundary files used for delineating the study area, and not an indication that those localities were partially studied. A future modeling of storm surge in Hampton Roads may include these localities. As high-resolution elevation data is not available for the entire Hampton Roads Planning District, storm surge zones are also used here as very rough approximations of areas vulnerable to sea level rise. An overlay analysis of Category 1 storm surge areas and available elevation data from the National Elevation Dataset shows that nearly all of the Category 1 storm surge area is lower than two meters above mean sea level. Based on historic trends, sea level rise in Hampton Roads would be between one and two feet by 2100. Incorporating higher rates of sea level rise due to global warming could result in more than five feet of sea level rise over the same time period (Pyke, et al. 2008). In this case, the land in Category 1 storm surge zones can be used as a proxy for areas that could be inundated due to sea level rise by 2100. An analysis using available elevation datasets will be included in the next phase of the project.

Population

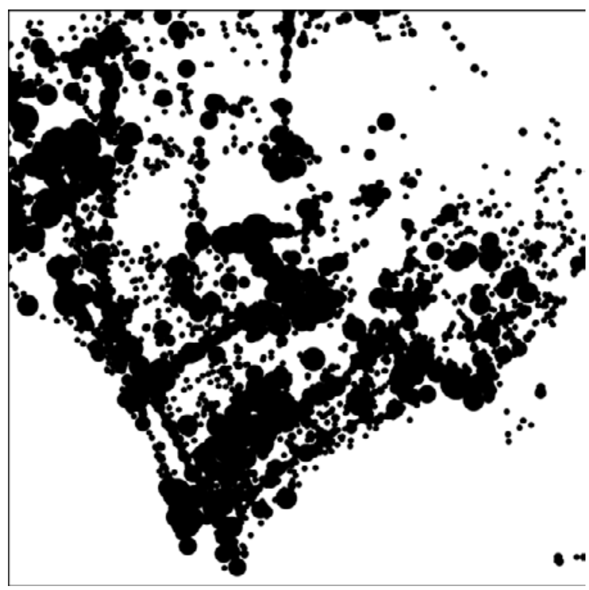
The population estimates for this analysis were developed using block-level data from the 2010 U.S. Census, using total population. The 2010 redistricting data distributed by the U.S. Census Bureau, upon which this analysis is based, contained a significant error in the City of Norfolk (Hoyer, Census error inflates count of Norfolk neighborhood 2011), where the population of one block, consisting of over 19,000 residents, was included in that of another block (Hoyer, Census Bureau admits goof in Norfolk population figures 2011). This error was corrected manually based on input from Norfolk city staff.[2] Census data is assigned to geographic areas, so populations are represented as groups living within a given area and not as individuals living at specific points.



Map 4: Example Census Blocks

Businesses

Business data, including locations, types, and numbers of employed, was obtained using ESRI's Business Analyst extension for the ArcGIS software suite (ESRI 2011). Each business is included in the dataset as a specific geographic location using longitude and latitude coordinates. Along with its location, the data includes such characteristics as the business name, address, and classification, using both the Standard Industrial Classification (SIC) and North American Industry Classification System (NAICS). For this analysis, the important information for each business was its location and number of employees.

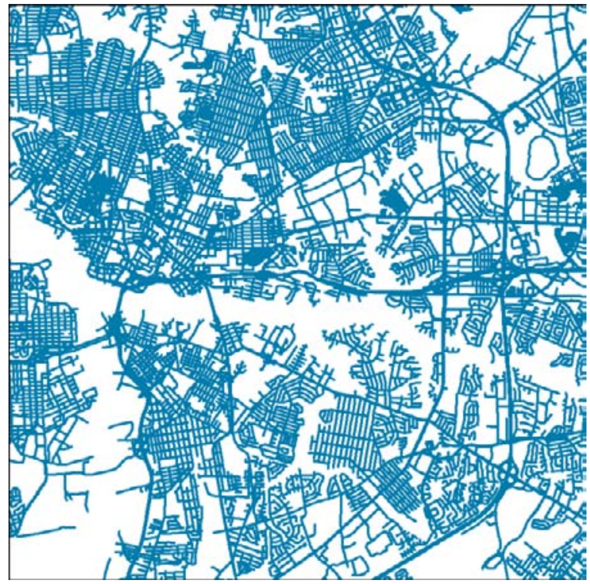


Map 5: Example Business Locations

[2] Specifically, the population of block 51710 0038.00 1000, in the West Ghent neighborhood, was reduced from 19,352 to 73, and the population of block 51710 0009.02 1044, within Norfolk Naval Base, was increased from 0 to 19,279. The technical documentation for this change from the Census Bureau is attached in Appendix A.

Roads

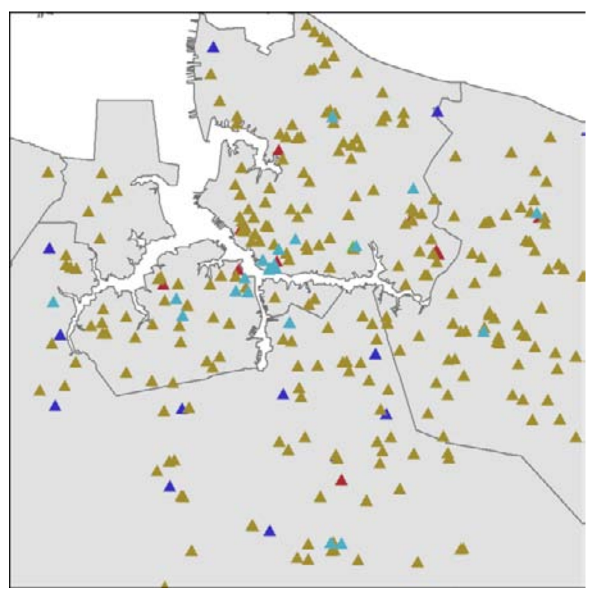
The roads dataset used in this analysis was the Virginia Geographic Information Network (VGIN) road centerline database, distributed in winter 2010, which includes addresses, road names, route numbers, classifications, and other information. The dataset is a "seamless digital road centerline file", jointly maintained by VGIN and localities (Virginia Information Technologies Agency 2007). This analysis required location, length, and classification (e.g. interstate, urban, collector, etc.) information. This analysis did not incorporate the number of lanes on a road, only its linear length. Additional information regarding this data was obtained from VGIN's Regional Road Centerline Supplemental Information Summer 2008 Release.



Map 6: Example Roads

Critical Infrastructure

Critical infrastructure data was obtained from the Federal Emergency Management Agency's (FEMA) Hazards U.S. Multi-Hazard (HAZUS-MH) software and data package. This software provides the methodology and data to "estimate potential losses from earthquakes, hurricane winds, and floods" (Federal Emergency Management Agency 2010). Storm surge is not yet included in the HAZUS-MH software, so only the critical infrastructure data was used. The critical infrastructure identified for this study included schools (including public and private schools as well as daycares and similar facilities), care



Map 7: Example Critical Infrastructure

facilities, emergency operations centers, police stations, and fire stations. The only information required for this analysis was the facility's type and its location. This data was obtained from the most recent software release, HAZUS-MH MR-5, which was released in December 2010.

Data Notes

Analyses are limited by the quality of the data and processing capacity available, which leads to results that are dependent on assumptions. In general, these limitations include the age of the datasets, incompleteness, inaccuracies, and imprecision. VDEM's storm surge zones are dependent on the SLOSH model, which is accurate within ± 20% of the stated water elevation; the zones also use various land elevations with different degrees of accuracy.[3] Population data from the Census is only given at the block level; the exact location of residents within the blocks is not released. Additionally, Census data is dependent on returns, so areas having low response rates affect the data's overall accuracy. The business data used in this analysis is similarly dependent on the various data collection methods used regarding where businesses are and how many people they employ. Employment numbers are not always disclosed for various reasons, such as national security. VGIN's road network data relies on localities to collect and report their data, so it is only as accurate as the original source data. In addition, this analysis assumes that all roads are at grade and does not account for raised highways or overpasses. FEMA's HAZUS data is similarly limited. Because of these limitations, the results of this analysis should be taken as estimates for general planning purposes and not as predictions of actual damages or population affected during storm events. The goal in this analysis is to provide a general idea of which areas in Hampton Roads are vulnerable to storm surge flooding and to assess the degree of vulnerability.

[3] Paul B. Moye (Norfolk District, USACE), e-mail, April27, 2010

METHODOLOGY

The general methodology used for this analysis was a spatial overlay, where one layer is used to extract a subset of another layer based on geographic overlap. The data from this subset is then aggregated. A separate analysis was conducted for each dataset (population, business, roads, and critical infrastructure); the specific steps used for each of these analyses depended on the type of data (line, polygon, point) and any other limiting characteristics. The analysis methodology is in part based on a generalized version of that found in the Coastal Inundation Mapping Guidebook (NOAA Coastal Services Center 2009), which prescribes four steps: obtaining and preparing elevation data, preparing water levels, mapping inundation, and visualizing inundation. This analysis uses storm surge zones generated by another study (the 2007 Virginia Hurricane Evacuation Study) which already used storm surge model results and elevation data to produce storm surge flooding maps. As mentioned previously, the areas vulnerable to Category 1 storm surges are also vulnerable to sea level rise. A future analysis will focus specifically on sea level rise instead of using storm surge zones to measure current vulnerability and as a proxy for future vulnerability. However, the analysis used here and for sea level rise in the next phase will follow the same four basic steps, described below.

Figure 8: Vulnerability Analysis Steps

Step 1: Identify Analysis Scenarios	The first step in this analysis is to define the scenarios by which to measure an area's vulnerability, such as an increment of sea level rise or a storm category. For this analysis, the scenarios selected were Category 1, 2, 3, and 4 hurricanes.
Step 2: Develop Vulnerability Areas	Once the scenarios are identified, the areas affected must be identified, either using a storm model like SLOSH or using elevation data and water levels.
Step 3: Identify Assets to Analyze	The next step is to select which assets or other indicators, such as infrastructure or land use, need to be analyzed. For this analysis, four asset groups were selected: population, businesses, roads, and critical facilities.
Step 4: Overlay Assets on Vulnerability Areas	Once assets are identified, they are overlaid on the vulnerable areas for each scenario using GIS.
Step 5: Extract Vulnerable Assets	Using GIS, those assets lying within vulnerable areas are extracted from their original datasets, creating a new dataset containing only those assets within each vulnerable area.
Step 6: Aggregate Vulnerable Asset totals by scenario and locality	The new datasets from Step 5 are analyzed as tables and aggregated, either within the GIS program or using a program such as Microsoft Excel.

Each of the asset datasets used contained different attributes to be counted as well as different properties that needed to be accounted for during the analysis. Those steps are described below. A more technical description of the processes used is attached in Appendix B.

Population

Population data was acquired from the U.S. Census in two parts, a boundary file and a separate database of demographic data. Attaching the demographic data to the boundary file for analysis required exporting a table from the database containing the required data, which in this case was the total population and unique identifier of each block. Once the data was in a usable form it was clipped using the VHES storm surge data, with one clip for each storm surge category. The results from the clip were compared to the total area of each block to calculate a ratio of storm surge area to total area for each storm category. These ratios were applied to the total population of each block to calculate the number of vulnerable residents in each block for each storm category. Since block-level population counts were the best population data available, the analysis of vulnerable population relied on an assumption of uniform distribution throughout each block. Since population distribution varies considerably among blocks, the results should be taken as a rough estimate only and not as a precise count. The areas calculated for the population analysis were also summed and converted to square miles to calculate total areas in each locality within each storm surge zone.

Businesses

Business data was obtained as a set of points representing individual business locations. The required information from the complete dataset included its location and number of employees. The business layer was spatially joined to a locality boundary layer to give each business a county/city identifier. The data layer was overlaid on top of the storm surge layer and spatially joined with the storm surge layer to categorize each business by the storm surge zone in which it was located.

Roads

VDOT's road centerline database was used as the base data for this layer. Roads were categorized as interstate, primary, secondary, urban, and other using VDOT's classification system. The database was split using county and city boundaries, with the resulting layers merged back together. This merged layer was then spatially joined with the locality boundary layer to give each road segment a county/city identifier. The data layer was overlaid on top of the storm surge layer and clipped to create a separate layer representing the roads in each of the four storm surge areas. The length of each segment in each of the road/storm surge layers was calculated in miles. Multiple lanes are not accounted for in these calculations.

Critical Infrastructure

Critical infrastructure facilities data was obtained from FEMA's HAZUS-MH software, and included five categories: care facilities, emergency operations centers, fire stations, police stations, and schools. These individual layers were merged into a single dataset and then spatially joined with the locality boundary layer to give each facility a county/city identifier. The resulting data layer was overlaid on top of the storm surge layer and spatially joined with the storm surge layer to categorize each facility by the storm surge zone in which it was located.

Once the individual data layers were processed using geographic information systems (GIS) software, they were exported as tables. Spreadsheets used to sort and aggregate the data using pivot tables to categorize each dataset by locality. Totals for each dataset were made for each locality for each storm surge category. The totals were then aggregated by region and sub-region to create overall totals for Hampton Roads, the Peninsula, and Southside Hampton Roads. In addition to the data summaries, maps were created for each locality showing storm surge areas, vulnerable critical infrastructure and roads, and vulnerable businesses.

RESULTS

The results of the Hampton Roads vulnerability analysis are presented in table and map form, as individual localities and as three multi-locality areas. Due to the lack of storm surge data for four localities from the VHES, the Hampton Roads regional totals only reflect twelve member localities of the HRPDC: Chesapeake, Gloucester County, Hampton, Isle of Wight County, Newport News, Norfolk, Poquoson, Portsmouth, Suffolk, Surry County, Virginia Beach, and York County. The Peninsula sub-regional total includes Gloucester County, Hampton, Newport News, Poquoson, and York County. The Southside Hampton Roads sub-regional total includes Chesapeake, Isle of Wight County, Norfolk, Portsmouth, Suffolk, Surry County, and Virginia Beach.

The results of this analysis should be seen as estimates of exposure and not predictions of specific storms or future events. The results can provide a rough idea of which localities in the region are more or less vulnerable to storm surge and sea level rise. In general, the results support the observation that Hampton Roads is highly exposed to storm surges, with considerable numbers of population and assets in low-lying, vulnerable areas. However, the Peninsula and Southside are not equally vulnerable. While they are similarly exposed during Category 1 and 2 storm events, Category 3 and 4 events have potentially much greater impacts on the Southside, due to its large area of low-lying topography. Several localities on both sides of the James River are particularly vulnerable, with large majorities of Chesapeake, Hampton, Norfolk, Poquoson, Portsmouth, and Virginia Beach potentially flooded during higher category storms. It is important to note, however, that actual flooding during storms depends on a number of factors in addition to wind speed, including storm size, wind patterns, a storm's angle of approach, as well as daily, monthly, and yearly tide cycles. Actual flooding during storm events depends on the observed "storm tide," which is the combination of storm surge and atmospheric tides (J. Boon 2003). The results from this analysis should be interpreted only as general estimates of which areas in the region are vulnerable and how exposed they are to flooding during storms.

Population

This analysis shows that most of the region's population lives in areas that are exposed to some degree of storm surge. The estimates range from over one hundred thousand (100,000) people living in Category 1 storm surge areas to over one million (1,000,000) living in Category 4 storm surge areas. Even given the assumptions made regarding population distribution, a significant number of residents are vulnerable to temporary disruptions due to storm flooding. In addition, many of these residents are also vulnerable to the long-term impacts of sea level rise. While both subregions are similarly vulnerable in terms of population to lower category storms (approximately 40,000 for the Peninsula and nearly 70,000 for the Southside), Southside Hampton Roads has nearly four times as many residents living in Category 4 areas as the Peninsula. The most exposed individual localities in terms of absolute numbers living in Category 1 storm surge areas are Chesapeake, Hampton, Norfolk, and Virginia Beach. In terms of the share of the population affected, the most exposed localities are Gloucester County, Hampton, and Poquoson. A more detailed analysis incorporating storm probabilities and vulnerable populations could identify neighborhoods or areas that are particularly at risk.

Built Environment

The region also has a large amount of infrastructure vulnerable to temporary flooding or permanent inundation due to sea level rise. Across the region, nearly five hundred linear miles of roads are in Category 1 storm surge areas, while over five thousand linear miles of roads are in Category 4 storm surge areas. Most of the vulnerable roadways are considered urban roads. Localities with particularly high levels of roadways vulnerable to Category 1 storm surges include Gloucester County, Hampton, Norfolk, and Virginia Beach. Additional infrastructure that could be analyzed to give a more complete assessment of vulnerability could include stormwater improvements and other transportation infrastructure.

Critical Infrastructure

A significant number of critical infrastructure facilities, defined as care facilities, emergency operations centers, fire stations, police stations, and schools, are located in areas vulnerable to storm surge. Most of the vulnerable facilities are schools; this holds true for both the Peninsula and Southside and for each category of storm surge. Localities with large numbers of critical facilities in vulnerable areas include Chesapeake, Hampton, Norfolk, Portsmouth, and Virginia Beach. Verifying the HAZUS-MH data and incorporating other regional critical infrastructure datasets would add to the utility of this analysis.

Economy

Economic impacts from flooding and sea level rise are indicated by the number of businesses within each storm surge zone and the total number of employees working in each storm surge zone. The results indicate that a significant number of businesses and employees are affected by even a

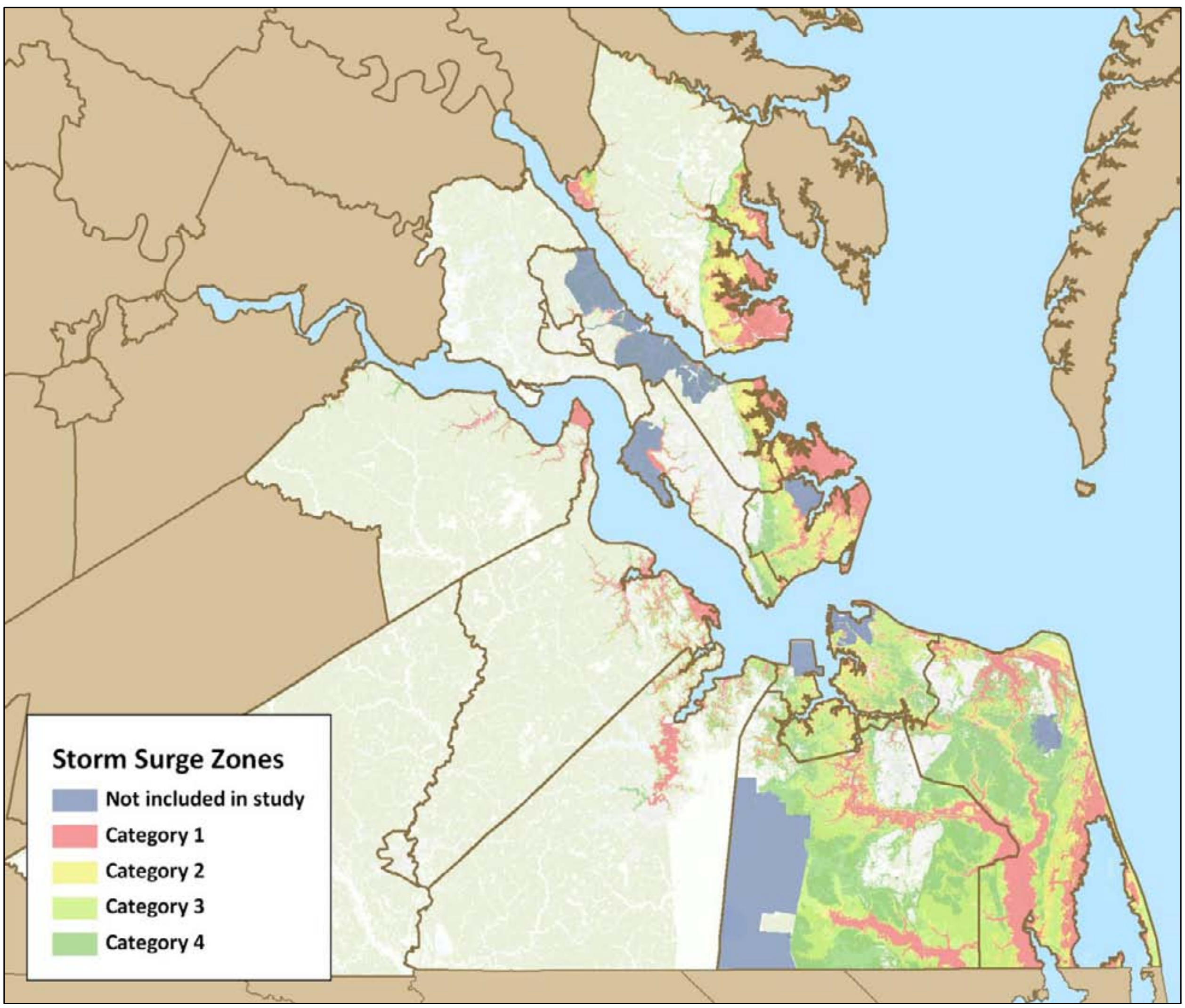
Category 1 storm surge, and that a large storm could be significantly more damaging. The Southside has over double the number of businesses located in Category 1 storm surge areas than the Peninsula, and nearly five times as many in Category 4 storm surge areas. The large number of businesses and employees working in Category 1 zones indicate that a significant amount of economic activity will have to shift around the region to cope with sea level rise by the end of the century. Localities that have a large number of businesses and employees vulnerable to storm surge include Chesapeake, Gloucester County, Hampton, Norfolk, Poquoson, Portsmouth, Virginia Beach, and York County.

Maps and Data

Maps and data tables for Hampton Roads, the Peninsula, Southside Hampton Roads, and each of the included localities are below. Twelve localities are included: Chesapeake, Gloucester County, Hampton, Isle of Wight County, Newport News, Norfolk, Poquoson, Portsmouth, Surry County, Suffolk, Virginia Beach, and York County. For each locality there is a table containing numerical data and three maps. The first map shows the storm surge zones for that locality. The second map shows roads and critical facilities located in these storm surge zones. The third map shows businesses (with symbols sized according to their number of employees) in those storm surge zones. Only critical facilities and businesses that are inside storm surge zones are shown on these maps.

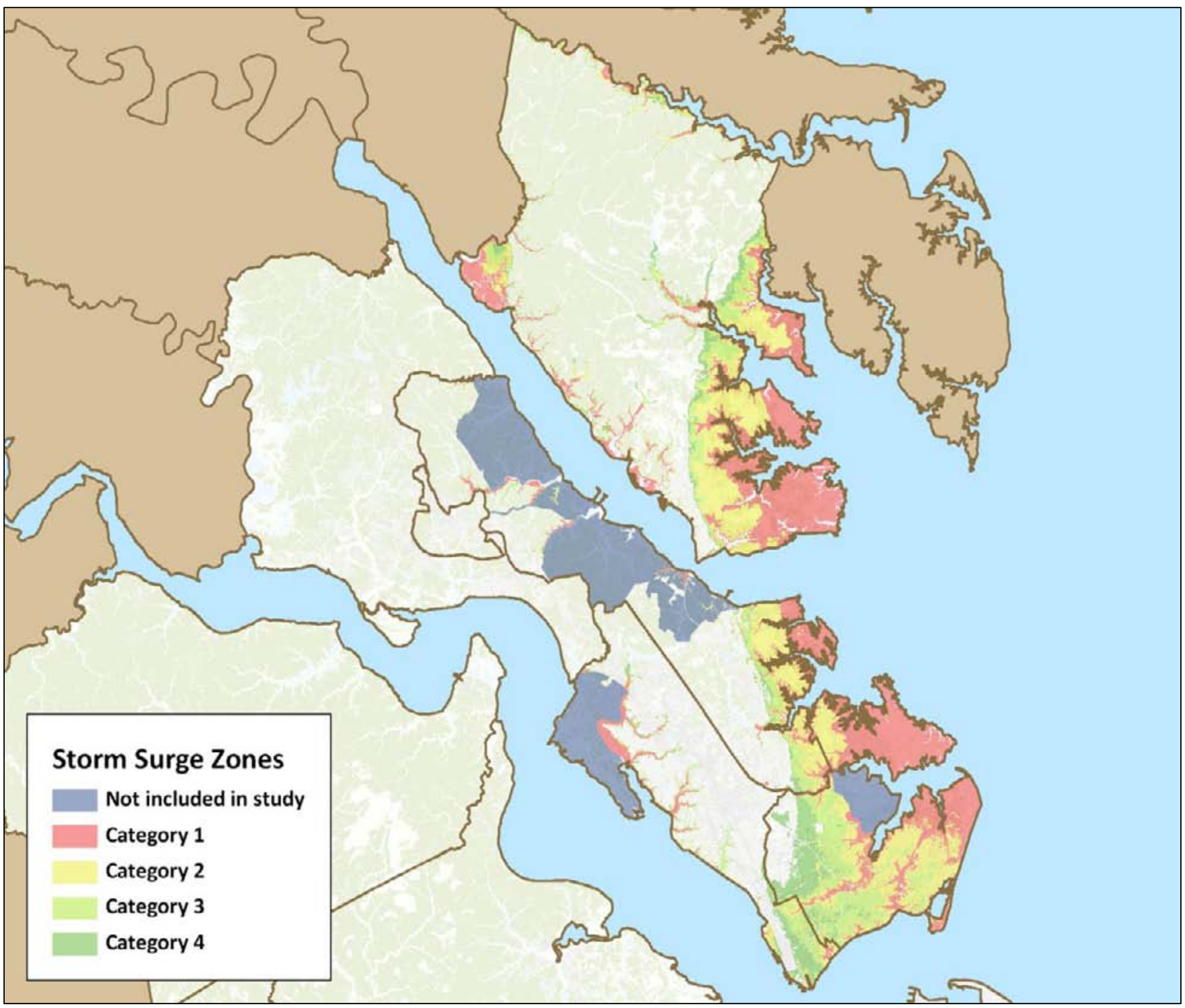
Disclaimer: These maps are designed to promote discussion and for use as general long-range planning tools, with the caveats mentioned in this report. They are not designed to be used for specific planning decisions, site planning, or emergency response. These maps are not intended to be used in making evacuation decisions. During actual storm events, residents should follow instructions from local and state emergency management officials.

