FUGRO ATLANTIC

PRELIMINARY CITY-WIDE COASTAL FLOODING MITIGATION CONCEPT EVALUATION AND MASTER PLAN DEVELOPMENT

City of Norfolk
City-Wide Coastal Flooding Contract No. 13062
Work Order No. 4

Prepared for:
CITY OF NORFOLK
DEPARTMENT OF PUBLIC WORKS

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Attention: Mr. John White, Director, Storm Water Division

Subject: **Preliminary City-Wide Coastal Flooding Mitigation Concept Evaluation and Master Plan Development, City of Norfolk, Work Order No. 4 (Contract 13062)**

Dear Mr. White:

Enclosed is Fugro Atlantic's report documenting Work Order No. 4 of the City-Wide Coastal Flooding contract (City of Norfolk Contract 13062). This report evaluates the potential risk associated with coastal flooding and identifies a range of potential mitigation options throughout the City.

The work, as documented herein, builds on the previous phase of City-wide coastal flooding evaluation program that identified areas susceptible to coastal flooding for various water levels. Identification of susceptible areas to coastal flooding were based on tide gauge measurements of water levels within the City were and GIS-based mapping which translated those measurements to flood depth predictions for various tide levels, as measured at Sewells Point. The measurements of tide heights within the City's waters are unique, in that no comparable data are available elsewhere within Hampton Roads.

Based on the predicted tidal levels and flood extents from the previous phase of the program, this study evaluated risk associated with the coastal flooding. The study describes a range of potential coastal flood mitigation options identified throughout the City, the associated cost of the various projects, and the potential reduction in flood damages. Mitigation options at three scales are considered in this study: watershed, neighborhood, and residence.

Understanding long term changes in the physical environment is important to consider when planning for the future. The study has also taken into consideration sea level rise in order to understand how that may affect project options and better understand how it may affect future flooding hazards throughout the City. For this study, we have considered the implications of sea level rise for the current and next generation and discuss what the City and residents can do to mitigate flooding resulting from potential changes in sea level in the "near" future while recognizing that long term planning is also important to society.

On behalf of the project team, we thank you for the opportunity to be of service to the citizens of Norfolk.

Sincerely,

FUGRO ATLANTIC

Kevin Smith
Associate Engineering Geologist

Thomas W. McNeilan, P.E.
Vice President, Fugro Atlantic

Fugro Atlantic is the Norfolk-based, U.S. East Coast operating group of Fugro N.V., an international engineering and survey firm with headquarters in Leidschendam, The Netherlands. Fugro N.V. was founded in 1962, has been publically traded on the Amsterdam stock exchange (AMX) since 1992, and has been a member of the stock exchange's MidKap Index since 2003. Fugro is the world's leading service provider of: 1) data relating to the earth's surface and sub-surface and 2) engineering and geological consulting services relative to the design and construction of infrastructure, energy, and development along the coastline and in the low lands around the globe. Fugro Atlantic's primary market focuses are: coastal infrastructure and industry; flood inundation and flood defense; and offshore energy development.

The Fugro team for the City-wide coastal flooding contract includes Moffatt & Nichol, a consulting engineering firm, whose core focus is the coastal, estuarine, and riverine environment. Moffatt & Nichol, established in 1945, is the oldest consulting firm in the country in this specialized discipline. The American Society of Civil Engineers' Harbor and Coastal Engineering award is named after Moffatt & Nichol's founders.

The City-Wide Coastal Flooding contract studies and this report are prepared by the Fugro Atlantic team that includes:

- Mr. Kevin Smith, the associate engineering geologist and GIS services manager with Fugro Atlantic is the Project Manager for the City-wide Coastal Flooding Contract,
- Mr. Thomas McNeilan, the general manager of Fugro Atlantic is Fugro's principal-in-charge and lead engineer for the contract,
- Mr. Kyle Spencer and Ms. Cornelia Dean, GIS analysts on Fugro Atlantic's staff have developed the GIS-based mapping and prepared the predictive maps for the contract,
- Mr. Brian Joyner, senior coastal engineer with Moffatt & Nichol has supervised Moffatt & Nichol's hydrological analyses efforts,
- Mr. Johnny Martin a coastal engineer with Moffatt & Nichol has assisted Mr. Joyner, and
- Ms. Rosemary Smith, senior oceanographer with Fugro GEOS, has provided the data analyses and interpretation of the tide gauge data.

Kevin Smith, Brian Joyner, and Tom McNeilan are the primary authors of this report.

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1.0 INTRODUCTION AND BACKGROUND

1.1 PROJECT BACKGROUND

The City of Norfolk (City) is situated in a combination of coastal and estuarine environments where it is bound by a number of different water bodies that include the Chesapeake Bay, the Hampton Roads Harbor, the Elizabeth and Lafayette Rivers and their numerous tributaries as well as several small lakes. The City is located in a low-lying physiographic region, which presents additional challenges in flood mitigation because drainage gradients are limited and nearly all portions of the City are below an elevation of 15 feet. Close proximity to water paired with low drainage gradients results in a significant percentage of the City being susceptible to flooding from high tides, nor'easters, hurricanes, and other storm events. The intensity of this flooding ranges from nuisance flooding, typically associated with high tides, to severe, albeit less frequent flooding from hurricanes and major nor'easters such as occurred in August 2011 (Hurricane Irene) and November 2009, respectively.

In recent years, the City has recognized an increased need to address coastal flooding problems. Historically, the City has addressed flood mitigation through stand-alone, small to intermediate-sized capital improvement projects. Today, the remaining flood mitigation projects are numerous, complex, and may require considerably larger capital improvement budgets than in the past. As with all municipalities in the region, implementation of flood mitigation and flood defense improvement projects is primarily constrained by the ability to fund such large-scale projects.

In addition, relative sea level in the local area is rising (at a current projected rate of 1.45 feet per 100 years[1]). Assuming that this trend continues (or increases), both nuisance flooding and flooding from storm events capable of causing significant damage will increase. This will further increase the need to address the issue of coastal flooding on both project-specific and a holistic basis.

Significant events like the November 2009 Nor'easter and Hurricane Irene have served to: 1) reinforce the City's decision to proactively evaluate coastal flooding and 2) elevate the City's needs and priorities for flood defense mitigation. In addition, smaller events such as the short but intense localized storm over the Broad Creek area in August 2009 can also cause local flooding and damage. Flood damage stemming from such short duration but intense storms can be significantly affected by the tidal conditions at the time of the storm. The August 2009 storm occurred at low tide but the large volume of rainfall captured in the Broad Creek basin caused water levels in the basin to increase by more than 1 foot and were elevated for about 6 hours (as measured by the local tide gauge). While the flooding and damage during that storm were significant, they were much less than would have occurred if that storm had coincided with peak rather than low tide conditions.

1.2 STUDY BACKGROUND

In 2008, the City began to develop a City-wide evaluation to: anticipate flooding scenarios, help prioritize problem areas, develop design criteria, and define objectives for various remediation flood defense improvements. The City-wide flood evaluation was

recognized to require a phased and iterative approach to be conducted over several years. The initial efforts of the City-wide coastal flooding contract included the procurement, installation, and monitoring of tide gauges at five locations within the City to define local variations of the tide levels relative to those at Sewells Point, which has the longest history of tidal measurements in the Hampton Roads region. These tide gauges are critical in understanding the tidal variation relative to Sewells Point. This insight is especially pertinent because the Sewells Point tide measurements are also the reference that has and continues to be used to communicate predicted tide levels to the City, the media, and to the population in general.

Sewells Point long term records were used to define tidal water levels for a range of return periods (e.g. 2-, 10-, 25-, 50-, and 100-year) and the return period levels were translated to the local watersheds in the City using the previously defined relationships between the City's and Sewells Point gauges. Using those various water levels, a GIS-based model was developed to predict coastal flooding extents and depths throughout the City. Based on the floodwater depths and extents, a range of flood mitigation concepts were identified that could be implemented throughout the City. Types of flood mitigation concepts included at policy, education, building codes, elevation of buildings and roadways, and infrastructure.

This study identifies various project areas where flood mitigation projects could potentially be implemented throughout the City, the approximate cost of the projects, and the potential reduction in flood damages. Flood mitigation options range from large infrastructure that would provide benefit to a watershed to options for individual structures.

1.3 OBJECTIVES OF THE CURRENT STUDY

The current phase of the Coastal Flooding Program evaluates the potential risk associated with coastal flooding throughout the City and identifies a range of mitigation options for each flood prone area. Mitigation options at the watershed, neighborhood, and resident scales are considered in this study. Estimated project cost and project benefit based on reduction of flood damages are included to help prioritize projects. This study seeks to:

- Define discrete project study areas to be considered for analysis,
- Estimate potential flooding impacts in terms of physical damage to structures and impacts to the transportation network. For this study, we consider impacts to the following from a 1% annual chance coastal flooding event:
    - Damages associated with building structures and contents as calculated from depth damage functions,
    - Reduction or restriction of accessibility resulting from flood inundation of roadways;
- Evaluate potential effects of sea level rise on flooding damages, requirements to accommodate sea level rise in a flood mitigation project, and evaluate changes in flood vulnerability resulting from projected sea level rise.
- Identify flood mitigation concepts for project areas throughout the City;
- Provide relative project cost estimates;

- Provide a comparison of projects in terms of project costs and reduction of flood damages.

1.4 PROJECT STUDY AREAS

Flood prone areas are generally delineated by the region's topography where topographic highs create hydrologic boundaries that define distinct watersheds or sub-basins. Surface and gravity storm water systems convey captured water from higher elevations to lower elevations and generally discharge through an outlet into river, lake, or ocean. Coastal flood waters usually enter an area or watershed through these outlets. Therefore, mitigation of coastal flooding typically focuses on the outlet location and the area within a watershed affected by the flooding. Figure 1-1 displays the major watersheds in the City of Norfolk and major tidal water bodies.

For this study, we have identified 15 project areas within the major watersheds that may be affected by coastal flooding. Each project area is delineated by distinct sub-basins or water catchment areas. Figure 1-2 shows the project areas defined in this study and planning districts they encompass. Buildings within the Norfolk Naval Base and Norfolk International Terminal (NNB-NIT) area are not considered in this study because they are not within the boundary of the City, and buildings located in the Lake Whitehurst area are presumed to be minimally affected by coastal flooding and thus are omitted from this study.

Project areas vary in size, number of parcels, number of critical and government infrastructure, number of structures at risk, as well as assessed values of structures at risk. Figures 1-3a and 1-3b and 1-4a and 1-4b display various general characteristics of each project area for a 1% annual chance event under current conditions and when considering 1-foot sea level rise, respectively. These characteristics demonstrate the wide scope of individual project areas and the relative impact flooding may have to each of these project areas. The total number of parcels, total number of buildings, and total assessed building values for each project area are summarized graphically on Figures 1-5, 1-6, and 1-7.

The assessed building values within in each project reflect the potential risk that flooding hazards may pose to each project area. The Lafayette project area clearly has the largest number of parcels, number of buildings and the highest total building values at risk for the respective project areas. Broad Creek, Downtown, Hague, Mason Creek, and Pretty Lake comprise a second tier of aggregate building values at risk, the lowest tier of aggregate building values at risk is comprised of Eastern Branch-264, Eastern Branch-Ingleside, Eastern Branch–Military, Lambert Point, Ohio Creek, Berkley-Campostella, Tidewater, West Ghent, and Willoughby-Ocean View project areas. These tiers reflect the range in number of parcels and buildings within each project area, and to a lesser extent, the number of large commercial or apartment buildings.

Detailed descriptions of each project area with maps illustrating the various project options are included in the appendices at the end of this report.

The 15 project areas encompass nearly all of the City's planning districts. Several planning districts near the Lake Whitehurst area are considered to be in an area that is not influenced by tidal flooding. Figure 1-2 shows a map of the project areas and City's planning

districts. A list of the planning districts and the project areas they are within is provided on Figure 1-8. In some cases planning district may overlie more than one project area.

1.5 AUTHORIZATION

Work Order No. 4 (Contract 13062) for the City-Wide Coastal Flooding Study was issued by the City on January 17, 2012. The scope of work is described in our proposal dated December 14, 2011.

2.0 COASTAL FLOODING

2.1 INUNDATION MAPPING

The City of Norfolk experiences flooding that results from precipitation, coastal surges, and combinations of both. This study focuses on coastal flooding; its impacts and mitigation opportunities. Coastal flooding occurs when water levels are raised as a result of meteorological forcing events (wind during storms) or unusually high tides during oceanographic processes (El Nino-type of events). Figure 2-1 presents a schematic of how meteorological forcing can produce coastal flooding.

Coastal surge effects can also increase flooding by raising the tailwater elevation. In this scenario, elevated tailwater (water level at storm water pipe outfall) can reduce the effective amount of water conveyed from the catchment area (e.g. street) to the outfall point (e.g. outfall in the bay). Figure 2-2 provides a schematic diagram of this phenomenon and how the two are inextricably linked.

The City is also susceptible to flooding resulting from precipitation events. In some watersheds within the city, flooding may be predominantly controlled by precipitation while in other areas it may be coastal (refer to Figures 2-3a and 2-3b for examples). The storm water infrastructure may not be capable of mitigating flooding during various events. For this City-wide study phase, we focus solely on the coastal surge component of flooding.

Therefore, flooding in low-lying areas like Norfolk is a multivariate, complex process that involves coastal processes, precipitation, and the storm water infrastructure. Due to the intricate nature of storm water infrastructure and amount of detailed information required to fully analyze the extent to which the infrastructure will mitigate flooding during various events, studies that characterize storm water infrastructure to this level are typically conducted at the sub-basin or watershed scale (small areas within the City). Those types of analyses evaluate the hydrologic and hydraulic processes of the basin and storm water infrastructure. For these reasons, detailed analysis of how the City-wide storm water infrastructure will mitigate flooding is beyond the scope of this phase of the program.

This study focuses on defining the expected extent of flood inundation that results from tidal flooding and the impact from flooding. Inundation extent is mapped through GIS-modeling that takes ground elevation and tidal variation into account. For this study, we selected the 1% annual flood event to estimate the flood damages and base mitigation options on. For sea level rise, we consider a 1-foot sea level rise, which corresponds to the sea level approximately 75 years from now using current relative sea level rise rates based on the Sewells Point records.

This window would encompass 25 years for planning, designing, and procuring funding for construction of a large capital improvement project and the 50 year life cycle of the project.

2.1.1 Tide Gauge Program

During 2009 and 2010, the City implemented a tide gauge program to better understand how water levels in the major tidal water bodies throughout the City relate to water levels at Sewells Point. Figure 2-4 presents the locations of the City's tide gauges and NOAA gauges in the region. Water level relationships between the major tidal water bodies and Sewells Point are used to more accurately characterize predicted water levels for various storm events (e.g. 10-year, 50-year, or 100-year) and what the respective tailwater elevations would be expected to be.

2.1.2 Floodwater Elevations Considered in this Study

We use the water levels and relationships between local watersheds relative to Sewells Point as described in our 2010 report (Fugro, 2010). We also incorporate coastal surge levels included on the Federal Emergency Management Agency's (FEMA) flood insurance rates maps. In addition, we consider flooding scenarios under the assumption that sea level rises one foot. Figure 2-5 presents a schematic example of how the various factors were used to define a flood water elevation and project design elevation.

3.0 COASTAL FLOODING IMPACTS

Coastal flooding can impact the City in a wide spectrum of ways whose effects, both direct and implicit, may be cascading and (geographically) far reaching. These impacts are broadly categorized as physical, economic, or social (Figure 3-1). Physical impacts include damage to infrastructure, buildings, contents within those buildings, vehicles, utilities, transportation network. Economic impacts include elements such as losses from business closures, lost jobs, and repair and reconstruction costs. Social impacts result from displaced residents, emergency management issues, shelter requirements, and exposure of population to flooding.

This study focuses on elements of physical impacts through evaluation of susceptibility and damage analysis of buildings and impact of flooding to roadways in terms of reduction and restriction of accessibility. Though impacts of flooding are far-reaching in a multitude of factors, an initial investigation into property damages enables a means of relative comparison of: 1) evaluating project areas to prioritize need for flood mitigation measures and 2) comparing project options by considering the level of damages of similar flood water level after a project is constructed. In order to more fully understand the impacts of flooding, future studies can assess the impacts to items shown on Figure 3-1 and described above (e.g. predicted flood damage to vehicles, utility systems, interruption of business, social impacts, etc.).

For this study we have also review available flood claim data to identify areas of repetitive damage and severe repetitive damage. Figures 3-2, 3-3, and 3-4 show the approximate locations of flood claims, repetitive claims, and severe repetitive claims since the City entered the NFIP (1977). This information is used to aid in the identification of flood

mitigation projects. Areas where reported severe flood problems, particularly repetitive claims, are concentrated help confirm flood prone areas that are severely affected by flooding.

In this study we also evaluate how flooding may impact local and regional transportation networks. Many roadways throughout the city and region flood during small storm surge events, and some local streets may flood a few times a month during spring high tides. During periods of flooding, traffic patterns may be altered, and access to buildings (e.g. residential, government, critical, etc.) may be completely impeded depending on water depth. In some instances, the water may be sufficiently deep that emergency response vehicles (e.g. ambulance, fire trucks, etc.) lose the ability to pass through the street. Additionally, the ability for employees to access critical or essential facilities may be impeded by street flooding and thus affect operation of the facility.

Flooded streets may also lead to a disruption of business, which constitutes a significant, implicit economic impact that can be difficult to quantify. Flooded streets also pose a hazard and nuisance to the citizens and businesses.

In this study we identify streets that may be potentially flood and the respective impacts to accessibility of emergency service or passenger vehicles as well as the number of houses that may experience reduced or restricted accessibility.

3.1 BUILDING DAMAGE ESTIMATES ANALYSIS

Building flood damage estimates, in terms of monetary costs, are assessed for a range of flooding scenarios under current conditions and 1-foot sea level rise. Flood mitigation alternatives are evaluated in terms of their relative reduction of damages in order to aid in their assessment as demonstrated in Figure 3-5. The analysis focuses on direct physical damage to structures and contents of private and public buildings. The intent of this analysis is to estimate the physical damages to buildings and contents associated with predicted future flood events in the city under existing infrastructure conditions as a basis for performing a benefit-cost comparison of flood damage mitigation alternatives. We note that future damage estimates can be further refined by incorporating additional factors such as vehicle damage, displacement costs, emergency response and management costs, and damage reductions that may result from responses to flood warnings.

