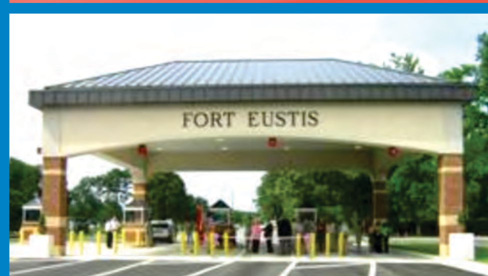
Hampton Roads Military Transportation Needs Study

Roadways Serving the Military and Sea Level Rise/Storm Surge

Prepared by:
Hampton Roads Transportation Planning Organization



T13-04

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July 2013

HAMPTON ROADS TRANSPORTATION PLANNING ORGANIZATION

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HAMPTON ROADS
MILITARY TRANSPORTATION NEEDS STUDY

ROADWAYS SERVING THE MILITARY AND SEA LEVEL RISE/STORM SURGE

PREPARED BY:

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REPORT DOCUMENTATION

TITLE:
Hampton Roads
Military Transportation Needs Study:
Roadways Serving the Military and Sea Level Rise/Storm Surge

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ABSTRACT

The Hampton Roads Military Transportation Needs Study is comprised of three phases:

1. Highway Network Analysis
2. Military Commuter Survey
3. Roadways Serving the Military and Sea Level Rise/Storm Surge

This report builds primarily on the first phase by estimating the sea level rise and potential storm surge threats to the "Roadways Serving the Military" network established in the Highway Network Analysis report. Updating the HRTPO Long-Range Transportation Plan Project Prioritization Tool to reflect this vulnerability will help the HRTPO Board direct transportation funds to address that vulnerability.

REPORT DATE
July 2013

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Introduction

Late in 2009, several local military representatives told the Hampton Roads Transportation Planning Organization (HRTPO) Board that congestion and delays at bridges and tunnels hurt mission performance effectiveness and efficiency. Rear Admiral Byron E. Tobin (Retired US Navy) addressed the HRTPO Board during February 2010 stating:

> "…we are dependent, in large measure, upon the resources and support of this region for the efficient and successful conduct of our mission. One of the key components of that success is mobility, [which is currently impeded] because our transportation infrastructure is in decline and struggling to meet our needs."

In response, the HRTPO Board placed greater emphasis on military transportation planning in the region and endorsed annual military briefings by military representatives to the HRTPO Board and to the Commonwealth Transportation Board, and included a military needs study in its work program. The purpose of the Hampton Roads Military Transportation Needs Study is to identify and address the transportation needs of the military in Hampton Roads.

The Hampton Roads Military Transportation Needs Study is comprised of three phases:

1. Highway Network Analysis[1]
2. *Military Commuter Survey*[2]
3. Roadways Serving the Military and Sea Level Rise/Storm Surge

This report builds primarily on the first phase by estimating the sea level rise and potential storm surge threats to the "Roadways Serving the Military" network established in the Highway Network Analysis report. Updating the HRTPO Long-Range Transportation Plan Project Prioritization Tool to reflect this vulnerability will help the HRTPO Board direct transportation funds to address that vulnerability.

Hampton Roads Metropolitan Planning Area

Sea levels are rising at an accelerated pace for many areas in Hampton Roads.

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[1] *Hampton Roads Military Transportation Needs Study: Highway Network Analysis*, HRTPO, September 2011.

[2] *Hampton Roads Military Transportation Needs Study: Military Commuter Survey*, HRTPO, September 2012.

Hampton Roads Military Transportation Needs Study: Summary of Prior Phases

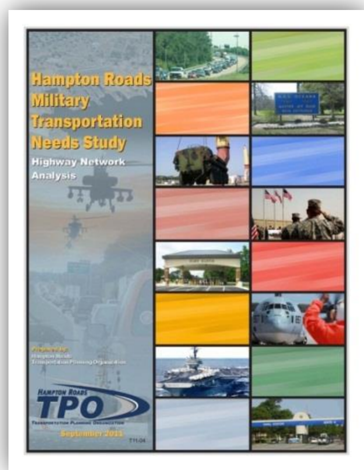
Phase I: Highway Network Analysis

Phase I of the Hampton Roads Military Transportation Needs Study was completed and approved by the HRTPO Board in September 2011. In this first phase, HRTPO staff worked with various stakeholders – local military representatives, state and federal agencies, port officials and local jurisdictions – to determine transportation concerns and needs of the local military. As described in detail on the following page, the HRTPO staff identified a roadway network that includes both the Strategic Highway Network (STRAHNET) and additional roadways that serve the military sites and intermodal facilities not included in the STRAHNET. STRAHNET (developed by the U.S. Department of Defense (DoD)) serves as the minimum national defense public highway network needed to support a defense emergency and are used for day-to-day military cargo movement. Staff analyzed this "Roadways Serving the Military" network to determine deficient locations, such as congested segments, deficient bridges, and inadequate geometrics. The study made numerous recommendations to address existing deficiencies and to accommodate future military travel needs, including revisions to current STRAHNET designations, increasing vertical clearance of tunnels, expanding the width of highway lanes to accommodate military vehicles, rehabilitating or replacing structurally deficient bridges, extending light rail transit to Naval Station Norfolk and high-speed passenger rail service to Washington, D.C.

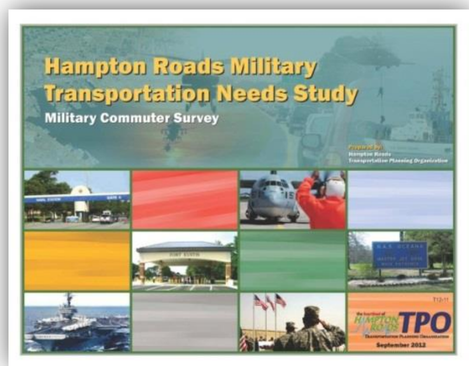
Phase II: Military Commuter Survey

The HRTPO staff continued this study with the creation of the first region-wide Military Commuter Survey, which was conducted from November 8, 2011 to February 24, 2012. Via the survey, the HRTPO collected information about the commuting experience of military personnel (active-duty, civilians, contractors, reservists and others) travelling to/from the region's military bases, receiving a total of 10,994 survey responses. The survey was developed by HRTPO staff in concert with the commands of the region's military installations and various other transportation stakeholders. The purpose of the survey was to determine the transportation challenges facing local military personnel during their daily commutes in Hampton Roads.

Phase I:
Highway Network Analysis



Phase II:
Military Commuter Survey



The survey was developed using Google documents and hosted on the HRTPO website. Even though survey responses were sought from all military commuters in the region, military commuters were specifically targeted who travel to/from 29 of the 38 military and supporting sites identified in phase I of the study. These 29 military sites are the primary locations for military-related employment. The remaining 9 locations are supporting sites, such as port terminals and airports, which move military personnel and goods in the event of a national or local emergency. Note that one benefit of hosting the survey on the HRTPO website was that thousands of military personnel who reside within Hampton Roads were introduced to the HRTPO, some learning about its metropolitan planning process and activities for the first time.

Respondents were asked to identify items such as length of morning and afternoon commutes, mode of transportation, transportation problems, and any locations of recurring trouble along their commute. The top reported transportation problems by military commuters were traffic congestion (79%), traffic backups at military gates (67%), and poor roadway maintenance (42%). At the end of the survey, respondents were asked to submit any suggestions they had regarding transportation in the region. Not only was excellent feedback provided, but many expressed thanks for having the opportunity to communicate their transportation challenges.

IDENTIFICATION OF "ROADWAYS SERVING THE MILITARY"

At initial meetings held for phase I of the Hampton Roads Military Transportation Needs Study: Highway Network Analysis, several stakeholders expressed concern that many military-related sites in Hampton Roads were not included as Strategic Highway Network (STRAHNET) sites. As a result, HRTPO staff identified additional Hampton Roads military sites and intermodal facilities not included in STRAHNET and prepared a list of roadways that serve those locations.

First, HRTPO staff worked with the stakeholder group to develop a list of 38 "Military and Supporting Sites" that were grouped into three categories: 1) STRAHNET Sites 2) Other Intermodal Facilities and 3) Other Military Sites.

Secondly, HRTPO staff developed a comprehensive "Roadways Serving the Military" network unique to Hampton Roads (see page 10). This new roadway network consists of existing Strategic Highway Network (STRAHNET) roadways as well as non-STRAHNET roadways that serve military sites or intermodal facilities in the region. Staff used the following criteria in selecting the non-STRAHNET roadways:

- Routes that are commonly used for access/egress (for commuting & daily activities), generally the most direct and highest functional class roadway
- Routes that provide access/egress to main entry gate
- Routes that provide access/egress to other entry gates (STRAHNET currently provides one connector roadway usually to the main gate)
- Routes that are currently identified as National Highway System (NHS) Intermodal Connectors
- Routes that provide connectivity to/from STRAHNET or between Military Sites
- Routes that provide access/egress to and from locations outside of Hampton Roads for military-related travel

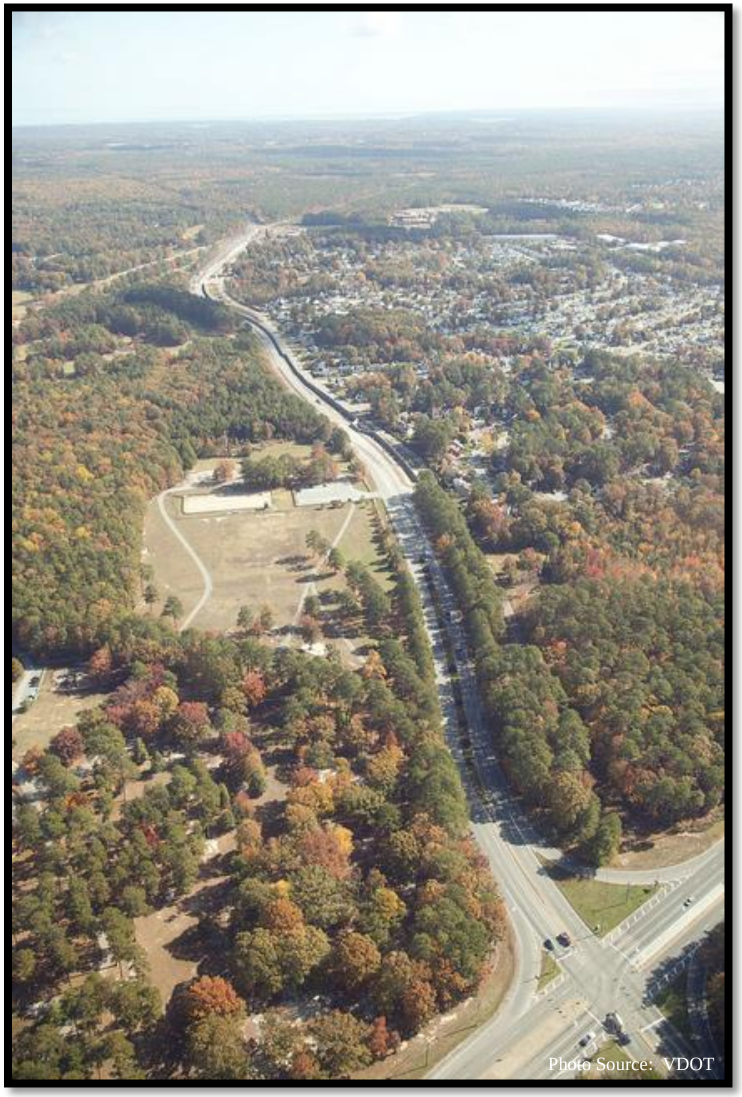
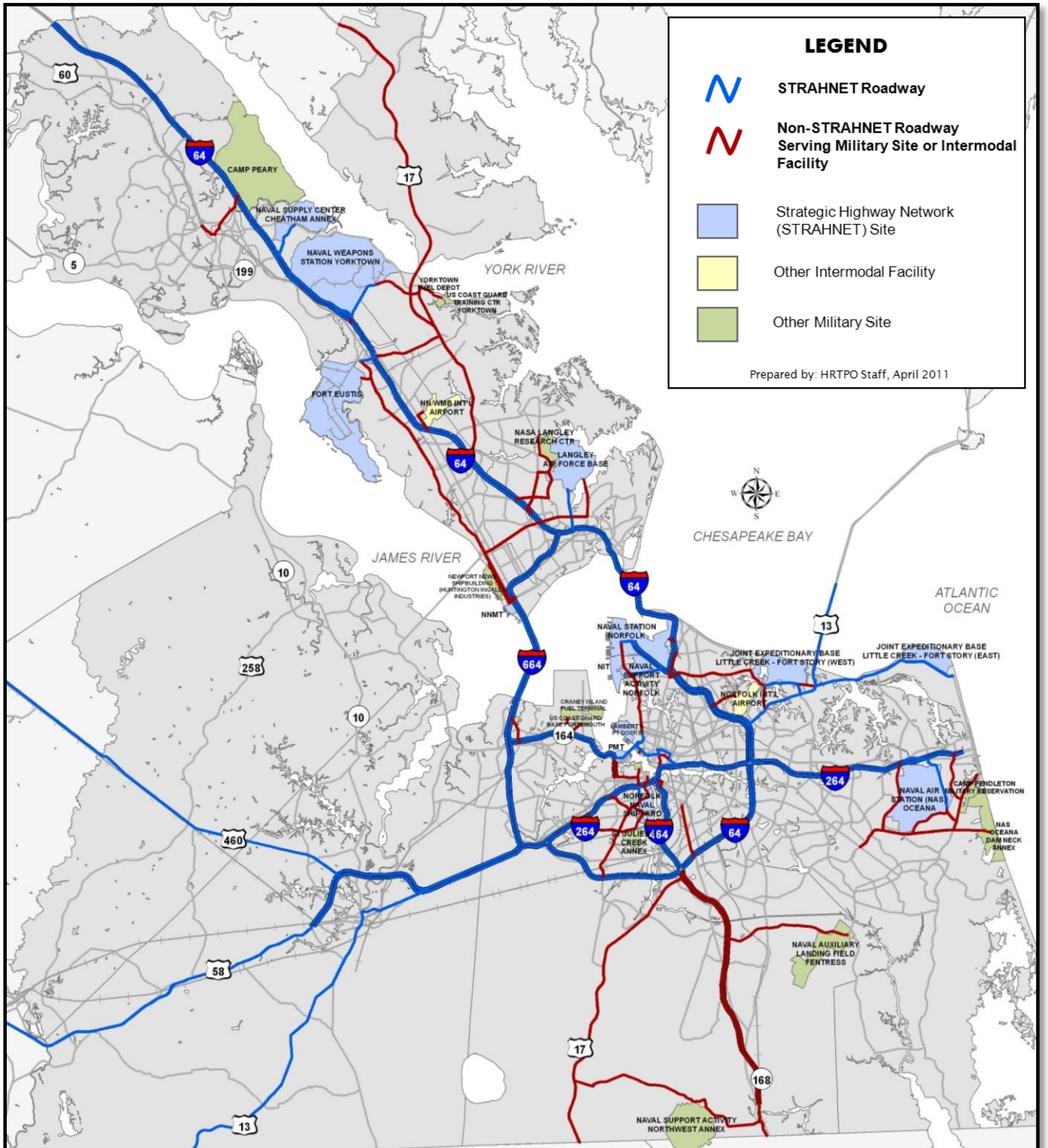


Photo Source: VDOT

Aerial view of Fort Eustis Boulevard (Newport News/York County), which was identified as one of the "Roadways Serving the Military".