Hampton Roads, VA Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	266.72	391.59	585.39	788.90
Population	109,636	322,099	652,319	1,003,617
Businesses	1,650	8,524	19,480	30,972
# of Employees	27,732	126,967	257,207	396,296
Total Roads (linear miles)	473.59	1,702.17	3,492.23	5,159.97
Interstate	6.27	13.83	33.64	62.55
Primary	39.77	149.73	352.39	527.31
Secondary	73.01	170.09	203.62	223.78
Urban	277.06	1,176.71	2,569.07	3,869.49
Other	77.48	191.81	333.51	476.84
Total Critical Infrastructure	24	111	253	390
Care Facilities	0	4	7	9
Emergency Operations Centers	0	1	1	2
Fire Stations	5	10	15	20
Police Stations	2	14	23	36
Schools	17	82	207	323



Map 8: Hampton Roads Storm Surge Inundation Areas

Peninsula Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	77.03	124.43	149.52	166.70
Population	40,976	116,542	169,073	207,267
Businesses	534	2,292	4,192	5,340
# of Employees	5,802	22,937	47,795	58,960
Total Roads (linear miles)	266.66	728.08	1,021.32	1,197.27
Interstate	1.16	5.54	10.38	16.70
Primary	11.94	47.37	86.17	106.23
Secondary	69.56	164.69	196.71	208.49
Urban	127.22	400.02	586.22	707.99
Other	56.78	110.47	141.84	157.86
Total Critical Infrastructure	15	47	74	88
Care Facilities	0	0	1	1
Emergency Operations Centers	0	1	1	1
Fire Stations	4	4	4	4
Police Stations	1	3	5	5
Schools	10	39	63	77



Map 9: Peninsula Storm Surge Inundation Areas

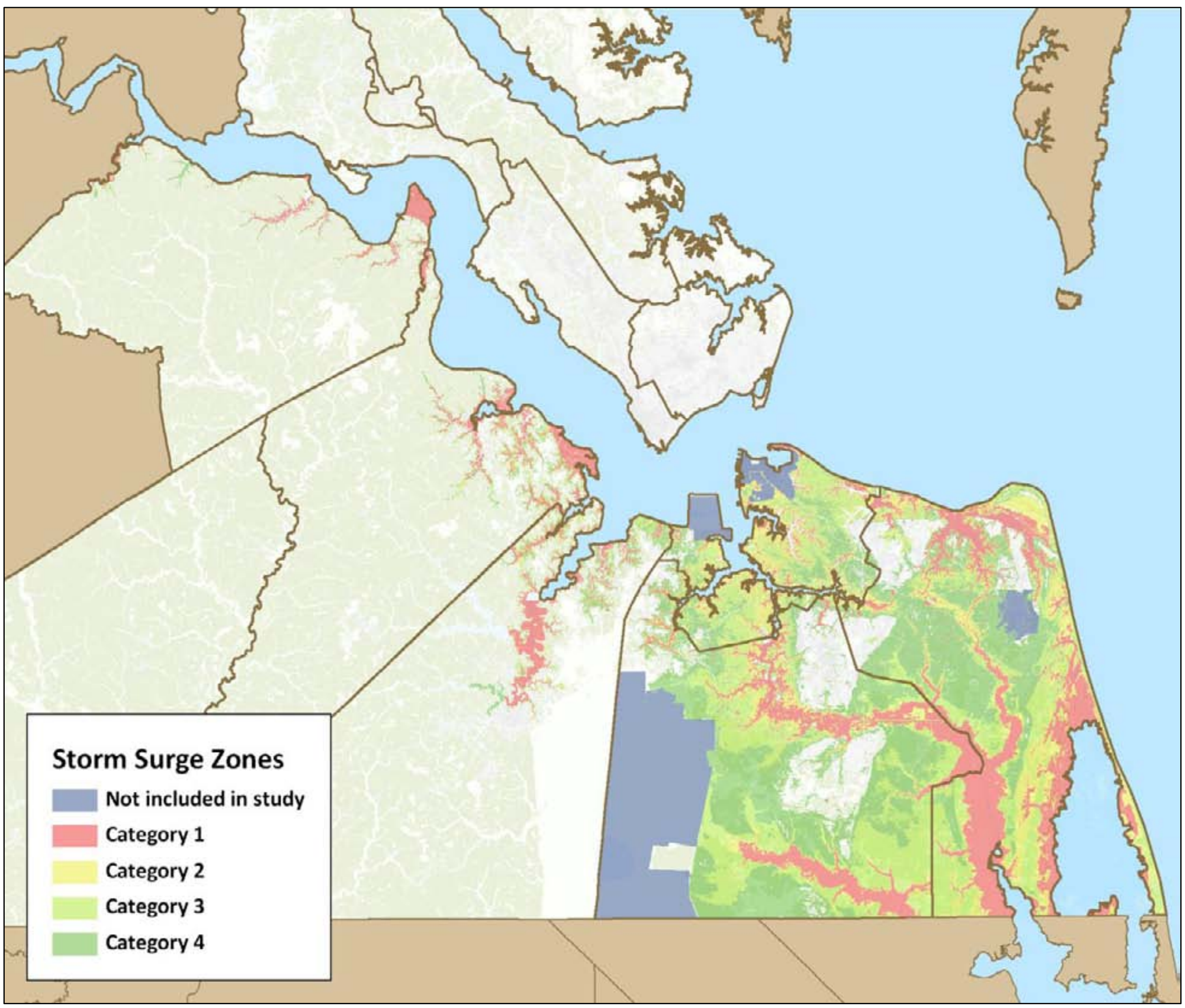
Southside Hampton Roads Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	189.70	267.17	435.87	622.20

Population	68,660	205,557	483,246	796,350

Businesses	1,116	6,232	15,288	25,632
# of Employees	21,930	104,030	209,412	337,336

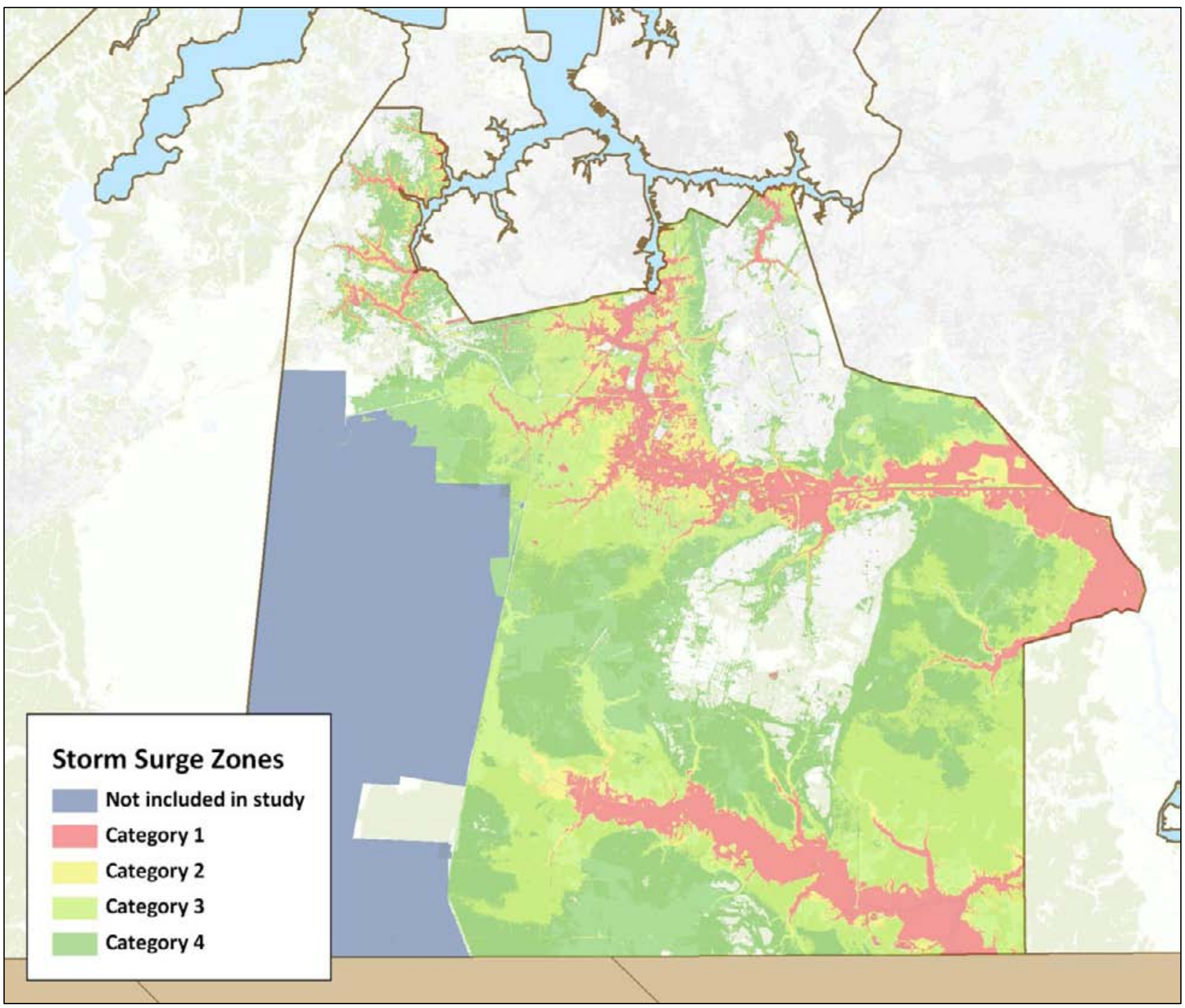
Total Roads (linear miles)	206.93	974.09	2,470.91	3,962.70
Interstate	5.11	8.29	23.26	45.85
Primary	27.83	102.37	266.22	421.08
Secondary	3.45	5.40	6.91	15.28
Urban	149.84	776.69	1,982.85	3,161.50
Other	20.70	81.34	191.67	318.98

Total Critical Infrastructure	9	64	179	302
Care Facilities	0	4	6	8
Emergency Operations Centers	0	0	0	1
Fire Stations	1	6	11	16
Police Stations	1	11	18	31
Schools	7	43	144	246

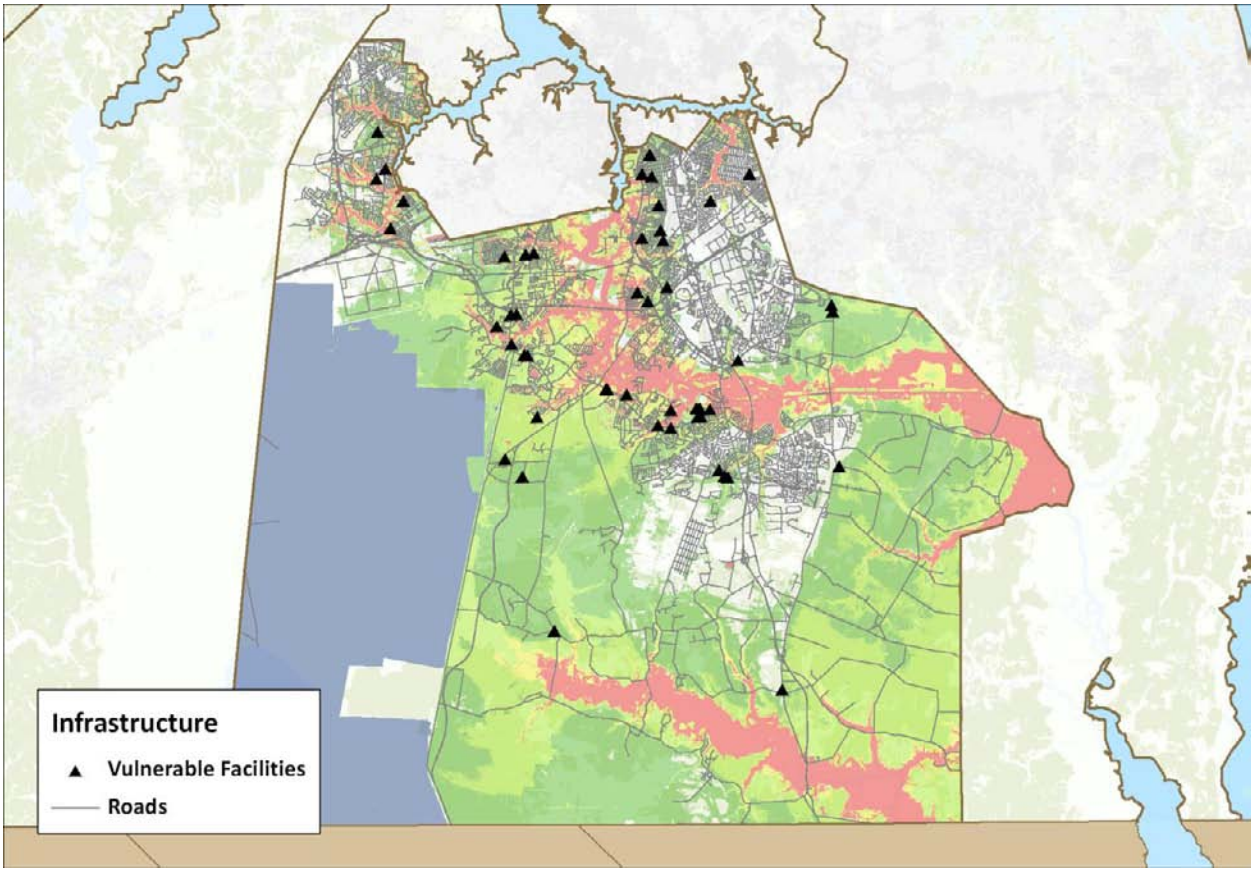


Map 10: Southside Hampton Roads Storm Surge Inundation Areas

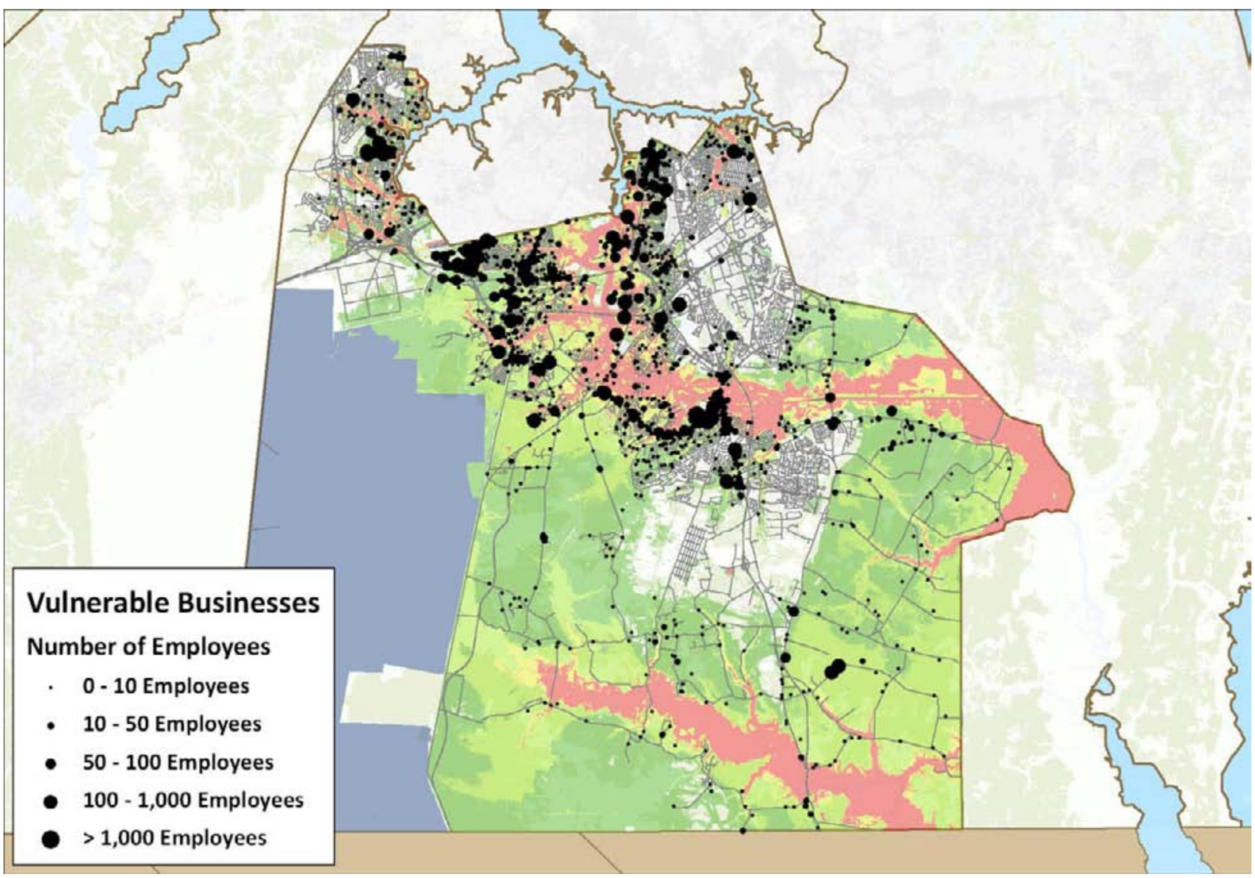
Chesapeake, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	35.71	52.32	125.14	216.41
Population	14,148	31,359	79,556	131,588
Businesses	221	604	1,778	3,373
# of Employees	3,277	7,869	19,998	36,380
Total Roads (linear miles)	33.71	131.80	441.04	810.17
Interstate	1.94	2.25	7.67	14.15
Primary	5.93	17.57	60.23	115.04
Secondary	0.00	0.00	0.00	0.00
Urban	23.96	104.57	352.67	641.09
Other	1.88	7.42	20.47	39.89
Total Critical Infrastructure	3	8	30	50
Care Facilities	0	0	0	0
Emergency Operations Centers	0	0	0	0
Fire Stations	0	2	6	10
Police Stations	1	1	3	5
Schools	2	5	21	35



Map 11: Chesapeake, Virginia Storm Surge Inundation Areas

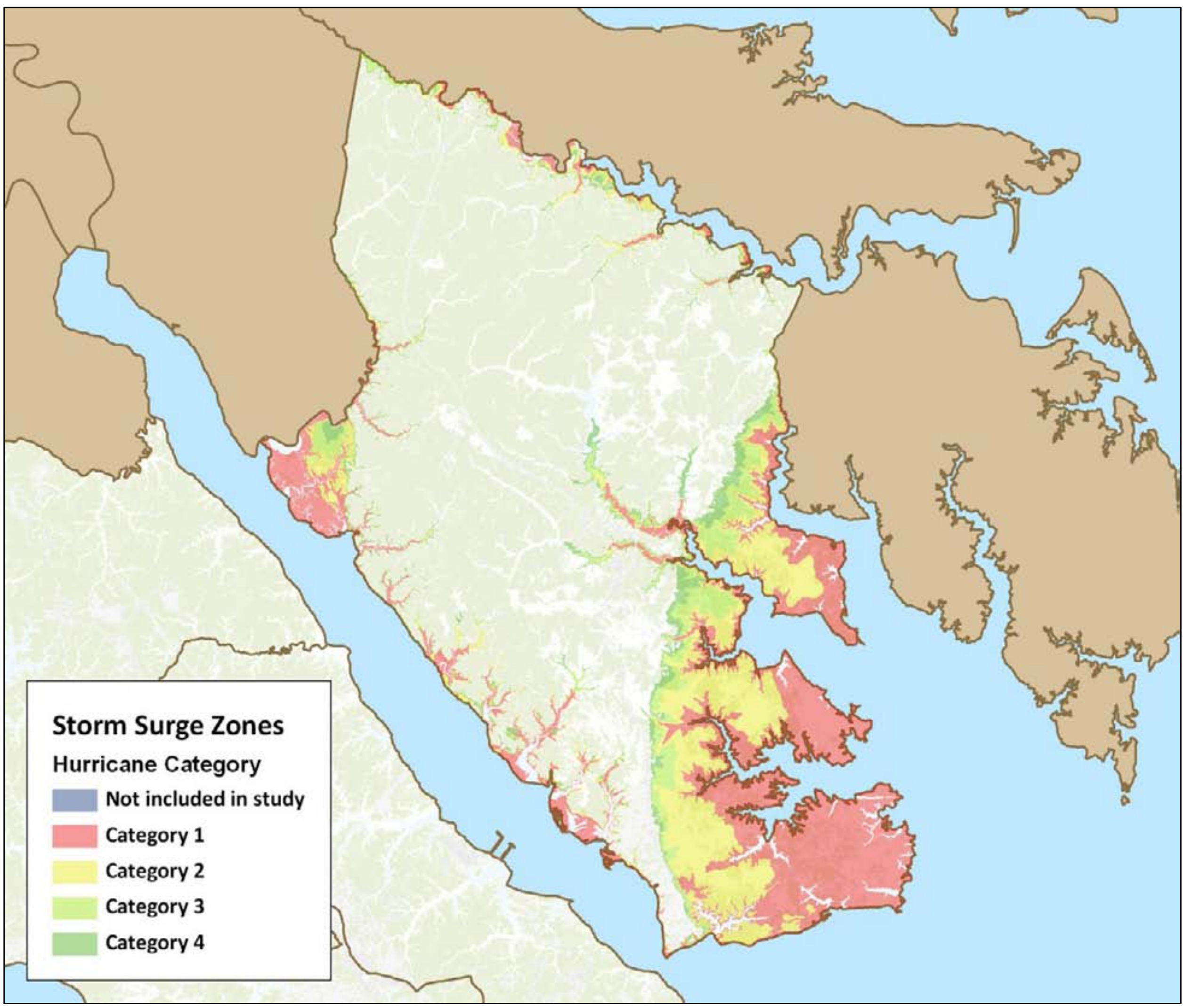


Map 12: Roads and Critical Infrastructure Vulnerable to Storm Surge in Chesapeake, Virginia

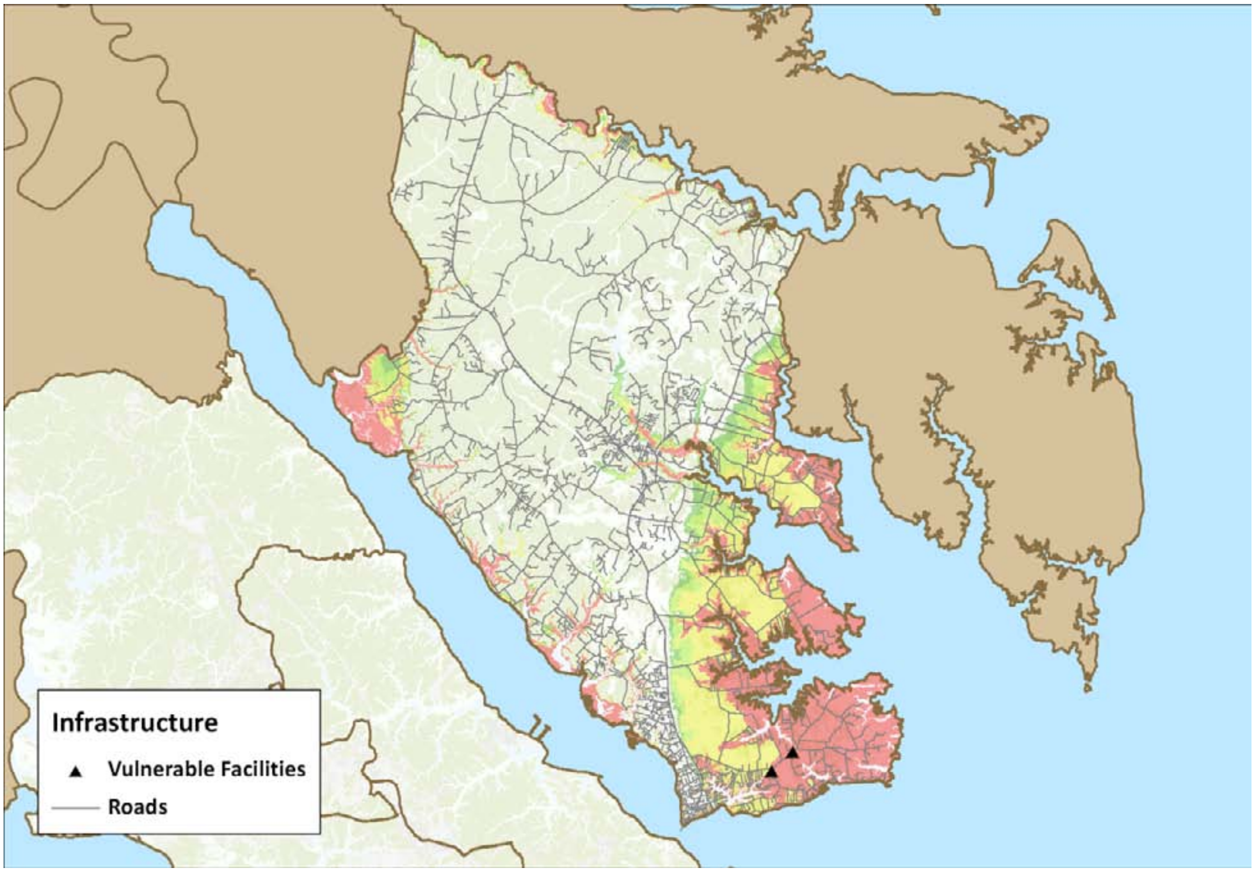


Map 13: Businesses Vulnerable to Storm Surge in Chesapeake, Virginia

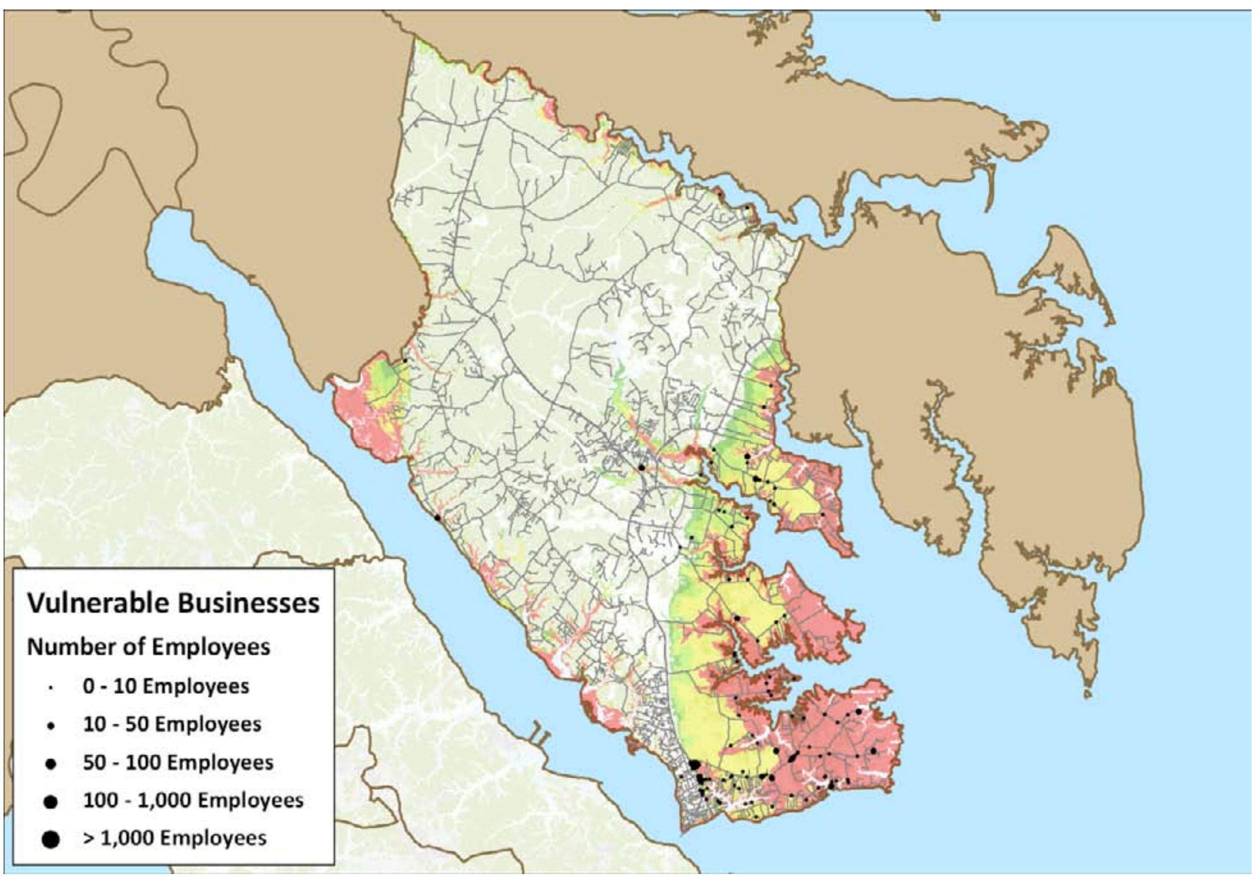
Gloucester County, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	34.95	56.71	64.23	69.94
Population	4,645	8,132	9,181	10,119
Businesses	80	136	172	183
# of Employees	517	689	899	937
Total Roads (linear miles)	88.90	167.57	191.08	203.89
Interstate	0.00	0.00	0.00	0.00
Primary	1.08	4.21	6.38	7.54
Secondary	42.10	88.11	100.70	107.55
Urban	0.11	0.14	0.14	0.14
Other	45.62	75.11	83.85	88.66
Total Critical Infrastructure	2	2	2	2
Care Facilities	0	0	0	0
Emergency Operations Centers	0	0	0	0
Fire Stations	1	1	1	1
Police Stations	0	0	0	0
Schools	1	1	1	1