Structure and contents flood damage assessments are based on predicted flood water depth above the first floor in a structure and the approximate value of the structure, and are calculated based on a percentage of the building value where the percentage is a function of the flood water depth. This Depth-Damage Function (DDF) generally increases as the flood water depth increases. DDFs have been developed for various types of buildings by the United States Army Corps of Engineers (USACE), and are published in the "Catalog of Residential Depth-Damage Functions" (USACE 1992), USACE's EGM 01-03 (USACE, 2000) and EGM 04-01 (USACE, 2003). This study uses a building inventory file developed by the project team with assistance from the City, predicted tidal flooding extent and depth results from the GIS-model, high-resolution LiDAR topography data, and flood water DDF curves to quantify damage estimates. A GIS-based routine was developed to calculate and compile the damage estimates for a 1% annual chance storm surge and a 1% annual chance storm surge with one foot of sea level rise.

3.1.1 Building Inventory Development

A GIS file of the building footprints developed for this study is used to define the spatial locations of buildings in each project area. The building inventory used in this study is comprised of 92,450 buildings. Accessory buildings (e.g. sheds, detached garages, etc.) were not used to calculate predicted flood damages. The remaining 56,272 buildings were used to calculate predicted flood damages. The project team coordinated with the City to update building footprints based on 2009 aerial photography.

The buildings are classified by type and building type classification is used to determine the appropriate DDF for damage estimate calculation. Classification of building type is based primarily on information provided by the City's Assessor's office. The information is further refined using high-resolution aerial photographs and site reconnaissance conducted during the study. Building classifications are summarized in Table 3-1.

Table 3-1: Typical Building Classifications

Primary Type	Sub-type	Sub-type	Comment
Residential			Dwelling
	1-Story		
	2-Story		Includes 2 or more stories
	Split-Level		
		Basement	
		No Basement	
Accessory			Detached garage, shed, etc.
Auto Supply			
Clothing			
Department Store			
Grocery Store			
Lodging			Hotel, motel, etc.
Single Story Office			
Multiple Story Office			
Restaurant			
School			
Service Station			

3.1.2 Building Values

Building values are assigned to the buildings based on information provided by the City's Assessor's office. The City's 2010 assessed values are used where available. In some cases, assessment values are not available, and are estimated based on similar structures and usage type.

3.1.3 First Floor Elevations

In order to estimate the flood depth at a building, first floor elevations (FFE) estimates are developed. FFE derived from surveyed results are not available for most buildings. Therefore, FFE are developed through the following procedure. For buildings outside of the 100-year flood zone or were constructed during 1979 or earlier, the 2009 LiDAR data is used to estimate the FFE. If a building did not have a crawl space (as defined in the assessor's database), the FFE is assumed to be 0.5 feet above the ground surface. This assumes an offset for a 6-inch ground slab. If the building has a crawl space, then the offset for the ground surface is assumed based on reconnaissance work conducted during the study. During the study, reconnaissance through the watershed is used to estimate and assign the FFE where crawl space height data was incomplete in the database.

If buildings are inside the 100-year flood zone and constructed after 1979, FFE were assigned based on 100-year flood elevation + 1 foot (e.g. 7.3 ft [NAVD88] + 1 ft = 8.3 feet). In August of 1979, the City of Norfolk entered the National Flood Insurance Program (NFIP), which requires new construction within 100-year flood zones as defined by FEMA to be 1 foot above the 100-year flood elevation.

3.1.4 Depth Damage Functions - Structures and Contents

A depth damage function (DDF) is a mathematical relationship between the depth of flood water above or below the first floor of a building and the amount of damage that can be attributed to that water. The DDFs that are used in this study for residential and non-residential buildings estimate the damage based on a function of the flood water depth at the building and a percentage of the building value. DDFs have been developed for various building types based on statistical studies. Figure 3-5 illustrates the relationship between DDF concept and FFE. The DDF curves published by the USACE (1992, 2000, 2003), as described above, are used in this study. The USACE guidance documents provide a "mean" percentage and a "standard deviation" percentage to use when estimating damage from various flood water depths.

3.1.5 Damage Assessment Estimates

The GIS-based damage assessment tool, developed for this study, reads the flood water body outputs from the GIS-based flood water level prediction and estimates the flood water depth for each building based on the building's FFE and flood model output. Structure and content damages are estimated using the flood water depth and respective DDFs.

3.2 FLOODING IMPACTS TO BUILDINGS

Several measures of flooding impacts are evaluated in this report under two scenarios: current conditions and when 1-foot sea level rise is considered. Results are intended to provide a basis of comparison to terms of: 1) magnitude i.e. how many buildings within a project area are susceptible to flooding (Table 1-1) and 2) damage estimation of total damages for each project area and the reduction of damages each project option may provide (Table 1-1).

Table 1-1 provides a summary of the total number of buildings potentially susceptible to flooding (e.g. building footprint within predicted flood extent) and the effect (reduction in flood damages) each flood mitigation project option may have on number of buildings protected. This

displays a relative measure of benefit attributed to each flood mitigation project option for each respective project area. We note that project areas, and thus number of susceptible buildings, vary greatly in scale from less than 20 to almost 7,000 buildings, and it is necessary to frame the impact of each project option in context of project area size, especially when comparing project options in different project areas.

Lafayette River project area contains the largest number of susceptible buildings. The number of susceptible buildings generally increases by a factor of 1.4 times from current conditions to 1-foot sea level rise for most project areas. In several areas, the effect of 1-foot sea level rise is more pronounced; Eastern Branch – Ingleside increases by a factor of 2.2 times, West Ghent, 2.5 times, and Lambert Point, 3.5 times.

Damage reduction estimates are performed under the assumption that flood protection measures mitigate all damages for buildings protected by each respective mitigation measure. While this is not entirely realistic since precipitation during a storm likely results in flooding, the intent of this analysis is to compare project areas in relative terms, not in terms of absolute costs arising from damages. Therefore for the scope of this study, we have incorporated this assumption to facilitate comparisons amongst project areas. The scope of damage reduction correlates to the size of the flood mitigation project, and vary from little benefit to being completely protective.

Total damages per project area range from less than $1 million to over $266 million under current conditions and approximately $2.1 million to over $477 million with 1-foot sea level rise, which are presented in Tables 3-5 through 3-7. Figures 3-6a and 3-6b, provide a graphical summaries of total damages in each project area). The majority of project areas incur damage estimates of approximately $12 to $44 million, and comprise 47% of total damages City-wide (Figures 3-6a and 3-7a). In these project areas, the average damage estimates are approximately $150,000 (Table 1-1). Four project areas, Eastern Branch – Ingleside, Eastern Branch – Military, Lambert Point, and Ohio Creek, have very low total damage estimates (less than $1 to approximately $5 million) compared to the majority of project areas, and comprise only approximately 4% of total damages City-wide (Figures 3-6a and 3-7a). Average damage estimates in these four project areas are approximately $4,000 (Figures 3-6a).

Lafayette River project area represents the largest project area in size and number of susceptible buildings, and correspondingly, incurs the greatest predicted damage estimates, approximately $266 million, which is 49% of total damages City-wide. Though a smaller project area in terms of number of susceptible buildings, the Hague project area accounts for a significant amount of damage estimates i.e. approximately $82 million, or 15%.

The effects of sea level on predicted flood damage is not uniform throughout the City. When comparing damages under current conditions and 1-foot sea level rise, the increase of damages ranges from a factor of 1.1 times in Berkley and Campostella to a factor of 5.2 times in West Ghent (Tables 1-1 and 1-2). Other areas with significant increases of predicted damages due 1-foot of sea level rise are Broad Creek, Lambert Point, Eastern Branch-Ingleside, -Military, and –I264. The general factor of increase is 1.9 times for project areas City-wide.

Comparison of the factors of increase in number of buildings from current conditions to 1-foot sea level rise enables general relationships between topography and flooding extent to be

inferred the non-uniform increase of water levels City-wide, however further analysis of different return periods e.g. 10- and 25-year coastal flood events would be needed to more completely characterize the initial trends observed in this analysis.

3.2.1 Damage Reduction – Infrastructure Component

Tables 1-1 and 1-2 provide a summary of the predicted damages and estimated reduction of damage associated with each infrastructure project option. Many of the larger scale project options may be significantly or even completely protective The Downtown Floodwall Connector, both the Clifton and South Main project options in the Berkley and Campostella project areas will reduce damages by insignificant amounts, approximately 2-10% (Table 3-3). When 1-foot sea level rise is taken into account, half of all project options have diminished percentage damage reduction to some degree i.e. >1% in several projects areas to 29% for Lambert Point (Tables 1-1 and 1-2).

3.2.2 Damage Reduction – House Raise Component

Table 3-2 provides a summary of the predicted damages and estimated reduction of damage when solely considering house raises in each project area. A house raise candidate is defined by the requirement to raise a house at least 2 feet to be 1 foot above flood waters. House raise candidates are limited in number, and damage reductions are low relative to infrastructure options in the majority of projects with an average of approximately 11% (Table 3-4). Willoughby and Ocean View benefit the most from the house raise option (approximately 57% damage reduction). Pretty Lake, Lafayette River, and Eastern Branch – I-264 may also benefit from house raises with damage reductions of approximately 37%, 22%, and 32%, respectively.

Table 3-2. Damage Reductions for House Raise Options

Project Area	Current Conditions			One Foot in Sea Level Rise		
	Total Damages ($, Millions)	**Building Damages ($, Millions)**	**Damage Reduction ($, Millions)**	**Total Damages ($, Millions)**	**Building Damages ($, Millions)**	**Damage Reduction ($, Millions)**
Eastern Branch - Military	4.7	Bulkhead Only		14.0	Bulkhead Only	
		4.5	0.3		13.3	0.6
		McGinnis Road Raise			McGinnis Road Raise	
		4.5	0.3		13.3	0.6
Broad Creek	15.0	Flood Gate		44.8	Flood Gate	
		14.2	0.7		42.4	2.3
		Bulkhead			Bulkhead	
		14.4	0.6		42.8	1.9
Eastern Branch - Ingleside	0.8	Tide Gate/Pump Station Option		2.1	Pump Station Option	
		0.8	0.0		1.4	0.8
Eastern Branch	8.0	House Raising Only		17.1	House Raising Only	

Project Area	Current Conditions			One Foot in Sea Level Rise		
	Total Damages ($, Millions)	**Building Damages ($, Millions)**	**Damage Reduction ($, Millions)**	**Total Damages ($, Millions)**	**Building Damages ($, Millions)**	**Damage Reduction ($, Millions)**
– I-264		5.4	2.5		13.5	3.6
Ohio Creek*	1.8	Pump Station and Culvert		2.6	Pump Station and Culvert	
		1.8	0.0		2.5	0.1
Tidewater	19.1	Harbor Park Floodwall		24.0	Harbor Park Floodwall	
		18.7	0.4		23.1	1.0
		I-264 Underpass Floodwall			I-264 Underpass Floodwall	
		18.7	0.4		23.1	1.0
		I-264/Holt St. Floodwall			I-264/Holt St. Floodwall	
		18.7	0.4		23.1	1.0
Downtown – Outboard of Existing Floodwall	11.2	Downtown Floodwall Connector		25.0	Downtown Floodwall Connector	
		n/a	n/a		n/a	n/a
Berkley and Campostella	17.5	Clifton Option		18.6	Clifton Option	
		17.1	0.4		17.8	0.8
		South Main Option			South Main Option	
		15.8	1.7		15.5	3.1
Hague*	82.1	Hague Flood Gate		133.5	Hague Flood Gate	
		80.7	1.4		119.2	14.3
West Ghent	43.9	Norfolk General – Existing Topography		62.1	Norfolk General – Road Raises for Sea Level Rise areas only	
		43.9	0.0		62.1	0.0
West Ghent	43.9	West Ghent Norfolk General/Hampton Blvd		62.1	West Ghent Norfolk General/Hampton Blvd	
		43.9	0.0		62.1	0.0
		West Ghent Midtown Tunnel			West Ghent Midtown Tunnel	
		43.1	0.9		60.9	1.2
Lafayette River	266.6	Hampton Blvd (Median)		477.4	Hampton Blvd (Median)	
		180.3	46.9		304.3	105.5
		Hampton Blvd (East of Blvd)			Hampton Blvd (East of Blvd)	
		180.3	46.9		67.6	409.8
		Lafayette River Larchmont-Eleanor Crossing			West Lafayette River-Eleanor Crossing	
		202.2	55.7		334.7	129.0
		Lafayette River Larchmont-NIT Crossing			West Lafayette River-NIT Crossing	

Project Area	Current Conditions			One Foot in Sea Level Rise		
	Total Damages ($, Millions)	**Building Damages ($, Millions)**	**Damage Reduction ($, Millions)**	**Total Damages ($, Millions)**	**Building Damages ($, Millions)**	**Damage Reduction ($, Millions)**
		208.0	58.6		341.5	136.0
		Lafayette River Lambert Point-NIT Crossing			Lafayette River Lambert Point-NIT Crossing	
		208.0	58.6		341.5	136.0
Mason Creek*	12.3	Pump Station and Culvert		23.0	Pump Station and Culvert	
		11.6	0.8		19.5	3.6
Willoughby and Ocean View	26.9	House Raises		38.3	House Raises	
		11.4	15.5		12.6	25.6
Pretty Lake*	31.3	Pretty Lake Flood Gate Option		53.0	Pretty Lake Flood Gate Option	
		19.7	11.6		30.4	22.6

* H&H analyses that incorporate precipitation and performance of existing stormwater infrastructure are currently being performed for this area

3.2.3 Building Damages – Project Options Including All Components

Tables 1-1 and 1-2 provide a summary of the predicted damages and estimated reduction of damage associated with each project option including both home raise and infrastructure components. The scope of damage reduction generally correlates to the size of the flood mitigation project, and project options vary from virtually no benefit to being completely protective. Damage reductions vary over a wide spectrum from approximately 2% for the Clifton Main project option to 100% for several projects (Tables 1-1 and 1-2). Only one project option, the West Ghent – Norfolk General optional has a marginal benefit of approximately 63%.

3.3 FLOODING IMPACTS TO ROADWAYS

Flooding of roadways impacts the City via a number ways. Flooded roadways will require the City to close roads, set up detours, and may require special pumps to be deployed to mitigate flooding, which require City man-power and resources to manage. Flooded roadways will also impede vehicular traffic and that traffic may range from City vehicles providing various services to the public (e.g. buses, public works vehicles, etc.), emergency response and police vehicles, vehicles conducting business in the City (e.g. delivery truck), and citizen vehicle traffic used to report to work.

Examination of flooded roadway centerline miles highlights areas of possible higher priority in terms of infrastructure projects that address road accessibility reduction and restriction. Three categories of flooding are considered: a) ‘Passable’ at 12 inches or less is associated with nuisance flooding where flood levels cause inconvenience, but virtually all vehicles ranging from passenger vehicles to emergency response vehicles can still pass, b) ‘Emergency only’ with a flood depth of 12-18 inches is considered to be passable for emergency response vehicles, but not passenger vehicles, and c) ‘Impassable’ at over 18 inches, which is considered impassable for all vehicles.

The approximate number of buildings that will have restricted access resulting from flooded roadways is shown in Tables 3-6 and 3-7. Areas more prone to road inundation in terms of extent include the Lafayette River, the Hague, and Pretty Lake project areas. Project areas less prone to road inundation include Downtown and Ohio Creek. Figures 3-8 and 3-9 are graphical representations that illustrate roadway flooding impacts relative to each project area. The Lafayette River project area again displays the largest mileage of flooded roadway centerlines. The bulk of flooding in certain areas like Willoughby – Ocean View and the Hague is categorized as impassable to all vehicles, which constitutes a significant risk as accessibility to escape routes may be limited in these areas. Figures 3-3 and 3-4 illustrate the relative percentage of flooded roadway centerline miles. The Lafayette River project area represents half of flooded roadway centerlines for the City. The Hague and Pretty Lake follow the Lafayette River project area in terms of percentage of flooded roadway centerline miles.

Table 3-3. Roadway Impacts for 1% Annual Chance Coastal Flooding Event

Project Area	Buildings with Blocked Access (18 inches of water or more) from Flooding	Roadway Miles Flooded Less than 12 inches (miles)	Roadway Miles Inaccessible To Passenger Vehicles (Flooded between 12 and 18 inches)	Roadway Miles Inaccessible To Emergency Vehicles (Flooded over 18 inches)
Eastern Branch – Military	962	4	1	3
Broad Creek	848	6	2	4
Eastern Branch – Ingleside	200	1	1	0
Eastern Branch – I-264	388	3	1	4
Ohio Creek	27	1	0	0
Tidewater	140	3	1	7
Downtown	33	0	0	2
Berkley and Campostella	140	3	1	7
Hague	1,080	8	4	17
West Ghent	523	4	2	5
Lamberts Point	194	1	0	1
Lafayette River	9,833	49	17	64
Mason Creek	597	4	1	3
Willoughby and Ocean View	953	1	0	9
Pretty Lake	1,483	9	2	9

Table 3-4. Roadway Impacts for 1% Annual Chance Coastal Flooding Event and 1-Foot Sea Level Rise

Project Area	Buildings with Blocked Access (18 inches of water or more) from Flooding	Roadway Miles Flooded Less than 12 inches (miles)	Roadway Miles Inaccessible To Passenger Vehicles (Flooded between 12 and 18 inches)	Roadway Miles Inaccessible To Emergency Vehicles (Flooded over 18 inches)
Eastern Branch – Military	962	4	2	6
Broad Creek	961	7	3	8
Eastern Branch – Ingleside	234	2	1	1
Eastern Branch – I-264	508	2	1	6
Ohio Creek	28	1	0	1
Tidewater	163	3	2	9
Downtown	33	0	0	2
Berkley and Campostella	602	4	2	7
Hague	1,093	6	4	25
West Ghent	563	6	3	8
Lamberts Point	200	2	1	3
Lafayette River	10,681	31	24	101
Mason Creek	657	7	2	6
Willoughby and Ocean View	981	1	0	10
Pretty Lake	2,157	9	4	17

An understanding of the extent and impact of flooding on a City-wide basis aids in identifying roadways prone to flooding, particularly those that are prone to flooding at more severe levels, which can diminish accessibility to vehicles. Figures 3-12a through 3-12c display roadway centerlines that are prone to flooding that a) hinders the accessibility to passenger vehicles (orange) and b) are inaccessible to all vehicles including emergency responders. In a 1% annual chance coastal flood event, significant inaccessibility may occur in Tidewater, Hague, portions of Lafayette River closest to the river water body, Larchmont, Willoughby and Ocean View. When taking 1-foot sea level rise into account, the aforementioned areas have an increased possibility of more widespread road accessibility due to flooding as seen in Figures 3-13a through 3-13c.