Roadways Serving the Military – Hampton Roads



EXISTING FLOODING FREQUENCY BY LOCATION

The Virginia Department of Transportation (VDOT) currently maintains a database with road closure locations as a result of flooding, but only for state maintained roadways. As a general rule, the state roadways that VDOT maintains include all roadways within counties as well as interstate highways within cities with a few local exceptions (i.e. Western Freeway and Midtown Tunnel are VDOT maintained). While these flooding data are excellent information, they only provide roadway locations that have recurrent flooding problems for a portion of the entire region. Flood location data for locally maintained roads in each Hampton Roads locality are not consistently available. Some cities maintain records of emergency calls or storm sewer backups, but these records are not uniform or readily available across the region.

For this study, two maps have been created using Geographic Information System (GIS) data from the Virginia Institute of Marine Science (VIMS). They show the flooding frequency of VDOT roadways within Hampton Roads from August 2008 – May 2012[3]. The VDOT data from VIMS included roadway closure locations that have flooded due to any cause (i.e. flood, hurricane, or standing water/ponding). Although VIMS included a similar map of these VDOT roadways within the Recurrent Flooding Study for Tidewater Virginia, it was difficult to identify specific roadway locations within Hampton Roads[4]. As a result, the HRTPO staff created new maps with closer views for the Hampton Roads Peninsula and Southside (see pages 12-13). Additionally, these recurrent flooding locations have been overlaid on top of the "Roadways Serving the Military" to identify current flooding problems on these roadways.

These maps were used to check the reasonableness of potentially submerged roadways due to relative sea level rise and storm surge in the future shown in upcoming maps/tables in the "Potential Flooding for Roadways Serving the Military" section.

Flooding may be due to rising water that submerges the area and/or inadequate drainage on the maps on the following two pages.

Photo by Amanda Lucier - Virginian-Pilot

Flooding along Hampton Boulevard in the Larchmont/Edgewater neighborhood in Norfolk as a result of severe rain on July 29, 2010.

Some of the flooding roadway sections shown in the maps on pages 12-13 are at bridge and tunnel locations. Flooding at bridge and tunnel facilities is a major concern as closures at these key locations inhibits the ability to evacuate, transport emergency services, and move military personnel/cargo during large rain events and coastal storms. Closures due to flooding at any of Hampton Roads' river crossings could result in long, complicated detours and significant increases in travel times.

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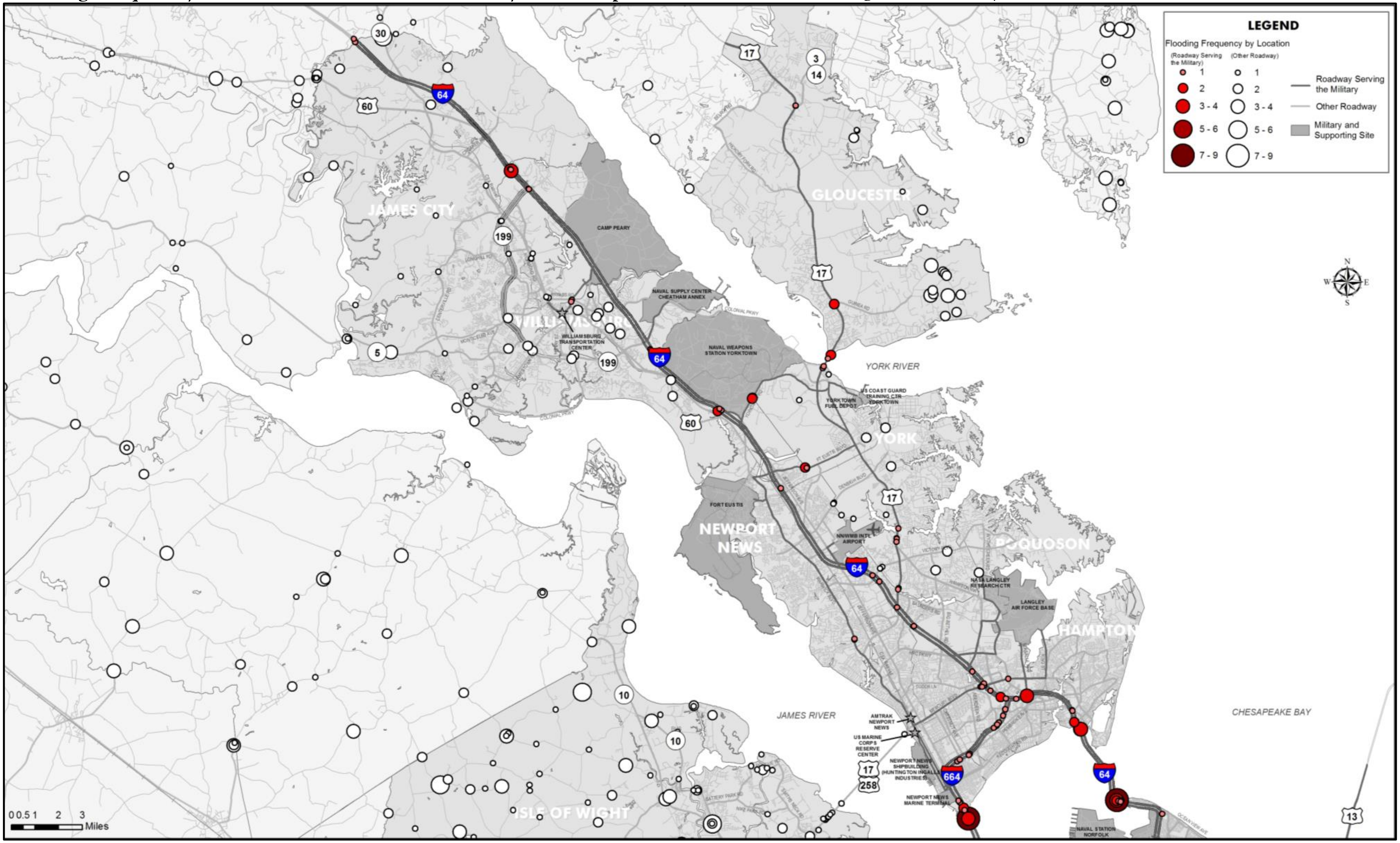
[3] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, 2013, p. 71.
[4] *Ibid, p. 71.*

Flooding Frequency for VDOT Maintained Roadways* – Hampton Roads Peninsula (August 2008 – May 2012)

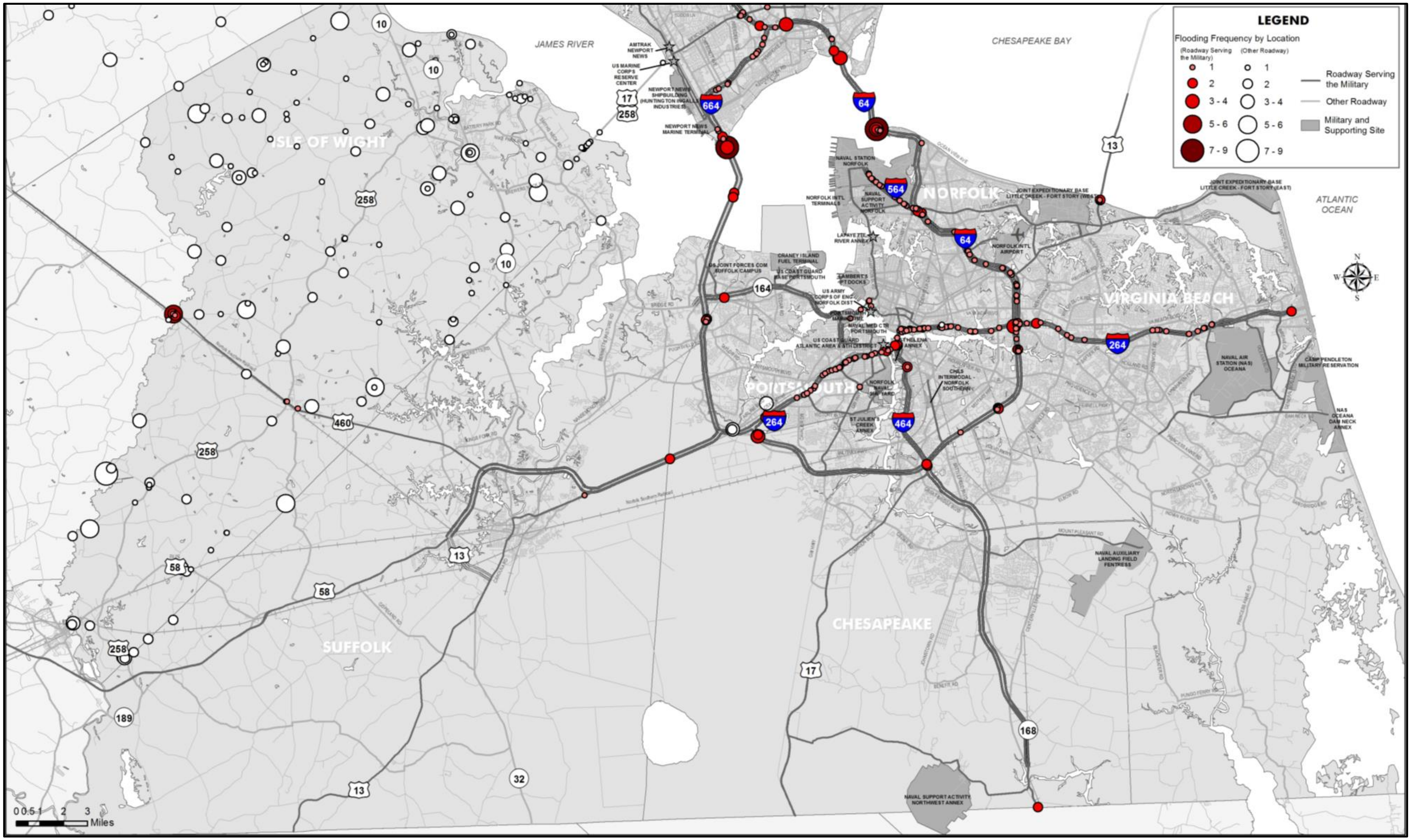


Prepared by: HRTPO Staff, March 2013

Flooding Frequency Data Source: VDOT, 2012 (from Virginia Institute of Marine Science)

*VDOT maintains all roadways within counties and interstate highways within cities with a few local exceptions (i.e. Western Freeway and Midtown Tunnel are VDOT maintained). VDOT also provides funding for principle arterial roadways in the cities through its urban maintenance program and is involved in several major roadway construction and improvement projects within city limits.

Flooding Frequency for VDOT Maintained Roadways* – Hampton Roads Southside (August 2008 – May 2012)



Prepared by: HRTPO Staff, March 2013

Flooding Frequency Data Source: VDOT, 2012 (from Virginia Institute of Marine Science)

*VDOT maintains all roadways within counties and interstate highways within cities with a few local exceptions (i.e. Western Freeway and Midtown Tunnel are VDOT maintained). VDOT also provides funding for principle arterial roadways in the cities through its urban maintenance program and is involved in several major roadway construction and improvement projects within city limits.

Hampton Roads, second only to New Orleans in terms of vulnerability to sea level rise in the United States, is seeing more frequent storm surges and higher tides than before[5]. Based on past storm events, Hampton Roads' east coast location makes it prone to significant storm surges about every four to five years.

The purpose of this section is to define sea level rise/storm surge terminology and trends for Hampton Roads, discuss potential impacts of sea level rise and storm surge on the military and roads systems, and provide a brief description of some related recent studies and work.

DEFINING SEA LEVEL RISE AND STORM SURGE

Sea Level Rise

The "relative" sea level rise for a given area is the change in sea level relative to the elevation of the land in that same area. This change is affected by three factors:

1) Global Sea Level Rise (change in ocean volume)
2) Land Subsidence
3) Ocean Circulation

> **"Relative Sea Level Rise"** = "Global Sea Level Rise" + "Land Subsidence" + Rise from "Ocean Circulation"

Global Sea Level Rise

Global sea level rises due to changes in the density and quantity of water in the world's oceans[6]. The two primary processes that have increased ocean water volume are 1) rising ocean temperatures – which cause the water to expand (thermal expansion) – and 2) melting glaciers, ice caps, and ice sheets. These two processes are estimated to have added over six inches to sea levels in the past century. These processes have increased in recent years and are now estimated to be adding water volume at double the prior rate[7].