Map 14: Gloucester County, Virginia Storm Surge Inundation Areas

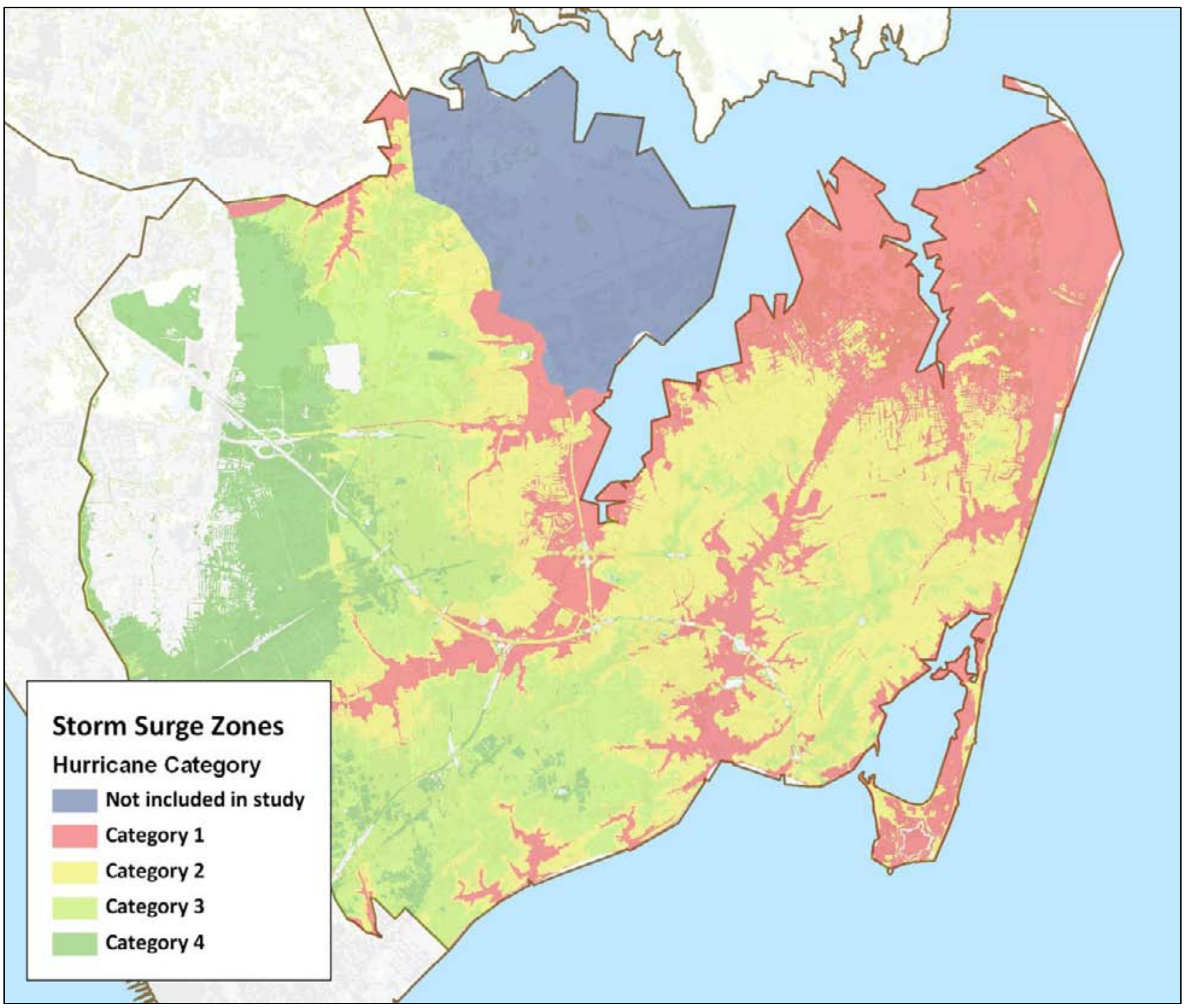


Map 15: Roads and Critical Infrastructure Vulnerable to Storm Surge in Gloucester County, Virginia

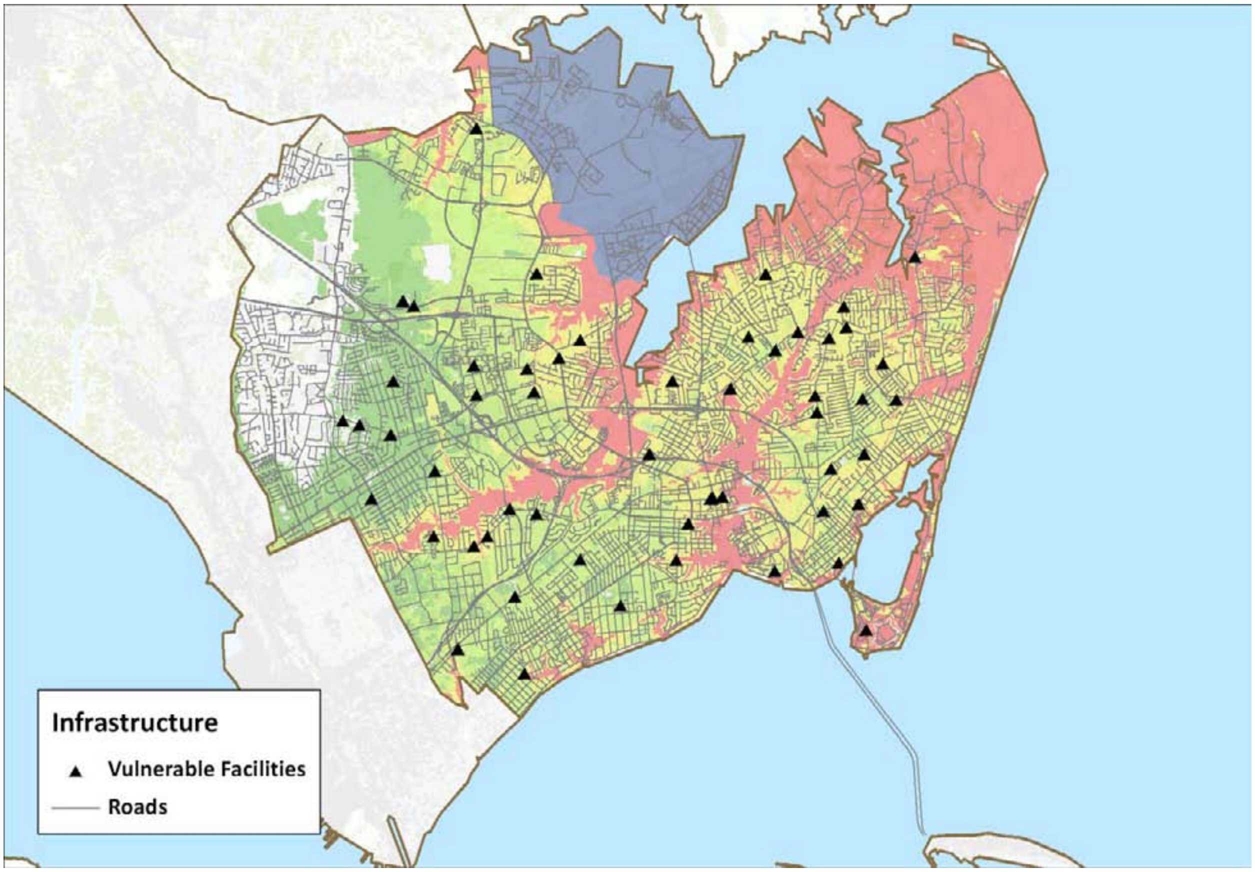


Map 16: Businesses Vulnerable to Storm Surge in Gloucester County, Virginia

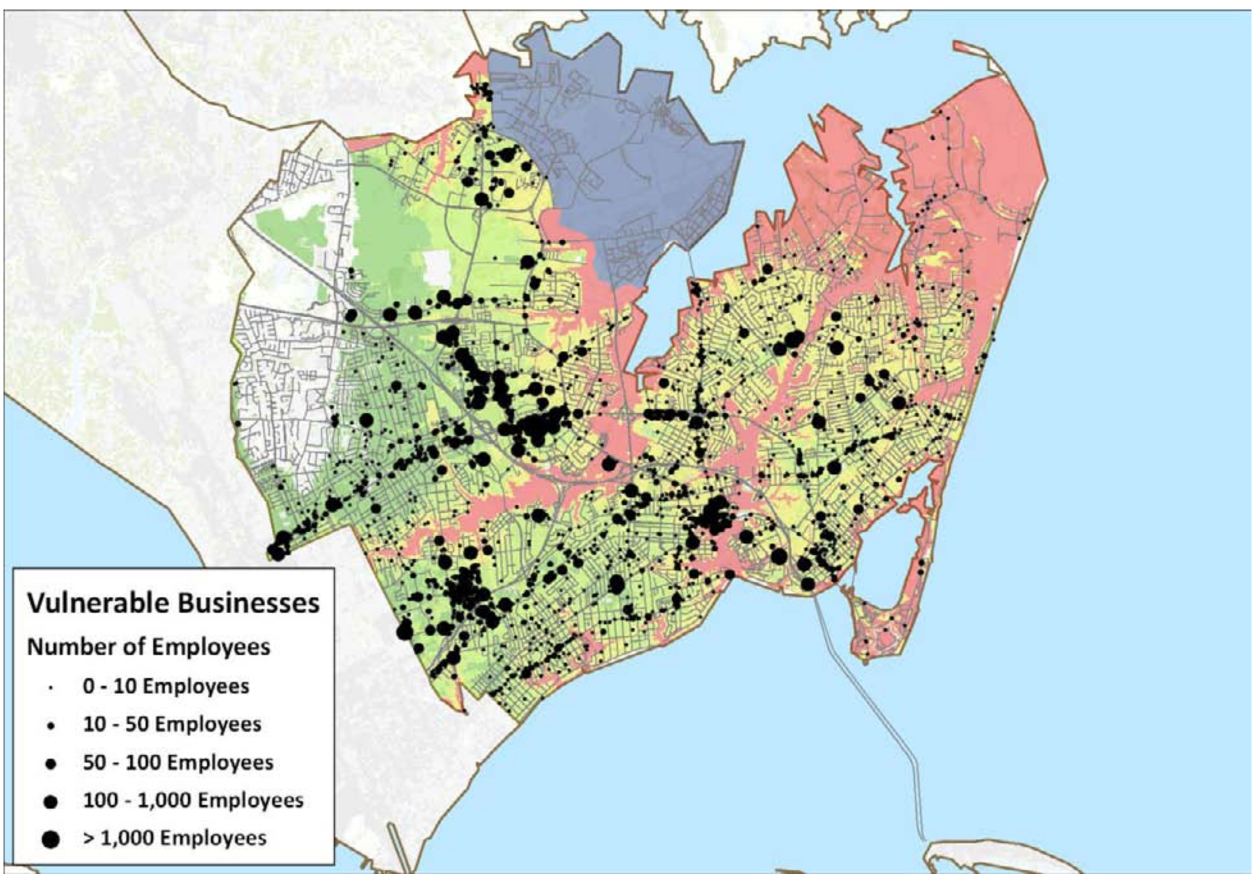
Hampton, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	14.56	27.76	38.68	45.09
Population	17,880	70,534	104,864	123,643
Businesses	239	1,523	3,083	3,812
# of Employees	3,290	17,364	39,559	47,195
Total Roads (linear miles)	94.86	358.76	555.14	650.54
Interstate	0.15	4.28	7.78	12.25
Primary	4.41	29.14	59.47	70.20
Secondary	0.00	0.00	0.00	0.05
Urban	86.11	304.26	446.15	518.23
Other	4.19	21.09	41.74	49.80
Total Critical Infrastructure	5	33	53	60
Care Facilities	0	0	0	0
Emergency Operations Centers	0	1	1	1
Fire Stations	2	2	2	2
Police Stations	0	2	3	3
Schools	3	28	47	54



Map 17: Hampton, Virginia Storm Surge Inundation Areas

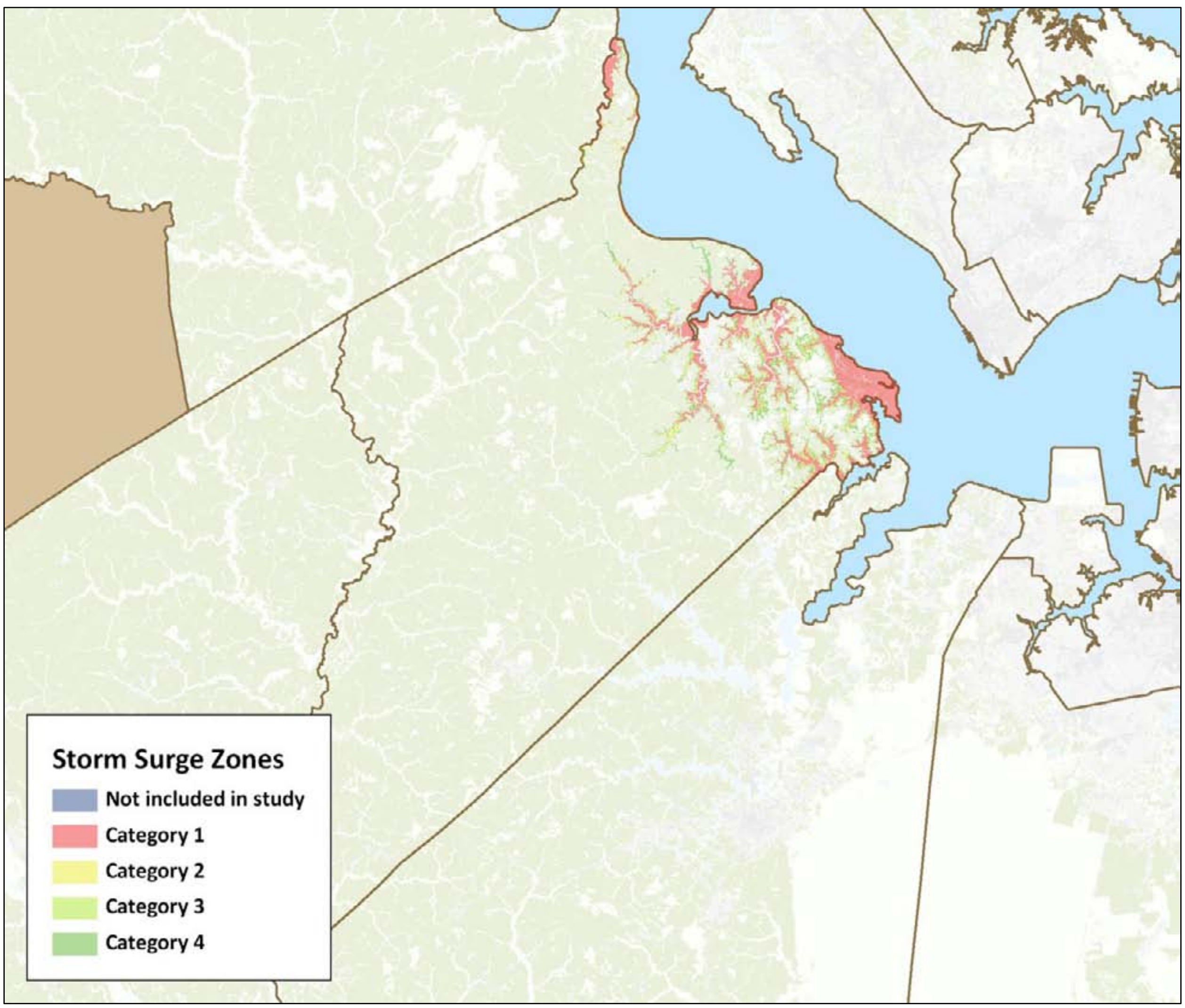


Map 18: Roads and Critical Infrastructure Vulnerable to Storm Surge in Hampton, Virginia

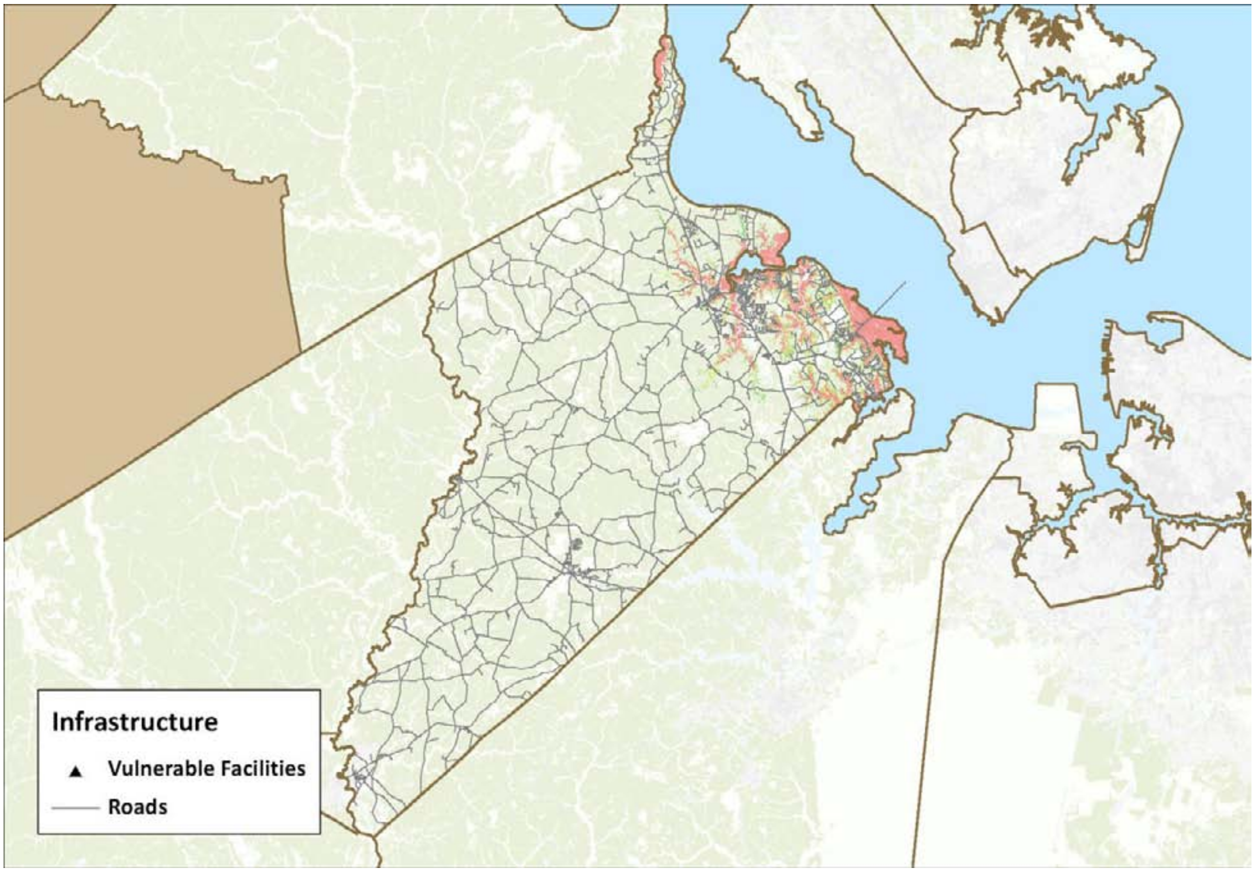


Map 19: Businesses Vulnerable to Storm Surge in Hampton, Virginia

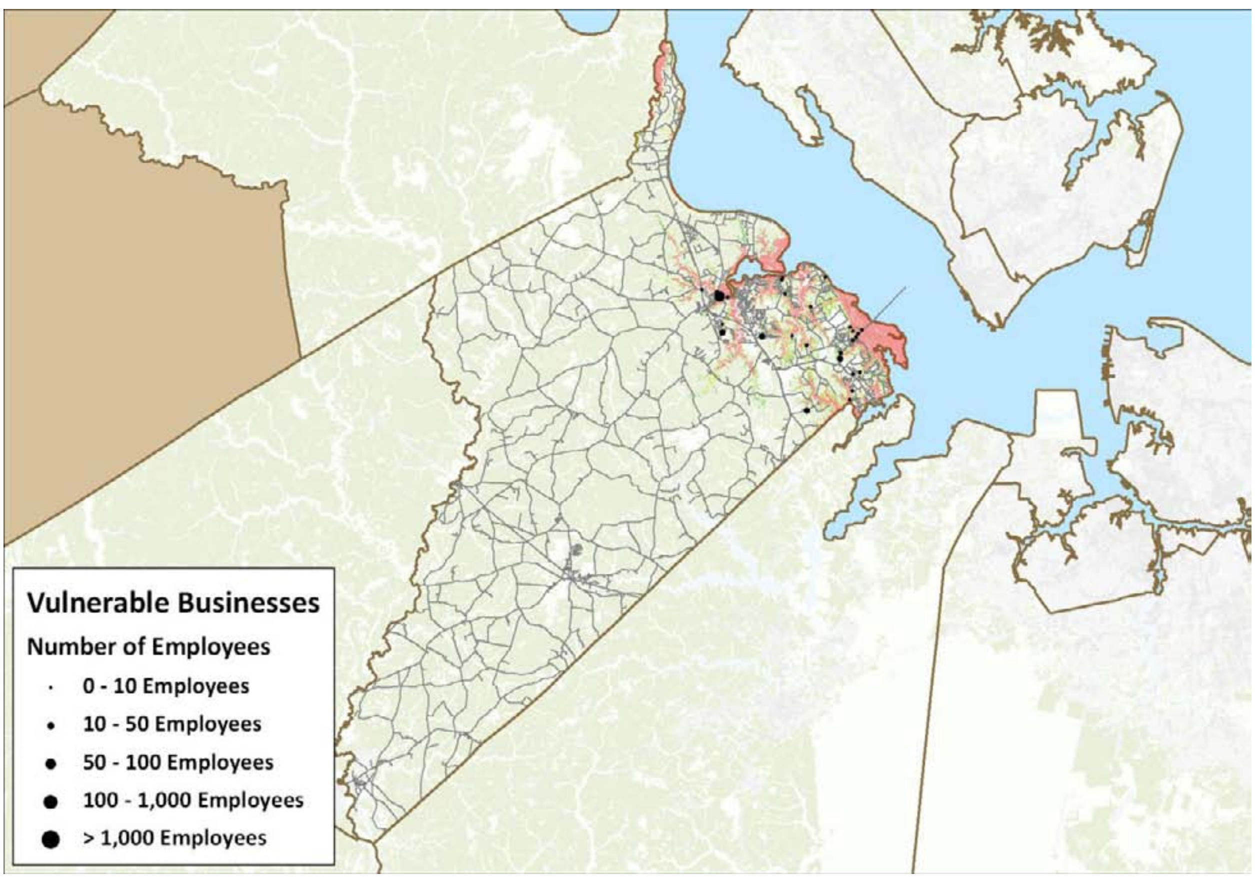
Isle of Wight County, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	12.03	14.93	16.18	21.18
Population	2,802	3,765	4,334	6,042
Businesses	15	21	44	69
# of Employees	163	176	218	382
Total Roads (linear miles)	5.90	9.77	14.52	30.27
Interstate	0.00	0.00	0.00	0.00
Primary	2.82	3.22	3.95	5.70
Secondary	1.28	2.84	4.10	9.92
Urban	0.60	1.10	1.55	3.17
Other	1.21	2.61	4.93	11.48
Total Critical Infrastructure	0	0	0	0
Care Facilities	0	0	0	0
Emergency Operations Centers	0	0	0	0
Fire Stations	0	0	0	0
Police Stations	0	0	0	0
Schools	0	0	0	0