Assessing potential roadway flooding in terms of traffic volume impact can provide powerful insight into possible traffic blockages and access restriction to both residents and emergency responders. Figures 3-14a through 3-14c display areas that may experience severe traffic volume impacts from flooding of major roadways. We note that in several areas roadways that lead up to bridge spans may experience flooding and restrict access to all vehicles. Taking 1-foot sea level rise into account, flooding of roadways may be further exacerbated as seen in Figures 3-15a to 3-15c.

4.0 FLOOD MITIGATION STRATEGIES

4.1 MITIGATION STRATEGIES AND APPROACHES

Mitigating flood hazards requires a sequence of steps; namely: 1) the identification of the flooding hazards, 2) an assessment of the flooding risks, 3) the evaluation of the consequences of flooding (and their acceptability or lack thereof), 4) an evaluation of alternatives, and 5) the development and implementation of mitigation and risk management plans.

The flood hazard and risk are defined by technical considerations, such as the predicted:

- Depth of the flooding,
- Extent and location of the flooded region, and
- Recurrence intervals or frequency of flooding.

The consequences of flooding range from the potential for loss of life or injury, population and population density, economic losses, disruption of City services, access, to other societal factors. Together, the hazards, risks and their consequences provide formative information to define flood mitigation objectives and priorities.

Flood mitigation involves either preventing the flood waters from entering an area, moving the flood waters away from the area, and/or adapting the area to accommodate the flood. These strategies can include both structural and non-structural measures. Different types of flood mitigation strategies can be grouped by the following categories of objectives:

- Drainage or conveyance system improvement,
- Elevation of ground surface or structures above flood elevation,
- Barriers to prevent flooding,
- Impoundment and storage of flood waters,
- Adaptive land use to accommodate flooding, and
- Public policy.

Often mitigation approaches include a combination of the above strategies. The following lists a number of types of flood mitigation elements that may be applicable to the City of Norfolk's flood mitigation objectives.

- Drainage and conveyance improvements:
  - Channelization or improved flood conveyance (stream channel improvements) and

  - Storm drainage system improvements;
- Elevation of the ground surface and/or structures;
- Barriers to flooding:
  - Earthen berms and levees,
  - Floodwalls,
  - Tidegates and barriers, and
  - Dams;
- Impoundment and storage:
  - Permanent detention and storage ponds or reservoirs and
  - Temporary use of land;
- Adaptive land use:
  - Wetlands, dunes, beach nourishment, and floodplain protected areas,
  - Setbacks and buffer areas, and
  - Land acquisition and set aside;
- Public policy:
  - Local building and construction code modifications,
  - Zoning and land use restrictions,
  - Education, and
  - Flood warning systems, modeling, and forecasting.

Although some flood mitigation strategies in the above list, like impoundment and storage, etc., are more commonly thought of as approaches to control flooding from precipitation and rainfall runoff, they also can be applied to coastal flooding defense. This is a valid assumption because extreme tides are associated with meteorological events that often produce large amounts of rainfall. In addition, as discussed subsequently, the design of any barriers to flooding also must be designed to accommodate rainfall and storm water runoff from the area behind the flood barrier. Thus, conventional upland storm water improvements and storage options also can be components of flood mitigation strategies for coastal flooding. These options may also be applied at various scales including watershed, neighborhood, or resident/single structure. Figure 4-1 provides examples of projects according to various scales.

A brief discussion of the various types of flood mitigation options follows. Figures 4-2 through 4-10 provide examples of many of the different potential elements of flood mitigation.

4.2 DRAINAGE AND CONVEYANCE IMPROVEMENTS

Improvements in stream channels and the channel of water through preferred flow paths can help reduce the rise of floodwaters and speed their recession. The greater the volume of water that can be quickly conveyed, the lower the flood level will be within the given area. Conveyance improvements may include debris clearing control programs, increased capacity of storm water drainage systems, channel widening, or stream realignment. Figure 4-2 provides several examples of flood conveyance improvements.

4.3 ELEVATION OF THE GROUND SURFACE AND/OR STRUCTURES

In low-lying areas, it is sometimes possible to raise the ground elevation so that the ground surface is higher than the storm tide elevations. Raising the ground elevation, however, can produce different secondary consequences for the various infrastructure and the conveyance of rainfall runoff.

Elevating buildings above flood levels is another approach that can be used for individual properties. Floodwaters flow under the building causing little or no damage to the structure or its contents. If floods are of long duration, however, this is potentially an unsafe approach since access is unsafe during flood conditions. If septic systems are present, the potential for water quality and public health risks are also an important consideration. Figure 4-8 illustrates the concept of structure elevation.

4.4 FLOOD BARRIERS

Flood barriers may include small earthen berms, protective sand dunes, larger levees, or concrete (or steel) floodwalls. All of these barriers are designed to keep floodwaters out of a low lying area. Earthen levees have side slopes that require land for their footprint; the width of the footprint is dependent on the height of the levee. For flood barriers to be effective, it is necessary to surround the entire area to be protected without gaps or any other deficiency, and/or for the barrier to tie into topography that is above the flood elevation. Additionally, the flood barrier must be able to withstand the forces associated with the floodwaters and waves.

Care must taken to ensure adequate drainage measures are provided within the contained area so that the rain associated with tide and storm events does not flood the interior. Larger barriers tend to have high initial costs and require long term monitoring and maintenance. Failure of large flood barriers can be catastrophic when large areas flood rapidly.

Temporary dams or flood barriers also can be used to block or redirect flows during flood events. Flood gates or inflatable dams have been successfully used for this purpose.

Figures 4-7 through 4-12 show examples of: small levees and walls, larger levees and walls, gates, pump stations, and temporary flood barriers.

4.5 IMPOUNDMENT AND FLOOD STORAGE

An alternative approach to flood mitigation is to attempt to store floodwaters in selected areas during floods and then release the stored water, in a controlled manner, after the flood. By storing and subsequently releasing water, it is possible to accommodate the floods without overwhelming the downstream areas. Approaches may include storm water detention and/or retention ponds to trap runoff from impervious surfaces, construction of dams along rivers and creeks to regulate the downstream flow, and the use of wetlands as storage areas. These approaches typically require considerable land areas. Parks, recreation areas, and golf courses are sometimes used to facilitate this purpose. Considering that much of the land in Norfolk is developed, this mitigation alternative does not offer significant opportunity to mitigate large volumes of flood water. However, small local storage options may provide local relief to some areas. During redevelopment of areas in the City, this option may have some value to develop these types of features.

4.6 ADAPTIVE LAND USE

Adaptive land use usually involves the purchase of property and the removal (demolition or relocation) of structures in flood prone areas and designating the land as undevelopable. Often such areas are then used flood water detention and storage. The undeveloped green space also aids in buffering the adjacent area. This approach offers a long-term solution that removes the structure from the path of the flood. Adaptive land use is typically limited to areas that are frequently flooded, where floods are deep and/or of long duration, or where flooding is associated with high and dangerous flood water velocities. Maintaining wetlands, beaches, and dunes as buffers are methods of adaptive land use. Figure 4-4 illustrates this concept as applied to coastal dunes.

4.7 PUBLIC POLICY

Building and Construction Codes. Local building codes can be used to improve performance of structures subjected to flood waters. For example, standards can be set with respect to foundations or floor elevations to help the structure survive temporary flooding. Another example is dry water proofing, which is an approach that requires all portions of structures below specified flood elevations to be sealed or made impervious to water. This approach is generally only appropriate for buildings subject to less than 3 feet of flooding. This approach has the obvious disadvantage in that the structure and contents still remain within the flood path.

Land Use Plans and Zoning. Zoning rules, land use plans, and coastal zone management can be used to prevent construction or restrict the types of development (building size, density, use, open space preservation, etc.) within flood prone areas and to direct future development with regard to relative sea level rise risks. The intent of such planning measurements is to minimize negative impacts associated with building structures that will not optimally withstand events that may occur in a particular area that is prone to flooding. While these plans do not prevent flooding in flood prone areas, they can reduce the damage and risk.

Education. Flood mitigation strategies can include public information and outreach in the form of communication about flooding risks, flood preparedness, access routes, flood protection information, funding support of mitigation measures, and least impact development techniques.

Flood Warning Systems. Part of an overall flood mitigation strategy may be flood warning and/or numerical simulation forecasting systems to alert both responsible City staff and the public of potential flooding events and their location and severity. Although this communication does not prevent flooding or long term damage, it can reduce safety risk and provide opportunity to relocate valuables. The water level monitoring gauge stations can provide the basis for developing such a system.

4.8 RELATIVE COSTS OF VARIOUS APPROACHES

The costs of various flood mitigation approaches are project specific and require detailed evaluation. Nevertheless relative comparison of the different types of approaches is possible. Tables 4-1 and 4-2 provide generalized comparisons of the relative capital and operational-maintenance costs associated with the different approaches.

Table 4-1. Relative Capital Investment Costs for Different Categories of Flood Mitigation Improvements

	Relative Cost		
	Low	Medium	High
Drainage & Conveyance Improvements	XXXXX	XXXXXXXXXX	XXXXX
Elevation of Ground or Structures	XXXXX	XXXXXXXXXX	XXXXXXXXXX
Flood Barrier Structures		XXXXX	XXXXXXXXXX
Impoundments and Storage	XXXXX	XXXXXXXXXX	
Adaptive Land Use	XXXXXXXXXX		
Public Policy	XXXXX	XXXXXXXXXX	XXXXX

Table 4-2. Relative Operational and Maintenance Costs for Different Categories of Flood Mitigation Improvements

	Relative Cost		
	Low	Medium	High
Drainage & Conveyance Improvements	XXXXX	XXXXXXXXXX	
Elevation of Ground or Structures	XXXXXXXXXX		
Flood Barrier Structures		XXXXXXXXXX	XXXXXXXXXX
Impoundments and Storage	XXXXX	XXXXX	
Adaptive Land Use	XXXXXXXXXX		
Public Policy	XXXXXXXXXX		

5.0 POTENTIAL FLOOD DEFENSE OPTIONS FOR THE CITY OF NORFOLK

Given the variability of conditions within the City of Norfolk, a wide range of flood mitigation projects and strategies will be required to provide meaningful relief. It should be noted that the first decision that will need to be made to assess potential options will be to define the appropriate return period of the flooding to be mitigated by the project. In some areas, a 100-yr return period flood may be mitigated with minor infrastructure improvements, while in other areas, significant projects will be required to mitigate a 2-yr return period flood. These decisions will have to be made on a case-by-case basis. The following discussion lists (in increasing order of existing coastal flood severity) the types of projects and their potential areas of applicability. General programmatic options and recommendations are included at the end of this section.

5.1 MITIGATING DAMAGE TO VEHICLES

People living and working in the City can mitigate flood damage to vehicles by simply moving vehicles to higher ground in advance of flooding. The City of Norfolk maintains a website that provides the ground surface elevation contours based on the latest available survey (http://gis.norfolk.gov/interactivemapper/). The website can be used to estimate the

street, driveway, or parking lot elevation where the vehicle is parked. The elevation values derived from LiDAR surveys on the City's website are likely accurate to within about 1 foot. Websites maintained and updated by credible sources (e.g. NOAA) can be accessed to obtain the most recent storm surge forecast and assist in determining where to (if necessary) move their vehicles. When in doubt, it is safe practice to advise the general public to err on the side of caution since actual storm surge elevations may differ from predicted levels for a variety of reasons. In general, passenger vehicles usually begin to incur damage when the water depth is about 12 inches. When the water depth reaches the dashboard level, the car is often totaled complete loss. Larger vehicles like trucks and heavy duty trucks are taller and require about 18-inches of water before they begin to incur damage. Immediately following the 2009 Nor'easter, at least 225 vehicles were towed and presumed to be complete losses in Norfolk based on a survey conducted during this study.

5.2 FLOOD PROOFING OF BUILDINGS (FLOODING DEPTHS UP TO 2 TO 3 FEET)

Flood proofing of individual buildings may include the placement of walls or levees around individual buildings, watertight closures for doors and windows, reinforcement of walls to resist water pressure, use of paints, membranes, and other sealants to reduce seepage of water, installation of pumps to control water levels, installation of check valves to prevent entrance of floodwaters at utility and sewer wall penetrations, and (re)locating electrical, circuits and HVAC equipment above expected flood levels. Barriers around homes may be removable or masked as landscaping boxes. Figures 4-5, 4-6, and 4-7 present several examples of flood proofing.

Coastal engineers should be consulted to assist in estimating floodwater. Additionally, civil engineers should be consulted to assist in designing a dry flood proofing system that can withstand the floodwater pressures. Some flood proofing measures may not be adequate for acceptance by FEMA to reduce flood insurance rate premiums or for funding support. For additional information regarding flood proofing options and criteria for NFIP acceptance, refer to documents such as FEMA 2011, 2010, 2009, 2001a, 2001b, 1999, and 1986.

5.3 STORM WATER DRAINAGE SYSTEM IMPROVEMENTS TO MITIGATE LOCALIZED FLOODING (FLOODING DEPTHS UP TO 2 FEET)

Where the current flooding behavior can be characterized as nuisance flooding, adequate relief may be achieved by installing storm water system drainage improvements (either as additional parallel systems or upgraded systems). In many areas of the City, the current infrastructure is undersized for the amount of development in the area. This factor coupled with higher tailwater conditions, impedes upland floodwaters from exiting the storm water systems in an expedient manner. The installation of larger pipes with inline check valves, sized for an appropriate tailwater condition, should reduce both flood depths and durations to more acceptable levels.

This approach can be cost effective in resolving the most frequently occurring flooding issues that produce small flooding depths over a wide area. The storm water system drainage improvements also can be an important component of larger scale flood mitigation measures. However, it must be realized that resizing existing storm water drainage systems can be problematic especially where existing pipes are buried within older infrastructure. Nonetheless,

storm water drainage improvements can help reduce flooding by conveying floodwaters out of localized areas more readily. Figures 4-4 and 4-5 show examples of local storm water drainage improvements.

5.4 ELEVATION OF EXISTING GROUND SURFACE TO MITIGATE LOCALIZED FLOODING (FLOODING DEPTHS UP TO 2 FEET)

Again where current flooding can be characterized as nuisance flooding, adequate relief also may be achieved by minor fill projects to raise the level of the ground surface. Areas along the shoreline that suffer mainly from river flooding may experience adequate relief by raising the elevation of the existing ground. In some areas, limited increases in ground surface elevation can prevent floodwaters caused by elevated tides from entering selected sites. It is expected that these types of improvements will only be practical or feasible in localized areas where existing flooding depths are less than 1 to 2 feet.

5.5 SMALL FLOODWALLS OR EARTHEN LEVEES TO PROTECT AGAINST NEIGHBORHOOD-SCALE FLOODING (FLOODING DEPTHS UP TO 3 TO 4 FEET)

Based on the analyses completed to date, it is likely that installation of small floodwalls or earthen levees may be a viable option within some areas of the City. These types of solutions are envisioned to require walls or earthen levees that are no more than 3 to 4 feet high. The failure of this height wall or levee has limited risk to the loss of human life. Figure 4-6 provides an example of a low floodwall in the City.

This mitigation approach will be most economical and beneficial in areas where the surrounding topography is higher so that the floodwall or levee length is relatively short. It is important to note that before these systems are installed, analysis of the storm water drainage system should be completed to verify that the floodwall does not serve as an impediment to the interior drainage. It is likely that some improvement of the storm water drainage systems behind floodwalls and levees may be required in concert with small wall or levee projects.

This scale of project often can be relatively unobtrusive when combined with appropriate landscaping. However, while these types of systems may be preferable in many locations, it should be noted that some ongoing maintenance may be required given the size of the structures and their vulnerability to wave attack.

5.6 ELEVATION OF STRUCTURES OR BUYOUT OF HOME OWNERS IN LOCAL AREAS OF HIGH FLOODING (FLOOD DEPTHS ABOVE 3 TO 4 FEET)

In localized areas, where flood depths are greater than 3 to 4 feet, elevating existing structures may be the most economically feasible solution. Alternately, where the flooding is limited to just a few properties, it may be more cost effective to buyout the homeowners of the subject properties. This option may be difficult to implement, but FEMA can provide funding for these options and thus make them more practical.

The advantage of these options is that once completed, limited maintenance is required. Special care and coordination with the property owners is required so that aesthetics and neighborhood character are maintained. The potential for contentious negotiations (especially with the buyout option) must be recognized. Thus, these options may be a last resort when no other options are feasible.

5.7 MAJOR CAPITAL IMPROVEMENTS IN AREAS WHERE FLOOD DEPTHS COULD EXCEED 4 TO 5 FEET

In locations where the potential for deep flood waters during extreme events could be wide spread, larger capital improvement projects may be required. These projects likely will include some combination of flood walls or levees, tide gates, and/or pump structures. These projects can be most easily and readily implemented where the drainage outlet from the flood prone area is relatively narrow.

The advantage of these systems is that they can be designed to provide the necessary level of flood protection. Various system components can be included to provide redundancy and additional flood protection. However, major capital improvements usually require significant budget. Also, maintenance is required to protect the value and effectiveness of the system. The complexity of these systems and their interactions and repercussions must be thoroughly examined as failures in these types of systems during large events can cause significant damage.

5.8 TEMPORARY BARRIERS (SUCH AS INFLATABLE DAMS, ETC.)

There may be special situations where temporary flood mitigation systems may be prudent or preferable to those listed above. For example, inflatable, bladder dams may be an option where recreational and aesthetic needs will not allow construction of a floodwall that would impede access or hinder views to the shoreline. We expect that these specialized, high maintenance systems will only be used in limited applications due to ongoing costs and susceptibility to failure.