Land Subsidence

Land subsidence is the sinking of land. Subsidence generally occurs from sediment compaction or extraction of subsurface liquids like water or oil. One of the ongoing causes of land subsidence in the mid-Atlantic coastal region is the result of retreating ice sheets from the last Ice Age. As the ice sheets melted and retreated north, pressure from the weight of the ice was released and the earth's crust is still slowly readjusting. In Virginia, groundwater withdrawals are an additional contributing factor[8]. Local paper mills in West Point and Franklin extract groundwater as part of their manufacturing process, which causes the overlying areas to settle and sediments to compact over time. In general, land subsidence accounts for between one-third and one-half of the relative sea level rise in the Hampton Roads region[9].

Photo by Stephen M. Katz - Virginian-Pilot

Colonial Place neighborhood in Norfolk during Nor'easter in November 2009.

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[5] *Virginia Conservation Network website*, "Confronting Climate Change" webpage, www.vcnva.org, April 2013.

[6] *Climate Change in Hampton Roads – Impacts and Stakeholder Involvement*, Hampton Roads Planning District Commission (HRPDC), February 2010, p. 5.

[7] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, January 2013, p. 110.

[8] *Ibid, p. 110-111.*

[9] *Climate Change in Hampton Roads: Impacts and Stakeholder Involvement*, HRPDC, February 2010, p. 6.

Ocean Circulation

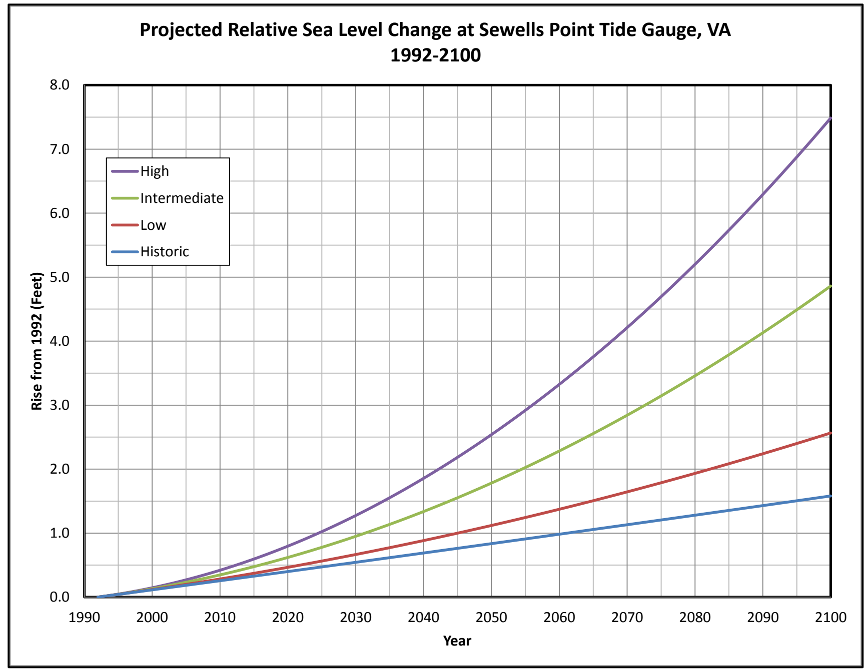
The decreasing rate of movement by the ocean currents that circulate the globe has contributed to the rapid rise in local sea levels discussed below. Some experts explain that this rise is occurring here in the Mid-Atlantic due to a slowing of the Gulf Stream as the polar region continues to warm. Slower moving water means less pressure is present to move water away from the coast, resulting in higher water levels[10].

Trends in Relative Sea Level Rise for Hampton Roads

Hampton Roads has experienced a total of 1.15 feet of relative sea level rise over the last 79 years (1927 to 2006), based on the Sewell's Point tide gauge located on Naval Station Norfolk[11]. According to VIMS, recent analyses and indicators have detected acceleration in the rate of relative sea level rise from the mid-Atlantic to New England[12]. Existing research of global atmospheric processes indicated that temperatures will continue to rise at least until the end of the century. The uncertainty, however, is how high these temperatures will go. The rate of land subsidence in Hampton Roads is expected to remain relatively constant.

1933 Flooding on Granby Street in Norfolk.

As shown on the graph on this page, the Hampton Roads Planning District Commission (HRPDC) staff has projected relative sea level rise in the range of approximately 1.6 to 7.5 feet between 1992 and the year 2100 for Sewells Point based on the four global sea level rise scenarios in the 2013 U.S.



Source: HRPDC, March 2013.

National Climate Assessment[13]. HRPDC staff incorporated local land subsidence into the global scenarios to develop the four regional scenarios. The four scenarios (historic, low, intermediate, and high) vary significantly due to the uncertainty of future global sea level rise estimates. Based on trends and local knowledge, HRPDC staff estimate that Hampton Roads may fall somewhere between the "low" and "intermediate" curves. According to HRPDC projections (see graph above), a 1.5 foot rise in relative sea level is estimated to occur sometime between 2044 (intermediate) and 2065 (low). The Virginia Institute of Marine Science recently stated that a 1.5 foot rise in relative sea level is "well within the best available forecasts for Virginia over the next 20 to 50 years"[14]. With the VIMS analysis completed in 2012, a 1.5 foot rise in relative sea level rise for the state can be expected between 2032 and 2062.

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[10] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, January 2013, p. 111.

[11] National Oceanic and Atmospheric Administration (NOAA) from *Climate Change in Hampton Roads – Impacts and Stakeholder Involvement*, Hampton Roads Planning District Commission (HRPDC), February 2010, p. 6-7.

[12] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, January 2013, p. 111.

[13] *Global Sea Level Rise Scenarios for the United States National Climate Assessment*, National Oceanic and Atmospheric Administration, NOAA Technical Report OAR CPO-1, December 6, 2012.

[14] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, January 2013, p. 8.

Based on Hampton Roads Planning Distric Commission (HRPDC) and Virginia Institute of Marine Science (VIMS) projections, it appears reasonable to anticipate **a 1.5 foot rise in relative sea level for Hampton Roads between 2032 and 2065.**

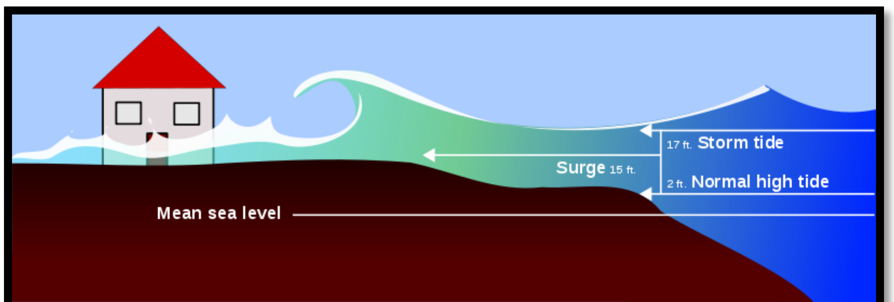
With the forecast year of the next HRTPO Long-Range Transportation Plan being 2040, a 1.5 foot relative sea level rise scenario will be used in the "potential flooding" analysis in this report.

Storm Surge

According to the National Oceanic and Atmospheric Administration (NOAA), storm surge is water that is pushed toward the shore by the force of the winds swirling around the storm. In addition, low atmospheric pressure associated with storms raises sea levels. Storm surge is caused by a severe storm, such as a hurricane, tropical storm, or nor'easter. This surge combines with the normal tides to create the storm tide, which can increase the mean water level 15 feet or more.

In addition, wind waves are superimposed on the storm tide. The resulting rise in water level can cause severe flooding in coastal areas, particularly when the storm tide coincides with diurnal high tides. Storm surges cause many deaths and devastating property losses, such as damaged roads and bridges, destroyed homes and businesses, and wiped out coastal communities. Because many properties in Hampton Roads lie less than 10 feet above mean sea level, the danger from storm tides is tremendous.

In Hampton Roads, storm surges were recorded at the Sewells Point, VA tide gauge at 4.2 feet during Hurricane Irene in 2011 and 4.4 feet during Hurricane Isabel in 2003.



Impact of a Storm Surge

Source: Wikipedia, Surg big.jpg by Pierre cb, June 2007.

Flooding during Hurricane Isabel in 2003.

Based on historical storm surges in Hampton Roads, **a 3 foot storm surge is a reasonable level to expect for moderate future storms.**

A 3 foot storm surge scenario will be used in the "potential flooding" analysis in this report.

Previous Studies and Related Work

The impacts of relative sea level rise and storm surge have been recognized along the southeast coast for many years, particularly for low-lying communities such as Hampton Roads, Virginia. National, state, regional, and local organizations have participated (or are currently participating) in initiatives that address this pressing issue in order to raise awareness and develop potential solutions. This section of the report provides a list and brief description of some recent studies and related work in sea level rise and storm surge:

City of Norfolk – City-Wide Coastal Flooding Study, Fugro Atlantic (Project Lead), Moffatt & Nichol, and Timmons Group, Initiated in 2007.

- This initiative is part of the City of Norfolk's ongoing effort to proactively address flooding. A series of studies have been completed throughout the city to determine vulnerability to sea level rise, high tides, and storm surges. Some recommendations include floodwalls, tide gates, elevated roads, water pumping stations, and upgrades to storm water pipes.

Integrating Climate Change into State and Regional Transportation Plans, Transportation Research Record: Journal of the Transportation Research Board, No. 2119, pp. 1-9, Gallivan, Ang-Olson, and Turchetta, 2009.

- This focus of this paper is on long-range planning documents as tools for climate change planning. Reviews included federal regulations and statutes that govern transportation planning as well as a sample of current planning documents from state departments of transportation and metropolitan planning organizations.

Incorporating Climate Change Considerations into Transportation Planning, Transportation Research Record: Journal of the Transportation Research Board, No. 2119, pp. 66-73, Schmidt and Meyer, 2009.

- In this paper, transportation plans and related documentation of metropolitan planning organizations and international cities were reviewed to ascertain whether climate change considerations are being incorporated in the transportation planning process. Recommendations are provided for greenhouse gas (GHG) emission mitigation and climate adaptation strategies.

Summary of Natural Resources/Shoreline Adaptation Strategy Recommendations of the Virginia Commission on Climate Change, Wetlands Watch, Skip Stiles, June 2009.

- This document summarizes the specific recommendations taken from the Virginia Commission on Climate Change that outline those adaptation provisions. It also contains a Virginia climate change adaptation strategy flow chart.

Climate Change in Hampton Roads – Impacts and Stakeholder Involvement, Hampton Roads Planning District Commission (HRPDC), February 2010.

- This report provides an overview of the potential impacts of climate change on the Hampton Roads region and describes various mitigation and adaptation strategies that can be taken to reduce and prevent damage from climate change impacts. A goal of this effort was to provide public outreach and education on these issues.

ODU Climate Change and SLR Research Initiative (CC/SLRI), Forum led by Old Dominion University, Initiated Fall 2010.

- The Hampton Roads Adaptation Forum is a regional dialogue among municipalities committed to adopting effective adaptation designs and plans, tailored to meet the needs of our communities in the face of rising sea levels due to climate change. The forum is composed of academic institutions and local, regional, state, and Federal agency officials with authority and responsibility for critical infrastructure and facilities in Hampton Roads (e.g., engineers, planners, facility managers, administrators, etc.). http://www.odu.edu/research/initiatives/ccslri

Climate Change Planning for Military Installations: Findings and Implications, Noblis, October 2010.

- The Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP) tasked Noblis to identify potential climate change effects on military installations and their missions and operations. This report presents the findings portion (collected June 2009 – February 2010) of this study and discusses some implications on policy and practice. Naval Base Norfolk was included as part of this study.

Vulnerability Analysis of Transportation Network Under Scenarios of Sea Level Rise, Transportation Research Record: Journal of the Transportation Research Board, No. 2263, pp. 174-181, Lu and Peng, 2011.

- This paper develops an accessibility-based process to analyze transportation network vulnerability to quantify networkwide vulnerability and to identify the most vulnerable regions under different scenarios of sea level rise.

Climate Change in Hampton Roads – Phase II: Storm Surge Vulnerability and Public Outreach, Hampton Roads Planning District Commission (HRPDC), June 2011.

- This report examines the impacts of storm surge flooding on various sectors, such as the built environment and economy, and on engaging the public. This effort was more quantitative and included a vulnerability analysis based on scenario development.

Economic Analysis of Impacts of Sea Level Rise and Adaptation Strategies in Transportation, Transportation Research Record: Journal of the Transportation Research Board, No. 2273, pp. 54-61, Lu, Peng, and Du, 2012.

- This paper attempts to quantify the economic impacts of the SLR as well as the costs and benefits of adaptation strategies by using cost–benefit analysis at the local level.

Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure: Hampton Roads Virginia Pilot, University of Virginia, Federal Highway Administration, January 2012.

- This report describes how anticipated impacts of climate change on transportation infrastructure in the Hampton Roads region of Virginia were assessed via a decision to help prioritize elements of the region's long range strategic plan. This study was part of a larger effort by the Federal Highway Administration to understand the vulnerability of critical transportation infrastructure in several regions.

Technical Report: Climate Change Sea Level Rise Initiative, Virginia Modeling, Analysis and Simulation Center, January 30, 2012.

- This report provides an initial design (conceptual model) of a Hybrid Simulation with the capability to assist stakeholders in a city or region to make strategic decisions to negate or mitigate the negative impacts of sea level rise.

Climate Change in Hampton Roads – Phase III: Sea Level Rise in Hampton Roads, Virginia, Hampton Roads Planning District Commission (HRPDC), July 2012.

- This report focuses on analyzing the potential future impacts of sea level rise on the region's population, built environment, infrastructure, economy, and natural environment. This was done through the development of a geographic information systems (GIS) tool to model the impacts of sea level rise.

Global Sea Level Rise Scenarios for the United States National Climate Assessment, National Oceanic and Atmospheric Administration (NOAA), NOAA Technical Report OAR CPO-1, December 6, 2012.

- This report provides a synthesis of the scientific literature of global sea level rise (SLR) at the request of a federal advisory committee charged with developing the next National Climate Assessment (NCA), which occurs every four years. It also provides a set of four global mean SLR scenarios to describe future conditions for the purpose of assessing potential vulnerabilities and impacts.

Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012), Virginia Institute of Marine Science, January 2013.