Map 20: Isle of Wight County, Virginia Storm Surge Inundation Areas

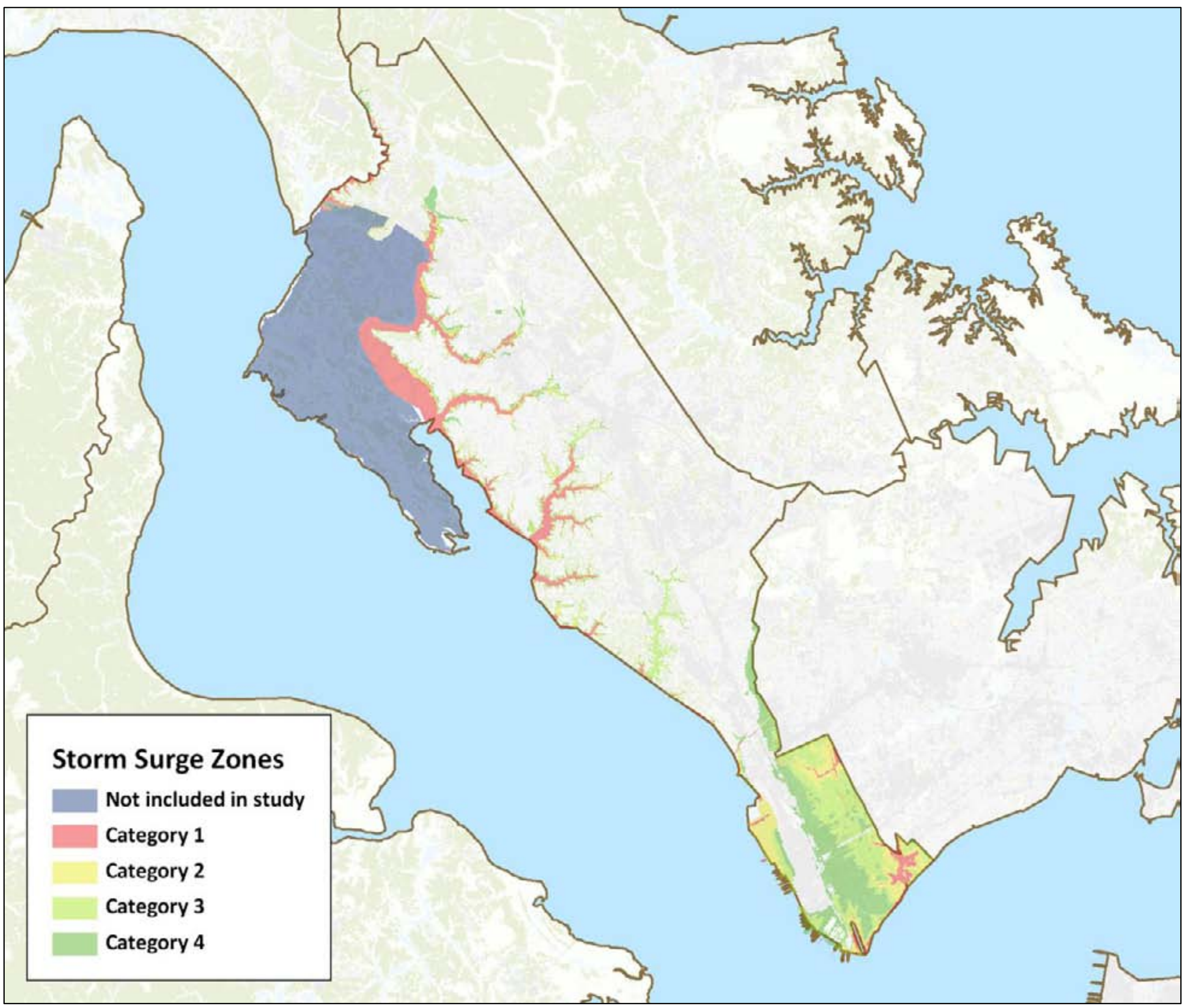


Map 21: Roads and Critical Infrastructure Vulnerable to Storm Surge in Isle of Wight County, Virginia

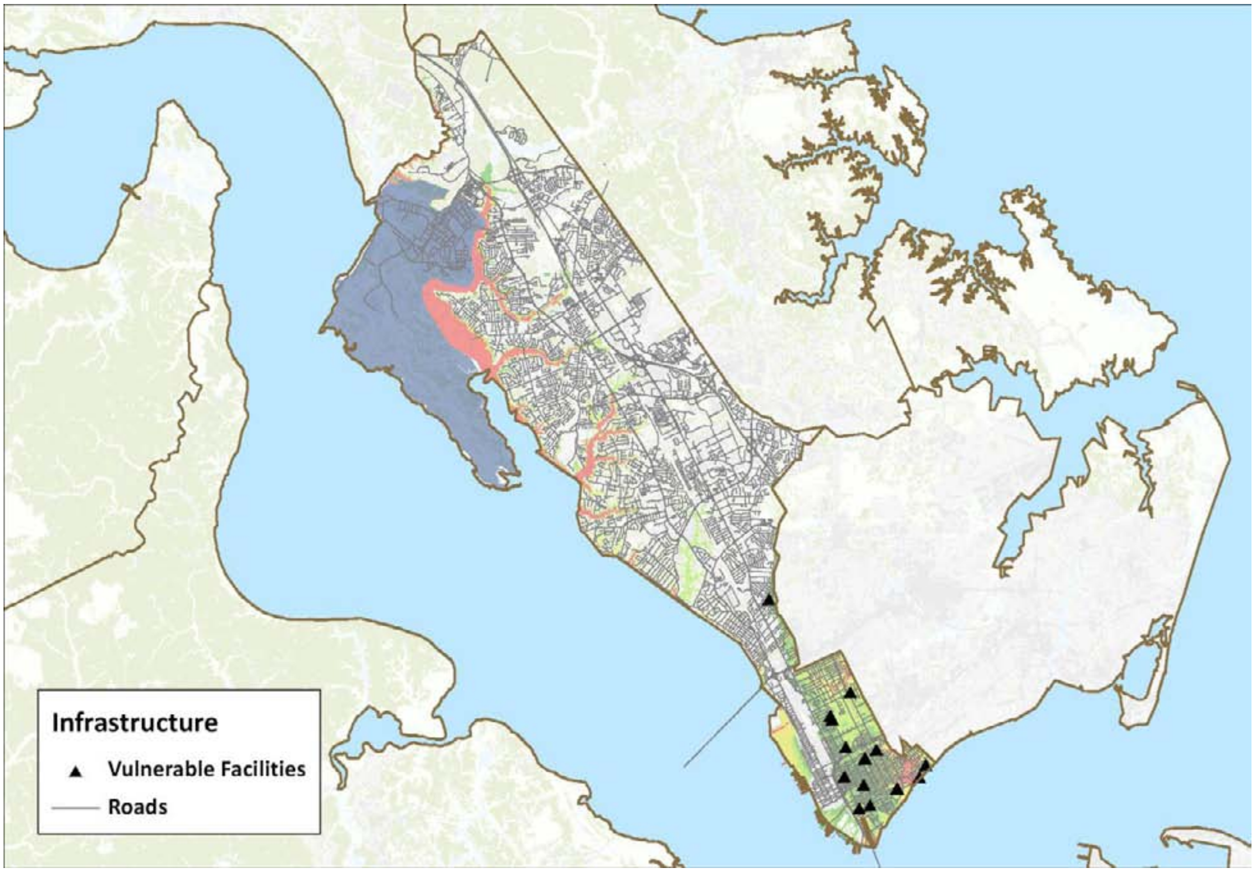


Map 22: Businesses Vulnerable to Storm Surge in Isle of Wight County, Virginia

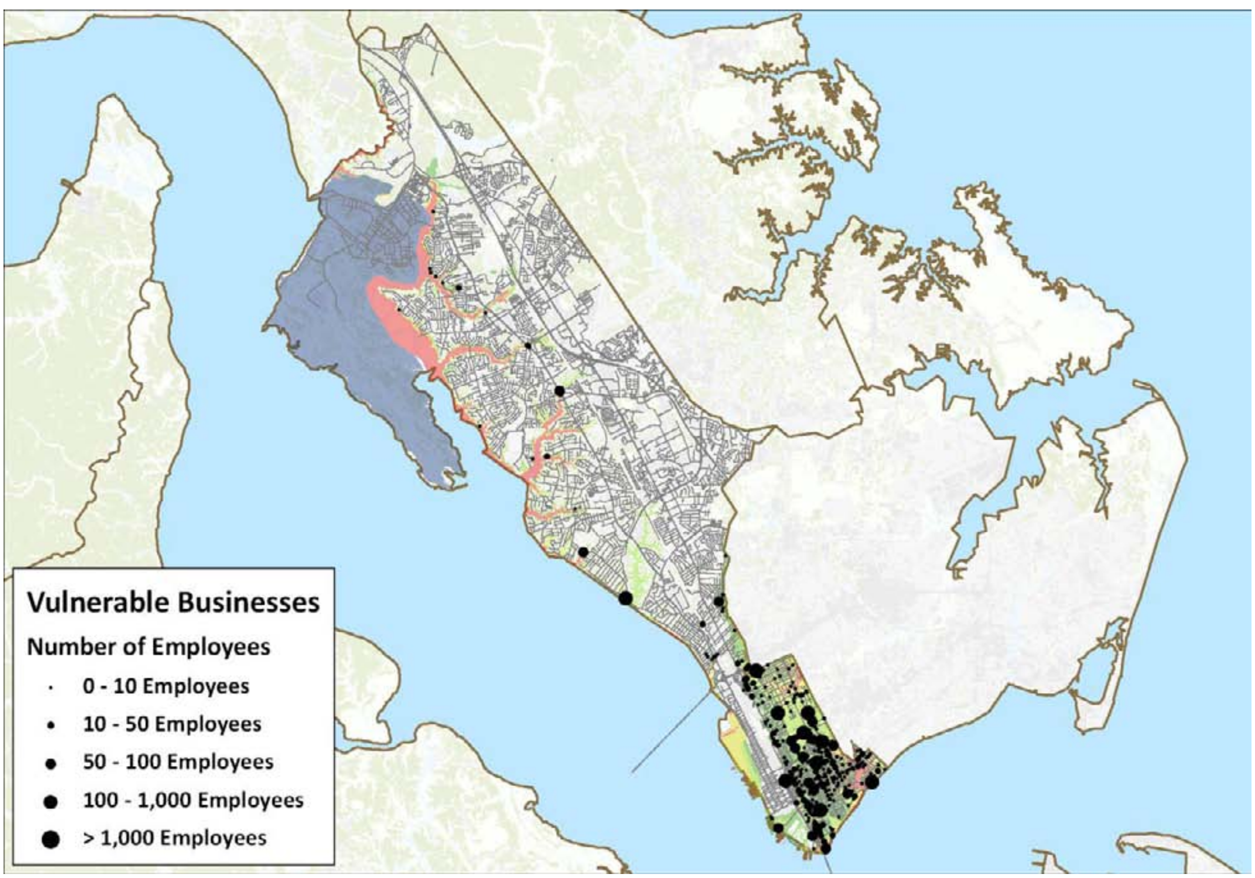
Newport News, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	5.78	7.72	10.92	14.55
Population	4,976	11,189	22,557	37,482
Businesses	18	105	333	720
# of Employees	258	1,211	3,176	6,567
Total Roads (linear miles)	6.67	30.30	71.08	125.63
Interstate	0.95	1.16	2.36	3.86
Primary	0.88	2.64	5.56	11.90
Secondary	0.00	0.00	0.00	0.00
Urban	4.37	25.03	60.15	103.75
Other	0.48	1.48	3.02	6.12
Total Critical Infrastructure	0	4	11	17
Care Facilities	0	0	1	1
Emergency Operations Centers	0	0	0	0
Fire Stations	0	0	0	0
Police Stations	0	0	1	1
Schools	0	4	9	15



Map 23: Newport News, Virginia Storm Surge Inundation Areas

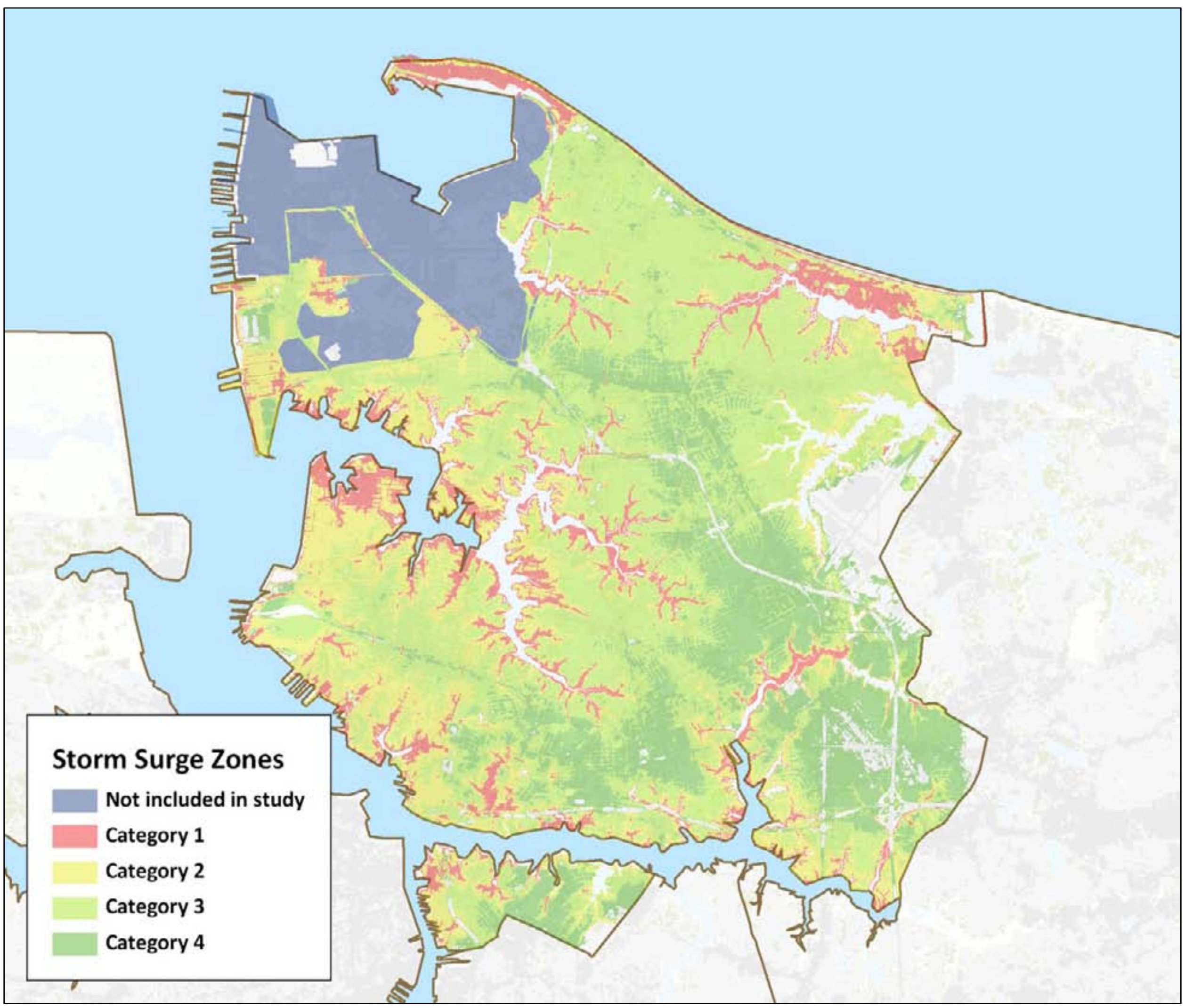


Map 24: Roads and Critical Infrastructure Vulnerable to Storm Surge in Newport News, Virginia

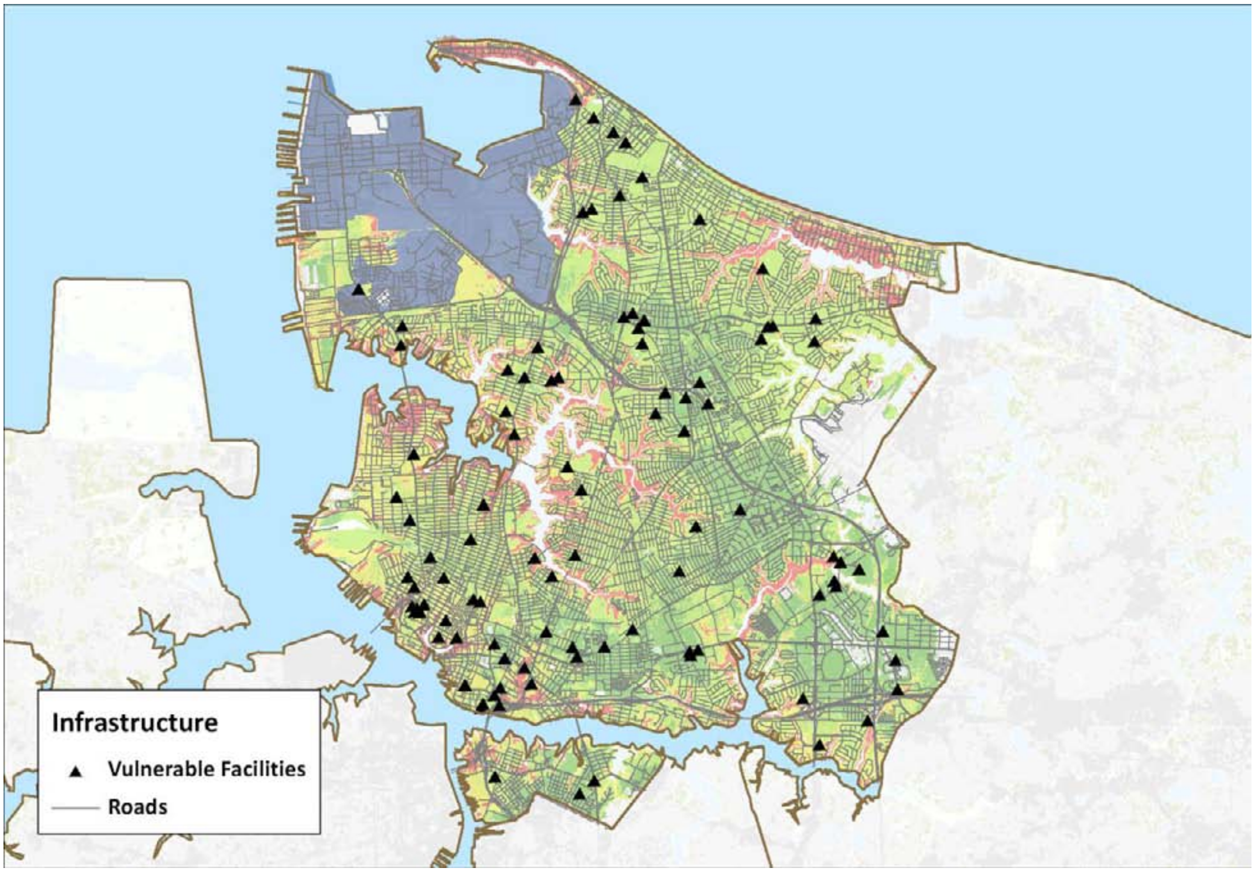


Map 25: Businesses Vulnerable to Storm Surge in Newport News, Virginia

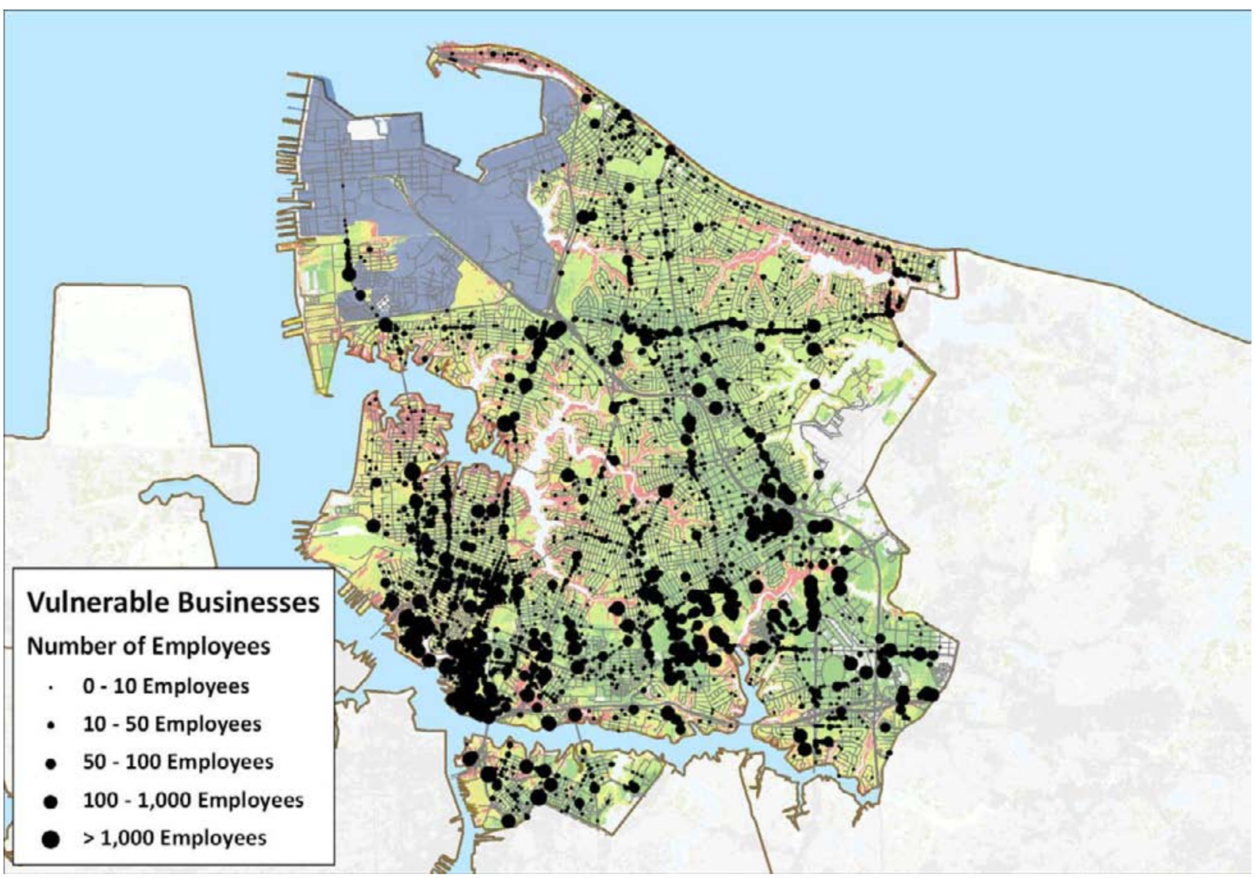
Norfolk, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	5.04	15.08	34.87	44.34
Population	19,082	65,539	168,069	209,958
Businesses	429	2,941	6,550	8,084
# of Employees	8,978	58,837	98,888	123,951
Total Roads (linear miles)	93.55	376.48	839.02	998.44
Interstate	2.18	4.45	10.23	19.92
Primary	12.05	43.09	106.72	139.49
Secondary	0.00	0.00	0.00	0.00
Urban	64.84	278.30	620.95	699.79
Other	14.48	50.64	101.13	139.24
Total Critical Infrastructure	4	31	77	100
Care Facilities	0	3	4	6
Emergency Operations Centers	0	0	0	1
Fire Stations	0	1	1	1
Police Stations	0	6	8	10
Schools	4	21	64	82