Temporary or removable structures are an option to protect individual buildings. Temporary barriers will allow access to a building or area in times when flood barrier is not erected. Such typical systems usually require permanent vertical posts to be installed. When erecting the barrier in anticipation of a potential flooding event, flood boards or planks are inserted in the slots of the vertical posts. Structures can vary greatly in strength and ability to withstand the lateral forces of floodwaters. Therefore, a coastal engineer should be consulted to recommend the anticipated floodwater elevation and a civil engineer should be consulted on the design and installation of such a system to ensure it can withstand floodwater forces. Typically these types of structures can protect up to 2 to 3 feet of floodwater.

More robust structures with diagonal brace supports reportedly can be used in floodwater of 3 to 8 feet deep. These types of structures are attractive since they can allow access to buildings, rail road tracks, and minimize obstruction of landscaping or views during periods of non-flooding. Depending on their size and length, they can usually be raised in a few hours or less. Figure 4-7 shows two examples of removable barriers.

5.9 BEACH AND SHORELINE PROJECTS

Along the coastal shoreline of the City, ongoing beach and dune maintenance and improvements provides flood protection from storm surges.

6.0 PROJECT COST ESTIMATES

For this study, we estimate the cost of the infrastructure projects described in Appendix A. The project cost estimates include approximate design and planning, construction materials, and operation and maintenance costs. The estimates provided herein represent very approximate, preliminary estimates based on broad assumptions. The cost estimates are used to compare relative cost between projects, and should not be used for budgetary planning purposes.

We have also included the cost estimate to elevate houses to 1 foot above the 100-year flood level. The criteria used to identify house raise candidates are 1) the structure is a residential property (excluding apartment buildings), 2) the structure requires a raise 2 feet or greater, 3) the house is susceptible to flooding. The cost estimate to raise a house is based in discussions with local contractors and previous costs associated with raising houses in the City through a FEMA program.

We have included the following items in our cost estimate for infrastructure options:

- Environmental Study
- Design
- Permitting
- Easements
- Construction
- Operation and Maintenance (50-year service life)

For floodwalls we have assumed they will typically be comprised of an inner sheetpile that extends below ground three times the height above ground, be capped with a concrete, and have 1-foot of freeboard as shown in Figure 2-5. For earthen berms we have assumed side slopes of 2.5H:1V and a 5-foot wide crest. For road raises that require low grade raise of up to 18 inches, we have assumed these can be accomplished through local crowning or modifications that appear similar to elevated crosswalks or enlarged speed bumps. These are considered for protecting against overland flow, leakage over the rim from an adjacent basin, and to mitigate sea level rise.

Detailed descriptions of each project and their consider components are provided in the appendices. A summary of the project cost estimates is provided in Table 1-1. Cost estimates for projects that accommodate 1-foot of sea level rise are provided in Table 1-2. The difference between the projects that plan for sea level rise and without sea level rise is primarily that the structures are 1-foot taller extend farther to reach higher ground elevation, and may require more walls or grade raises to prevent overland flows into a basin for scenarios with 1-foot of sea level rise. A comparison of the two tables suggests that 1-foot of sea level rise will increase the infrastructure component cost by about 15 percent.

7.0 SUMMARY

This study defines 15 areas susceptible to tidal flooding. The areas were defined based primarily on hydrologic boundaries. The areas vary widely in size and encompass areas

between about 200 to 9,000 acres. The Lafayette River project area is the largest project area by a significant margin. We have evaluated potential tidal flooding impacts for a 1% annual chance storm tide event. In descending order of magnitude the predicted flooding damages per project area are Lafayette, Hague, West Ghent, and Pretty Lake.

In terms of monetary physical damage to structures and contents and flooding impacts to roadways, the Lafayette project area has the greatest amount per project. This owes largely to the extent and the number of houses that are encompassed in this project area, Also, the infrastructure projects considered in this project area are anticipated to be the most expensive to implement and technically the most challenging. This is due to the large water body crossing of the Lafayette River. Options of constructing a wall along the shoreline area also has significant challenges in that along the north section of shoreline in Larchmont area, the wall will be significantly tall to mitigate a 1% annual chance tidal level while accommodating the necessary freeboard requirements per FEMA guidelines. The option for construct a wall/berm along Hampton Blvd also presents significant challenges. There is very little room to construct such a feature and in order to do so may require comprising some of the turns on Hampton to the side streets, impact homes and access to homes along Hampton, or compromise a lane of traffic.

The Hague, Pretty Lake, and West Ghent areas follow behind Lafayette in terms of predicted flood damages to buildings. The Hague, Pretty Lake, Broad Creek, Tidewater, and Willoughby areas are also expected to have significant flooding of roadways that could restrict passenger and emergency vehicles during tidal flooding.

Lafayette, Broad Creek, the Hague, and Pretty Lake will likely experience the greatest increase in flooding damages when considering one foot of sea level rise for a future 1% annual chance storm. The low, flat-lying nature of the topography in those areas make those areas increasingly more vulnerable to flooding with increase in sea level.

We scored the projects based on project cost, predicted reduction in flood damages for a 1% annual chance storm event and flood damage to critical or essential facility that was mitigated. The reduction in flood damages was divided by the project cost and multiplied by 100. Five points was added for each critical or essential facility that had the flood hazard mitigated by the project.

Project Area	Project Option	Score
Eastern Branch - Military	Bulkhead Only	3
	McGinnis Road Raise	3
Broad Creek	Flood Gate	13
	Bulkhead	7

Project Area	Project Option	Score
Eastern Branch - Ingleside	Tide Gate/Pump Station Option	5
Eastern Branch – I-264	House Raising Only	147
Ohio Creek*	Pump Station and Culvert	9
Tidewater	Harbor Park Floodwall/Earthen Berm	111 to 121
	I-264 Underpass Floodwall	173
	I-264/Holt St. Floodwall	203
Downtown – Outboard of Existing Floodwall	Downtown Floodwall Connector	27
Berkley and Campostella	Clifton Option	7
	South Main Option	11
Hague*	Hague Flood Gate	122
West Ghent	West Ghent Norfolk General/Hampton Blvd	268
West Ghent	West Ghent Midtown Tunnel	322
Lafayette River	Hampton Blvd (Median)	133
	Hampton Blvd (East of Blvd)	115
	Lafayette River Larchmont-Eleanor Crossing	147
	Lafayette River Larchmont-NIT Crossing	146

Project Area	Project Option	Score
	Lafayette River Lambert Point-NIT Crossing	92
Mason Creek*	Pump Station and Culvert	48 to 101
Willoughby and Ocean View	House Raises	40
Pretty Lake*	Pretty Lake Flood Gate Option	68

Based on project cost and relative benefit we have summarized the recommended options for future consideration (Table 7-2).

Table 7-2. Project Summaries

Project Area	Project Option	Potential for Future Consideration
Eastern Branch - Military	Bulkhead Only	Not Recommended
	McGinnis Road Raise	Not Recommended
Broad Creek	Flood Gate	Low
	Bulkhead	Low
Eastern Branch - Ingleside	Tide Gate/Pump Station Option	Low
Eastern Branch – I-264	House Raising Only	Low
Ohio Creek*	Pump Station and Culvert	Low to Moderate
Tidewater	Harbor Park Floodwall	Moderate to High
	I-264 Underpass Floodwall	Moderate to High

Project Area	Project Option	Potential for Future Consideration
	I-264/Holt St. Floodwall	Moderate to High
Downtown – Outboard of Existing Floodwall	Downtown Floodwall Connector	Low
Berkley and Campostella	Clifton Option	Low to Moderate
	South Main Option	Low to Moderate
Hague*	Hague Flood Gate	Moderate to High
West Ghent	Norfolk General – Existing Topography	Low to Moderate
West Ghent	West Ghent Norfolk General/Hampton Blvd	Moderate
	West Ghent Midtown Tunnel	
Lafayette River	Hampton Blvd (Median)	Moderate to High
	Hampton Blvd (East of Blvd)	Moderate to High
	Lafayette River Larchmont-Eleanor Crossing	Moderate to High
	Lafayette River Larchmont-NIT Crossing	Moderate to High
	Lafayette River Lambert Point-NIT Crossing	Moderate to High
Mason Creek*	Pump Station and Culvert	Low to Moderate
Willoughby and Ocean View	House Raises	Low to Moderate
Pretty Lake*	Pretty Lake Flood Gate Option	Moderate to High

8.0 REPORT LIMITATIONS

8.1 REPORT USE

This draft report has been prepared for the exclusive use of the City of Norfolk and its authorized agents for specific application to the City-wide Coastal Flooding Study. In our opinion, the findings, conclusions, professional opinions, and recommendations presented herein were prepared in accordance with generally accepted coastal engineering practice of the project region.

The information in this report is to be considered solely in the context of the scope of the study, which is to identify areas of potential coastal flooding for a 1% annual chance flooding event with and without 1-foot sea level rise and possible flood mitigation projects designed for this event. Precipitation was not considered in flooding evaluation, and the extent of flooding that may be attributed to precipitation events is not characterized within this report. Precipitation events paired with coastal flooding events may cause increased extent and severity of flooding than is otherwise characterized within this report.

One return period under two scenarios (1% annual chance coastal flooding event; with and without 1-foot sea level rise) is analyzed in this report. This report seek to identify project areas that may be negatively impacted by coastal flooding and establish a basis for relative comparison of flood mitigation projects throughout the City. We contend that this approach aids in identifying and comparing project areas and flood mitigation options, but further analysis to address and annualize other return periods, e.g. a 10% annual chance coastal flooding event, is necessary to better characterize coastal flooding and to construct a more comprehensive model before planning decisions can be made.

Damage estimates are limited to structural and contents damages associated with individual buildings, and do not include damages and/or losses associated with other explicit and induced factors (refer to Figure 3-1). Other factors that may contribute to damages and losses include, but are not limited to, impacts to utilities, economic losses, displacement of residents, etc. Damage estimates contained within the report are to be considered preliminary. Project costs are to be considered preliminary estimations, and are intended to be used to compare project options. Project costs included within this report are not intended for budgetary use. Estimates of project costs are based on a combination of available data from local contractors, equipment vendors, records of prior construction project costs, RS Means construction cost publications, VDOT publications, and other sources as needed.

The project cost estimates are developed in 2012 dollars and do not include an allowance for inflation between the present and a future construction date.

Although information contained in this report may be of some use for other purposes, it may not contain sufficient information for other parties or uses. If any changes are made to the project as described in this report, the conclusions and recommendations in this report shall not be considered valid unless the changes are reviewed and the conclusions and recommendations of this report are modified or validated in writing by Fugro.

9.0 REFERENCES

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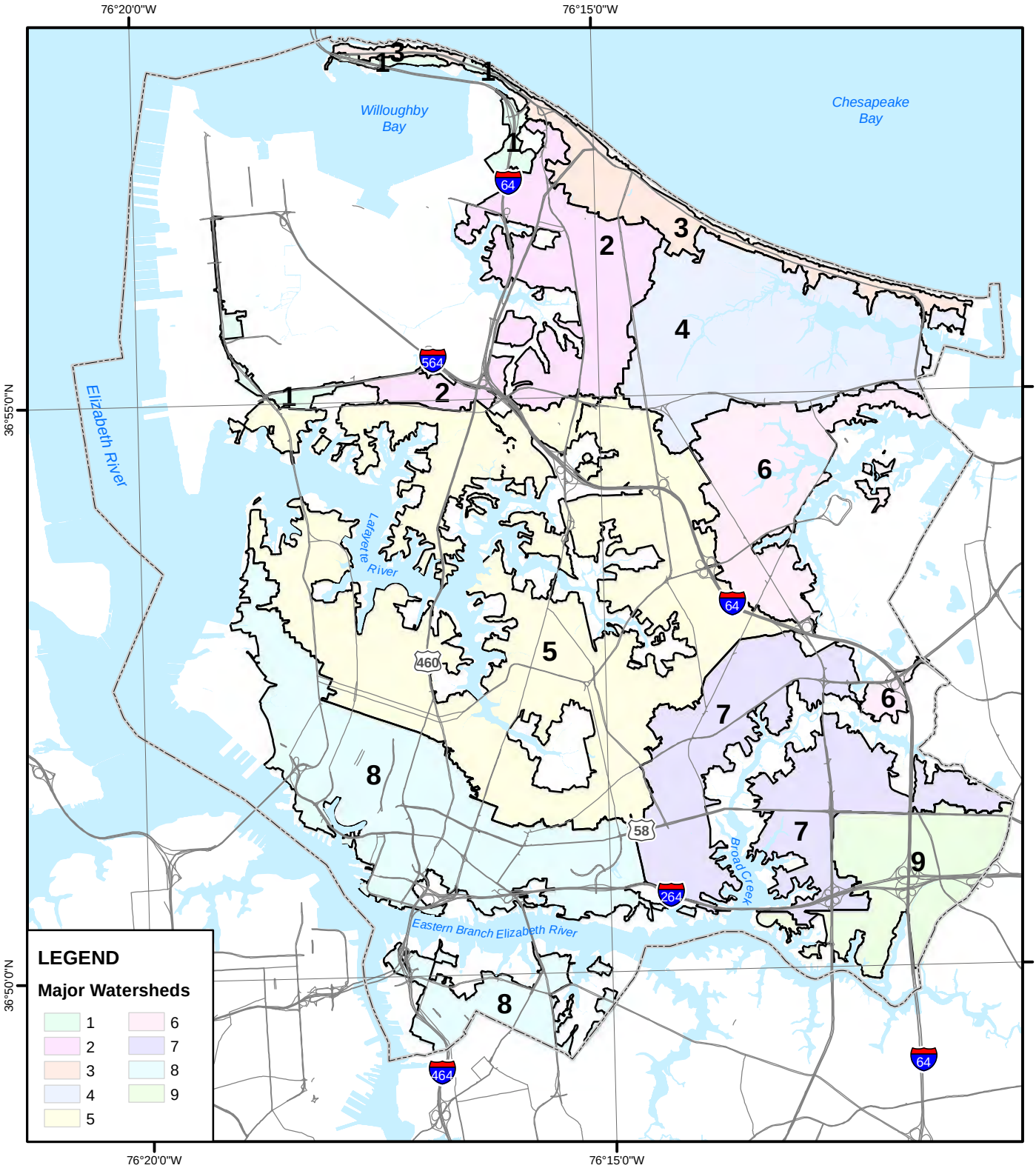

MAJOR WATERSHEDS
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 1-1

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PROJECT AREAS
City-wide Coastal Flooding Study
Norfolk, Virginia

LEGEND
Project Area Boundary
88 Planning District Boundary

FIGURE 1-2

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-1-2_Project_Areas_8x11.mxd, 4/19/2012, jfisher

Project Area	General Project Area Characteristics						Project Cost ($, Millions)			Potential Susceptibility of Buildings for 1% Annual Chance Tidal Flood Event				Predicted Building Damages		
	Total Area[a] (acres)	Parcels	Critical and Essential Infrastructure[b]	Total Real Estate Values[c] ($, Million)	Total Assessed Building Values ($, Million)	Total Number of Buildings in Project Area[d]	Infrastructure	Building Raises	Total	Assessed Building Values of Potentially Susceptible Buildings[e] ($, Millions)	Buildings Potentially Susceptible to Flooding	Protected Buildings (Infrastructure and Raises)	Unprotected Buildings (Infrastructure and Raises)	Total Damages without a Project ($, Millions)	Total Building Damages with a Project ($, Millions)	Damage Reduction ($, Millions)
Eastern Branch - Military	1,303	1,909	0	455	266	1,265	Bulkhead Only			133	400	Bulkhead Only		4.7	Bulkhead Only	
							131.2	-	131.2			269	131		0.6	4.1
							McGinnis Road Raise					McGinnis Road Raise			McGinnis Road Raise	
							108.6	-	108.6			226	174		1.0	3.8
Broad Creek	3,857	5,599	7	1,518	1,039	4,528	Flood Gate			280	520	Flood Gate		15.0	Flood Gate	
							111.4	-	111.4			520	0		0	15.0
							Bulkhead					Bulkhead			Bulkhead	
							57.5	0.4	57.9			145	375		11.0	4.0
Eastern Branch - Ingleside	456	979	0	345	166	871	17.0	-	17.0	9	63	63	0	0.8	<0.1	0.8
Eastern Branch - I-264	487	1,210	2	210	138	599	-	1.7	1.7	62	278	19	259	8.0	5.5	2.5
Ohio Creek*	275	720	0	1,740	254	527	20.7	-	20.7	15	16	16	0	1.8	<0.1	1.8
Tidewater	520	828	10	1,666	257	334	Harbor Park Floodwall/Earthen Berm			110	89	Harbor Park Floodwall		19.1	Harbor Park Floodwall	
							16.4 - 18.1	-	16.4 - 18.1			88	1		<0.1	19.1
							I-264 Underpass Floodwall					I-264 Underpass Floodwall			I-264 Underpass Floodwall	
							11.4	-	11.4			88	1		<0.1	19.1
							I-264/Holt St. Floodwall					I-264/Holt St. Floodwall			I-264/Holt St. Floodwall	
							9.6	-	9.6			88	1		0.1	19.0
Downtown	202	260	11	1,220	842	92	4.4	-	4.4	142	15	0	15	11.2	10.0	1.2
Berkley and Campostella	1,340	3,272	3	1,687	270	1,710	Clifton Option			60	285	Clifton Option		17.5	Clifton Option	
							19.5	-	19.5			45	240		17.1	0.4
							South Main Option					South Main Option			South Main Option	
							30.3	0.6	30.9			118	167		15.7	1.8

* Hydrologic and Hydraulic (H&H) analyses that incorporate precipitation and performance of existing storm water infrastructure are currently being performed for this area

[a] Total Area includes overland area only.

[b] Critical and Essential Infrastructure include hospitals, fire stations, police stations, shelters, schools etc.

[c] Includes real estate (property and building) values.

[d] Potentially Susceptible Buildings include houses and non-residential buildings. Accessory structures (e.g. detached garages, sheds, etc.) are not included.