- This study was directed by SJ76ER, and was for the purpose of requesting the Virginia Institute of Marine Science (VIMS) to study strategies for adaptation to prevent recurrent flooding in Tidewater and Eastern Shore Virginia localities. It was passed by the Virginia Senate (February 28, 2012) and the Virginia House of Delegates (February 24, 2012). It is discussed in detail throughout this report.

Assessing Impacts of Climate Change on Coastal Military Installations: Policy Implications, Strategic Environmental Research and Development Program (SERDP), US Department of Defense, January 2013.

- This paper discusses the policy context and technical considerations related to climate change impacts, drawing on lessons learned to date from four studies funded by the SERDP. This paper focuses on military coastal installations, but also informs of the DoD's overall approach to climate change.

Risk Quantification for Sustaining Coastal Military Installation Assets and Mission Capabilities, RC-1701, Strategic Environmental Research and Development Program (SERDP), US Department of Defense, 2013.

- The objective of this project is to develop and demonstrate an integrated, multi-criteria, multi-hazard impact assessment framework that will be suitable for evaluating changes in vulnerability or risk to coastal military installation assets and mission capabilities in the Hampton Roads region due to global climate change effects, with a focus on sea level rise and associated phenomena.

Quantifying the Influence of Climate Change to Priorities for Infrastructure Projects, IEEE Transactions on Systems, Man and Cybernetics: Part A. You, H., J.H. Lambert, A.F. Clarens, and B.J. McFarlane, 2013.

- This paper identifies and quantifies the influence of climate change combining with other sources of uncertainty to the priority order of projects in a portfolio of infrastructure investments, including a demonstration of the Hampton Roads region.

Climate Change Influence on Priority Setting for Transportation Infrastructure Assets, ASCE Journal of Infrastructure Systems. Vol. 19, No. 1, pp. 36-46, J.H. Lambert, Y.J. Wu, H. You, A. Clarens, and B. Smith, 2013.

- This paper extends a scenario-based multicriteria decision framework that can assist decision makers in effectively allocating limited resources to adapt transportation assets to a changing climate, including a demonstration of the Hampton Roads region.

Emergency Operations Plan: Transportation Plan: Annex D: Hurricane Emergency Response, Virginia Department of Transportation.

- This document describes VDOT responsibilities and operational concepts for the preparation, response and recovery from a hurricane disaster.

Hurricane Lane Reversal Plan, Virginia Department of Transportation, May 2013.

- This document provides "guidelines for an evacuation of Hampton Roads", covering measures to improve traffic flow on routes 10, 17, 58, 60, 143, 199, and 460, and details for reversing the lanes of I-64 (should the Governor order this reversal).

What is climate change?

- "any change in climate over time, whether due to natural variability or as a result of human activity" *

How does it relate to relative sea level rise/storm surge?

- Relative sea level rise and changes in storm surge are specific natural occurrences that result from changes in climate over time.

**Intergovernmental Panel on Climate Change (2007)*

Vulnerability to Relative Sea Level Rise and Storm Surge by Hampton Roads Jurisdiction – VIMS Study

Jurisdictions within Hampton Roads all have unique land elevations and development patterns. Even though flooding occurs in all Hampton Roads jurisdictions, existing and potential submergence risks from relative sea level rise and storm surges are not uniformly distributed due to this variation in topography and development. In a recent study, Virginia Institute of Marine Science (VIMS) created a summary table of all coastal localities within Virginia showing vulnerability to a total rise in water level of 4.5 feet (predicted relative sea level rise of 1.5 feet plus a storm surge of 3 feet)[15]. Within the VIMS analysis, "flooded areas" referred to locations that are expected to be submerged as a result of relative water rise, not resulting from rainwater that cannot drain fast enough. Three flooding estimates were made by jurisdiction: 1) the proportion of each locality that was at risk for increasingly frequent flooding over the next 20 to 50 years, 2) the proportion of the potentially flooded area that is currently classified as developed land, and 3) the number of centerline miles of primary, secondary, and tertiary roads within the potentially flooded area of each jurisdiction.

[15] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, January 2013, p. 8-10.

Table of Vulnerability to a Rise in Water Level of 4.5 feet (Predicted Relative Sea Level Rise of 1.5' plus Storm Surge of 3') – Hampton Roads

Hampton Roads Jurisdiction	Total Area (acres)	Proportion of Total Area with Potential to Flood	Proportion of Total Area with Potential to Flood (Classified as developed)	Centerline Road Miles within Potentially Flooded Area
Norfolk	34,723	12%	60%	119
Portsmouth	21,578	9%	57%	51
Hampton	33,171	15%	28%	50
Chesapeake	217,011	11%	11%	103
Virginia Beach	145,465	26%	11%	289
Poquoson	9,882	69%	11%	38
Newport News	44,297	13%	8%	15
York	68,484	7%	6%	24
Suffolk	261,592	3%	4%	4
Gloucester	139,849	13%	3%	118
Isle of Wight	204,515	4%	2%	5
James City	91,716	11%	1%	11
Williamsburg	5,710	3%	1%	0

Source: Virginia Institute of Marine Science, January 2013.

For the VIMS study, the Hampton Roads jurisdictions were compiled and sorted by the proportion of potentially flooded area that is currently classified as developed land (see table above). This information shows that the localities of Norfolk, Portsmouth, Hampton, Chesapeake, Virginia Beach, and Poquoson face significant challenges and are vulnerable to potential flooding in developed areas. It is also evident that those same jurisdictions have significant flooding vulnerabilities to their roadway systems.

Future Impacts to Transportation Infrastructure

According to the VIMS study, there are three primary threats to roadway networks as a result of relative sea level rise/storm surge[16]:

1) Flooding of evacuation routes
2) Increased hydraulic pressure on tunnels
3) Alteration to drainage capacity

[16] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, 2013, p. 93.

In the event of flooding waters and damage to these transportation systems, mission performance and defense readiness could be impaired for weeks or months, in some cases.

Flooding of Evacuation Routes
As sea levels continue to rise and during storm surge events, access to critical evacuation routes may become unusable. Evacuation decisions will need to be made sooner in order to preserve the safety of citizens within the community.

Increased Hydraulic Pressure on Tunnels
Bridges and tunnels are widely used throughout Hampton Roads to traverse many of the waterways. These facilities are static structures that cannot be easily retrofitted to compensate for rising sea levels like roadways. Tunnel entrances that cannot be raised pose potential flooding risks for the tunnel, and a higher water level (groundwater) resulting from relative sea level rise increases the hydraulic pressures on the tunnel structure[17].

Alteration to Drainage Capacity
Roadway drainage systems rely on the hydraulic gradient to drain water properly. In Hampton Roads, many roadways were constructed in low elevation areas, which makes drainage a challenge. As sea levels rise, hydraulic gradient is reduced, which slows the flow of water and can cause stormwater to back up or pond on the roadway and create a flooding condition.

Other Impacts
Relative sea level rise is expected to create coastal erosion, which may erode roadways in Hampton Roads that are adjacent to waterways. Rising sea levels will add to the overall channel depths, aiding large containerships traveling to the Port of Virginia. Although clearances under bridges will be reduced[18], this is not expected to be a major problem since many important local bridges are drawbridges. Finally, airport runways or railroad lines located near or adjacent to coastlines, may be impacted by rising sea levels and/or storm surge flooding[19].

Flooding in Virginia Beach on August 1, 2012.

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[17] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, 2013, p. 93.
[18] *Ibid, p. 93.*
[19] *Ibid, p. 93.*

Potential Flooding for Roadways Serving the Military

The purpose of this section is to identify where flooding is expected to occur along "Roadways Serving the Military" in Hampton Roads as a result of relative sea level rise and storm surge. Flooding may be due to rising water that submerges the area or inadequate drainage. The analysis within this section estimates flooding only by submergence.

Potential Flooding – 2 Scenarios

For this study, maps of potentially submerged areas for two scenarios were developed using the best available elevation data:

1) **1.5 foot relative sea level rise**
2) **4.5 foot total relative water level rise (1.5 foot relative sea level rise + 3 foot storm surge)**

Given the uncertainty in how much relative sea level rise will occur and how fast it will accelerate, current research suggests that 1.5 feet of rise could occur in Hampton Roads sometime between 2032 and 2065. With the forecast year of the next HRTPO Long-Range Transportation Plan being 2040, a 1.5 foot relative sea level rise scenario was used in this analysis. Based on past storm events, a 3 foot storm surge is a reasonable level to expect for moderate future storms. For example, the surge at Sewell's Point during Hurricane Irene (2011) was measured at 4.2 feet, while the surge from Hurricane Isabel (2003) at the same location was measured at 4.4 feet. The combination of 1.5 feet of relative sea level rise and 3 feet of storm surge would result in a total relative water rise of 4.5 feet.

Locations along the "Roadways Serving the Military" network that are projected to be submerged by 4.5 feet of relative water rise are shown in red on maps on pages 23-24 and tables on page 36. Additionally, subarea maps that provide a closer view of various Hampton Roads jurisdictions are provided on pages 26-35. The flood locations were determined according to the GIS mapping methodology section described below.

GIS Mapping Methodology

Analyses for this portion of the study were developed using elevation data from the Hampton Roads Planning District Commission (HRPDC) for the two scenarios described above. The HRPDC geographic information system (GIS) methodology used to determine the potential flooded areas was similar to that of Virginia Institute of Marine Science's (VIMS) recurrent flooding study[20]. Land elevation (or topographic) surfaces were determined for all Hampton Roads jurisdictions using the most recent and highest resolution LiDAR (Light Detection and Ranging) data[21]. The LiDAR data layers are referenced to North American Vertical Datum 1988 (NAVD88), a standard geodetic vertical datum. The LIDAR data used in this analysis was collected over a period of several years, 2004 to 2012.

Tidal datums are calculated based on observations taken and averaged over a period of several years. For most of the United States, the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service averages measurements taken over a specified 19-year period, called a National Tidal Datum Epoch (NTDE), to calculate local tidal datums such as Mean Sea Level (MSL) or Mean Higher High Water (MHHW) for each station (see definitions for NTDE and MHHW on page 22). Since tidal datums are the average of many observations, the assigned year for a specific tidal datum is the average of the years of that epoch (current NTDE is for 1983-2001), which is currently 1992.

In order to determine which areas of land would be submerged, HRPDC staff first identified tidal datums to use as a reference. HRPDC staff chose to use Mean Higher High Water (MHHW) as the reference tidal datum. As defined on page 22, this datum reflects a regularly occurring tidal condition near the top of the normal tidal range. HRPDC staff used VDatum, a software program developed by NOAA, to develop a surface representing the elevation of MHHW (referenced to NAVD88) on both water and land. The process required converting points on water and near the shore from MHHW to NAVD88 and then interpolating that surface inland to create a consistent surface. HRPDC staff added 1.5 and 4.5 feet increments of relative sea level rise to this 1992 tidal surface, and compared the results to existing land elevations.

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[20] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, 2013.

[21] For Mulberry Island/Fort Eustis in Newport News and the western shore of Craney Island in Portsmouth, the best available data (1/9 arc-second resolution) from the National Elevation Dataset was used instead.

Any areas with elevations less than the modified tidal surfaces were determined to be potentially vulnerable to the relative water rise of the selected amount. All elevations less than or equal to MHHW plus 1.5 feet were extracted to represent areas vulnerable to relative sea level rise, and all elevations less than or equal to MHHW plus 4.5 feet were extracted to represent areas vulnerable to relative sea level rise plus a 3-foot storm surge.

The GIS elevation layer was comprised of 5 feet by 5 feet pixels, with each pixel having a given land elevation. A roadway network shapefile from the Hampton Roads Congestion Management Process[22] (CMP) was then overlain by HRTPO staff on the elevation scenarios to test potentially submerged roadway locations. Within GIS, the identity analysis tool was used to identify the specific roadway segments in the potentially submerged areas.

It is important to note that this GIS identity analysis was based only on submergence from relative water level rise. It did not consider flooding due to rainwater that cannot drain fast enough.

Lacking elevations specifically for roadways, the original GIS identity analysis assumed that all roadways are at the same elevation as the surrounding area. To partially address the lack of road elevations, the HRTPO staff used Google maps to identify locations on "Roadways Serving the Military" where elevated structures currently exist, and removed any of these roadway segments to ensure that no submergence is forecasted for them.

Downtown Portsmouth near Naval Medical Center Portsmouth during Nor'easter in November 2009.

Vertical Datum – a reference for measuring elevations or depths.

National Tidal Datum Epoch – the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present NTDE is 1983 through 2001 and is actively considered for revision every 20-25 years.

Mean Higher High Water* (MHHW) – The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.

*Hampton Roads has semidiurnal tides – the tide typically cycles through a high and low twice each day, with one of the two high tides being higher than the other and one of the two low tides being lower than the other.