Map 26: Norfolk, Virginia Storm Surge Inundation Areas

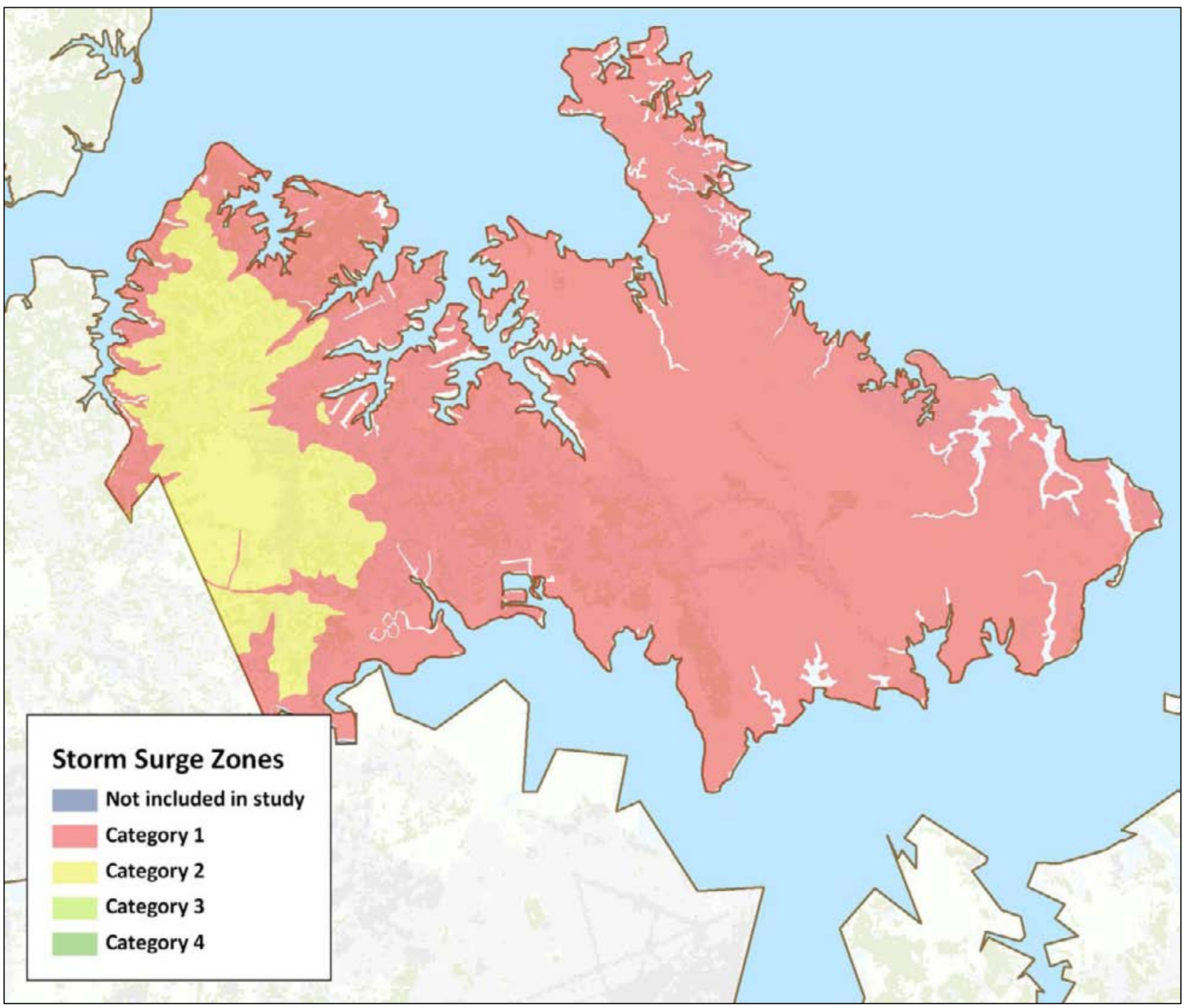


Map 27: Roads and Critical Infrastructure Vulnerable to Storm Surge in Norfolk, Virginia

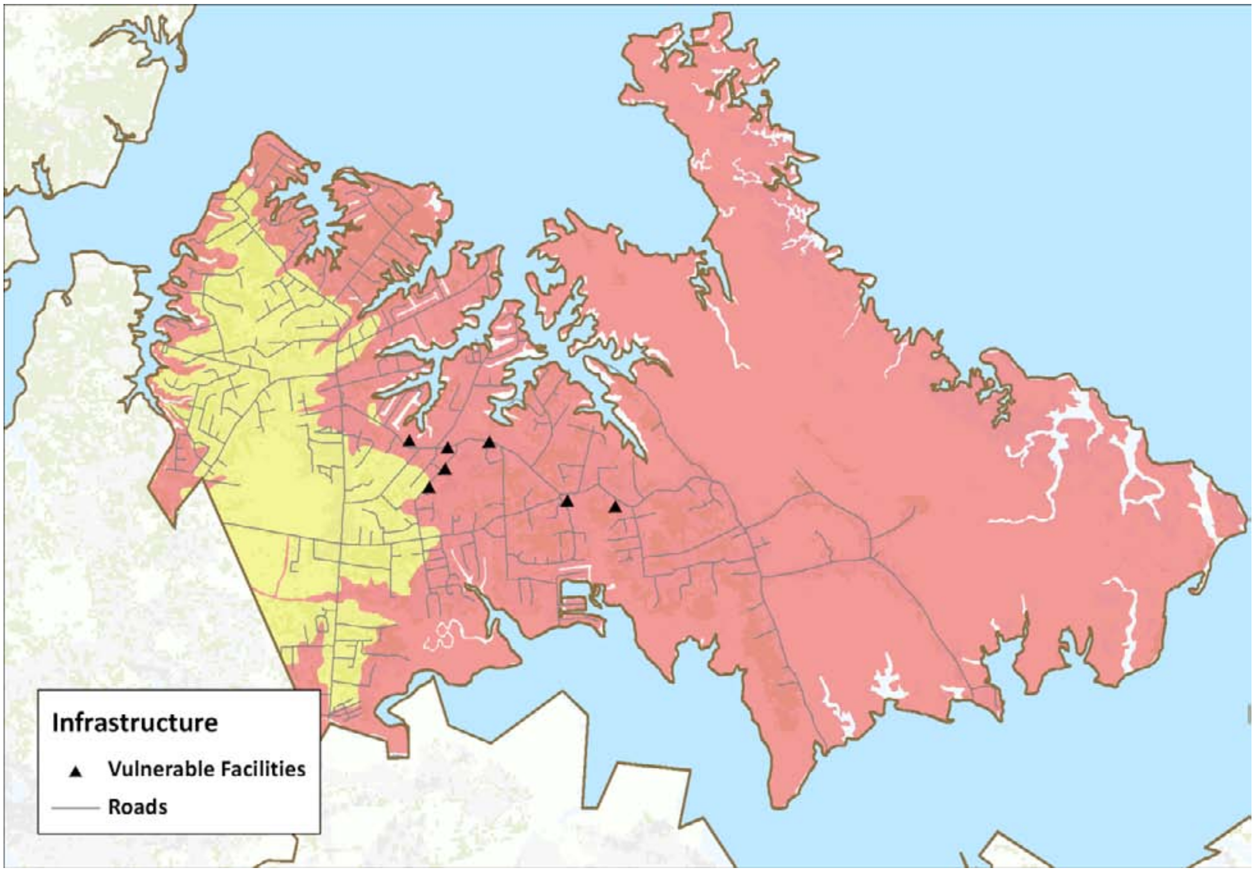


Map 28: Businesses Vulnerable to Storm Surge in Norfolk, Virginia

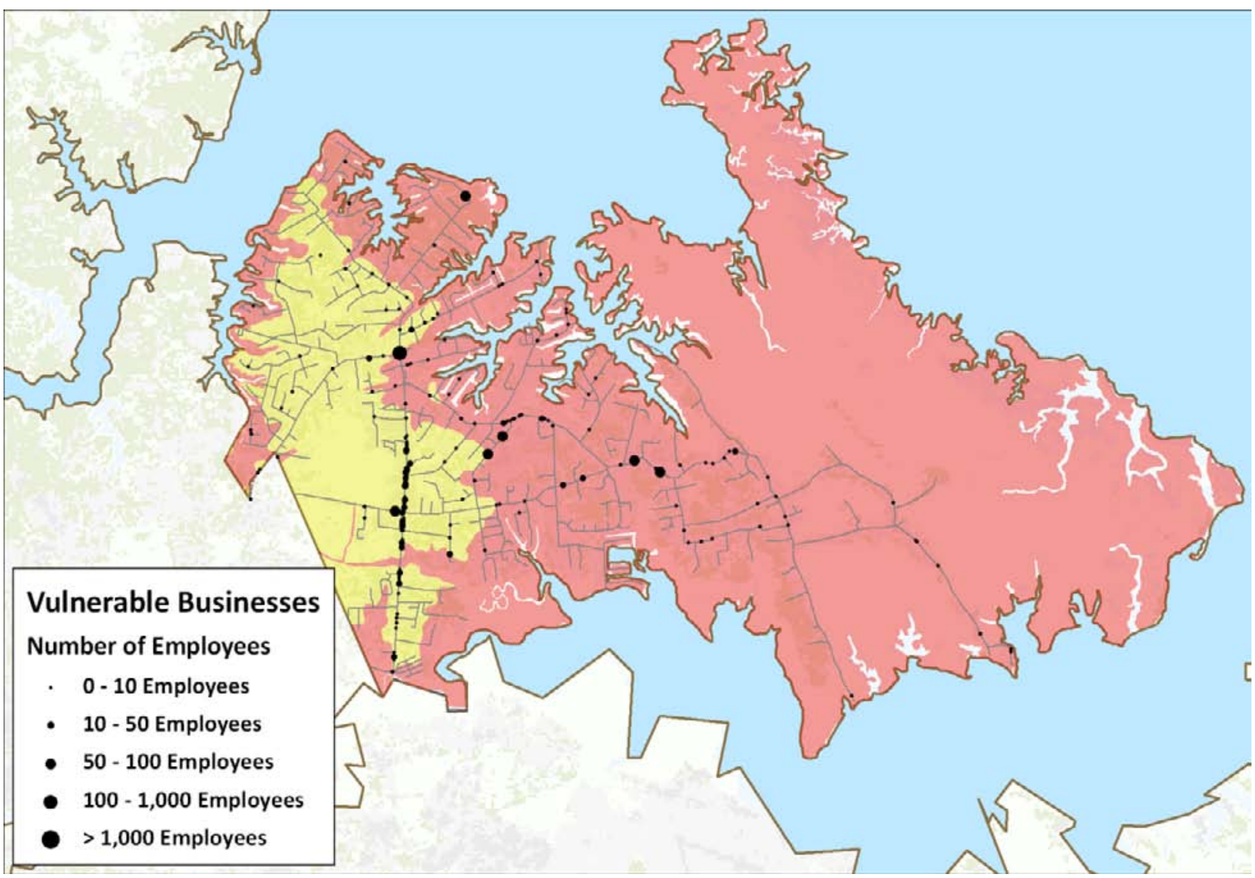
Poquoson, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	13.32	15.76	15.76	15.76
Population	7,904	12,146	12,146	12,146
Businesses	105	285	285	285
# of Employees	1,316	2,305	2,305	2,305
Total Roads (linear miles)	43.73	66.72	66.94	66.94
Interstate	0.00	0.00	0.00	0.00
Primary	4.80	7.80	7.85	7.85
Secondary	0.15	0.24	0.34	0.34
Urban	32.84	49.01	49.06	49.06
Other	5.95	9.68	9.68	9.68
Total Critical Infrastructure	7	7	7	7
Care Facilities	0	0	0	0
Emergency Operations Centers	0	0	0	0
Fire Stations	1	1	1	1
Police Stations	1	1	1	1
Schools	5	5	5	5



Map 29: Poquoson, Virginia Storm Surge Inundation Areas

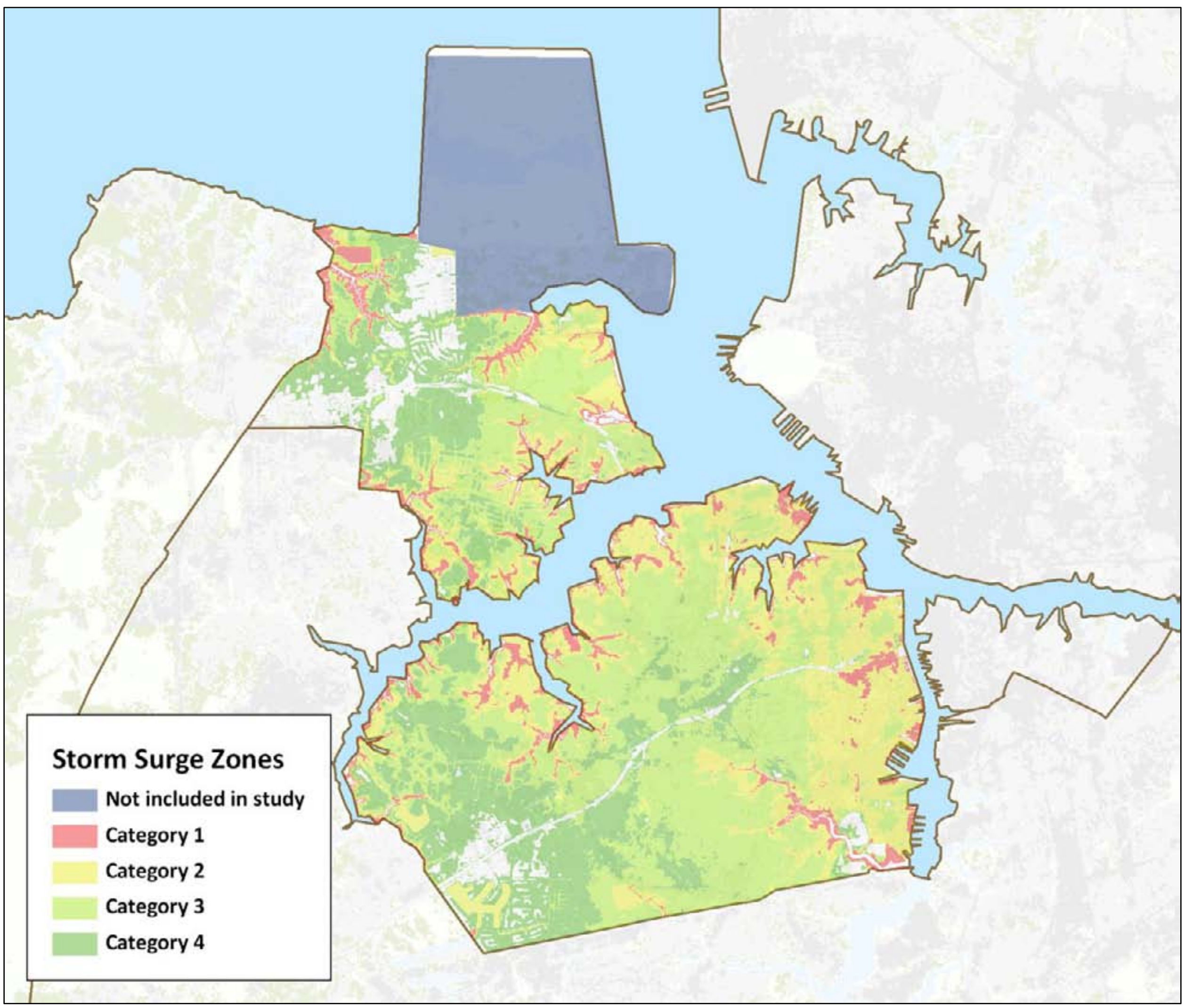


Map 30: Roads and Critical Infrastructure Vulnerable to Storm Surge in Poquoson, Virginia

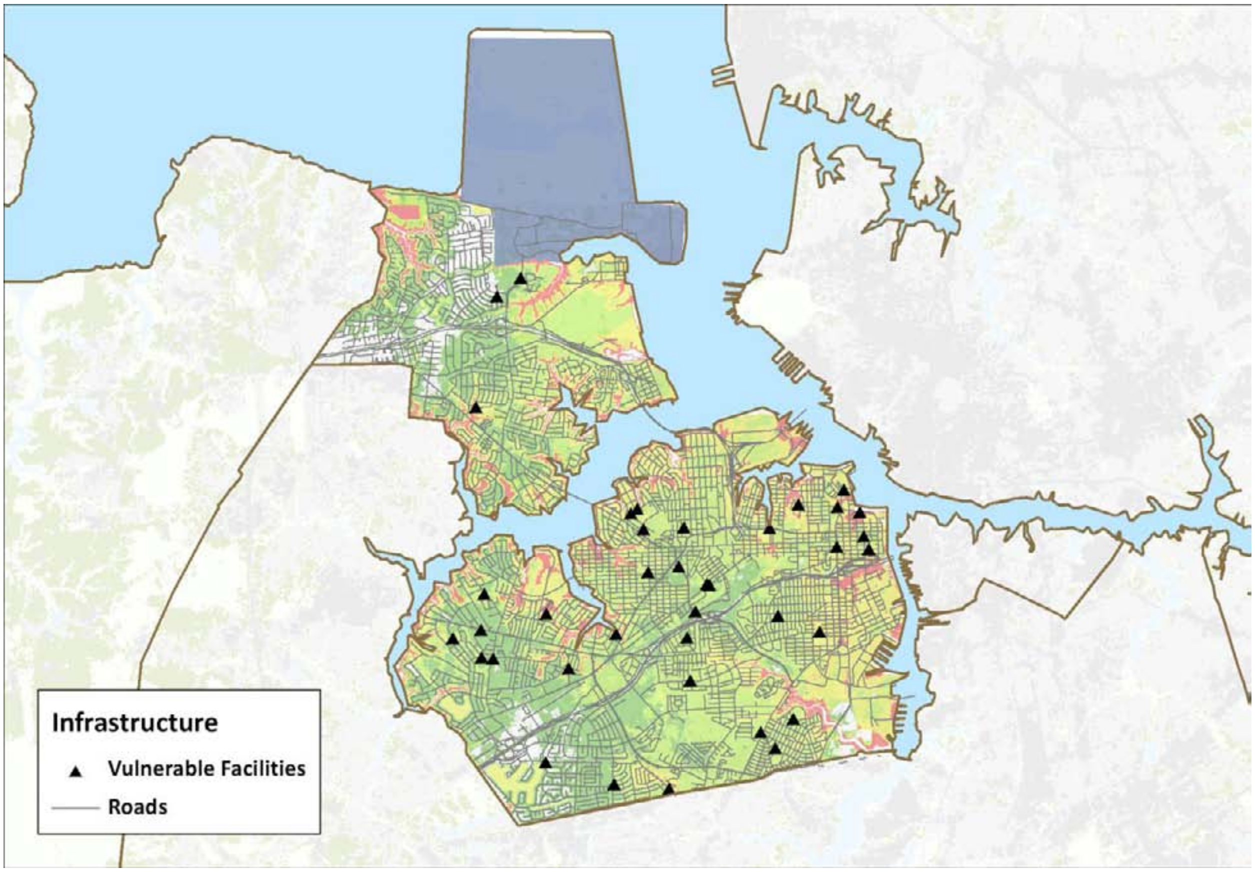


Map 31: Businesses Vulnerable to Storm Surge in Poquoson, Virginia

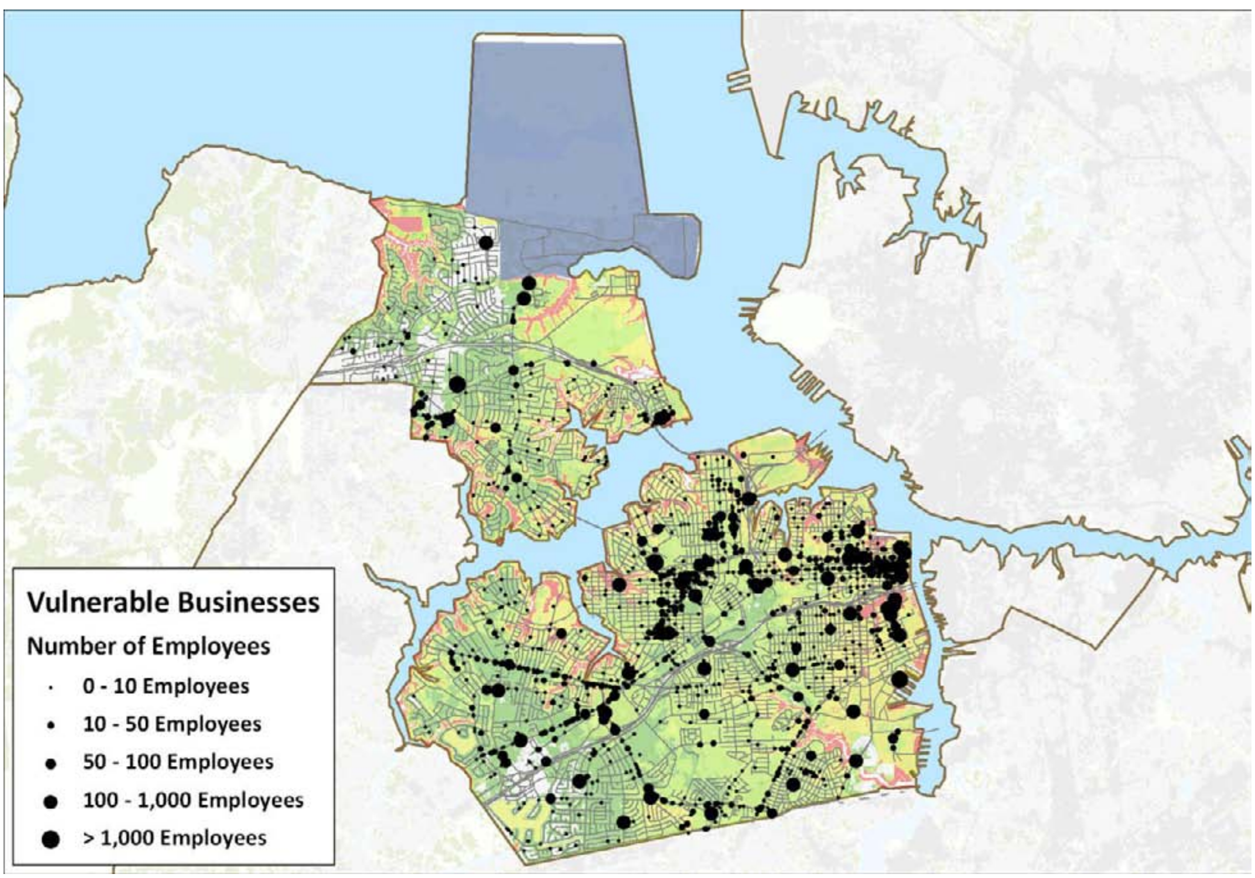
Portsmouth, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	2.18	8.82	19.65	26.07
Population	3,770	24,974	64,696	87,209
Businesses	115	936	2,170	2,843
# of Employees	5,980	16,708	36,047	43,058
Total Roads (linear miles)	14.17	145.91	361.14	465.70
Interstate	0.55	0.75	1.06	1.65
Primary	0.90	11.69	33.66	47.39
Secondary	0.00	0.00	0.00	0.00
Urban	11.85	122.45	303.11	389.82
Other	0.86	11.01	23.30	26.83
Total Critical Infrastructure	0	13	32	39
Care Facilities	0	1	2	2
Emergency Operations Centers	0	0	0	0
Fire Stations	0	1	1	1
Police Stations	0	3	4	5
Schools	0	8	25	31



Map 32: Portsmouth, Virginia Storm Surge Inundation Areas

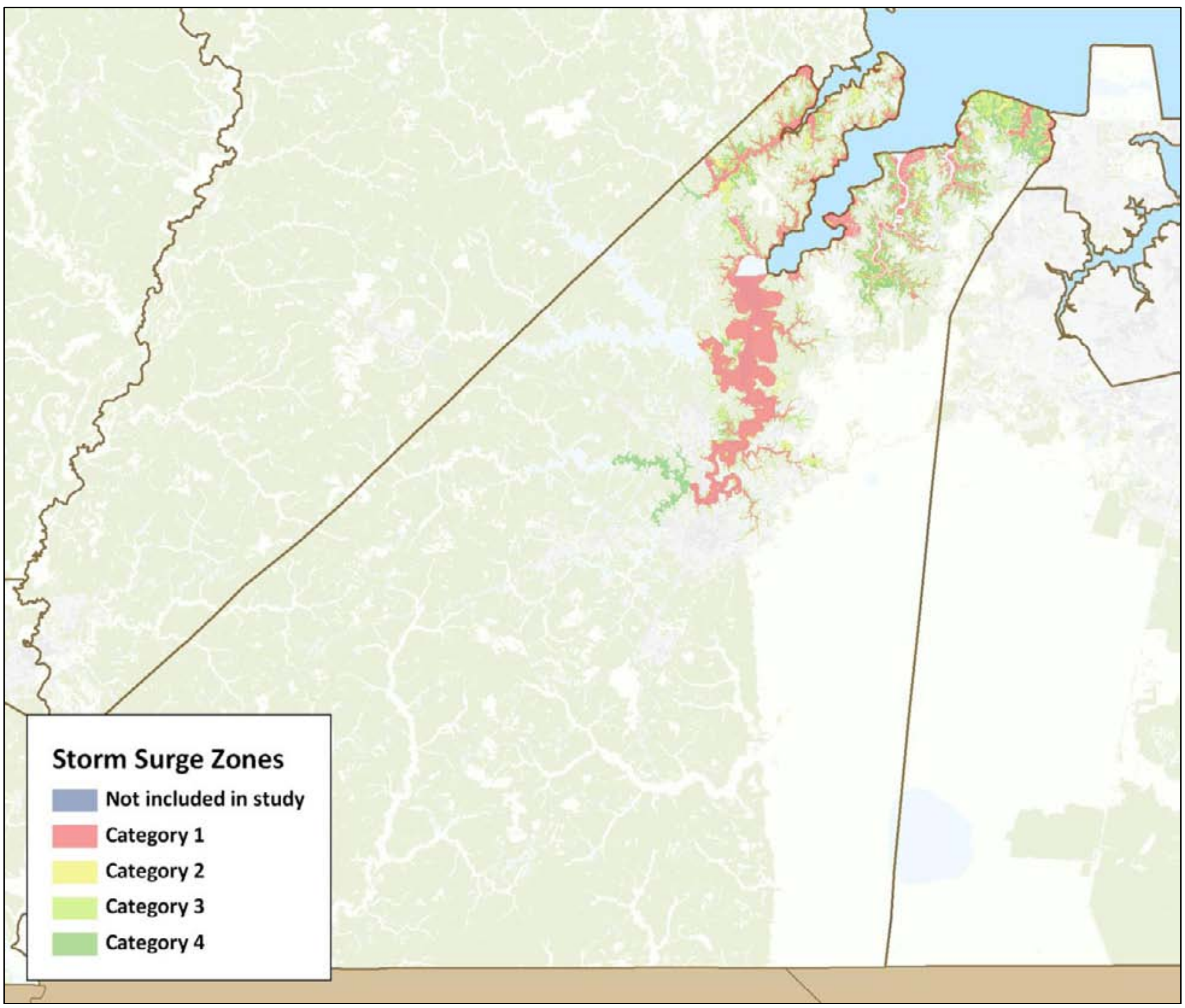


Map 33: Roads and Critical Infrastructure Vulnerable to Storm Surge in Portsmouth, Virginia