[e] Based on 2010 tax assessor database.

PROJECT AREA SUMMARIES FOR
1% ANNUAL CHANCE TIDAL FLOOD EVENT
Current Sea Level
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 1-3a

Project Area	General Project Area Characteristics						Project Cost ($, Millions)			Potential Susceptibility of Buildings for 1% Annual Chance Tidal Flood Event				Predicted Building Damages		
	Total Area[a] (acres)	Parcels	Critical and Essential Infrastructure[b]	Total Real Estate Values[c] ($, Million)	Total Assessed Building Values ($, Million)	Total Number of Buildings in Project Area[d]	Infrastructure	Building Raises	Total	Assessed Building Values of Potentially Susceptible Buildings[e] ($, Millions)	Buildings Potentially Susceptible to Flooding	Protected Buildings (Infrastructure and Raises)	Unprotected Buildings (Infrastructure and Raises)	Total Damages without a Project ($, Millions)	Total Building Damages with a Project ($, Millions)	Damage Reduction ($, Millions)
Eastern Branch - Military	1,303	1,909	0	455	266	1,265	Bulkhead Only			133	559	Bulkhead Only		14.0	Bulkhead Only	
							156.6	-	156.6			453	106		0.6	13.4
							McGinnis Road Raise					McGinnis Road Raise			McGinnis Road Raise	
							139.5	-	139.5			398	161		1.0	13.0
Broad Creek	3,857	5,599	7	1,518	1,039	4,528	Flood Gate			280	763	Flood Gate		44.8	Flood Gate	
							111.7	-	111.7			763	0		0	44.8
							Bulkhead					Bulkhead			Bulkhead	
							65.2	0.7	65.9			169	594		39.1	5.7
Eastern Branch - Ingleside	456	979	0	345	166	871	17.0	-	17.0	9	140	140	0	2.1	<0.1	2.1
Eastern Branch - I-264	487	1,210	2	210	138	599	-	3.0	3.0	62	357	26	331	17.1	15.7	1.4
Ohio Creek*	275	720	0	1,740	254	527	20.7	-	20.7	15	24	24	0	2.6	<0.1	2.6
Tidewater	520	828	10	1,666	257	334	Harbor Park Floodwall/Earthen Berm			110	128	Harbor Park Floodwall		24.0	Harbor Park Floodwall	
							21.3 – 23.5	-	21.3– 23.5			127	1		<0.1	24.0
							I-264 Underpass Floodwall					I-264 Underpass Floodwall			I-264 Underpass Floodwall	
							12.1	-	12.1			127	1		<0.1	24.0
							I-264/Holt St. Floodwall					I-264/Holt St. Floodwall			I-264/Holt St. Floodwall	
							10.6	-	10.6			127	1		0.1	23.9
Downtown	202	260	11	1,220	842	92	6.7	-	6.7	142	18	0	18	25.0	10.0	15.0
Berkley and Campostella	1,340	3,272	3	1,687	270	1,710	Clifton Option			60	419	Clifton Option		18.6	Clifton Option	
							22.1	-	22.1			58	361		17.1	1.5
							South Main Option					South Main Option			South Main Option	
							35.5	0.4	35.9			157	262		15.7	2.9

* Hydrologic and Hydraulic (H&H) analyses that incorporate precipitation and performance of existing storm water infrastructure are currently being performed for this area

[a] Total Area includes overland area only.

[b] Critical and Essential Infrastructure include hospitals, fire stations, police stations, shelters, schools etc.

[c] Includes real estate (property and building) values.

[d] Potentially Susceptible Buildings include houses and non-residential buildings. Accessory structures (e.g. detached garages, sheds, etc.) are not included.

[e] Based on 2010 tax assessor database.

PROJECT AREA SUMMARIES FOR
1% ANNUAL CHANCE TIDAL FLOOD EVENT
With 1-Foot Sea Level Rise
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 1-4a

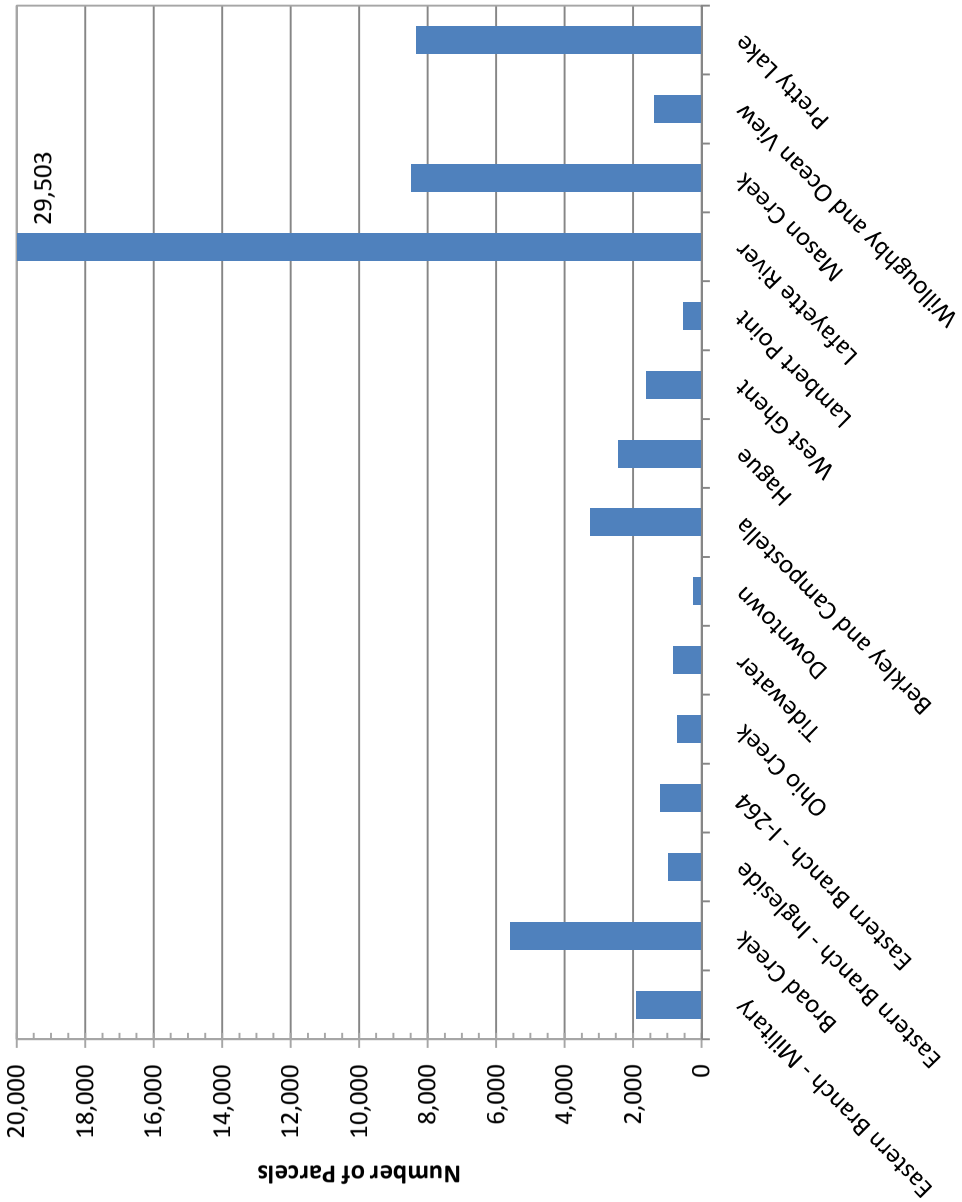
Project Area	General Project Area Characteristics						Project Cost ($, Millions)			Potential Susceptibility of Buildings for 1% Annual Chance Tidal Flood Event				Predicted Building Damages		
	Total Area[a] (acres)	Parcels	Critical and Essential Infrastructure[b]	Total Real Estate Values[c] ($, Million)	Total Assessed Building Values ($, Million)	Total Number of Buildings in Project Area[d]	Infrastructure	Building Raises	Total	Assessed Building Values of Potentially Susceptible Buildings[e] ($, Millions)	Buildings Potentially Susceptible to Flooding	Protected Buildings (Infrastructure and Raises)	Unprotected Buildings (Infrastructure and Raises)	Total Damages without a Project ($, Millions)	Total Building Damages with a Project ($, Millions)	Damage Reduction ($, Millions)
Hague*	971	2,437	9	4,063	1,126	1,564	Flood Gate at Brambleton Ave			692	1,024	Flood Gate at Brambleton Ave		133.5	Flood Gate at Brambleton Ave	
							78.0	-	78.0			1,014	10		3.6	129.9
							Road Raises					Road Raises			Road Raises	
							7.8	-	7.8			97	927		117.3	16.2
West Ghent	959	1,639	2	818	586	1,060	West Ghent Norfolk General/Hampton Blvd			327	530	West Ghent Norfolk General/Hampton Blvd		62.1	West Ghent Norfolk General/Hampton Blvd	
							14.4	0.2	14.6			142	388		15.9	46.2
							Midtown Tunnel					Midtown Tunnel			Midtown Tunnel	
							11.9	-	11.9			294	236		10.4	51.7
Lambert Point	296	544	0	286	59	415	32.5	0.7	33.2	9	263	261	2	2.1	<0.1	2.1
Lafayette River	9,082	29,503	22	13,557	4,713	22,838	Hampton Blvd (Median)			2,421	8,638	Hampton Blvd (Median)		477.4	Hampton Blvd (Median)	
							194.0	47.2	241.2			7,557	1,081		39.4	438.0
							Hampton Blvd (East of Blvd)					Hampton Blvd (East of Blvd)			Hampton Blvd (East of Blvd)	
							200.8	47.2	248.0			7,560	1,078		39.4	438.0
							Larchmont-Eleanor Crossing					Larchmont-Eleanor Crossing			Larchmont-Eleanor Crossing	
							183.7	9.1	192.8			8,511	127		8.7	468.7
							Larchmont-NIT Crossing					Larchmont-NIT Crossing			Larchmont-NIT Crossing	
							193.4	-	193.4			8,638	0		<0.1	477.4
							Lambert Point-NIT Crossing					Lambert Point-NIT Crossing			Lambert Point-NIT Crossing	
							306.5	-	306.5			8,638	0		<0.1	477.4
Mason Creek*	4,173	8,480	2	3,700	1,768	8,327	12.8 to 28.8	-	12.8 to 28.8	102	667	623	44	23.0	10.7	12.3
Willoughby and Ocean View	554	1,392	1	587	293	1,284	-	47.9	47.9	175	872	808	64	38.3	11.4	26.9
Pretty Lake*	2,714	8,345	11	2,450	1,249	7,875	46.3	-	77.9	197	1,806	1,806	0	53.0	<0.1	53.0

* Hydrologic and Hydraulic (H&H) analyses that incorporate precipitation and performance of existing storm water infrastructure are currently being performed for this area

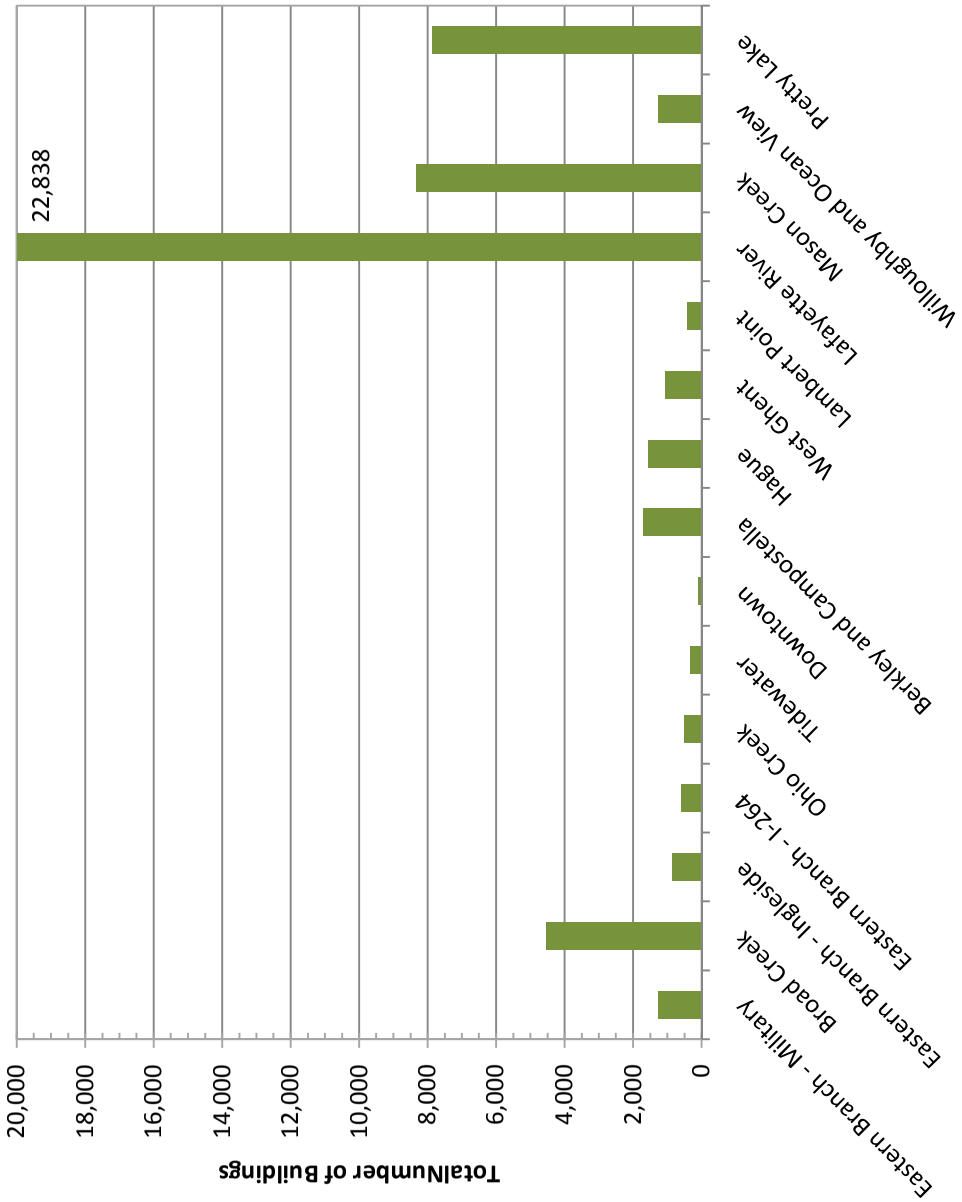
[a] Total Area includes overland area only.
[b] Critical and Essential Infrastructure include hospitals, fire stations, police stations, shelters, schools etc.
[c] Includes real estate (property and building) values.
[d] Potentially Susceptible Buildings include houses and non-residential buildings. Accessory structures (e.g. detached garages, sheds, etc.) are not included.
[e] Based on 2010 tax assessor database.

PROJECT AREA SUMMARIES FOR
1% ANNUAL CHANCE TIDAL FLOOD EVENT
With 1-Foot Sea Level Rise
City-wide Coastal Flooding Study
Norfolk, Virginia

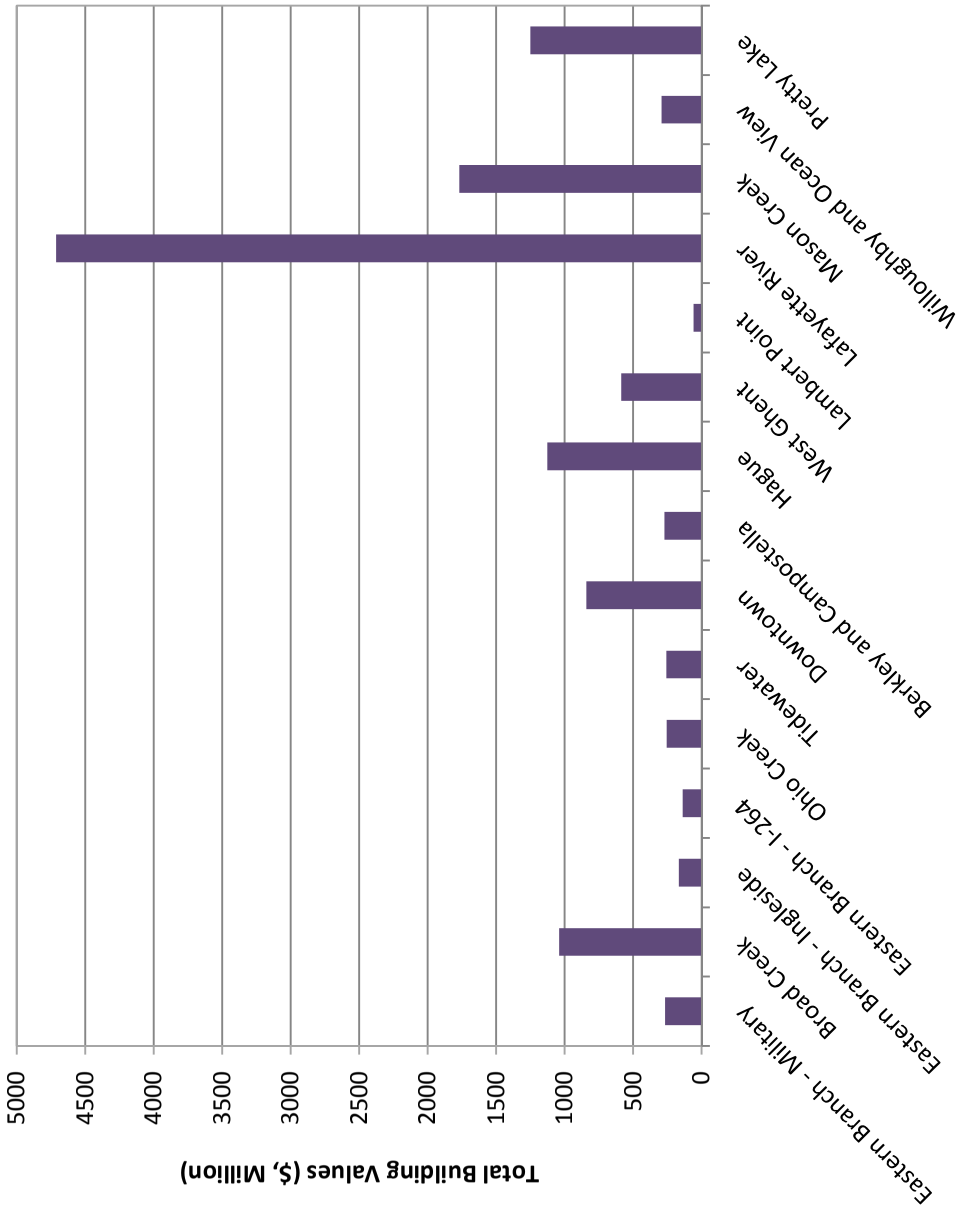
FIGURE 1-4b



TOTAL NUMBER OF PARCELS BY PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia



TOTAL NUMBER OF BUILDINGS BY PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia



TOTAL BUILDING VALUES BY PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

Project Area	Project Option	Score
Mason Creek*	Pump Station and Culvert	48 to 101
Willoughby and Ocean View	House Raises	40
Pretty Lake*	Pretty Lake Flood Gate Option	68

Based on project cost and relative benefit we have summarized the recommended options for future consideration (Table 7-2).