Source: National Oceanic and Atmospheric Administration (NOAA)

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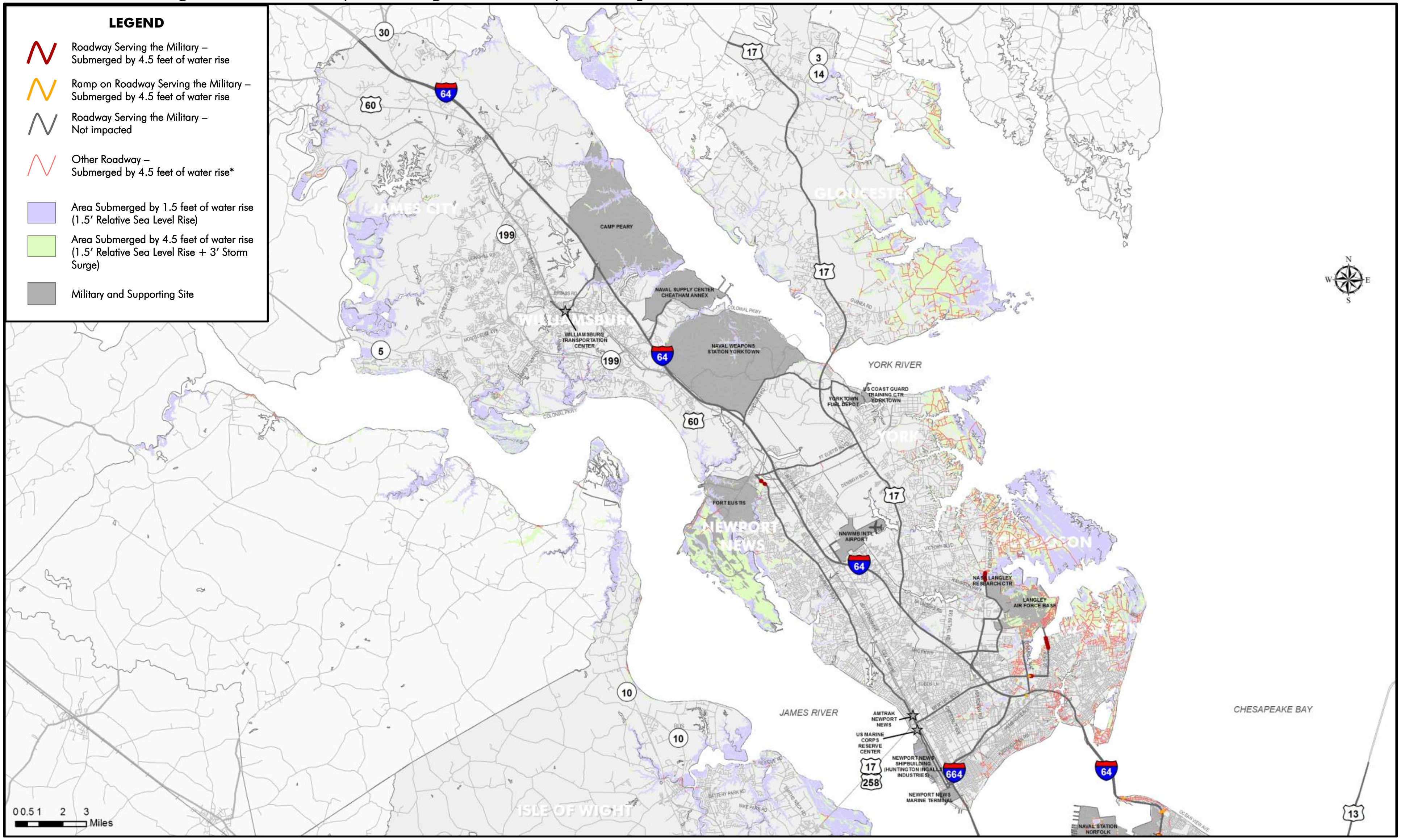
[22] *Hampton Roads Congestion Management Process: 2010 Update*, HRTPO, September 2010.

Potential Submergence of Roadways Serving the Military – Hampton Roads Peninsula

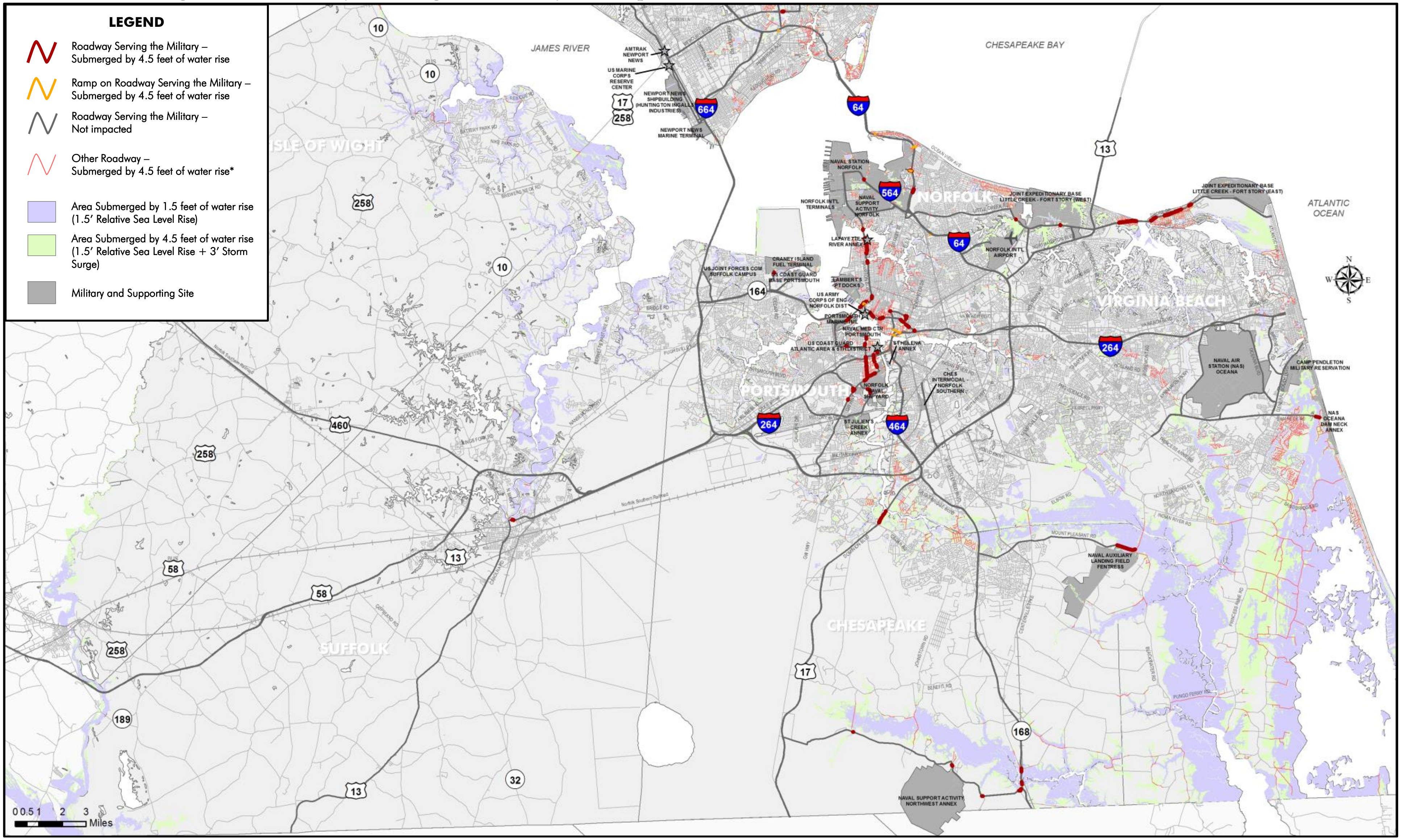


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Hampton Roads Southside



Prepared by: HRTPO Staff, April 2013

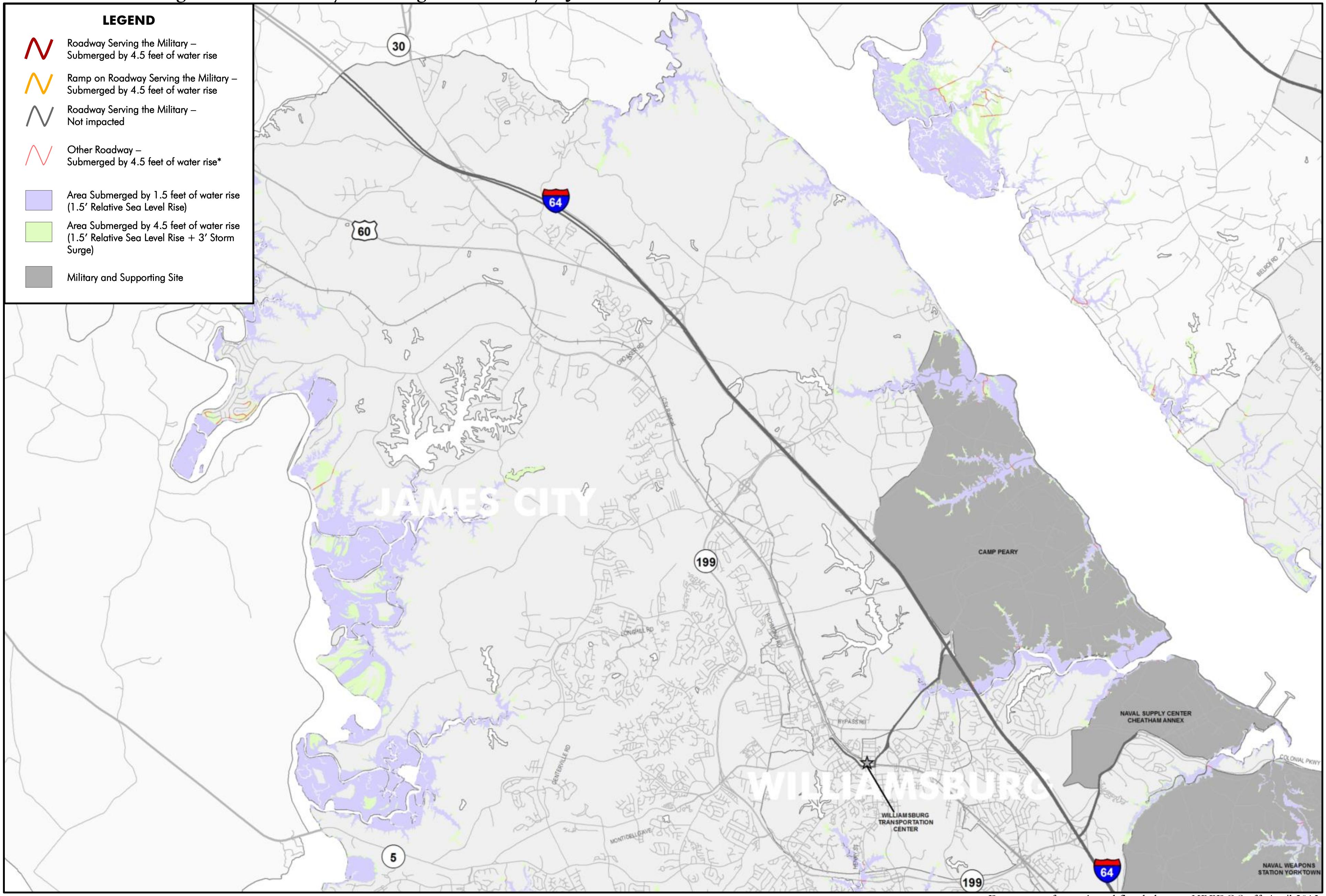
Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Subarea Maps for Hampton Roads Jurisdictions