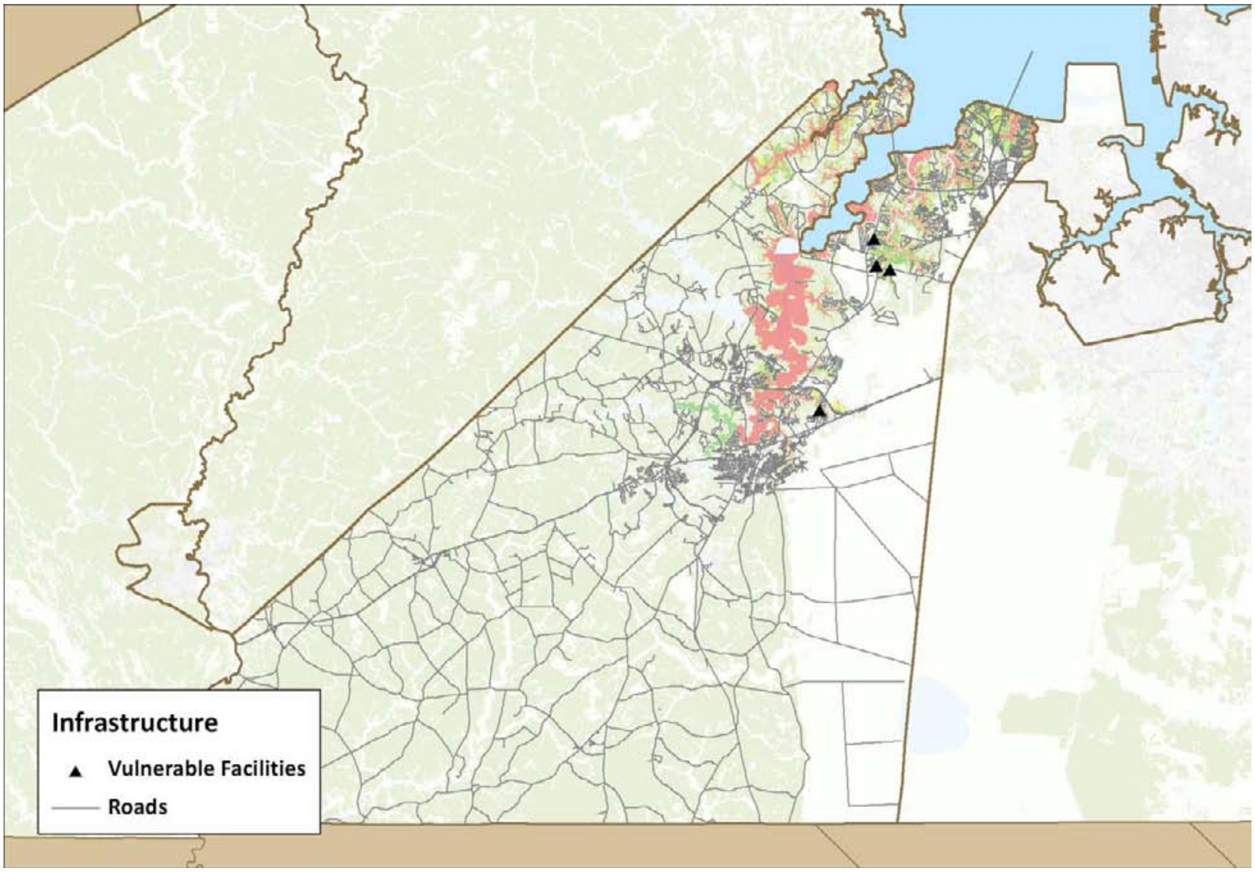


Map 34: Businesses Vulnerable to Storm Surge in Portsmouth, Virginia

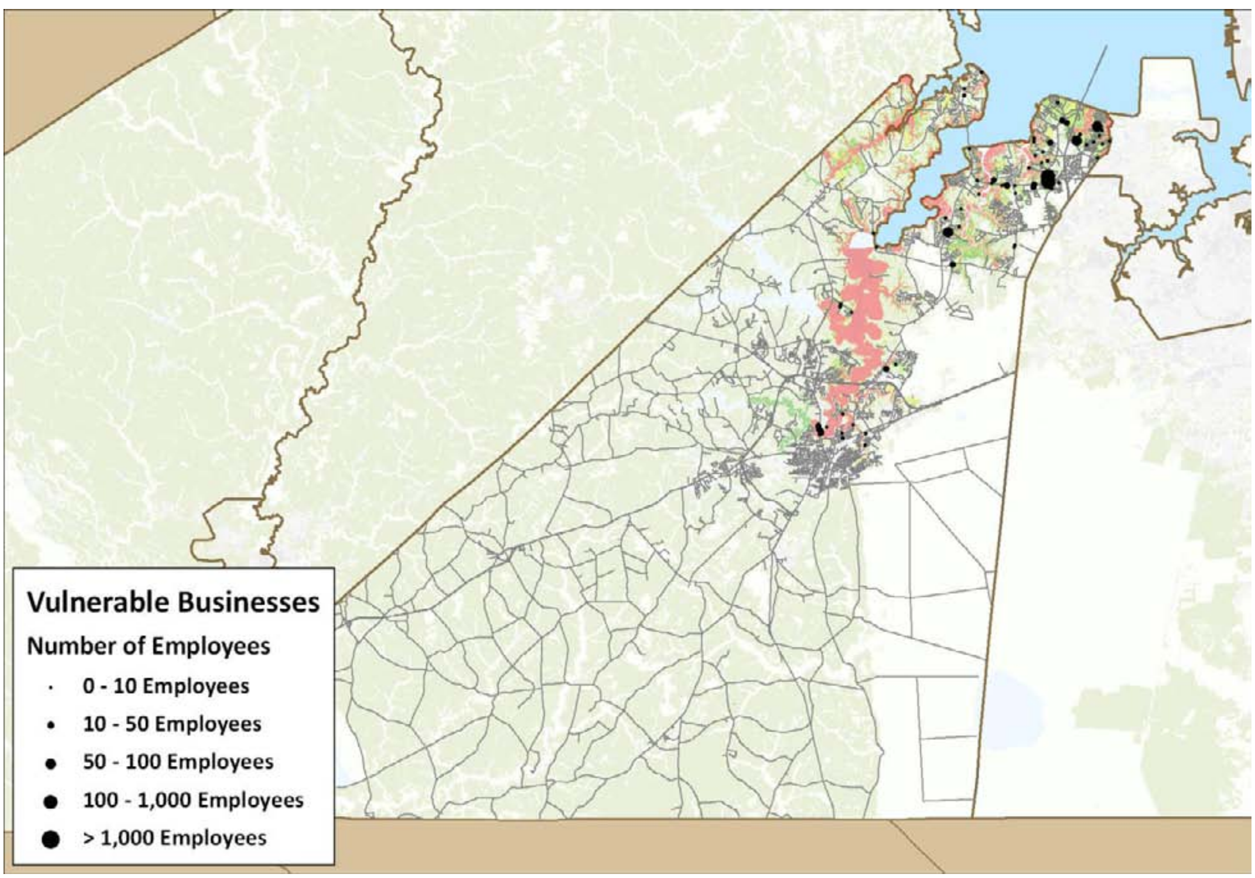
Suffolk, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	13.23	16.05	20.16	27.13
Population	4,281	5,648	8,478	14,511
Businesses	16	21	95	196
# of Employees	121	131	1,023	1,705
Total Roads (linear miles)	2.31	5.89	23.47	76.26
Interstate	0.01	0.01	0.01	0.58
Primary	1.00	1.85	4.48	9.17
Secondary	0.00	0.13	0.36	1.16
Urban	1.06	3.45	16.96	57.25
Other	0.23	0.45	1.66	8.11
Total Critical Infrastructure	0	0	1	4
Care Facilities	0	0	0	0
Emergency Operations Centers	0	0	0	0
Fire Stations	0	0	0	0
Police Stations	0	0	0	0
Schools	0	0	1	4



Map 35: Suffolk, Virginia Storm Surge Inundation Areas

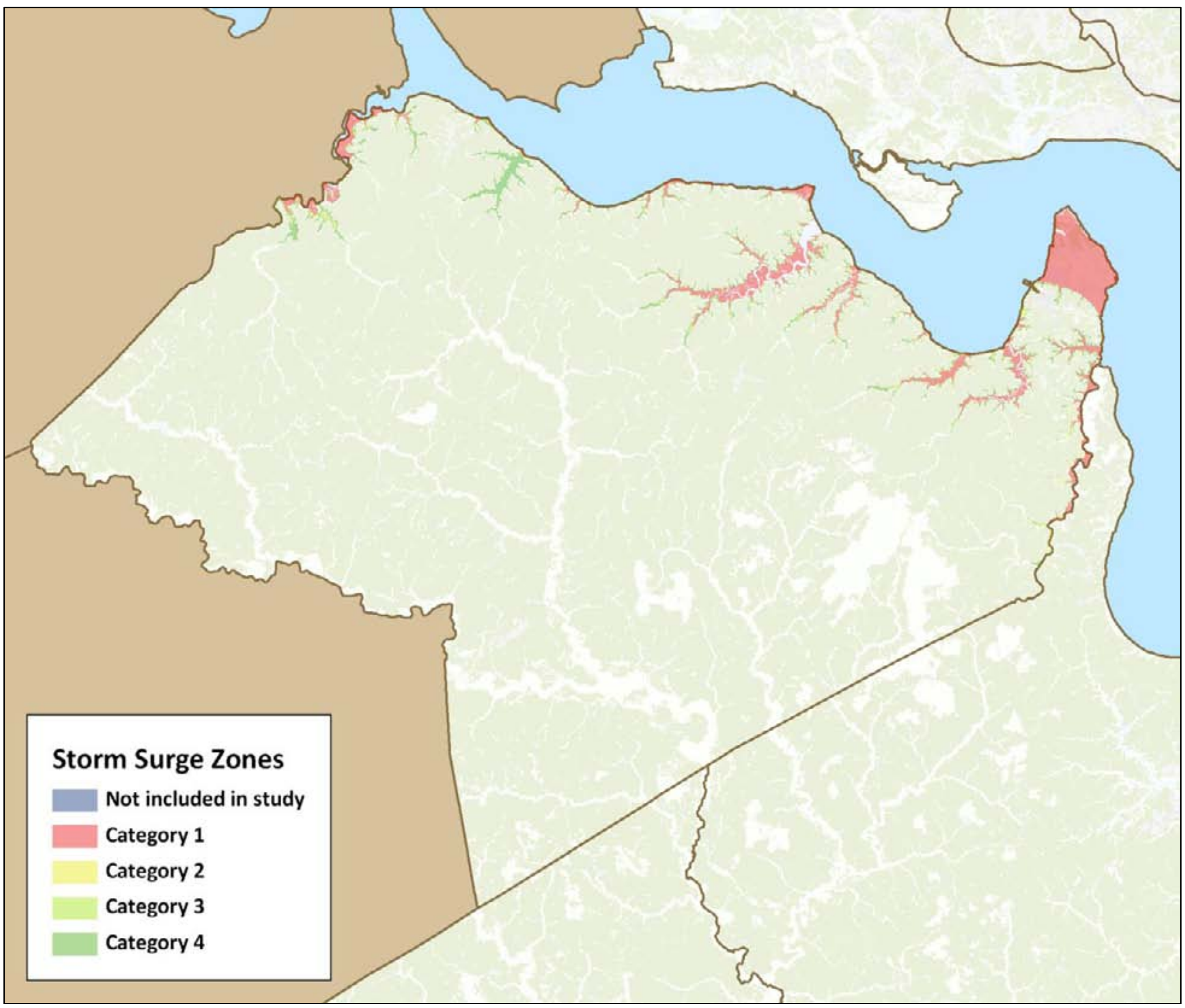


Map 36: Roads and Critical Infrastructure Vulnerable to Storm Surge in Suffolk, Virginia

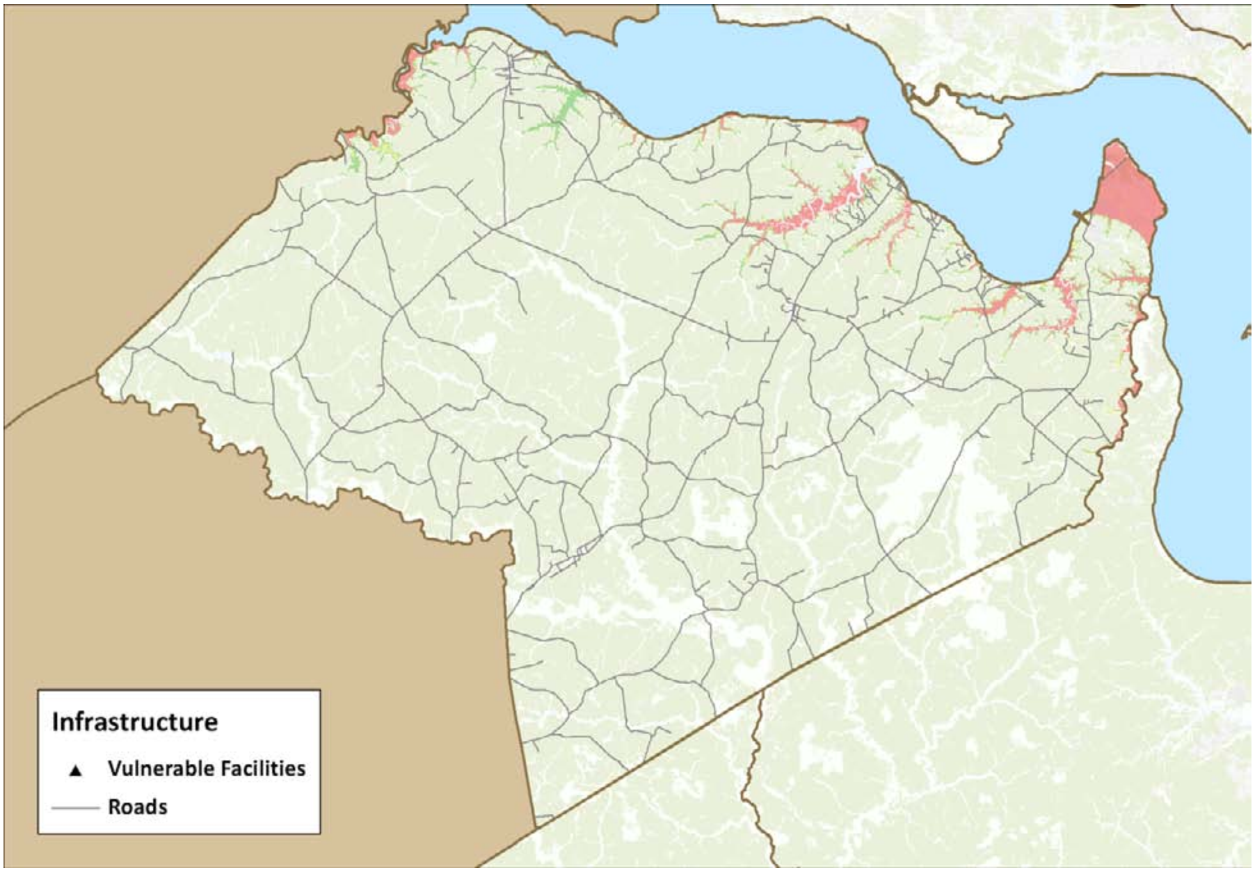


Map 37: Businesses Vulnerable to Storm Surge in Suffolk, Virginia

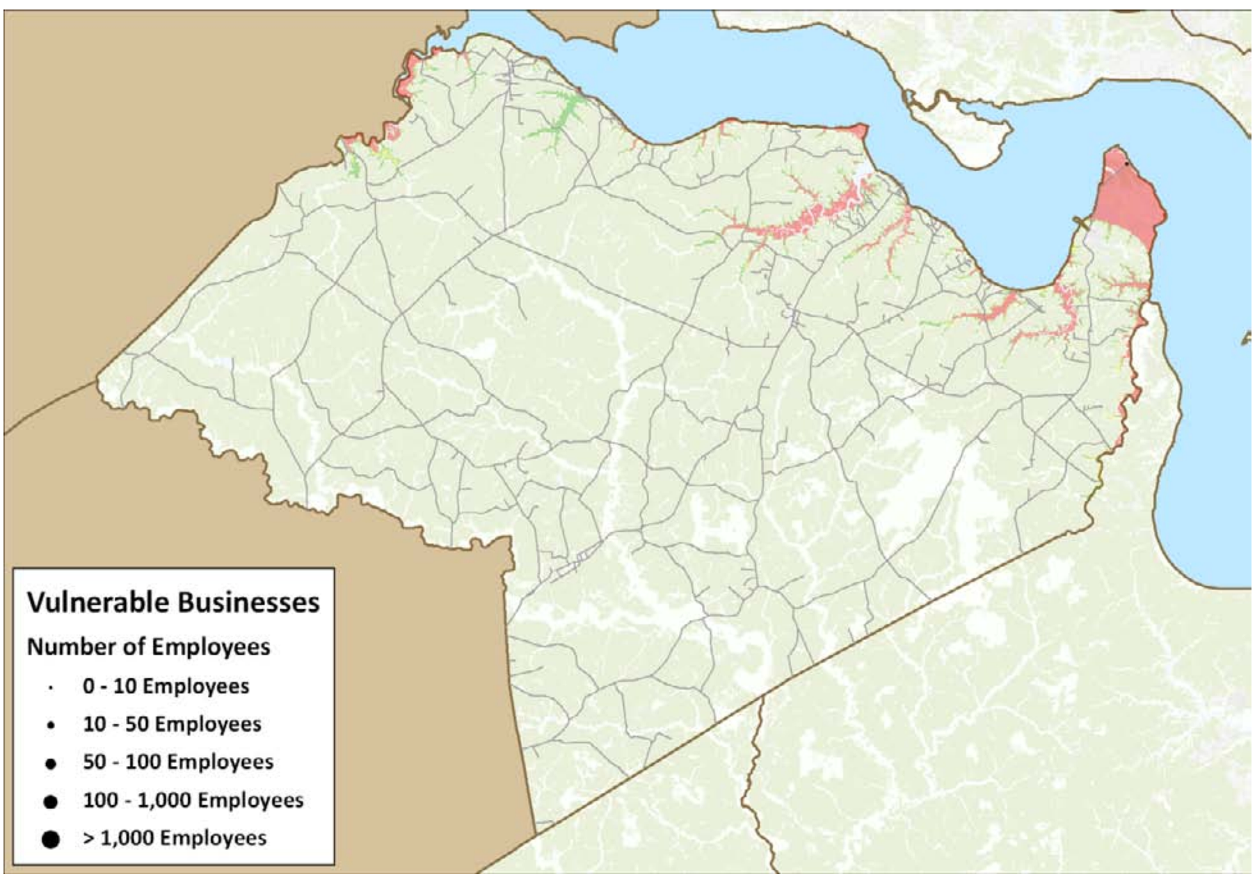
Surry County, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	6.37	7.13	7.14	10.55
Population	96	116	116	215
Businesses	1	1	1	1
# of Employees	2	2	2	2
Total Roads (linear miles)	2.41	2.89	2.88	5.14
Interstate	0.00	0.00	0.00	0.00
Primary	0.02	0.02	0.02	0.16
Secondary	2.18	2.44	2.44	4.19
Urban	0.00	0.00	0.00	0.00
Other	0.22	0.43	0.43	0.76
Total Critical Infrastructure	0	0	0	0
Care Facilities	0	0	0	0
Emergency Operations Centers	0	0	0	0
Fire Stations	0	0	0	0
Police Stations	0	0	0	0
Schools	0	0	0	0



Map 38: Surry County, Virginia Storm Surge Inundation Areas

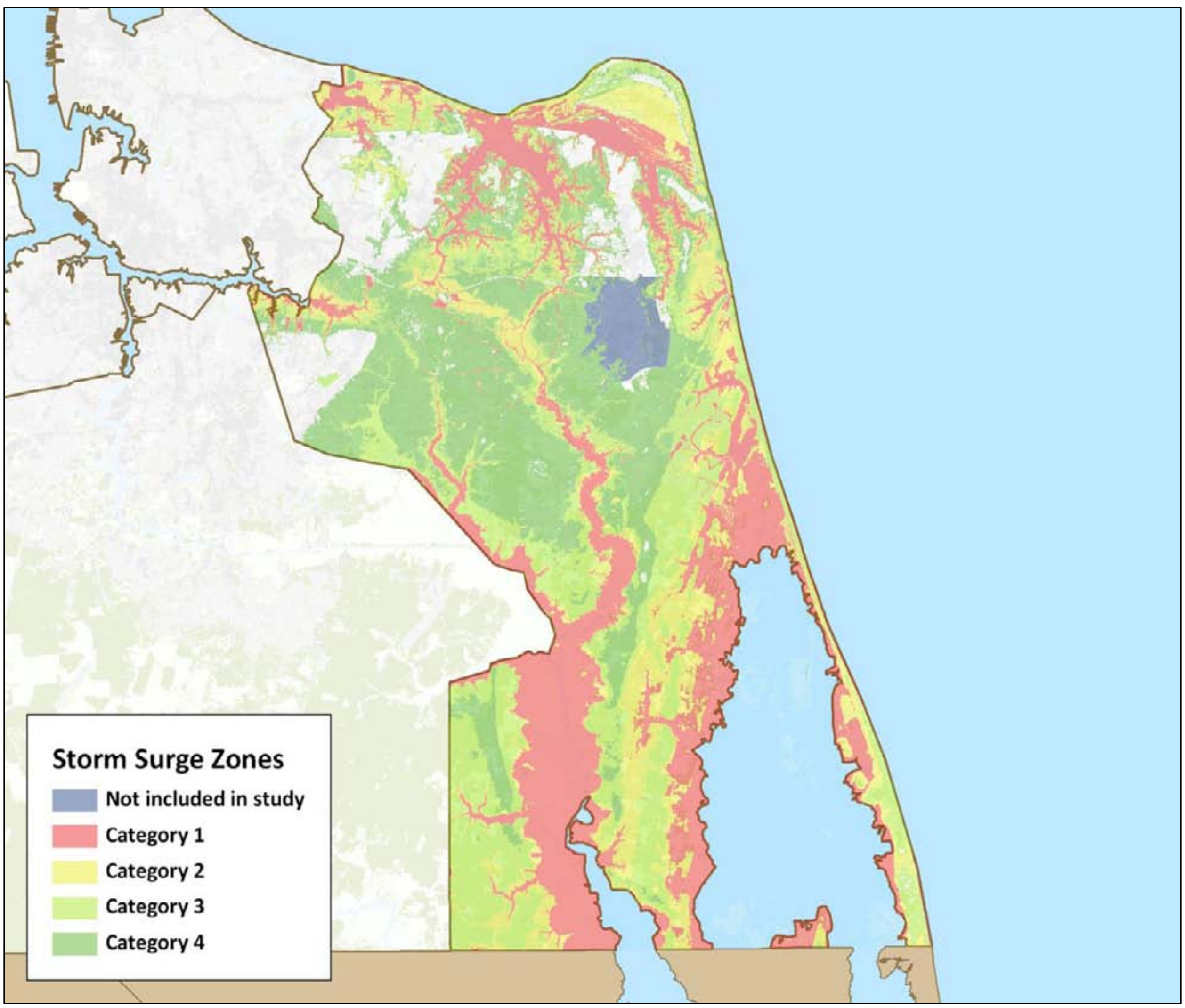


Map 39: Roads and Critical Infrastructure Vulnerable to Storm Surge in Surry County, Virginia