Table 7-2. Project Summaries

Project Area	Project Option	Potential for Future Consideration
Eastern Branch - Military	Bulkhead Only	Not Recommended
	McGinnis Road Raise	Not Recommended
Broad Creek	Flood Gate	Low
	Bulkhead	Low
Eastern Branch - Ingleside	Tide Gate/Pump Station Option	Low
Eastern Branch – I-264	House Raising Only	Low
Ohio Creek*	Pump Station and Culvert	Low to Moderate
Tidewater	Harbor Park Floodwall	Moderate to High
	I-264 Underpass Floodwall	Moderate to High
	I-264/Holt St. Floodwall	Moderate to High
Downtown –	Downtown Floodwall Connector	Low

Project Area	General Project Area Characteristics						Project Cost ($, Millions)			Potential Susceptibility of Buildings for 1% Annual Chance Tidal Flood Event				Predicted Building Damages		
	Total Area[a] (acres)	Parcels	Critical and Essential Infrastructure[b]	Total Real Estate Values[c] ($, Million)	Total Assessed Building Values ($, Million)	Total Number of Buildings in Project Area[d]	Infrastructure	Building Raises	Total	Assessed Building Values of Potentially Susceptible Buildings[e] ($, Millions)	Buildings Potentially Susceptible to Flooding	Protected Buildings (Infrastructure and Raises)	Unprotected Buildings (Infrastructure and Raises)	Total Damages without a Project ($, Millions)	Total Building Damages with a Project ($, Millions)	Damage Reduction ($, Millions)
Hague*	971	2,437	9	4,063	1,126	1,564	Flood Gate at Brambleton Ave			692	765	Flood Gate at Brambleton Ave		82.1	Flood Gate at Brambleton Ave	
							67.1	-	67.1			755	10		3.6	78.5
							Existing Topography					Existing Topography			Existing Topography	
							-	-	-			-	-		-	-
West Ghent	959	1,639	2	818	586	1,060	West Ghent Norfolk General/Hampton Blvd			327	213	West Ghent Norfolk General/Hampton Blvd		43.9	West Ghent Norfolk General/Hampton Blvd	
							10.5	-	10.5			44	169		15.9	28.1
							Midtown Tunnel					Midtown Tunnel			Midtown Tunnel	
							10.2	-	10.2			135	78		10.4	33.5
Lambert Point	296	544	0	286	59	415	24.2	0.2	24.4	9	75	75	0	0.8	<0.1	0.8
Lafayette River	9,082	29,503	22	13,557	4,713	22,838	Hampton Blvd (Median)			2,421	6,997	Hampton Blvd (Median)		266.6	Hampton Blvd (Median)	
							158.8	18.6	177.4			5,866	1,131		39.4	227.2
							Hampton Blvd (East of Blvd)					Hampton Blvd (East of Blvd)			Hampton Blvd (East of Blvd)	
							187.9	18.6	206.5			5,869	1,128		39.4	227.2
							Larchmont-Eleanor Crossing					Larchmont-Eleanor Crossing			Larchmont-Eleanor Crossing	
							178.1	4.0	182.1			6,869	128		8.7	257.9
							Larchmont-NIT Crossing					Larchmont-NIT Crossing			Larchmont-NIT Crossing	
							188.9	-	188.9			6,997	0		<0.1	266.6
							Lambert Point-NIT Crossing					Lambert Point-NIT Crossing			Lambert Point-NIT Crossing	
							306.5	-	306.5			6,997	0		<0.1	266.6
Mason Creek*	4,173	8,480	2	3,700	1,768	8,327	12.8 to 28.8	-	12.8 to 28.8	102	398	354	44	12.3	<0.1	12.3
Willoughby and Ocean View	554	1,392	1	587	293	1,284	-	28.2	28.2	175	808	579	229	26.9	11.4	15.5
Pretty Lake*	2,714	8,345	11	2,450	1,249	7,875	46.3	-	46.3	197	1,339	1,339	0	31.3	<0.1	31.3

* Hydrologic and Hydraulic (H&H) analyses that incorporate precipitation and performance of existing storm water infrastructure are currently being performed for this area

[a] Total Area includes overland area only.
[b] Critical and Essential Infrastructure include hospitals, fire stations, police stations, shelters, schools etc.
[c] Includes real estate (property and building) values.
[d] Potentially Susceptible Buildings include houses and non-residential buildings. Accessory structures (e.g. detached garages, sheds, etc.) are not included.
[e] Based on 2010 tax assessor database.

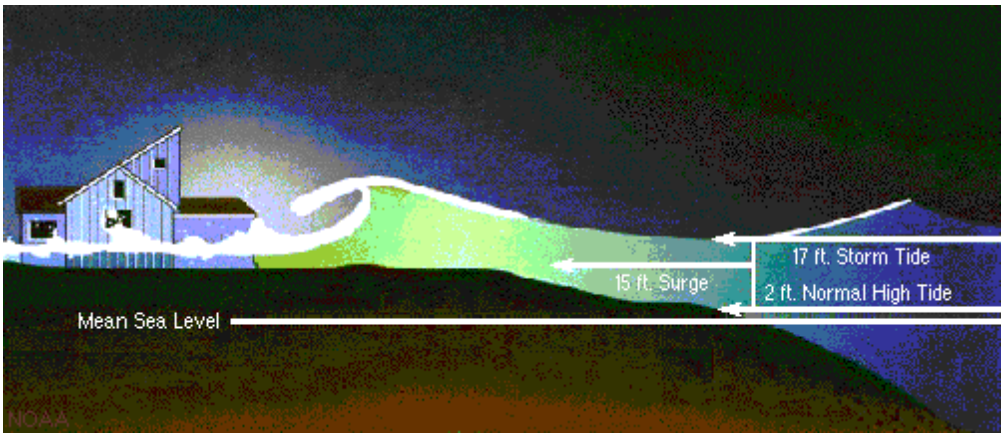
PROJECT AREA SUMMARIES FOR
1% ANNUAL CHANCE TIDAL FLOOD EVENT
Current Sea Level
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 1-3b

Planning District	Project Name	Planning District	Project Name	Planning District	Project Name
PD 1 - WILLOUGHBY	Lafayette, Willoughby	PD 32 - SUSSEX	Lafayette, Mason Creek	PD 62 - NORTH GHENT	Hague, West Ghent
PD 2 - WEST OCEAN VIEW	Mason Creek, Willoughby	PD 33 - SUBURBAN	Lafayette	PD 63 - EAST GHENT	Hague
PD 3 - PINEWELL	Mason Creek, Willoughby	PD 34 - ROLAND PARK	Lafayette	PD 64 - GHENT	Hague, West Ghent
PD 4 - OCEANVIEW	Mason Creek, Willoughby	PD 35 - LAKEWOOD	Lafayette	PD 65 - TIDEWATER-YOUNG PARK	Hague, Tidewater
PD 5 - CAPE VIEW	Pretty Lake, Willoughby	PD 36 - TALBOT PARK	Lafayette	PD 66 - HUNTERSVILLE	Hague, Tidewater
PD 6 - PRETTY LAKE	Pretty Lake, Willoughby	PD 37 - EDGEWATER-LARCHMONT	Lafayette	PD 67 - LINDENWOOD	Lafayette
PD 7 - SHORE DRIVE	Willoughby	PD 38 - DENBY PARK	Lafayette, Mason Creek	PD 68 - TIDEWATER DRIVE INDUSTRIAL	Downtown, Tidewater
PD 8 - PAMLICO	Mason Creek	PD 39 - NAVAL BASE ROAD	Lafayette, Mason Creek	PD 69 - BRAMBLETON	Eastern Branch, Tidewater
PD 9 - MERRIMAC PARK	Lafayette, Mason Creek	PD 40 - CHESAPEAKE MANOR	Lafayette	PD 70 - LIBERTY-ROBERTS PARK	Eastern Branch, Ohio Creek
PD 10 - COMMODORE PARK	Mason Creek	PD 41 - ROSEMONT	Lafayette, Pretty Lake	PD 72 - CHESTERFIELD	Eastern Branch - I-264, Eastern Branch - Ingleside
PD 11 - NORTHSIDE	Mason Creek	PD 42 - CORONADO	Lafayette	PD 73 - INDUSTRIAL PARK	Broad Creek, Lafayette
PD 12 - OCEANAIR	Mason Creek	PD 43 - SEWELLS GARDENS	Lafayette	PD 74 - CROMWELL ROAD INDUSTRIAL	Broad Creek, Lafayette
PD 13 - WILLOW TERRACE	Mason Creek, Pretty Lake	PD 44 - EAST NORVIEW	Lafayette	PD 75 - RIVER OAKS	Broad Creek
PD 14 - SNUG HARBOR	Mason Creek, Pretty Lake	PD 45 - NORVIEW	Broad Creek	PD 76 - LAKE TAYLOR	Broad Creek,
PD 15 - NORTH CHESAPEAKE BLVD.	Lafayette, Pretty Lake	PD 46 - NORVELLA	Lafayette	PD 77 - LAKE TERRACE	Broad Creek
PD 16 - OAKDALE FARMS	Lafayette, Mason Creek	PD 47 - ESTABROOK	Broad Creek, Lafayette	PD 78 - MAPLE HALL-HOLLYWOOD	Broad Creek
PD 17 - BEL-AIRE	Pretty Lake	PD 48 - FOXHALL	Broad Creek,	PD 79 - KEMPSVILLE	Eastern Branch - Military
PD 18 - ROOSEVELT GARDENS	Pretty Lake	PD 49 - COLEMAN PLACE	Broad Creek, Lafayette	PD 80 - EASTON	Eastern Branch - Military
PD 19 - NORTH CAMELLIA	Pretty Lake	PD 50 - BALLENTINE PARK	Lafayette	PD 81 - RIVER FORREST	Eastern Branch - Military
PD 20 - SOUTH CAMELLIA	Pretty Lake	PD 51 - LAYFAYETTE	Lafayette	PD 83 - INGLESIDE	Broad Creek, Eastern Branch - Ingleside
PD 21 - LARRYMORE	Lafayette, Pretty Lake	PD 52 - PARK PLACE	Lafayette, West Ghent	PD 84 - POPLAR HALLS	Broad Creek
PD 22 - AZALEA		PD 53 - COLONIAL PLACE	Lafayette	PD 85 - GLENROCK	Broad Creek
PD 23 - INTERNATIONAL AIRPORT	Lafayette	PD 54 - NORTH COLLEY	Lafayette	PD 86 - CROWN POINT	Broad Creek
PD 24 - SOUTHERN SHOPPING CENTER	Lafayette, Pretty Lake	PD 55 - LAMBERTS POINT-ODU	Lafayette, West Ghent	PD 87 - JANAF-MILITARY CENTER	Broad Creek
PD 25 - WARDS CORNER	Lafayette, Mason Creek	PD 56 - LAMBERTS POINT INDUSTRIAL	Lafayette, West Ghent	PD 88 - CAMPOSTELLA HEIGHTS	Berkley & Campostella
PD 26 - NAVAL BASE	Lafayette, Willoughby	PD 57 - WEST 21st STREET	Hague, West Ghent	PD 89 - CAMPOSTELLA	Berkley & Campostella
PD 27 - SEWELLS POINT	Lafayette	PD 58 - EAST 21st STREET-MONTICELLO	Hague, Lafayette	PD 90 - BERKLEY	Berkley & Campostella
PD 28 - GLENWOOD PARK	Lafayette, Mason Creek	PD 59 - DOWNTOWN	Downtown, Tidewater		
PD 30 - NORTH SHORE	Lafayette, Mason Creek	PD 60 - MEDICAL CENTER	Hague, West Ghent		
PD 31 - TITUSTOWN	Lafayette, Mason Creek	PD 61 - WEST GHENT	West Ghent		

PLANNING DISTRICTS AND PROJECTS
City-wide Coastal Flooding Study
Norfolk, Virginia

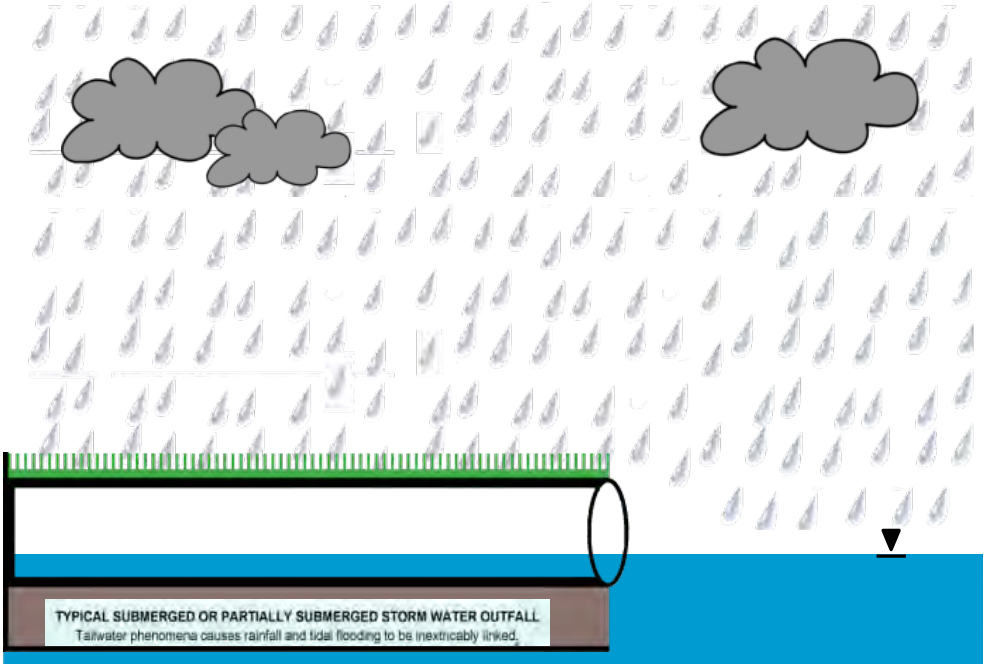
FIGURE 1-8



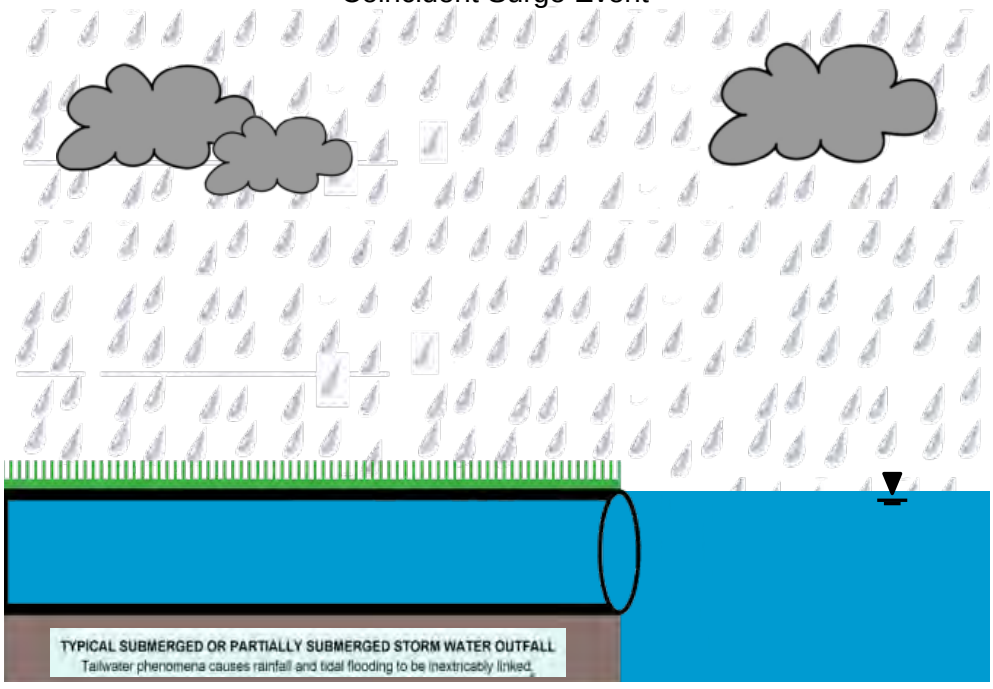
During storm events, tidal water levels can rise above normal levels and cause coastal flooding. Elevated water levels are a result of winds and/or low atmospheric pressure related to the storm. Graphic modified from NOAA.