Potential Submergence of Roadways Serving the Military

Potential Submergence of Roadways Serving the Military – James City

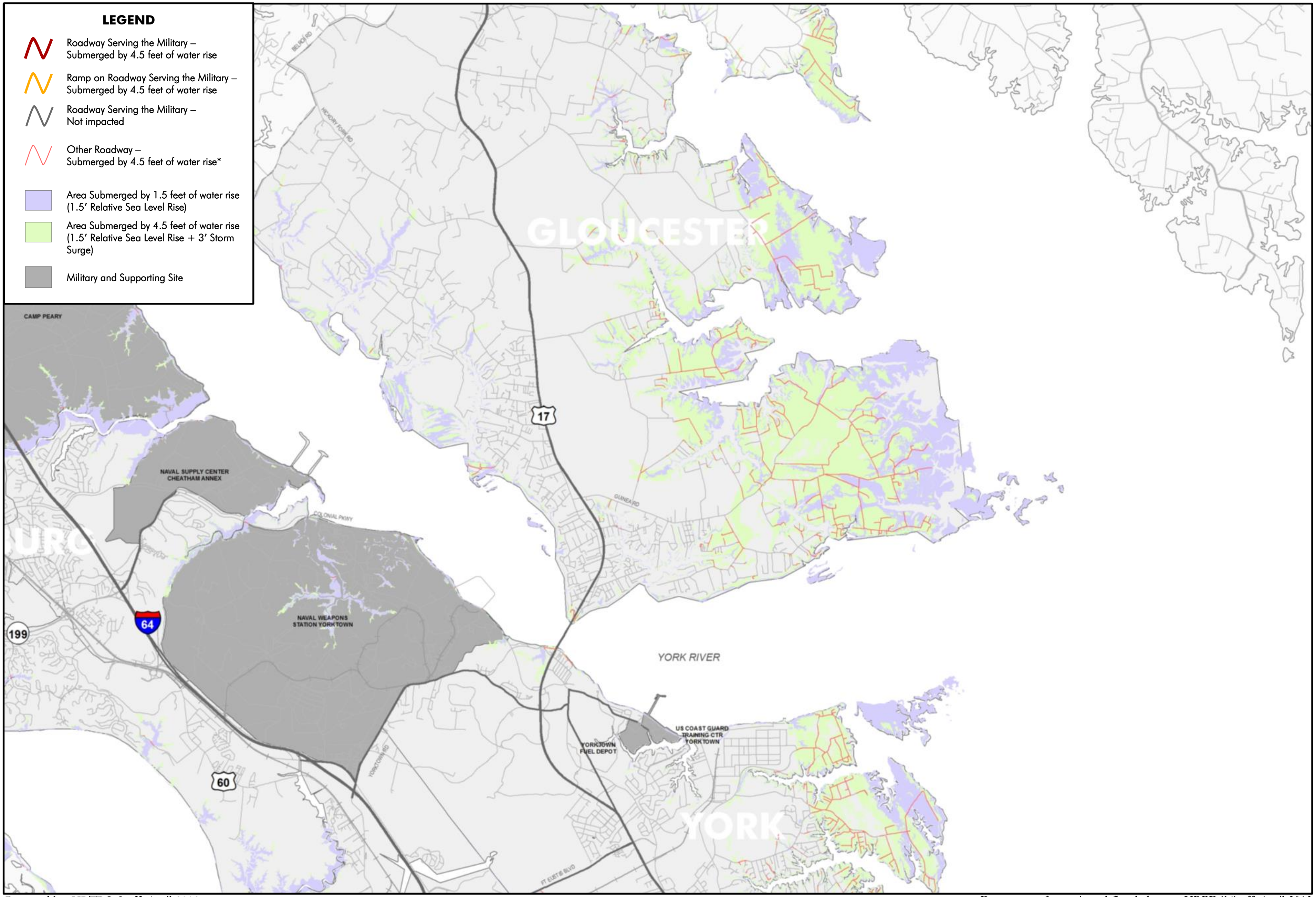


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Gloucester and York

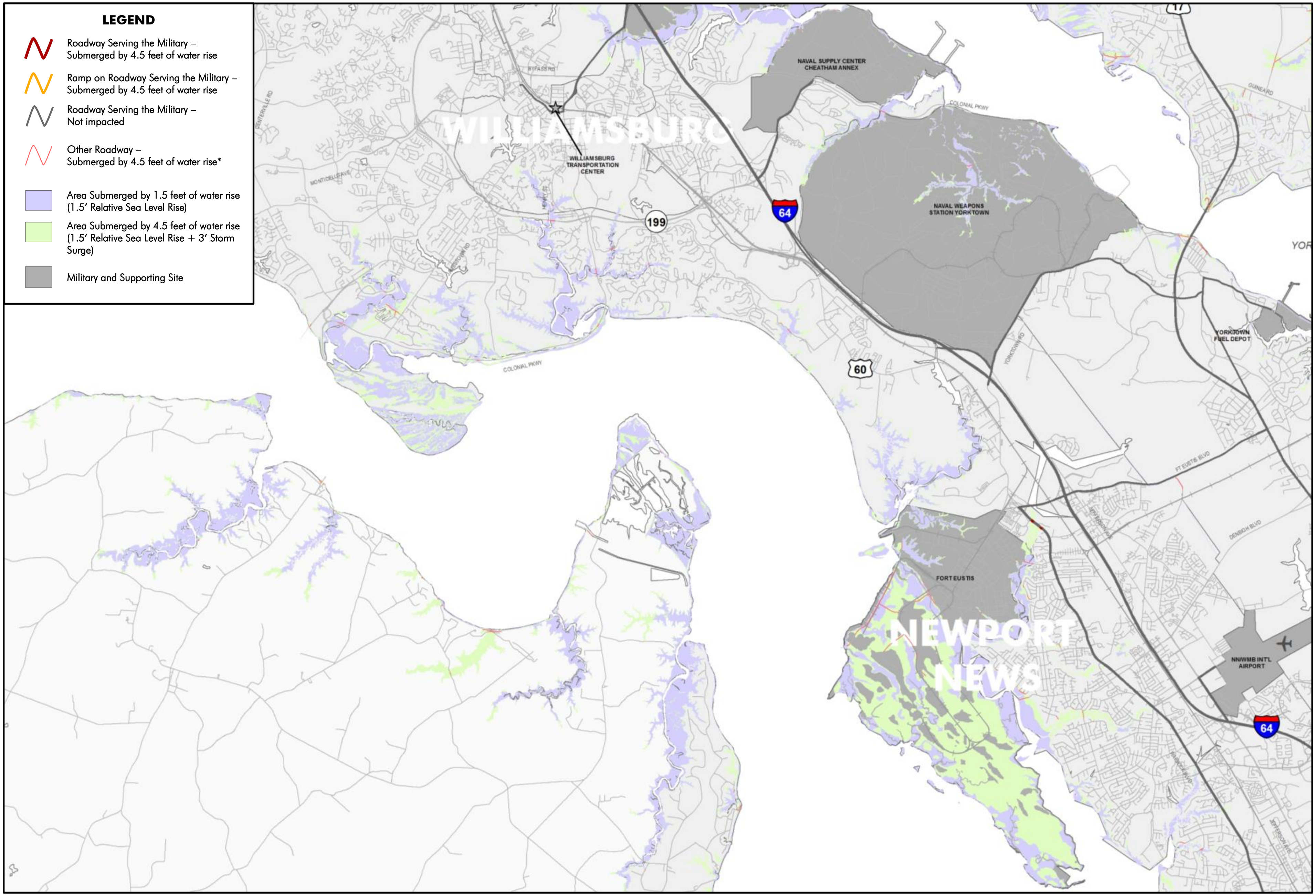


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Williamsburg

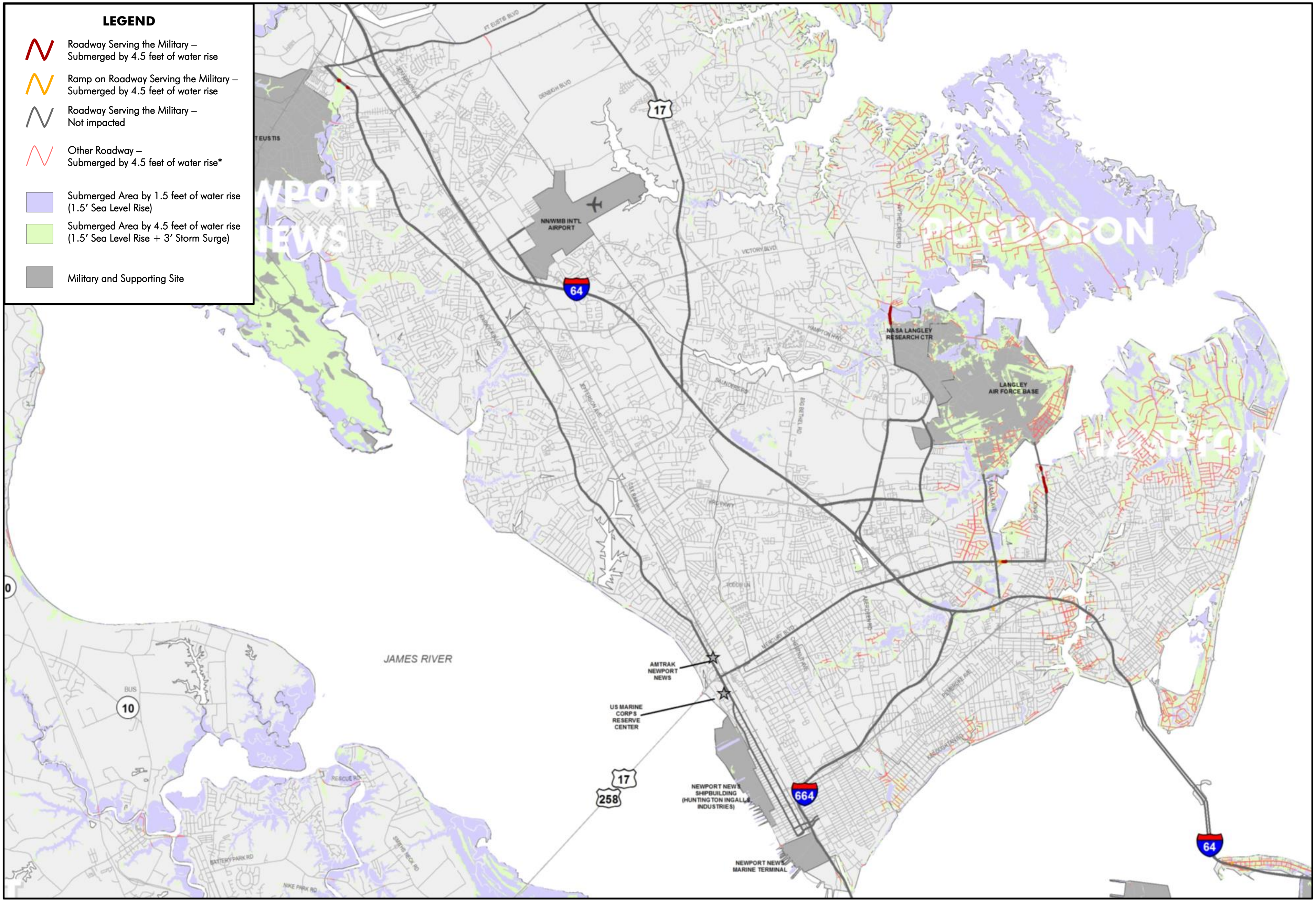


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Hampton, Poquoson, and Newport News