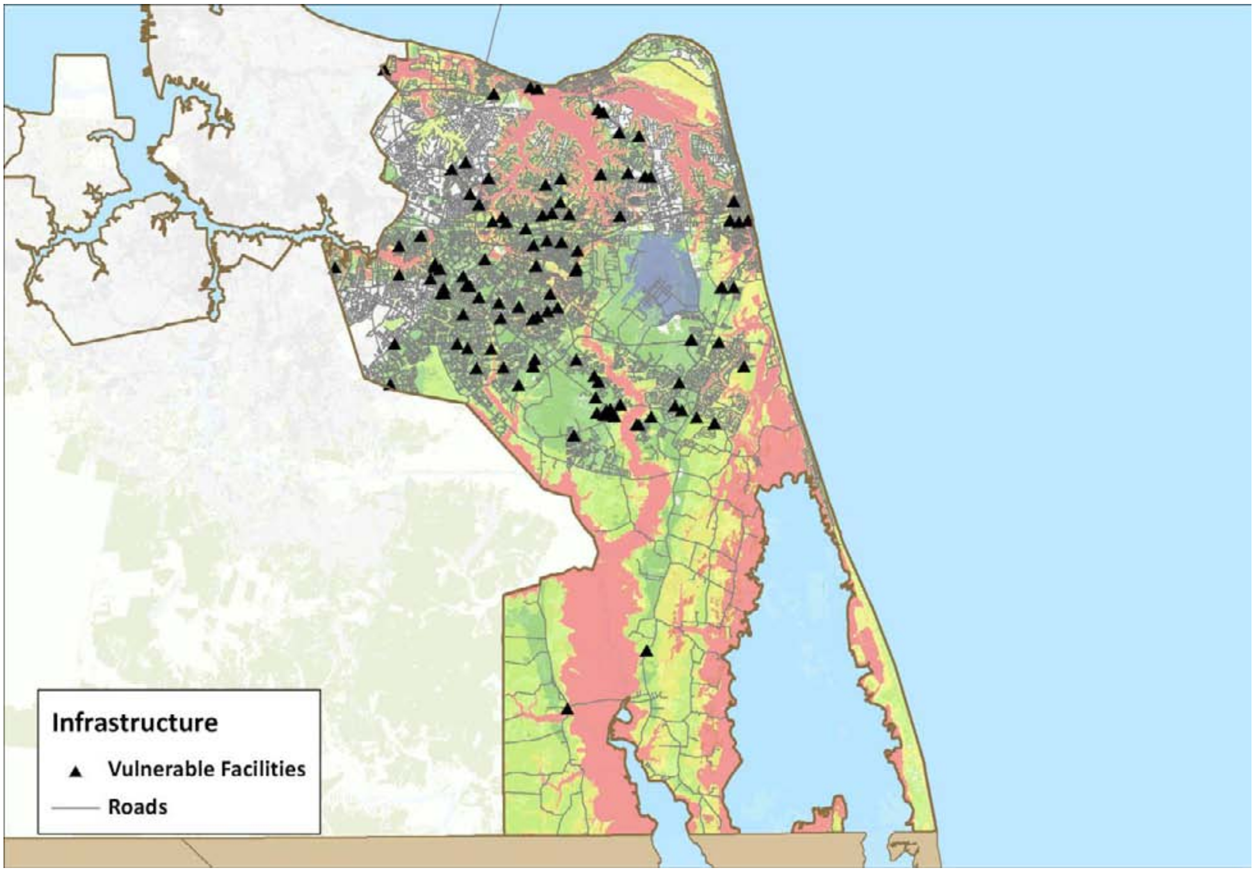


Map 40: Businesses Vulnerable to Storm Surge in Surry County, Virginia

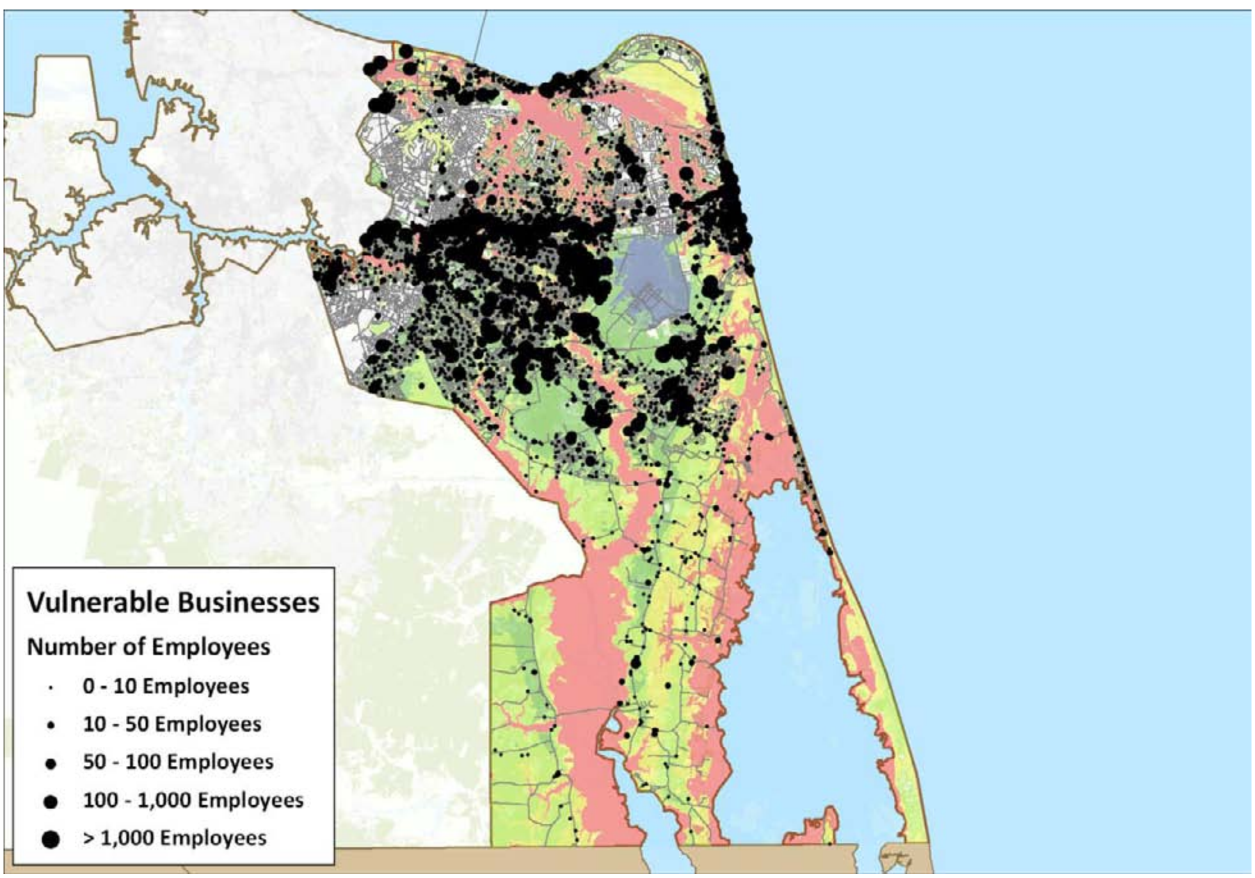
Virginia Beach, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	115.13	152.84	212.72	276.52
Population	24,481	74,156	157,997	346,827
Businesses	319	1,708	4,650	11,066
# of Employees	3,409	20,307	53,236	131,858
Total Roads (linear miles)	54.89	301.35	788.83	1,576.74
Interstate	0.43	0.83	4.29	9.55
Primary	5.10	24.92	57.18	104.14
Secondary	0.00	0.00	0.01	0.01
Urban	47.53	266.83	687.62	1,370.37
Other	1.82	8.77	39.74	92.67
Total Critical Infrastructure	2	12	39	109
Care Facilities	0	0	0	0
Emergency Operations Centers	0	0	0	0
Fire Stations	1	2	3	4
Police Stations	0	1	3	11
Schools	1	9	33	94



Map 41: Virginia Beach, Virginia Storm Surge Inundation Areas

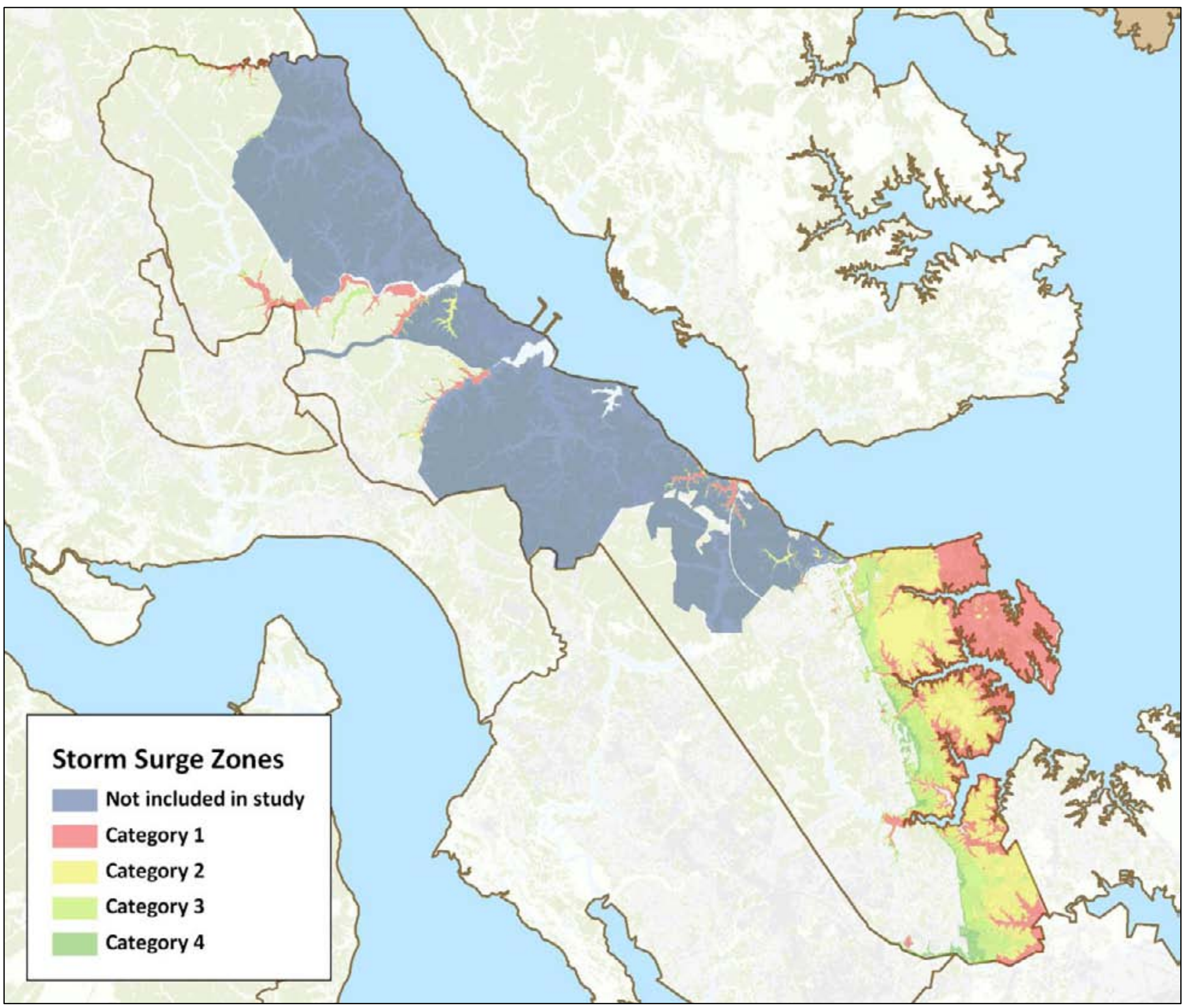


Map 42: Roads and Critical Infrastructure Vulnerable to Storm Surge in Virginia Beach, Virginia

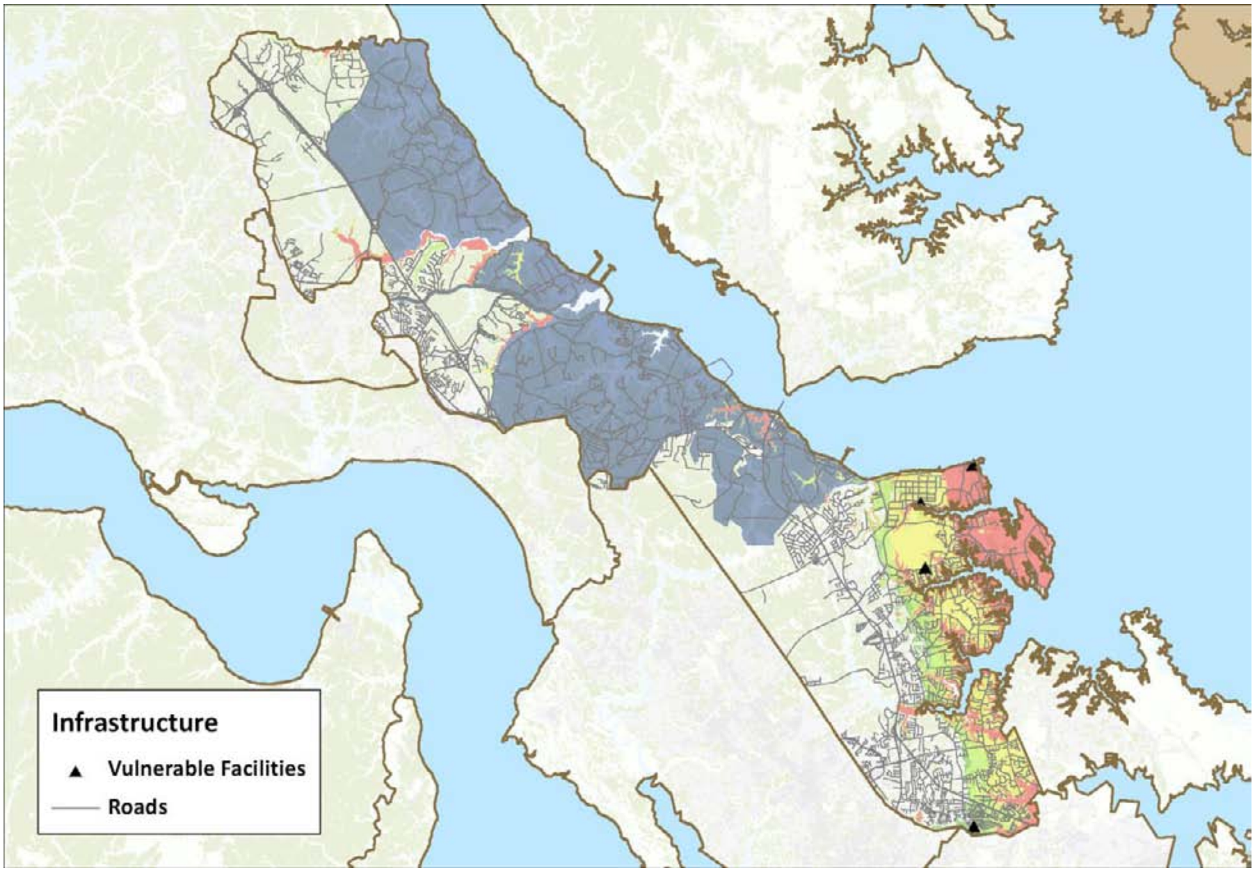


Map 43: Businesses Vulnerable to Storm Surge in Virginia Beach, Virginia

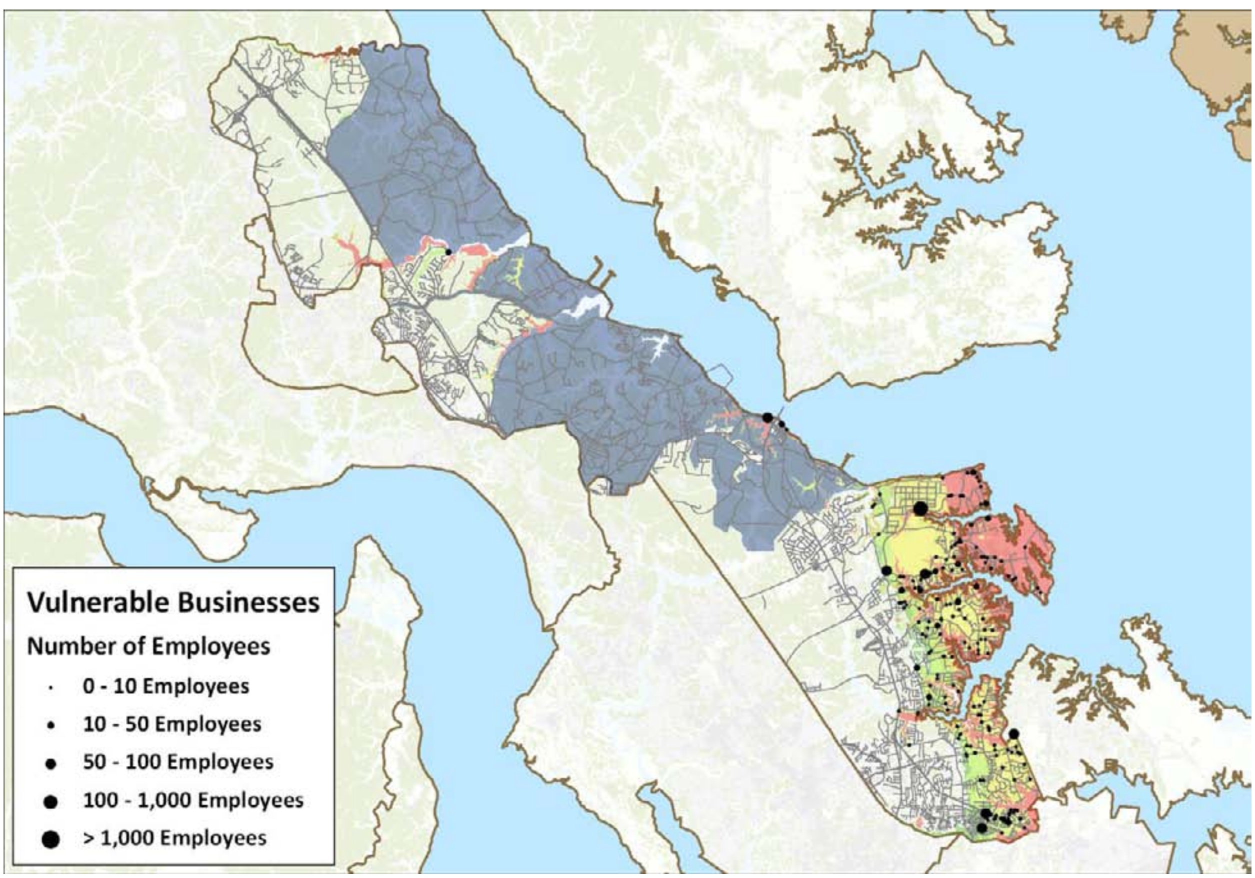
York County, Virginia Storm Surge Exposure	Category 1	Category 2	Category 3	Category 4
Area (square miles)	8.24	16.28	19.74	21.14
Population	5,514	14,465	20,245	23,788
Businesses	92	243	319	340
# of Employees	421	1,368	1,856	1,956
Total Roads (linear miles)	32.48	104.71	136.82	149.88
Interstate	0.07	0.10	0.24	0.60
Primary	0.76	3.57	6.65	8.42
Secondary	27.31	76.34	95.67	100.46
Urban	3.80	21.59	30.71	36.80
Other	0.54	3.11	3.55	3.59
Total Critical Infrastructure	1	3	3	4
Care Facilities	0	0	0	0
Emergency Operations Centers	0	0	0	0
Fire Stations	0	1	1	1
Police Stations	0	0	0	0
Schools	1	3	3	4



Map 44: York County, Virginia Storm Surge Inundation Areas



Map 45: Roads and Critical Infrastructure Vulnerable to Storm Surge in York County, Virginia



Map 46: Businesses Vulnerable to Storm Surge in York County, Virginia

Public Outreach

During the second year of HRPDC's climate change work, the focus shifted from stakeholder involvement with local governments to a broader public outreach and education effort, which consisted mostly of meetings with municipal boards and presentations to various groups. Over the course of the current grant period, from January 2010 to March 2011, HRPDC staff participated in eighteen (18) such events, ranging from presentations to university classes to participating in conference panels. Most events consisted of HRPDC staff giving presentations followed by periods for extended comment or question and answer sessions. A sample presentation is included in Appendix C. Attendance numbers are approximate. HRPDC staff that participated in these outreach efforts included:

John Carlock, Deputy Executive Director
Lisa Hardy, Physical and Environmental Planner
Whitney Katchmark, Principal Water Resource Planner
Benjamin McFarlane, Physical and Environmental Planner
Eric Walberg, Physical and Environmental Planning Administrator (former staff)

Government

Several of the events that HRPDC staff participated in involved discussions with or presentations to local government staff or elected officials. Eight (8) of the events during this grant period are included in this category.

- February 10, 2010 – Mr. Walberg gave a presentation to the Hampton Roads Planning District Commission at its annual retreat, focusing on the risks the Hampton Roads region faces from sea level rise caused by climate change. The presentation included a summary of the recommendations from the Governor's Commission on Climate Change, as well as some initial results from an effort by VIMS and Noblis to model the impacts of sea level rise and storm surge on the region. The presentation included some information on the status of offshore wind developments off Virginia Beach. Mr. Walberg made several recommendations to the Commission, including:
    - Obtaining consistent, high resolution elevation data for the entire region
    - Continuing to develop modeling tools that link storm surge and sea level rise

- Conducting a vulnerability model for Hampton Roads' built and natural environments under various storm surge and sea level rise scenarios
- Developing improved real-time predictive tool for storm surge
- Developing long-range plans based on vulnerability analyses.

Attendance: 50

❖ February 10, 2010 – Mr. Walberg gave a presentation to the Hampton City Council that described the threat posed by climate change to Hampton and the rest of the region and described the work HRPDC staff was engaged in through this grant. The presentation covered the scope of the three-year focal area grant, described some of the possible impacts of climate change on the region, including temperature and precipitation increases and sea level rise, and related regional planning efforts. The presentation also described a potential regional working group that would involve different stakeholders in addressing climate change and sea level rise from a regional perspective. This group would include elected officials, government staff, Department of Defense representatives, business and industry representatives, academics and researchers, and various advocacy groups. This presentation was covered by the *Daily Press*, the Peninsula's daily newspaper (Macaulay 2010).

Attendance: 40

❖ March 8, 2010 – Mr. Walberg presented to the Portsmouth City Council. This presentation covered much of the same material as the earlier presentation to the Hampton City Council. In addition, a discussion of changing predictions of sea level rise was added to illustrate the uncertainties involved in planning for sea level rise at the municipal level.

Attendance: 35

❖ August 24, 2010 – Mr. McFarlane and Mr. Carlock met with Norfolk Public Works staff and engineering consultants to discuss HRPDC's climate change work, Norfolk's coastal flooding study, and how HRPDC could support Norfolk's efforts. The meeting also included discussion of case studies for how to address sea level rise and flooding, as well as HRPDC's green infrastructure work.

Attendance: 5

- August 25, 2010 – Mr. McFarlane and Mr. Carlock attended a work sessions of the Norfolk City Council focused on the City's efforts to address flooding. Mr. McFarlane made some comments about sea level rise in the region and HRPDC's research efforts.
  Attendance: 40

- November 15, 2010 – Mr. McFarlane participated in a workshop organized by the Cabell Brand Center for Global Poverty and Resource Sustainability Studies. The workshop brought together representatives from the three Coastal Zone Planning District Commissions working on climate change projects as well as researchers to present to representatives from local governments and organizations in the western part of Virginia on how climate change could affect communities in Virginia. Mr. McFarlane's presentation focused on the results from HRPDC's first year of research and analysis. Representatives from MPPDC and NVRC also presented.
  Attendance: 15

- March 1, 2011 – Mr. McFarlane and Mr. Carlock presented to the Hampton Waterway Management Plan Steering Committee as part of its technical presentation series. This Steering Committee is helping the City Council identify potential solutions to addressing longstanding problems with flooding and stormwater management in the City. The presentation covered regional water management issues in Hampton Roads, including stormwater quality, the Chesapeake Bay TMDL, hazard mitigation, storm and tidal flooding, sea level rise, and climate change. The presentation included a description of institutional, regulatory, and technical issues, as well as local and regional efforts related to water management in Hampton Roads.
  Attendance: 50

- March 22, 2011 – Mr. McFarlane and Ms. Katchmark met with representatives from the U.S. Geological Survey and VIMS to discuss subsidence and sea level rise in Hampton Roads. Dr. John Boon from VIMS discussed the results of research he and some colleagues conducted on relative sea level rise in Hampton Roads using data from NOAA tide gauges. The USGS representatives discussed their work looking at the impacts of groundwater withdrawals on local subsidence. HRPDC staff led a discussion of possible directions for future research and

collaboration to help identify the causes of local subsidence and the impacts of subsidence on relative sea level rise in the region.
Attendance: 8

Other Groups and Organizations

Engagement with citizen groups is critical to educating the public about important regional environmental issues such as climate change and sea level rise. HRPDC staff continued to engage non-governmental organizations through this grant period. Ten (10) of the events during this grant period, including the listening sessions described at the end of this section, are included in this category.

- April 8, 2010 – Mr. Carlock presented to Virginia Beach Vision, a group of business and professional executives that focuses on economic development and quality of life issues in Virginia Beach. The presentation covered the same material as the presentation to the Portsmouth City Council.
  Attendance: 20

- April 26, 2010 – Mr. Walberg participated in a panel discussing "Sea-level rise and its effect on the Peninsula," hosted by the Hampton Roads Section of the American Institute of Aeronautics and Astronautics. Also participating on the panel were Joe Frank, Mayor of the City of Newport News, Dr. Barry Stamey, an oceanographer with Noblis, Dr. Harry Wang, a professor at the Virginia Institute of Marine Science, Dr. Douglas Dwoyer of the Hampton Roads Research Partnership, and Dr. Samuel Martin, President of ECOS 360 LLC. The panel discussed the science behind climate change, the projected impacts of sea level rise on the region, and how these impacts may affect local policies.
  Attendance: 40

- May 5, 2010 – Mr. Walberg and Mr. McFarlane participated in a panel session at the annual conference of the Virginia Chapter of the American Planning Association in Norfolk, Virginia. Also participating in the panel was Laura Grape, a Senior Environmental Planner for the Northern Virginia Regional Commission; staff from the Middle Peninsula Planning District Commission also provided material on its climate change efforts. The panel covered each of the three ongoing Virginia CZMP climate change focal area grant projects, including

processes, initial findings, climate change science and impacts, and next steps. The panelists also took questions from the audience.
Attendance: 25

- May 19, 2010 – Mr. McFarlane presented to the Sierra Club, York River Group and the Hampton Roads Cool Communities Coalition at an event at the Sandy Bottom Nature Park in Newport News, Virginia. The presentation covered HRPDC's climate change research and included information for the audience on resources they could use to learn more about climate change, sea level rise, and how communities could adapt.
  Attendance: 30

- June 25, 2010 – Mr. McFarlane and Mr. Carlock gave a presentation to the members of the Unitarian Church of Norfolk on the issue of sea level rise in Hampton Roads and the efforts the region and localities are taking to prepare for it. This presentation covered the role of the HRPDC in planning for climate change, the status of the focal area grant project, and the findings from the research through the first year of the project, including information on climate change impacts, the threat flooding poses for both developed areas and natural resources, and how the region could potentially begin adapting to sea level rise and increased flooding.
  Attendance: 35

- February 2, 2011 – Mr. McFarlane gave an online presentation to an ODU class. The presentation covered the role of the HRPDC in addressing climate change, and covered the HRPDC's climate change work, impacts to Hampton Roads from climate change, and various challenges to effectively planning for climate change.
  Attendance: 5

Virginia Beach Listening Sessions

Through much of this grant period, HRPDC staff worked with several other organizations, including the University of Virginia's Institute for Environmental Negotiation (IEN), Wetlands Watch, Old Dominion University, and the City of Virginia Beach's Environment and Sustainability Office to develop and implement a proposal for a series of public listening sessions focusing on flooding and sea level rise in Virginia Beach. IEN and UVA's Department of Urban and Environmental Planning received a Virginia Sea Grant to fund these listening sessions along with a graduate urban planning workshop. These two groups asked HRPDC, Wetlands Watch, and Virginia Beach to help with planning and organizing the listening sessions and to provide information for public education. The planning process occurred over several months in 2010 and early 2011, consisting mainly of a series of conference calls to develop the listening session concept into an implementable plan. Regular participants on these conference calls included Tanya Denckla Cobb and Melissa Keywood from the Institute for Environmental Negotiation, Skip Stiles from Wetlands Watch, Benjamin McFarlane from the HRPDC, and Clay Bernick from the City of Virginia Beach, with others occasionally joining in. This work culminated in a series of four listening sessions held March 30th and 31st at four locations in Virginia Beach. A total of 128 residents participated in the sessions: 49 at the Virginia Aquarium and Marine Science Center; 22 at Red Mill Elementary School; 25 at the Meyera Oberndorf Central Library; and 32 at the Bayside Recreation Center.