SCHEMATIC STORM TIDE
City-wide Coastal Flooding Study
Norfolk, Virginia

Rainfall Predominant

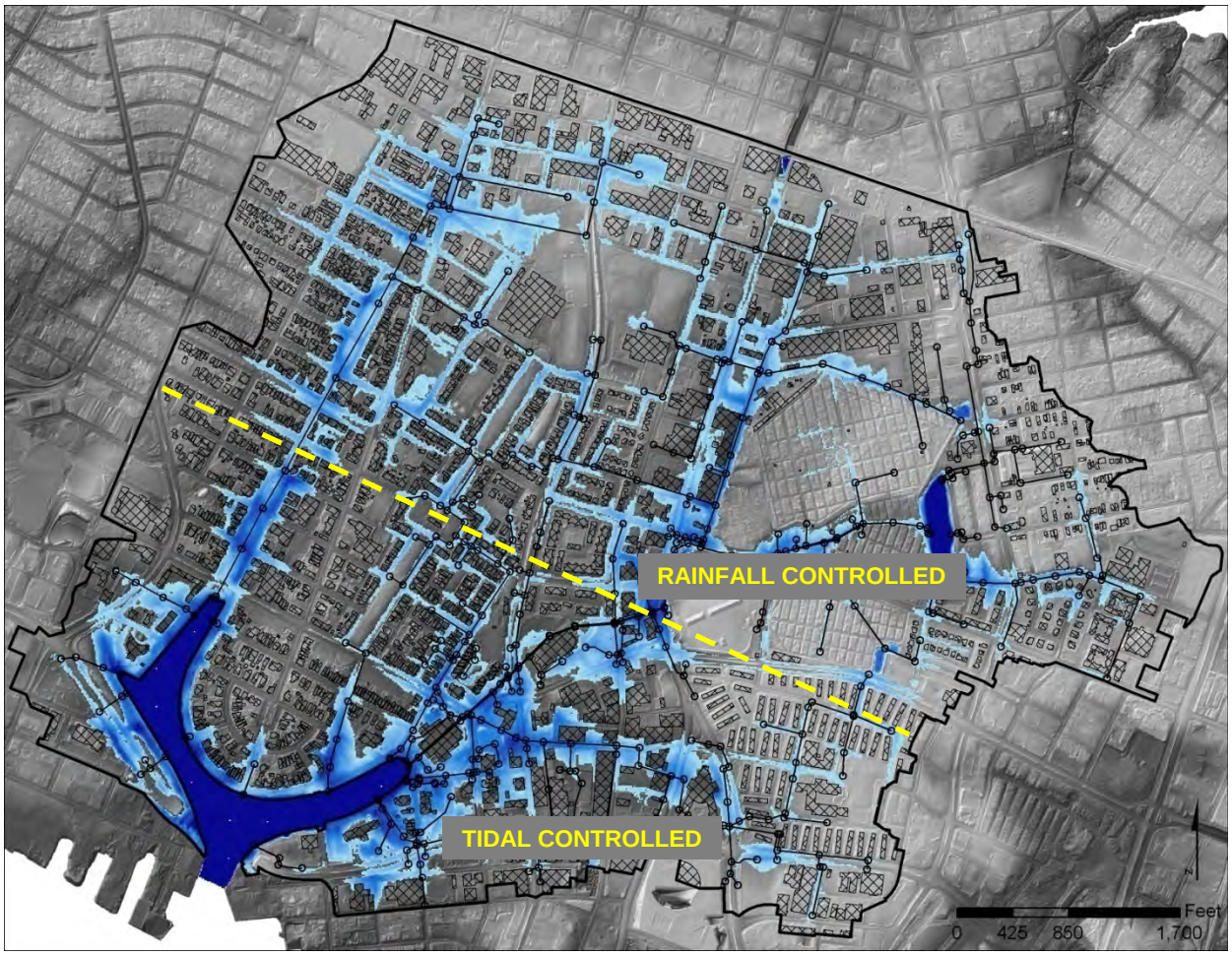


Coincident Surge Event

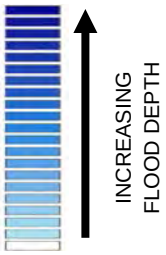


Note that during a surge event the tailwater can be elevated and the storm water pipe may be filled or partially filled with water. This can reduce the storm water pipe's ability to convey captured precipitation from catchment areas and may lead to flooding in the catchment areas along streets and neighborhoods.

TAILWATER PHENOMENA
City-wide Coastal Flooding Study
Norfolk, Virginia

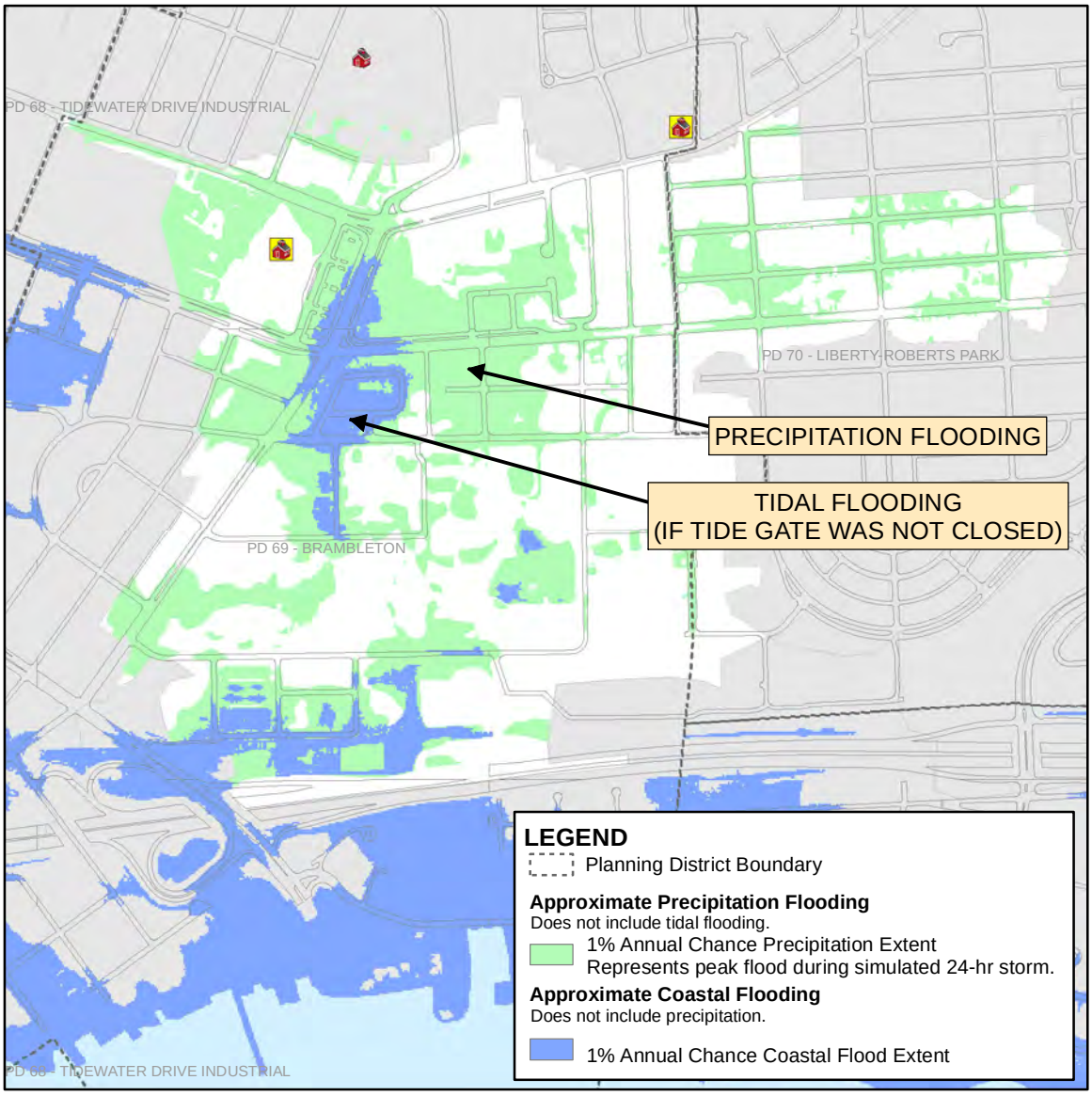


The graphic above shows the predicted maximum flooding during a simulated 24 hour period where coincident 10-year tidal water level and 10-year precipitation event were simulated. The simulation incorporates a model of the existing storm water infrastructure (e.g. pipes and inlets). The results suggest that flooding areas in the lower section of the watershed are tidal controlled and flooding areas in upper areas are rainfall controlled during this simulated event. However, tidal flooding will increase area extent, depth, and duration of rainfall flooding. Refer to Figure 2-2 for an example of how tidal water levels and associated tailwater elevation can affect a storm water pipe's ability to convey storm water.



TIDAL AND PRECIPATION FLOODING
Coincident 10 year Rainfall and 10 year Tidal Surge Event
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 2-3a



Critical and Government Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

The area where the arrows are pointing to has a tide gate installed near the sub-basin outlet that is typically closed during storm tide events to prevent backflow and flooding from coastal water. The blue-shaded flood extent depicts the area that would likley flood if the tide gate was not closed and the coastal water backfowed into this sub-basin.

The green shaded zone illustrates the simulated flood extent from a precipitation event based on hydraulic and hydrologic analyses that incorporated the storm water infrastructure.

This image illustrates that flooding in the region can be influenced by precipitation and tidal events. During storms, the flooding in Norfolk is influenced by a combination of both while in some areas it may be controlled by one type of flooding.

N
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0 1,000 Feet

COMPARISON OF COASTAL FLOODING AND PRECIPITATION FLOODING OHIO CREEK AREA

City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 2-3b

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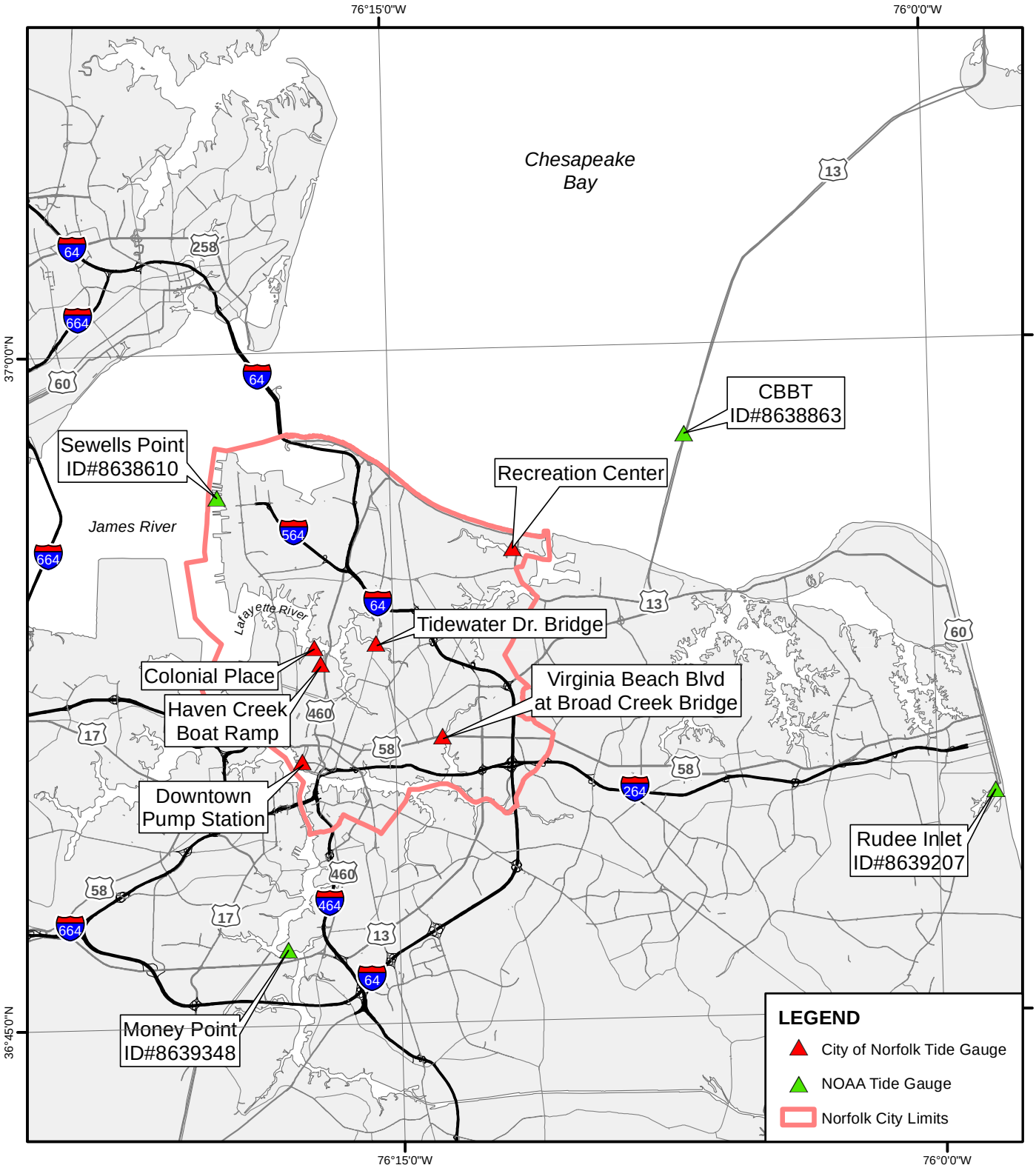

TIDE GAUGE STATION LOCATIONS
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 2-4

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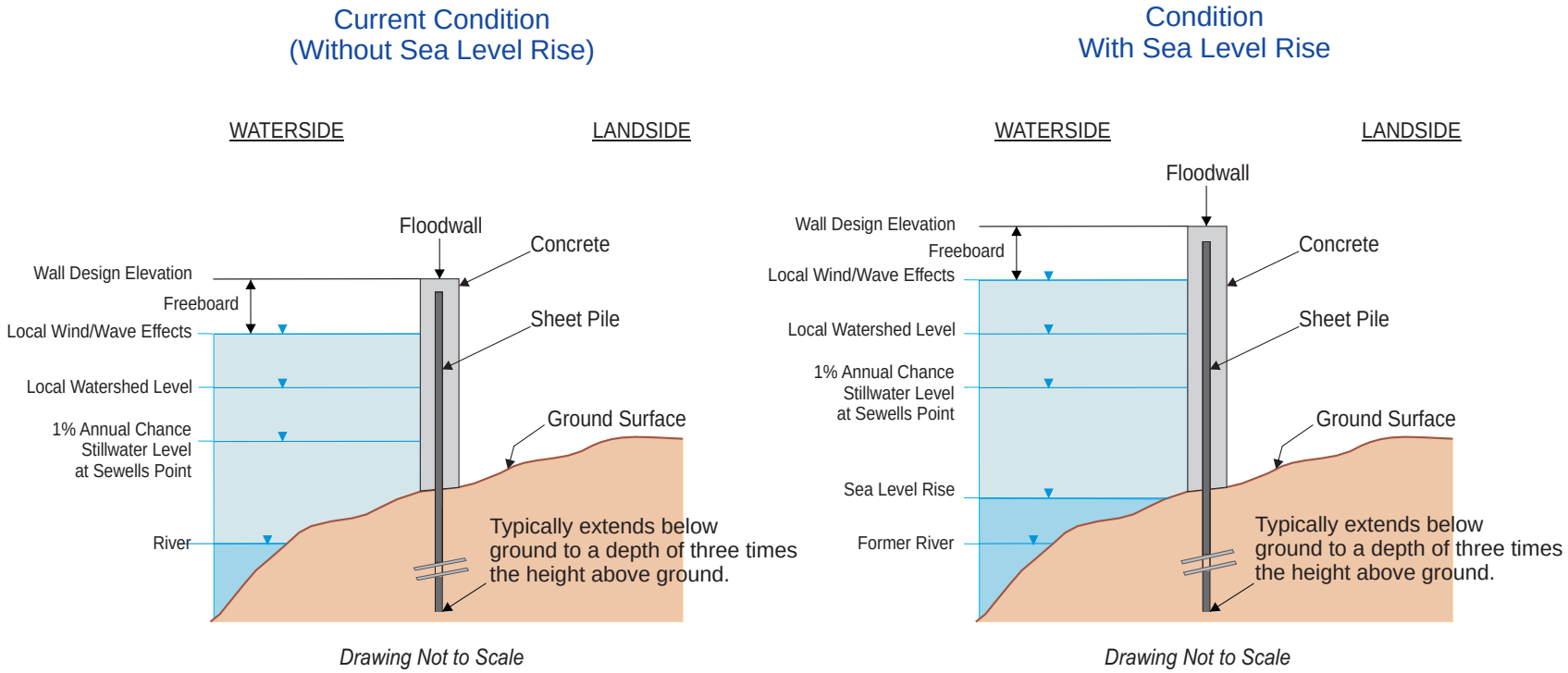