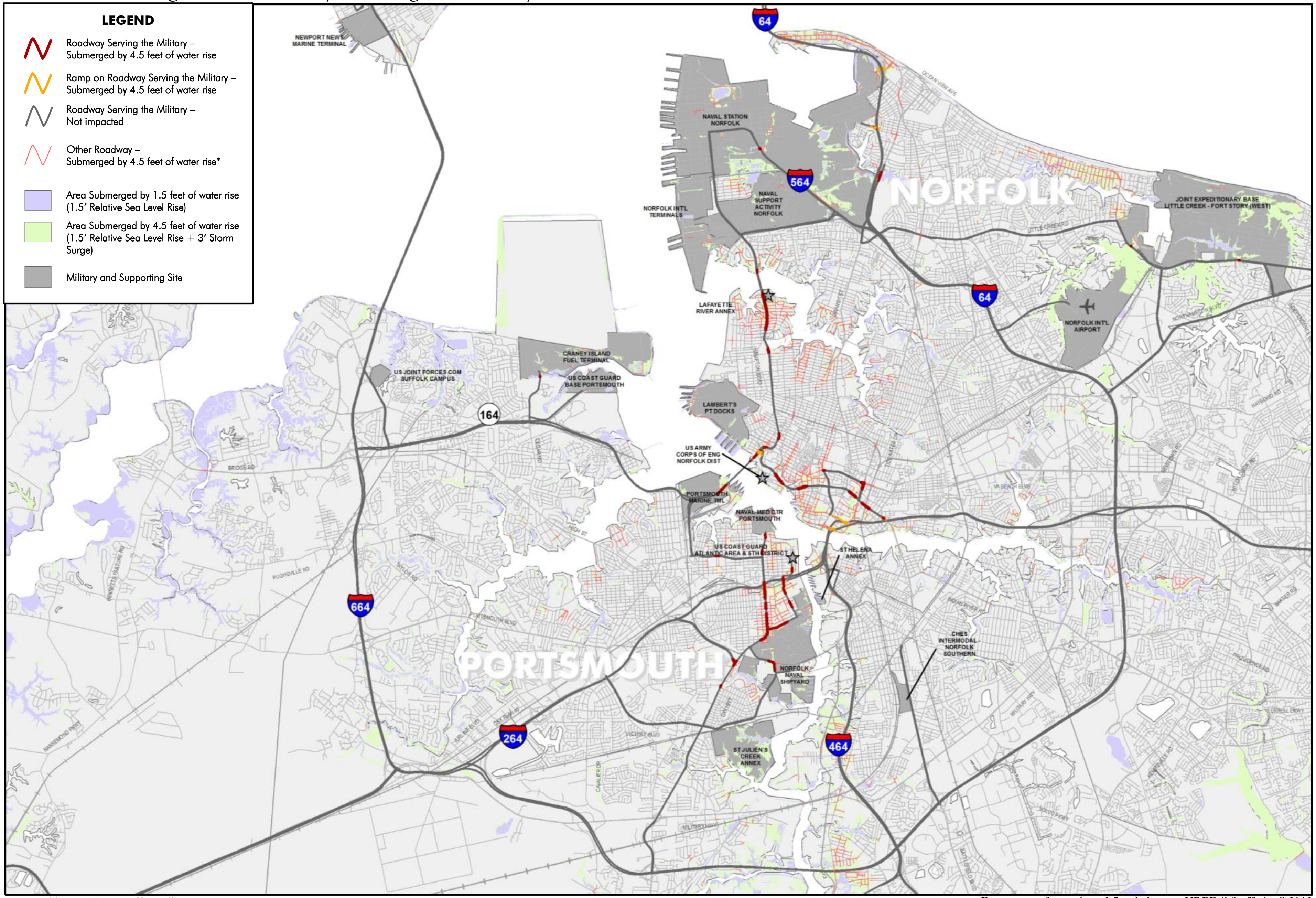


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Norfolk & Portsmouth

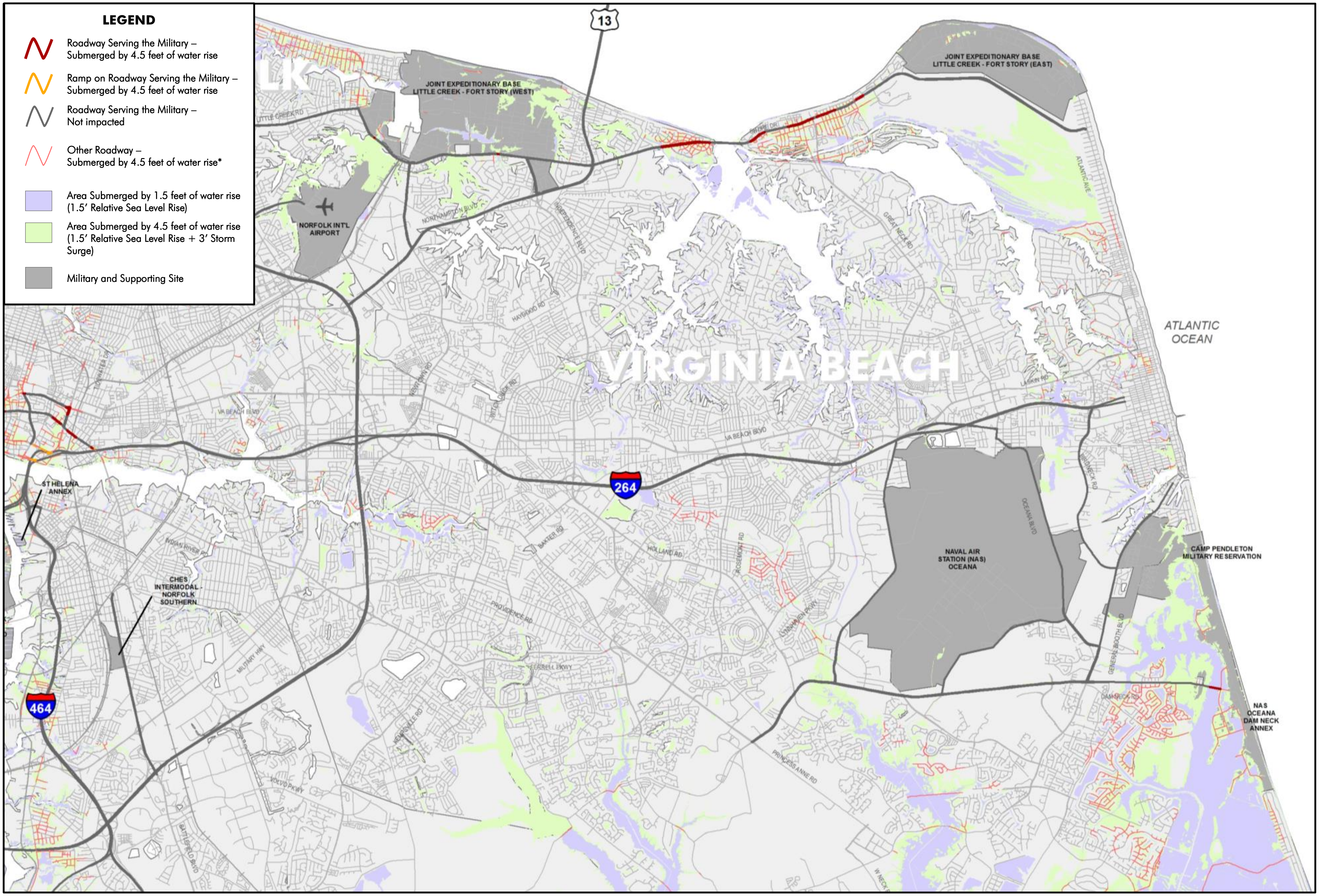


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Northern Virginia Beach

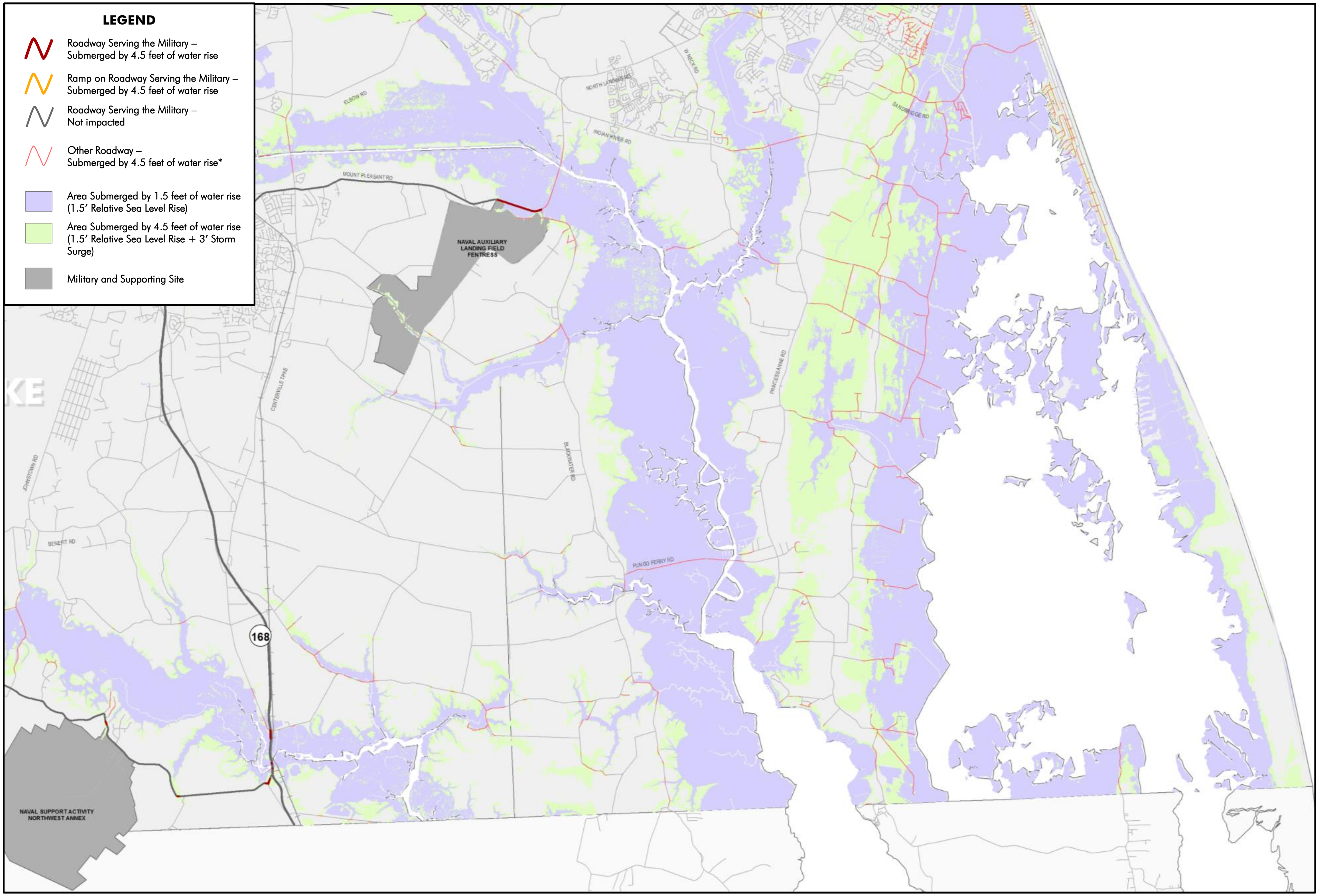


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Southern Virginia Beach

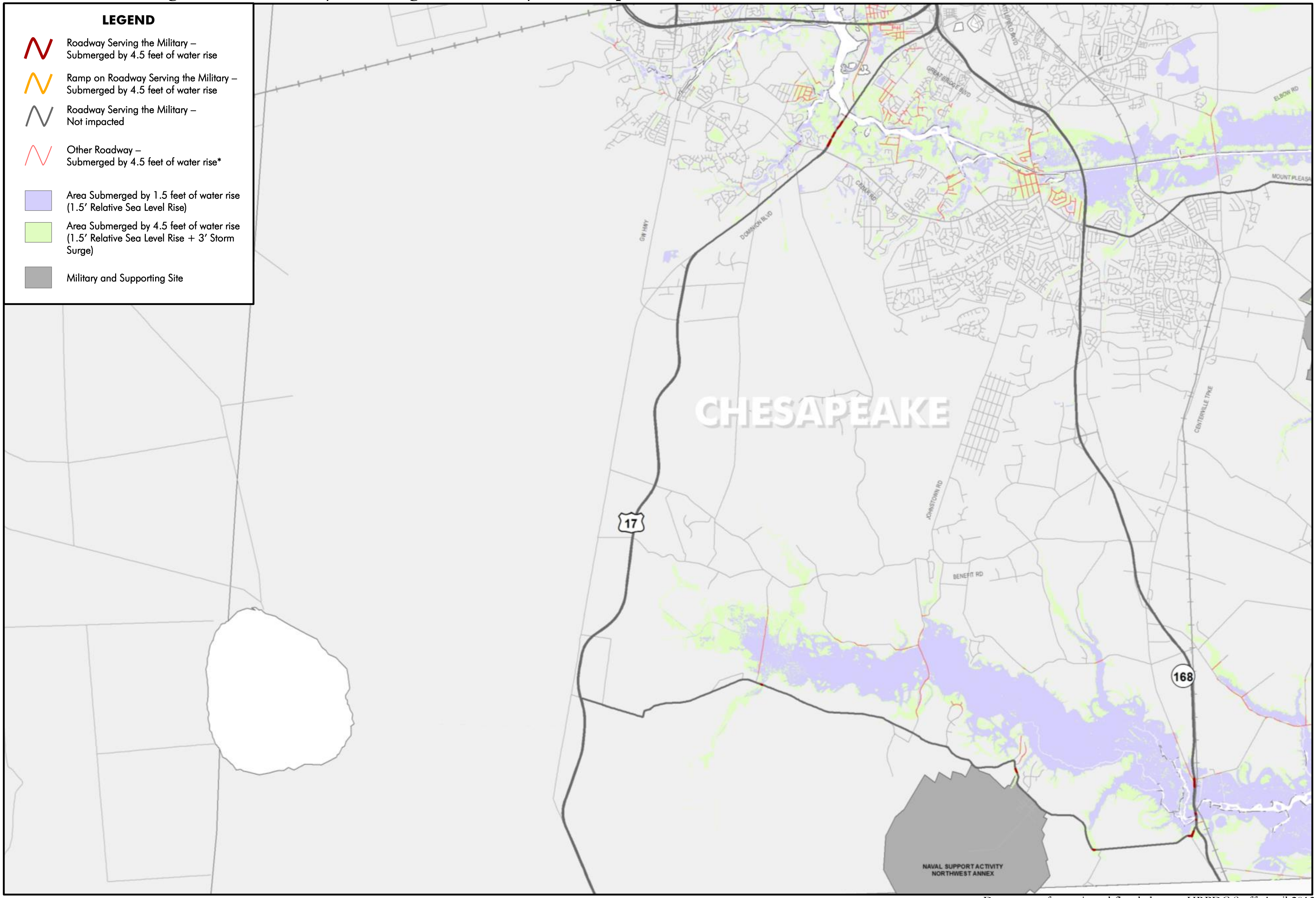


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Chesapeake

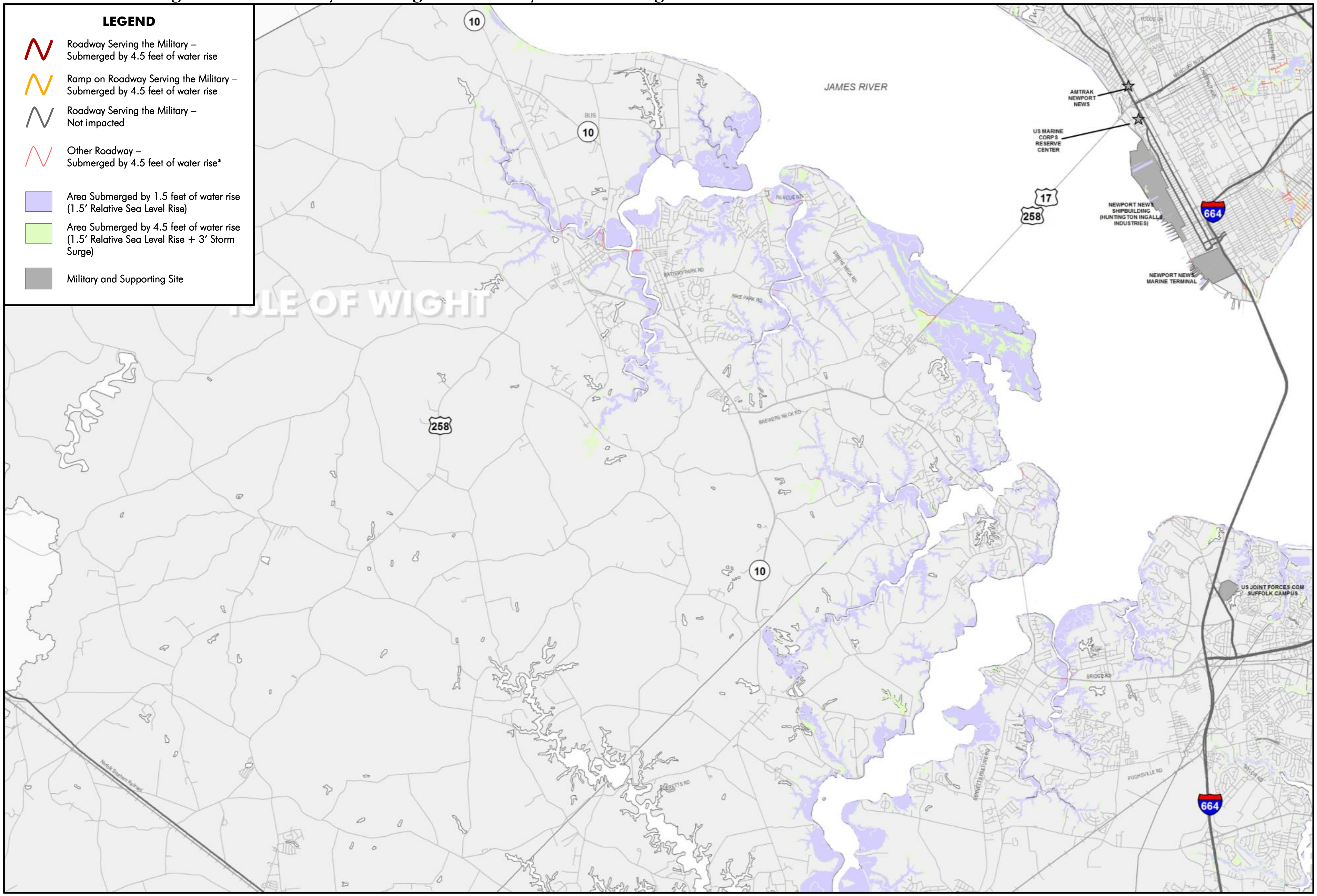


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Isle of Wight

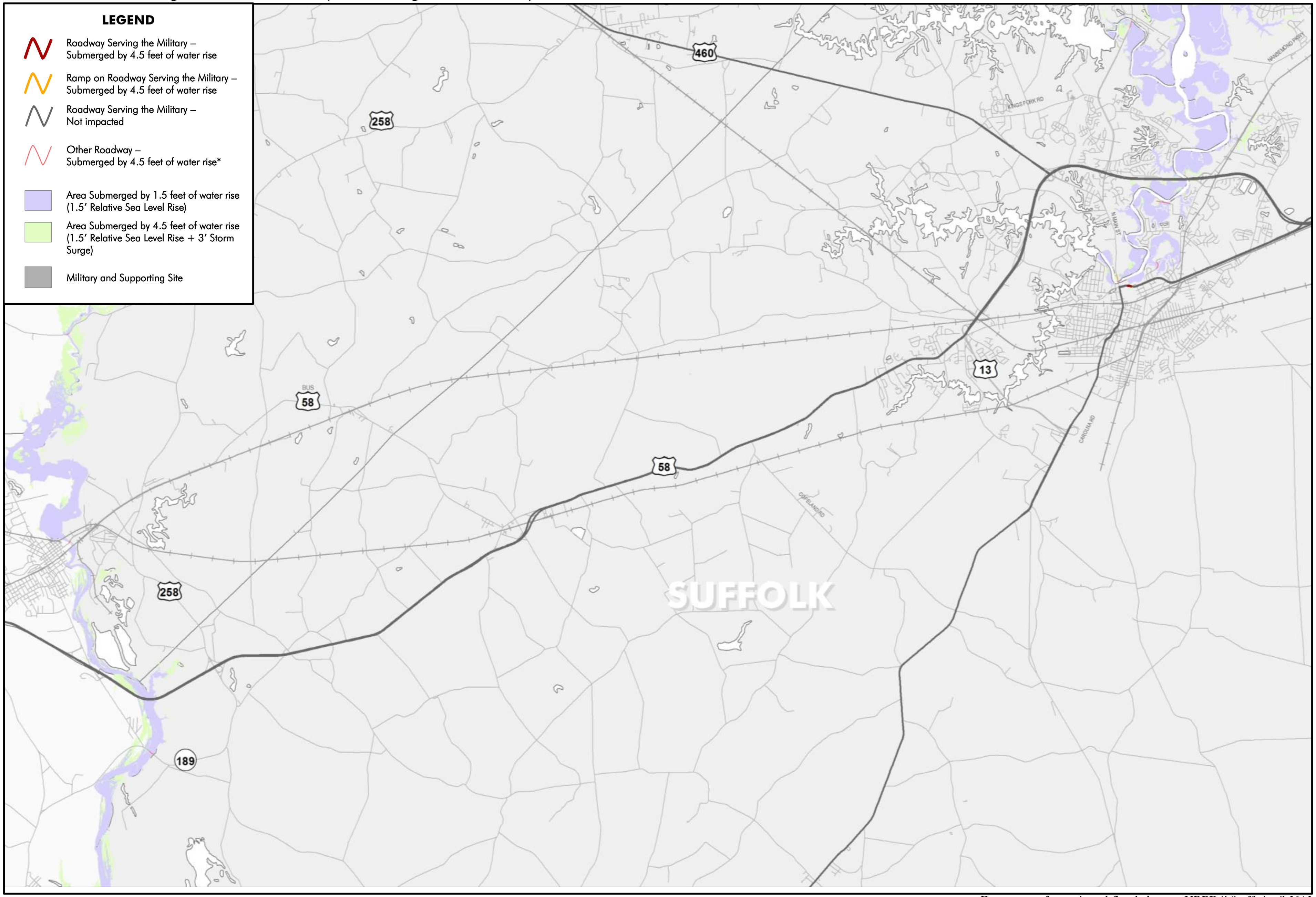


Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Potential Submergence of Roadways Serving the Military – Suffolk



Prepared by: HRTPO Staff, April 2013

Data source for projected flooded areas: HRPDC Staff, April 2013

*These roadways were assumed to be at the same elevation as the surrounding area. Some sections of the road may not actually flood if they contain elevated structures, such as bridges or overpasses.

Roadways Serving the Military Submerged by 4.5 feet of Relative Water Rise (1.5' of Relative Sea Level Rise plus 3' of Storm Surge)

Locations by Locality
Chesapeake
Ballahack Road (just east of Lake Drummond Cswy)
Ballahack Road (just east of Pine Grove Lndg)
Ballahack Road (just west of Old Battlefield Blvd)
Battlefield Blvd (Gallbush Rd to Old Battlefield Blvd)
Dominion Blvd (Cedar Rd to Steel Bridge)
Old Battlefield Blvd (Ballahack Rd to Chesapeake Expressway)
Mount Pleasant Rd (Doolittle Ave to Fentress Airfield Rd)
Hampton
King St (Walkers Landing Ln to Clover St)
King St (Waters Edge Cir to Percy Ln)
Mercury Blvd (LaSalle Ave to Seldendale Dr)
Mercury Blvd ramps at LaSalle Ave
Wythe Creek Rd (Carys Chapel Rd to Wythe Landing Loop)
Newport News
Warwick Blvd (Lees Mill Dr to Industrial Park Dr)
Norfolk
Bay Ave (Potomac Pl to I-64)
Brambleton Ave (Colley Ave to 2nd St)
Brambleton Ave (Dunmore St to Duke St)
Brambleton Ave (Pulaski St to Tidewater Dr)
Brambleton Ave (May Ave to Maltby Ave)
Brambleton Ave (just north of I-264)
Granby St (Patrol St to E Bayview Blvd)
Hampton Blvd (just south of Claud Ln)
Hampton Blvd (N Fairwater Dr to Westmoreland Ave)
Hampton Blvd (just north of 49th St)
Hampton Blvd (Baldwin Ave to Graydon Ave)
Hampton Blvd ramps at Brambleton Ave/Midtown Tunnel
Hampton Blvd ramp at Gresham Dr
Midtown Tunnel/Hampton Blvd (Brambleton Ave to east side entrance/exit)
Shore Dr (0.15 miles east of Heutte Dr)
Tidewater Dr (Tabb St to Virginia Beach Blvd)
Virginia Beach Blvd (at Monticello Ave)
Virginia Beach Blvd (at Tidewater Dr)

Locations by Locality
Portsmouth
Court St (Bart St to Premier Pl)
Crawford St (County St to Columbia St)
Effingham St (Firehouse Ln to North St)
Effingham St (Crawford Pkwy to Williamson Dr/Naval Medical Center Portsmouth gate)
Effingham St (George Washington Hwy to Fayette St)
Effingham St (Nelson St to Henry St)
Effingham St (Randolph St to Bart St/I-264)
Elm Ave (just west of Williams Ave/Victory Blvd)
Frederick Blvd (at George Washington Hwy)
George Washington Hwy (Bainbridge Ave to Hanbury Ave)
George Washington Hwy (Alabama Ave to Andrews St)
George Washington Hwy (Peach St to Effingham St)
London Blvd (Ruth Brown Way to Chesapeake Ave)
Midtown Tunnel (west side entrance/exit)
Port Centre Pkwy (Nelson St to Jefferson St)
Portsmouth Blvd (Effingham St/George Washington Hwy to 6th St)
Suffolk
Constance Road (just east of N Main St)
Virginia Beach
Dam Neck Rd (at NAS Oceana Dam Neck Annex main gate)
Shore Dr (Jack Frost Rd to Staples Mill Ln)
Shore Dr (Bayville Rd to E Stratford Rd)
Shore Dr (Vista Point to Kleen St)
Shore Dr (Sea Shell Rd to Bayberry St)
Shore Dr (just east of Kendall St)

Interstate and Ramp Locations
Hampton Roads
I-264 ramps at Brambleton Ave
I-264 ramps at E City Hall Ave
I-264/Berkley Bridge ramps at Waterside Dr
I-564 (near Tower St)
I-64 ramps at W Bay Ave
I-64 ramps at 15th View St/W Ocean View Ave
I-64 ramps at 4th View St
I-64 ramp at LaSalle Ave

Note: Locations specified within these tables are based on the nearest roadway segment. Please refer to maps on pages 23-35 for specific locations.

Hampton Roads Military Installation Gates Affected By 4.5 Feet of relative water rise

Based on the analysis above for the 4.5 foot relative water rise scenario, due to submergence, external roadway access is not expected to be available to/from the following military installation gates:

- Naval Auxiliary Landing Field Fentress (Chesapeake) – Main Gate (Fentress Airfield Rd)
- Naval Support Activity Northwest Annex (Chesapeake) – Main Gate (Relay Rd)
- Langley Air Force Base (Hampton) – King St Gate
- Naval Station Norfolk (Norfolk) – Gate 4 (Bay Ave)
- Naval Station Norfolk (Norfolk) – Gate 10 (Ridgewell Ave/Bellinger Blvd)
- Craney Island Fuel Terminal (Portsmouth) – Main Gate (Cedar Ln)
- Naval Medical Center Portsmouth (Portsmouth) – Main Gate (Effingham St)
- Norfolk Naval Shipyard (Portsmouth) – Gate 3 (Lincoln St/Gosport Row)
- Norfolk Naval Shipyard (Portsmouth) – Gate 10 (Port Centre Pkwy/Portsmouth Blvd)
- Norfolk Naval Shipyard (Portsmouth) – Gate 15 (Effingham St)
- Norfolk Naval Shipyard (Portsmouth) – Gate 36 (Elm Ave)
- Joint Expeditionary Base Fort Story (Virginia Beach) – Gate 6 (Atlantic Ave – west end from Shore Dr)
- Joint Expeditionary Base Fort Story (Virginia Beach) – Gate 8 (Atlantic Ave – east end from 89th St)
- NAS Oceana Dam Neck Annex (Virginia Beach) – Main Gate (Dam Neck Rd/Vanguard St)

Potential Impacts of Sea Level Rise and Storm Surge on Military Facilities and Road Systems

The Hampton Roads region contains one of the largest natural harbors in the world, making the region an attractive location for military facilities. This coastal location also makes many of these military facilities susceptible to projected relative sea level rise and storm surge threats, impacting overall defense readiness. The region's military presence is comprised of the Norfolk Naval Base, the largest in the world, and dozens of other military facilities, including the U.S. Coast Guard, U.S. Army, and U.S. Air Force. As a result of the area's large military presence, much of the local economy is driven by the U.S. Department of Defense (DoD). The total direct economic impact of the U.S. Navy alone on Hampton Roads was $14.9 billion in 2011[23]. The threat of flooding analyzed above is a concern for the military in the region since military operations require a transportation network that moves cargo and personnel quickly and safely.