The four listening sessions included presentations from Wetlands Watch, the Hampton Roads Planning District Commission (HRPDC), and the City of Virginia Beach Environment and Sustainability Office (ESO). Skip Stiles, Executive Director of Wetlands Watch, described the process of sea level rise and how it is affecting Virginia Beach. Benjamin McFarlane, a Regional Planner for the HRPDC, gave a presentation on HRPDC's regional climate change and sea level rise planning and research efforts. Clay Bernick, Administrator for the Virginia Beach ESO, concluded the presentations by describing how the City of Virginia Beach is addressing sea level rise and outlining the City's sustainability planning efforts.

Staff and volunteers from the UVA Institute for Environmental Negotiation, Wetlands Watch, the City of Virginia Beach, and the Hampton Roads Planning District Commission (Planners Lisa Hardy and Benjamin McFarlane) facilitated small group discussions to help citizens understand the issues and identify which parts of the city were being affected by sea level rise and flooding. These small group discussions allowed residents to share their personal experiences with sea level rise and flooding in all parts of the City. The residents also were able to point out the impacts of sea level rise and flooding (such as erosion, stormwater overflows, etc.) on maps. Residents were also given an opportunity to make suggestions for distributing information to City residents on sea level rise and flooding, as well as for the City's Sustainability Plan. Preliminary findings from the sessions along with results from a related graduate planning course will be presented to the Virginia Beach

City Council, and a final report will be released by IEN later in 2011. The report will be available on the IEN website.[4]

Other Efforts

In addition to the efforts described above, HRPDC staff is working with several academic institutions to further planning for climate change and flooding. Dr. James Koch, President Emeritus of Old Dominion University, has established an informal "water group" that brings together regional institutions and leaders to discuss the threat of sea level rise on the region. In addition, HRPDC staff is working with Dr. Koch and Dr. Vinod Agarwal, an economics professor at ODU, to analyze the short- and long-term economic and fiscal impacts of storm surge and sea level rise on Hampton Roads.

[4] http://www.virginia.edu/ien/sealevelrise/index.html

POLICY OPTIONS

Existing hazards such as storm surge and long-term threats such as sea level rise can impose high costs on communities that are unprepared. Therefore, it is important to consider the potential costs of these hazards when making decisions involving where development and infrastructure construction should occur, as well as how to adapt existing development and infrastructure. Incorporating hazard mitigation or climate adaptation policies can reduce costs to property owners and local governments when those threats materialize.

ADAPTATION OPTIONS

Adaptation options for sea level rise generally fall under three categories: protection, accommodation, and retreat (Karl, Melillo and Peterson 2009). Protection includes structural solutions such as shoreline armoring. Accommodation attempts to improve existing buildings or environments so that they can better withstand flooding or surges, and can include raising dunes, beach nourishment, or elevating buildings. Retreat focuses on moving natural resources, people, or buildings away from the hazard, through changes to zoning ordinances, conservation easements, or outright purchase of property. The costs and benefits of adaptation vary with the option chosen. Structural measures such as sea walls can be very expensive financially, while moving residents to safer areas can be both expensive and politically and socially difficult to accomplish. Structural adaptation can also pose costs for the natural environment. Shoreline armoring, for example, can help reduce erosion or protect against flooding, but it can prevent wetlands from migrating inland in response to sea level rise or increase erosion in adjacent, unprotected areas (Titus and Craghan, Shore protection and retreat 2009). Accommodation or retreat, on the other hand, can reduce exposure to coastal hazards while allowing for natural resources to adapt as well. One way of looking at the non-financial costs of adaptation is that protective measures have high environmental costs, while retreat measures have high social costs. Accommodation is only a temporary solution and may merely delay those costs.

A report from NOAA's Coastal Services Center identifies the inherent contradiction in structural adaptations to hazards such as storm surge and sea level rise: they create a moral hazard, encouraging development in areas where it may not have occurred (or at least not to the same extent) otherwise (Booz Allen Hamilton 2010). Limiting development in hazard-prone areas through outright prohibitions, restrictions, or incentives to develop elsewhere can help mitigate hazards before they become disasters. Similar policies can help with adapting to sea level rise.

Decreasing future development in areas that may be inundated through prohibitions, incentives, or planning tools such as setbacks is the most effective mitigation strategy.

Decisions made in the present regarding infrastructure and development can have significant impacts on how well a community will be able to adapt to sea level rise in the future. Infrastructure systems such as drinking water and storm water systems are financed and constructed with the expectation of a certain lifespan to justify their costs. Sea level rise can reduce their usefulness if it is not taken into account during planning. Development decisions in the present may also have long-term implications. Construction in vulnerable areas will necessitate later removal or adaptation. In addition, developing areas that are not vulnerable may still have negative impacts on the natural environment if they impede wetland migration. Research indicates that nearly 60% of the land within one meter of elevation of tidal wetlands between Massachusetts and Florida is either already developed or planned for development, and that less than 10% is protected from development (Titus, Hudgens, et al. 2009). Preventing the upland migration of wetlands may result in their disappearance, along with the water quality and flooding protections they provide, as sea level rises.

Planning for Sea Level Rise

Typical planning tools are insufficient for addressing sea level and climate change. One reason is that the impacts of climate change and sea level rise are for the most part decades into the future, so it will be hard to gauge the benefits of planning for them today, while the costs will certainly be endured in the present or near future. Another reason is that there remains a great deal of uncertainty about the extent of climate change and sea level rise over the next century. Effective adaptation requires sufficient lead times to prevent losses, yet using normal planning practices could result in either over- or under-adaptation, resulting in localities either wasting funds or not being prepared. Planning in some fashion is still required though. Three possible ways for planning for climate change and sea level rise are hazard mitigation planning, scenario planning, and anticipatory planning.

Hazard mitigation planning is presently used for current hazards such as hurricanes, tornadoes, earthquakes, etc. Its goal is the mitigation of "risks associated with natural and other hazards in terms of losses of life, property, and natural and economic resources" and is usually conducted through an interdisciplinary process involving emergency managers, public works officials, land use planners, and the public (Booz Allen Hamilton 2010). Through hazard mitigation planning, officials identify potential hazards, assess vulnerability to those hazards, and then devise and implement policies designed to reduce exposure and vulnerability (Godschalk, Urban Hazard Mitigation: Creating Resilient Cities 2003). Hazard mitigation planning is proactive and can produce both structural (e.g. flood control measures) and non-structural (e.g. redirecting development away from floodplains) recommendations.

Scenario planning is a tool that allows for consideration of multiple paths. Planners can use scenarios to assess how changes in policies or conditions could affect their communities. Scenario planning has been used in the business world to account for uncertainty about the future (Schwartz 1991). It has also been used with urban planning to test alternative visions (Hopkins and Zapata 2007). Scenario planning can utilize other analysis tools such as build-out analyses to measure the impacts of changes to policies or other conditions on future development (Godschalk, Buildout Analysis: A Valuable Planning and Hazard Mitigation Tool 2006). Even though the extent of climate change will depend on many future events and decisions, scenarios can allow for testing different pathways and sets of variables to project future conditions. The IPCC used this approach in its most recent synthesis report to project climate change impacts based on different socioeconomic conditions and levels of greenhouse gas emissions (Intergovernmental Panel on Climate Change 2007). A local application of scenario planning could analyze the impacts of different amounts of sea level rise. Combining build-out analyses with hazard scenarios can measure future as opposed to current vulnerability. Scenario planning can help mitigate uncertainty in planning by providing for a range of inputs and results. More likely scenarios can be given greater weight in analyzing results.

Hazard mitigation planning and scenario planning are both effective planning tools, but when dealing with the level of uncertainty found in climate change they come up short. Hazard mitigation planning is generally based on existing hazards and measurable data to analyze vulnerability and generate costs and benefits of different mitigating actions. Scenario planning alleviates this somewhat by testing multiple pathways, but still generally results in a single pathway. Alternatively, anticipatory planning or anticipatory governance addresses this uncertainty by building flexibility into the planning process. Anticipatory governance consists of three steps: analysis of future possibilities (similar to the development of alternatives in scenario planning), creation of flexible and modular adaptation strategies, and monitoring conditions and responding to changes as they occur (Quay 2010). The first phase requires the development of a range of scenarios and their potential impacts. Various adaptation strategies are then devised to address these impacts, with special attention paid to strategies that are useful in multiple scenarios. Strategies are developed as discrete pieces that can be implemented as needed or halted, depending on the results of the monitoring of conditions. Anticipatory guidance requires the continuous reassessment of adaptation strategies as new information and data becomes available. Quay cites the cities of Phoenix, New York, and Denver as case studies of institutions using anticipatory governance to plan for climate change adaptation. As it explicitly accounts for uncertainty in future conditions, anticipatory guidance provides a promising alternative to traditional planning methods when planning for climate change.

Conclusions and Next Steps

This report has summarized the work of the second grant period of the HRPDC's Climate Change Adaptation Focal Area Grant, funded in part by the Virginia Coastal Zone Management Program. The goals of this grant year period were to develop a tool to estimate the impacts of climate change, specifically sea level rise, on Hampton Roads, to analyze the projected impacts of climate change and sea level rise on Hampton Roads' built environment, natural environment, and economy, and to continue involving the public and other institutions, governmental and non-governmental, on the issue of climate change through education and engagement. This report includes the results of the initial technical analysis of vulnerability. While only a rough estimate, the results show that Hampton Roads is already vulnerable to storm surge flooding, and for the same reasons (low elevation and flat topography) is vulnerable to sea level rise. The methodology developed provides a baseline for future research and analysis. The mix of public outreach events provided a great deal of feedback for this project as well as opportunities to educate the public on sea level rise.

The work conducted during this grant year has also helped identify specific needs for the final grant period of this grant. These include data acquisition and analysis, policy research, and establishment of regional groups tasked with developing and providing advice and recommendations. Data and research remains one of the greatest needs for effective climate change planning. This includes utilizing available high-resolution elevation data for vulnerability analysis as well as refining asset datasets. Research is also needed on subsidence; it is necessary to expand upon the research from VIMS and refine both the extent and the causes of subsidence in Hampton Roads so that it may be planned for or mitigated. Working groups that bring together representatives from local government staffs and technical experts are also needed to help enhance the technical capacity in Hampton Roads for climate change planning as well as to refine and consider adaptation options. Such working groups can help form an important part of a regional framework for climate change planning and adaptation. Continued cooperation and engagement with other organizations and institutions, such as Old Dominion University's Climate Change and Sea Level Rise Initiative and various programs at the Virginia Institute of Marine Science, is an important part of expanding technical capacity in the region and promoting regional discussion of the implications of climate change on Hampton Roads.

Looking forward, HRPDC staff will continue during the next grant period to work with other institutions, including ODU and VIMS, to promote discussion and to develop decision tools to model impacts, assess vulnerabilities, and analyze potential responses. HRPDC staff will also continue with analysis of the impacts of climate change on the Hampton Roads region and to engage the public, other stakeholders, and regional local governments on planning for climate change and sea level rise.

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Appendix A: Census Documentation for Data Change in Norfolk, VA

The following attachments are documents sent by the U.S. Census Bureau to the City of Norfolk that document changes made to the official 2010 Census count for purposes of redistricting. Included are a letter from the Director of the U.S. Census Bureau to the Mayor of Norfolk, an errata table containing the corrected data, and a data note summarizing the updated population counts for the 2010 Census Advance Group Quarters Summary File. This documentation is referenced on page 18 of the main report.

UNITED STATES DEPARTMENT OF COMMERCE
Economics and Statistics Administration
U.S. Census Bureau
Washington, DC 20233-0001
OFFICE OF THE DIRECTOR

February 22, 2011

The Honorable Paul D. Fraim
Mayor, City of Norfolk
1001 City Hall Building
810 Union Street
Norfolk, VA 23510

Dear Mayor Fraim:

I was recently alerted to an error with the census block level population counts in the Norfolk area following the release of the Public Law (P.L.) 94-171 for the Commonwealth of Virginia.

State and municipal officials discovered this error when they began analyzing the data for the Norfolk area and noticed that a census block, which should have contained a large portion of the Norfolk Naval Station, was showing a population of approximately 20,000 fewer people than projected. Moreover, a nearby census block contained a much higher population than anticipated.

The U.S. Census Bureau determined that this error was the result of a geocoding discrepancy. Such discrepancies can occur when a living quarter, such as a house, apartment, or military vessel, is placed in an incorrect location. In this instance, ships ported at the Norfolk Naval Station were incorrectly located in Block 51710 0038.00 1000. These ships correctly belong in Block 51710 0009.02 1044, approximately three miles to the north of the incorrect block.

The Census Bureau is providing new population counts that will enable data users to correct the census populations for these two blocks. The enclosed *errata* table shows the updated population counts for the two blocks affected by this error. We are also transmitting this updated block information by e-mail to the Virginia General Assembly. We will post *errata* notices on our Redistricting Data Program Web site and the American FactFinder, the 2010 Census dissemination Web site.

This new information should allow the City of Norfolk, the General Assembly, and other data users to correct for the error in the P.L. 94-171 data, as well as subsequent data products. Based on discussions with representatives from the General Assembly, we are confident that this solution will enable the General Assembly to proceed with redistricting on schedule.

I apologize for this error and the subsequent confusion. In addition, I would like to thank you and the citizens of Norfolk for your understanding in this matter, as well as your support and participation in the 2010 Census.

Sincerely,

Robert M. Groves
Director

Enclosure

Norfolk Errata

	Corrected Block 51710 0038.00 1000	Corrected Block 51710 0009.02 1044	Original (PL) Block 51710 0038.00 1000	Originel (PL) Block 51710 0009.02 1044
RACE				
Universe: Total population				
Total	73	19,279	19,352	0
White alone	37	11,702	11,739	0
Black or African American alone	20	5119	5,139	0
American Indian and Alaska Native alone	0	202	202	0
Asian alone	11	678	690	0
Native Hawaiian and Other Pacific Islander alone	1	73	74	0
Some Other Race alone	3	784	787	0
Population of Two or More Races	1	720	721	0
HISPANIC OR LATINO, AND NOT HISPANIC OR LATINO				
Universe: Total population				
Total	73	19,279	19,352	0
Hispanic or Latino	6	2,584	2,590	0
Not Hispanic or Latino	67	16,695	16,762	0
RACE FOR THE POPULATION 18 YEARS AND OVER				
Universe: Total population 18 years and over				
Total	69	19,278	19,347	0
White alone	33	11,702	11,735	0
Black or African American alona	20	5118	5,138	0
American Indian and Alaska Native alone	0	202	202	0
Asian alone	11	679	690	0
Native Hawaiian and Other Pacific Islander alone	1	73	74	0
Some Other Race alone	3	784	787	0
Population of Two or More Races	1	720	721	0
HISPANIC OR LATINO, AND NOT HISPANIC OR LATINO BY FOR THE POPULATION 18 YEARS AND OVER				
Universe: Total population 18 years and over				
Total	69	19,278	19,347	0
Hispanic or Latino	6	2,584	2,590	0
Not Hispanic or Latino	63	16,694	16,757	0
OCCUPANCY STATUS				
Universe: Housing units				
Total:	5	0	5	0
Occupied	5	0	5	0
Vacant	0	0	0	0

2010 Census
Advance Group Quarters Summary File
Data Note 1

Geocoding errors can occur when a living quarter such as a house, apartment, or military vessel, is placed in an incorrect location. As a result of a geocoding error, the Census Bureau is providing revised population counts for two 2010 Census tabulation blocks in Norfolk, Virginia. The geocoding error placed ships ported at the Norfolk Naval Station incorrectly in block 1000, census tract 38, Norfolk city. These ships correctly belong in block 1044, census tract 9.02, Norfolk city.

The corrected and original population counts are:

Population in corrected block 1000, census tract 38	Population in corrected block 1044, census tract 9.02	Population in original block 1000, census tract 38	Population in original block 1044, census tract 9.02
73	19,279	19,352	0

For additional information, see <www.census.gov/rdo/pdf/VA_errata.pdf>.

This note is applicable to 2010 Census data products containing data at the census tract or block levels, including:

- Redistricting Data (Public Law 94-171) Summary File
- Advance Group Quarters Summary File
- Summary File 1
- Summary File 2
- Congressional District Summary File (113th Congress) and subsequent releases
- State Legislative District Summary File and subsequent releases

April 2011

APPENDIX B: GIS CALCULATIONS

These are the calculations used to perform the population vulnerability analysis within ArcGIS. The analysis for quantifying the vulnerable population in Hampton Roads to various categories of storm surge required, first, calculating how much of each census block was within each category of storm surge, and second, calculating the population within each block within the vulnerable areas. The datasets used for this analysis were the 2010 Census Blocks (boundary files) and Redistricting Data (demographic data).

Extracting vulnerable areas from Census blocks

Step 1: Overlay storm surge areas on blocks.

Step 2: Using the Clip tool, extract the areas of the census blocks within each storm surge zone (this creates four new datasets).

Calculating storm surge areas within blocks

Step 3: Create a new table containing the following fields for each census block: ID number, county FIP code, total population, area (acres), category 1 area (acres), category 2 area (acres), category 3 area (acres), and category 4 area (acres). Name the category area categories Cat1_Acres, Cat2_Acres, etc.

Step 4: Open the attribute table of the clipped dataset.

Step 5: Create a new field, Area_Acres (double).

Step 6: Using the Calculate Geometry function, calculate the area of the clipped blocks in acres (U.S.).

Step 7: Join the clipped dataset (as a table) to the new table.

Step 8: Using the Field Calculator, copy the values for storm surge areas to the table using this formula:

Cat1_Acres = area1a

Dim area1a as double

If [HRblocks2010_sp_2.Area_Acres] > 0 Then

area1a = [HRblocks2010_sp_2.Area_Acres]

elseif [HRblocks2010_sp_2.Area_Acres] = "<Null>" Then

area1a = 0

end if

Note: HRblocks2010_sp_2 is the name of the census blocks shapefile or feature class that has been clipped to the category 2 storm surge zone.

Step 9: Repeat Steps 4-8 for each storm surge/census feature class or shapefile.

Calculating the ratio of storm surge areas to total areas within blocks

Step 10: In the table, create four new fields (double): Cat1_Ratio, Cat2_Ratio, Cat3_Ratio, and Cat4_Ratio.

Step 11: Using the Field Calculator, calculate the ratio of storm surge area to total area for each block using the following formula:

Cat3_Ratio =

[Cat3_Acres] / [Area_Acres]

Note: Cat3_Acres is the area of a block that is within the category 3 storm surge zone, and Area_Acres is the total area of a block.

Step 12: Repeat Step 11 for each storm surge area.

Calculating the vulnerable population within each block for each category of storm surge

Step 13: In the table, create four new fields (long integer): Cat1_POP, Cat2_POP, Cat3_POP, and Cat4_POP.

Step 14: Using the Field Calculator, calculator the vulnerable population for each block using the following formula:

Cat1_POP =

[Cat1_Ratio] * [POP100]

Note: POP100 is the total population of the census block.

APPENDIX C: SAMPLE PRESENTATION

The following attachment contains slides from a presentation given to the members of the Unitarian Church of Norfolk on June 25, 2010. Mr. Benjamin McFarlane and Mr. John Carlock were invited to speak to the congregation about the issues of flooding and sea level rise. The event is described in greater detail in the Public Outreach section of the main report (page 58).

CLIMATE CHANGE, SEA LEVEL RISE, AND HAMPTON ROADS

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Environmental Planner, HRPDC

Image courtesy of Dr. David Powell – Portsmouth, VA

June 25, 2010

Presentation to the Unitarian Church of Norfolk

What is the HRPDC?

- 1 of 21 Regional Planning Agencies in Virginia
- State enabled – locally created
- Commission: 45 members (25 elected, 16 CAO)
- Staff – Executive Director & 45 staff
- Technical Advisory Committees
- Areas – Economics, Housing, Emergency Management, Environmental, Planning, Transportation
- Budget - $11,000,000 +/-
- Functions – Policy and Technical Analysis, Planning and Engineering Studies, Cooperative Problem Solving, Coordination

Key HRPDC Issues for CY 2010

- Water Quality Management including SSO Requirements, Stormwater Programs, Chesapeake Bay Program, TMDLs
- **Climate Change & Sea Level Rise**
- Catastrophic Planning
- Comprehensive Education Programs
- Security and Emergency Management
- Transportation Project Prioritization
- Long Range Transportation Plan
- Regional &/or Local Water Supply Plans
- Funding – Infrastructure and Programs

HRPDC Climate Change Project

- 3-year grant project with the Virginia Coastal Zone Management Program
- Year 1: Research on Mid-Atlantic climate change impacts, begin stakeholder process
- **Year 2: Establishment of regional climate change working group, assessment of potential impacts and development of policy recommendations through stakeholder process**
- Year 3: Continued assessment of infrastructure and environmental impacts and completion of the regional framework for adaptation to climate change

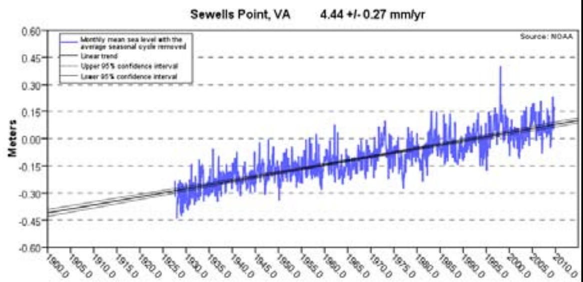
Climate Change in Hampton Roads

- Temperature Rise
  - 3.1° C (5.6 ° F) average warming for Virginia by 2100
- Precipitation increase
  - 11% increase by 2100
  - Shift in when precipitation occurs
- Sea Level Rise: Broad range of forecasts

Changing Flood Threat

- Sea Level Rise
  - Forecasting sea level rise rates is a difficult challenge
    - Unknown future greenhouse gas emission rates
    - Incomplete understanding of ice melt dynamics
    - Projections are typically given as ranges by 2100
      - IPCC 2007 Low Emission Scenario: 0.6-1.3 feet
      - IPCC 2007 Higher Emission Scenario: 0.7-1.6 feet
      - IPCC 2007 Even Higher Emission Scenario: 0.8-1.9 feet
      - More recent projections: 3-4 feet

Historic Sea Level Rise

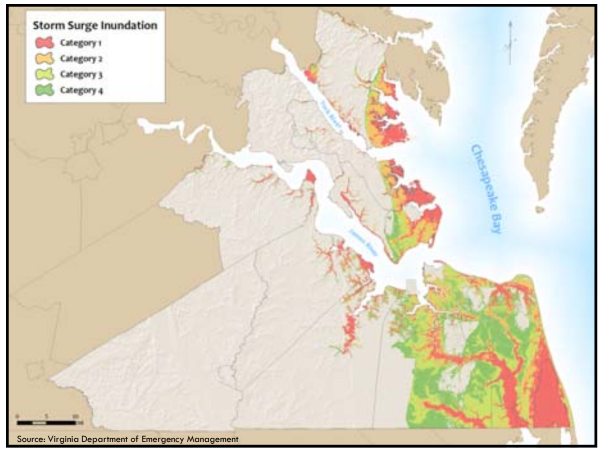


Changing Flood Threat

- Land Subsidence
  - Combination of factors contribute to land subsidence in Hampton Roads
    - Located on a passive continental margin
    - Withdrawal of groundwater for drinking water and other uses
    - Rate of land subsidence varies across Hampton Roads
    - 2mm per year is an average rate of subsidence for the region
    - At the Sewell's Point tide gage subsidence likely accounts for 1/3 to 1/2 of the total sea level rise for the period of record

Impacts of Sea Level Rise in Hampton Roads

- Major Challenges for Hampton Roads
  - **Flood threat** will increase over time:
    - Increased frequency and severity of flooding from small storm events
    - Increased risk of catastrophic flooding from large storm events
  - **Infrastructure impacts** due to sea level rise and associated increase in storm surge
  - **Flooding and loss of wetlands** due to sea level rise



Responding to Climate Change

- Two responses:
  - Mitigation
  - Adaptation
- Mitigation reduces *the extent* of climate change
- Adaptation reduces *the impacts* of climate change

Responding to Climate Change: Mitigation

- Mitigation can reduce the rate or extent of climate change and focus on reducing emissions
- Proactive rather than reactive
- Achieved through technology changes or policy decisions

Responding to Climate Change: Adaptation

- Adaptation can reduce the impacts of climate change on human and natural systems
- Three categories:
  - Protection
  - Accommodation
  - Retreat

HRPDC Ongoing Efforts and Next Steps

- Mitigation efforts:
  - Regional greenhouse gas emissions inventory
  - Energy efficiency efforts
- Adaptation efforts:
  - Data and information acquisition
  - Vulnerability analyses
- Planning efforts:
  - Regional climate change working group
  - Development of Regional Framework for Mitigation and Adaptation to Climate Change

Conclusion

- Climate change is a very complicated and daunting problem – institutionally, scientifically, and physically
- Planning for climate change now can help reduce costs and impacts in the future

Thank you

- Questions?
- Contact:
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  bmcfarlane@hrpdcva.gov