In addition to submergence of "Roadways Serving the Military", relative sea level rise and potential storm surge pose serious risks for military facilities in Hampton Roads, since a good portion of them are located on or near the coast at lower elevations. 25 of the 38 "Military and Supporting Sites" identified in Phase I of the Hampton Roads Military Transportation Needs Study (see map on page 10) are located within Hampton Roads' most vulnerable jurisdictions to flooding based on the VIMS study[24] and the analysis contained within this section.

[23] Navy Region Mid-Atlantic Public Affairs Office News Release, October 18, 2012.

[24] *Recurrent Flooding Study for Tidewater Virginia (SJR 76, 2012)*, Virginia Institute of Marine Science, January 2013, p. 8-10.

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The Hampton Roads region contains one of the largest natural harbors in the world, making the region an attractive location for military facilities. This coastal location also makes many of these military facilities susceptible to projected relative sea level rise and potential storm surge threats, impacting overall defense readiness. The threat of flooding is a concern for the military in the region since military operations require a transportation network that moves cargo and personnel quickly and safely.

The impacts of relative sea level rise and storm surge have been recognized along the southeast coast for many years, particularly for low-lying communities such as Hampton Roads, Virginia. National, state, regional, and local organizations have participated (or are currently participating) in initiatives that address this pressing issue in order to raise awareness and develop potential solutions. This study (phase three) builds on previous studies and related work to estimate the relative sea level rise and potential storm surge threats to the "Roadways Serving the Military" network established in phase one of the Hampton Roads Military Transportation Needs Study. In the first phase, HRTPO staff reviewed the "Roadways Serving the Military" to determine deficient locations, such as congested segments, deficient bridges, and inadequate geometrics. This third phase of the study continues the work in phase one by determining flooding-based deficient locations along the roadway network. It expands upon the work and methodologies developed by the Hampton Roads Planning District Commission (HRPDC) and the Virginia Institute of Marine Science (VIMS), by identifying military roadway segments vulnerable to submergence. Additionally, submergence of other local roadways that provide access to and from the "Roadways Serving the Military", which may be vulnerable to flooding have been identified.

Given the uncertainty in how much relative sea level rise will occur and how fast it will accelerate, current research suggests that 1.5 feet of rise could occur in Hampton Roads sometime between 2032 and 2065. With the forecast year of the next HRTPO Long-Range Transportation Plan being 2040, a 1.5 foot relative sea level rise scenario was used in this analysis. Based on past storm events, a 3 foot storm surge is a reasonable level to expect for moderate future storms. For example, the surge at Sewell's Point during Hurricane Irene (2011) was measured at 4.2 feet, while the surge from Hurricane Isabel (2003) at the same location was measured at 4.4 feet. The combination of 1.5 feet of relative sea level rise and 3 feet of storm surge would result in a total relative water rise of 4.5 feet.

This study (phase three) used elevation data from the HRPDC in conjunction with Geographic Information System (GIS) software to identify potential flooding for "Roadways Serving the Military", specific segments that would be submerged by 4.5 feet of relative water rise (1.5' relative sea level rise plus 3' storm surge). **Maps of these locations are provided on pages 23-35 and are listed in tabular format on page 36.** The results show that the "Roadways Serving the Military" in the Cities of Chesapeake, Hampton, Norfolk, Portsmouth, and Virginia Beach are vulnerable to potential future relative water rise.

The HRTPO plans to update the Hampton Roads Military Transportation Needs Study as necessary. HRTPO staff may update phases I (Highway Network Analysis), II (Military Commuter Survey), and III (Roadways Serving the Military and Sea Level Rise/Storm Surge) of the study as conditions change and warrant additional analysis. The three-phase study can also serve as a basis for future military-related studies.

RECOMMENDATIONS

Based on the analysis presented in this report, the following recommendations are provided below:

- It is recommended that the HRTPO Board consider relative sea level rise and potential storm surge impacts when selecting future transportation projects. New/improved roadways can be built higher, removing the potential for flooding due to submergence. The HRTPO staff plans to review components of the HRTPO Project Prioritization Tool[25] and incorporate any changes if warranted.
- It is recommended that the operators of military and supporting sites work with the Virginia Department of Transportation (VDOT), cities, and counties to develop detour plans for all

[25] *Hampton Roads Prioritization of Transportation Projects*, HRTPO, December 2010.

"Roadways Serving the Military" that are projected to be submerged by 4.5 feet of water rise in order to move military personnel and cargo during these occurrences (See pages 23-37).

- It is recommended that VDOT/cities/counties consider the latest projections for relative sea level rise/storm surge when a roadway project is designed.
- It is recommended that VDOT/cities/counties conduct further studies to determine impact on roadway drainage systems of "Roadways Serving the Military" considering the projected relative sea level rise and potential storm surge.

Public Review and Comments

As part of the Hampton Roads Transportation Planning Organization's (HRTPO) efforts to provide opportunities for the public to review and comment on this draft report prior to the final product being published, a public review period was conducted from May 1, 2013 through May 17, 2013. No public comments were received.