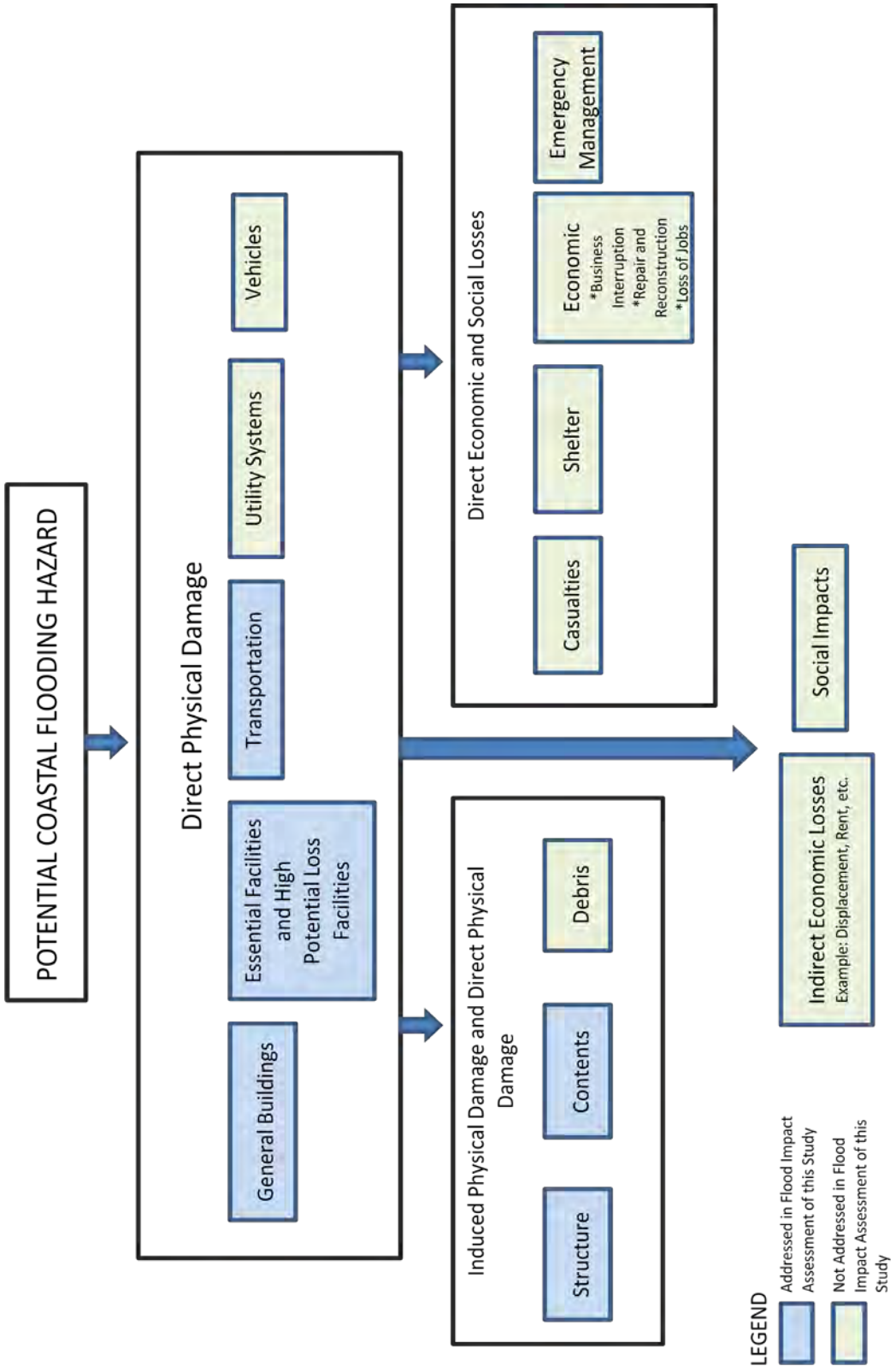
FACTORS USED TO ESTIMATE FLOOD WATER AND INFRASTRUCTURE ELEVATION

City-wide Coastal Flooding Study

Norfolk, Virginia

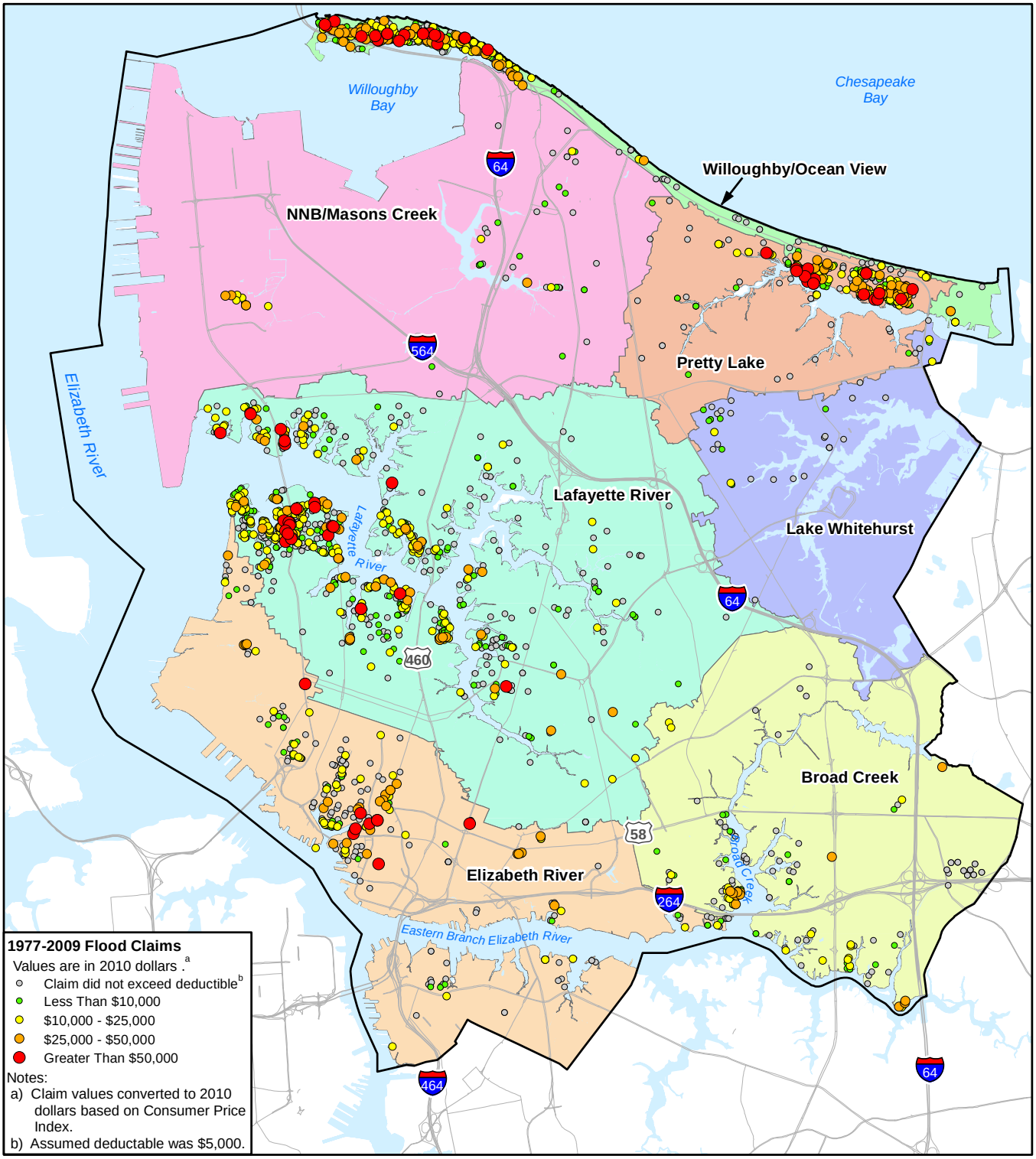
FIGURE 2-5

N:\PROJECTS\3627_CITY_NORFOLK\04_8111_0022_PRELIM_FLD_MSTR_PLAN\OUTPUTS\2012-03_DRAFT_PRELIM_FLD_MSTR\DOC\FIG-2-5 FLOODWATERELEVFACTORS.DOCX



TYPES OF FLOODING IMPACTS
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-1



N
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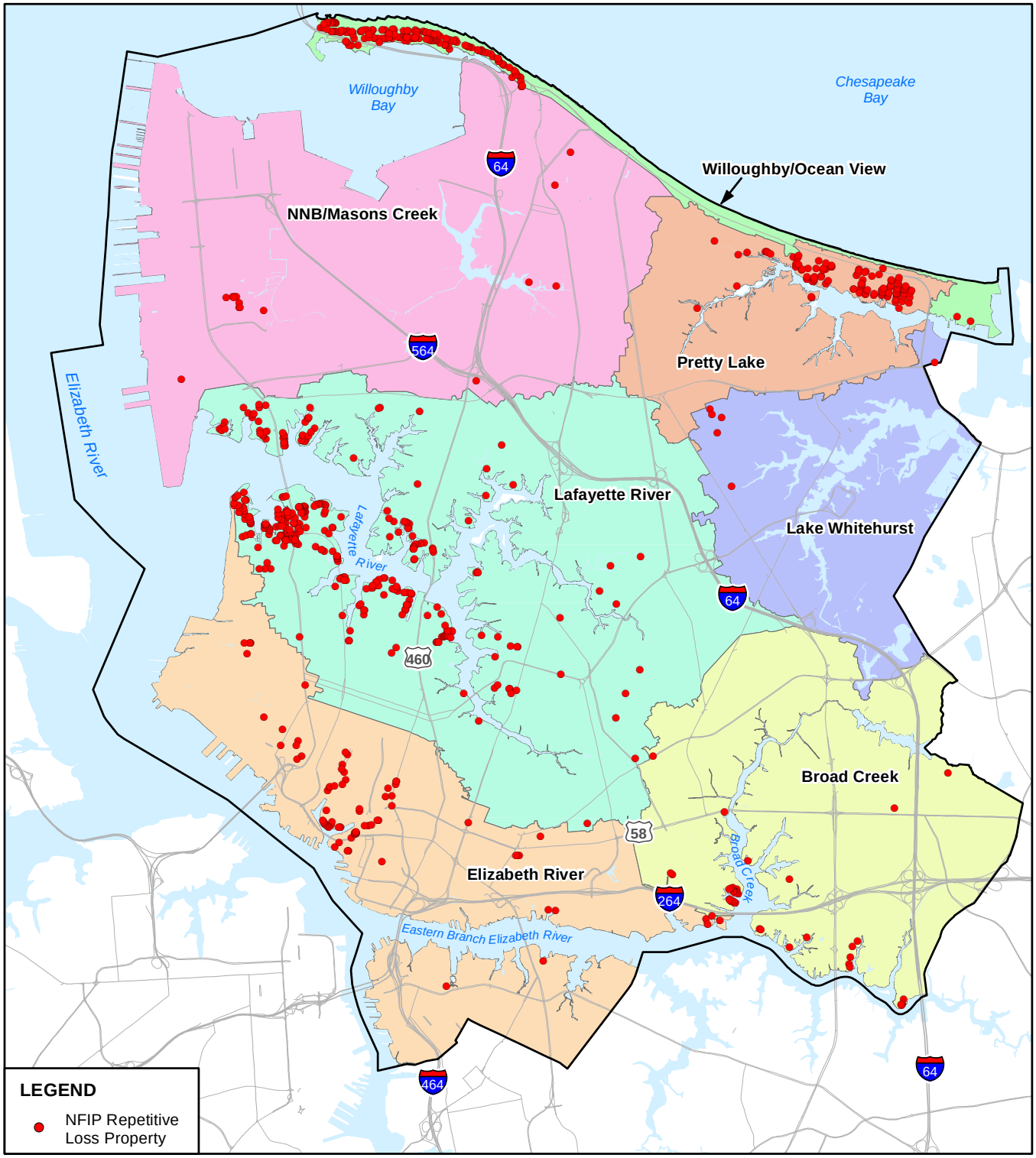
NFIP FLOOD CLAIMS
City-wide Coastal Flooding Study
Norfolk, Virginia

0 1 Miles
0 1 Kilometers

FIGURE 3-2

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-2_Flood_Claims_Watersheds_Global.mxd, 4/26/2012, jfisher



N
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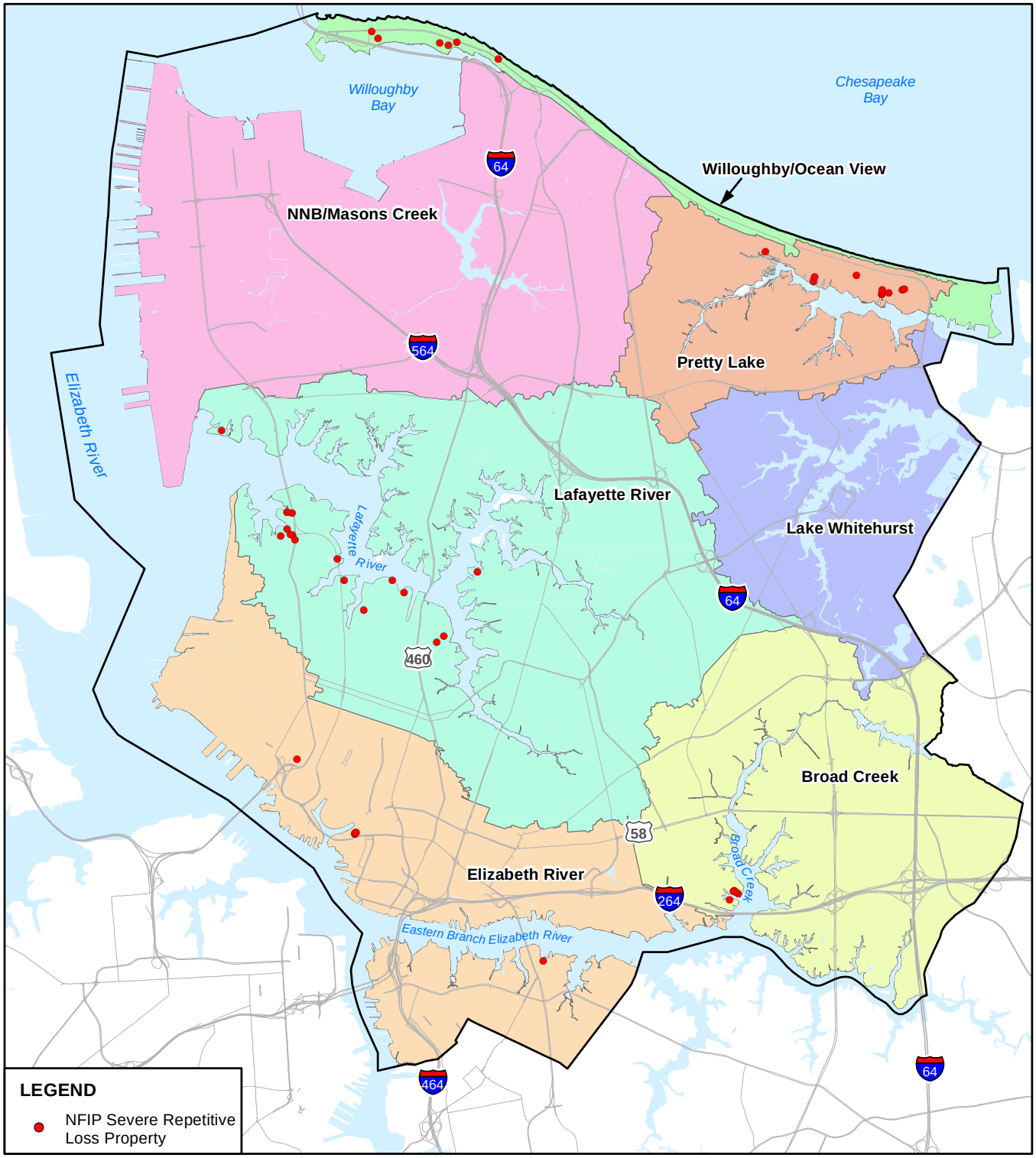
NFIP REPETITIVE LOSS CLAIMS
City-wide Coastal Flooding Study
Norfolk, Virginia

0 1 Miles
0 1 Kilometers

FIGURE 3-3

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-3_NFIP_RepetitiveLoss_Claims.mxd, 4/26/2012, jfisher



N
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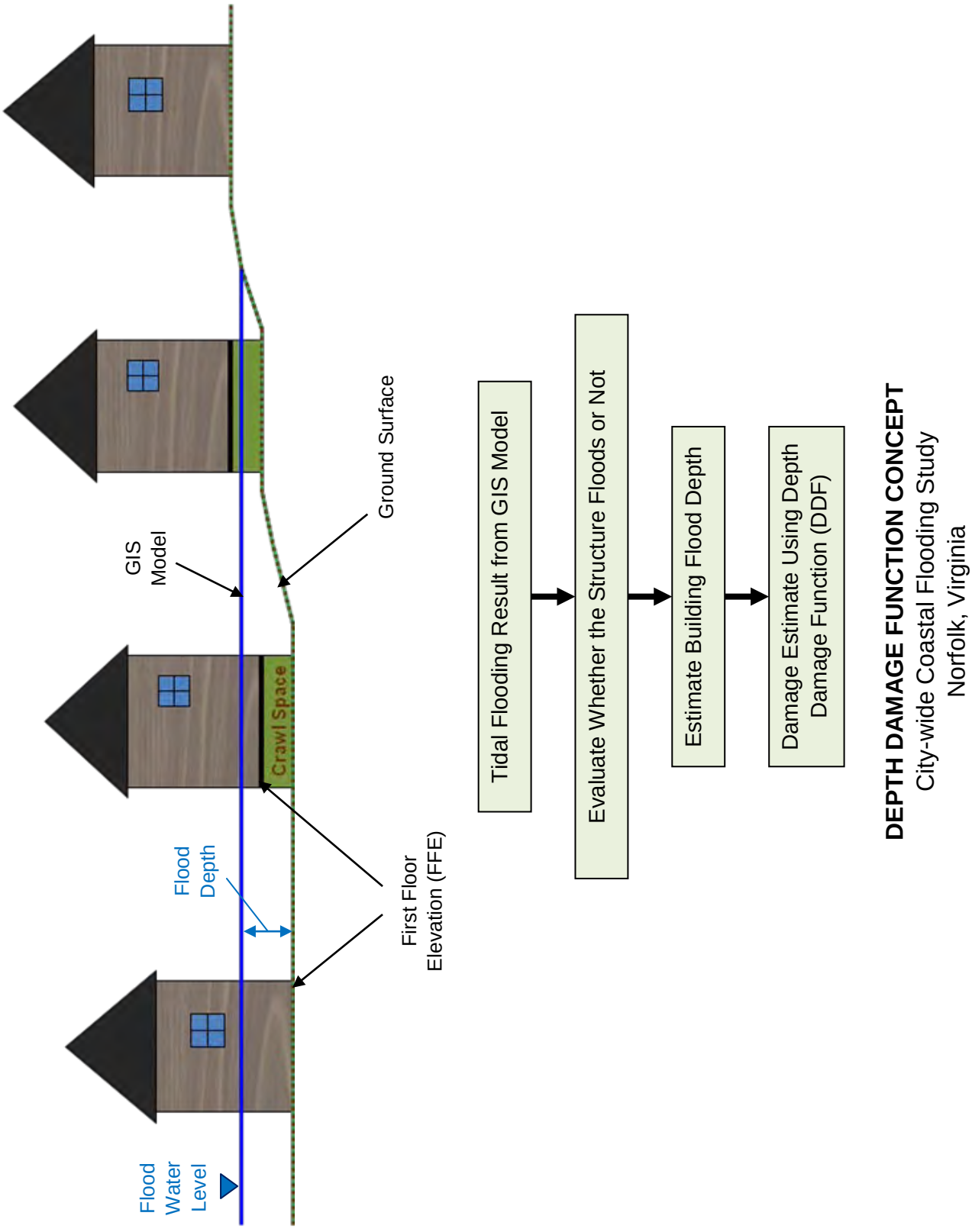
NFIP SEVERE REPETITIVE LOSS CLAIMS
City-wide Coastal Flooding Study
Norfolk, Virginia

0 1 Miles
0 1 Kilometers

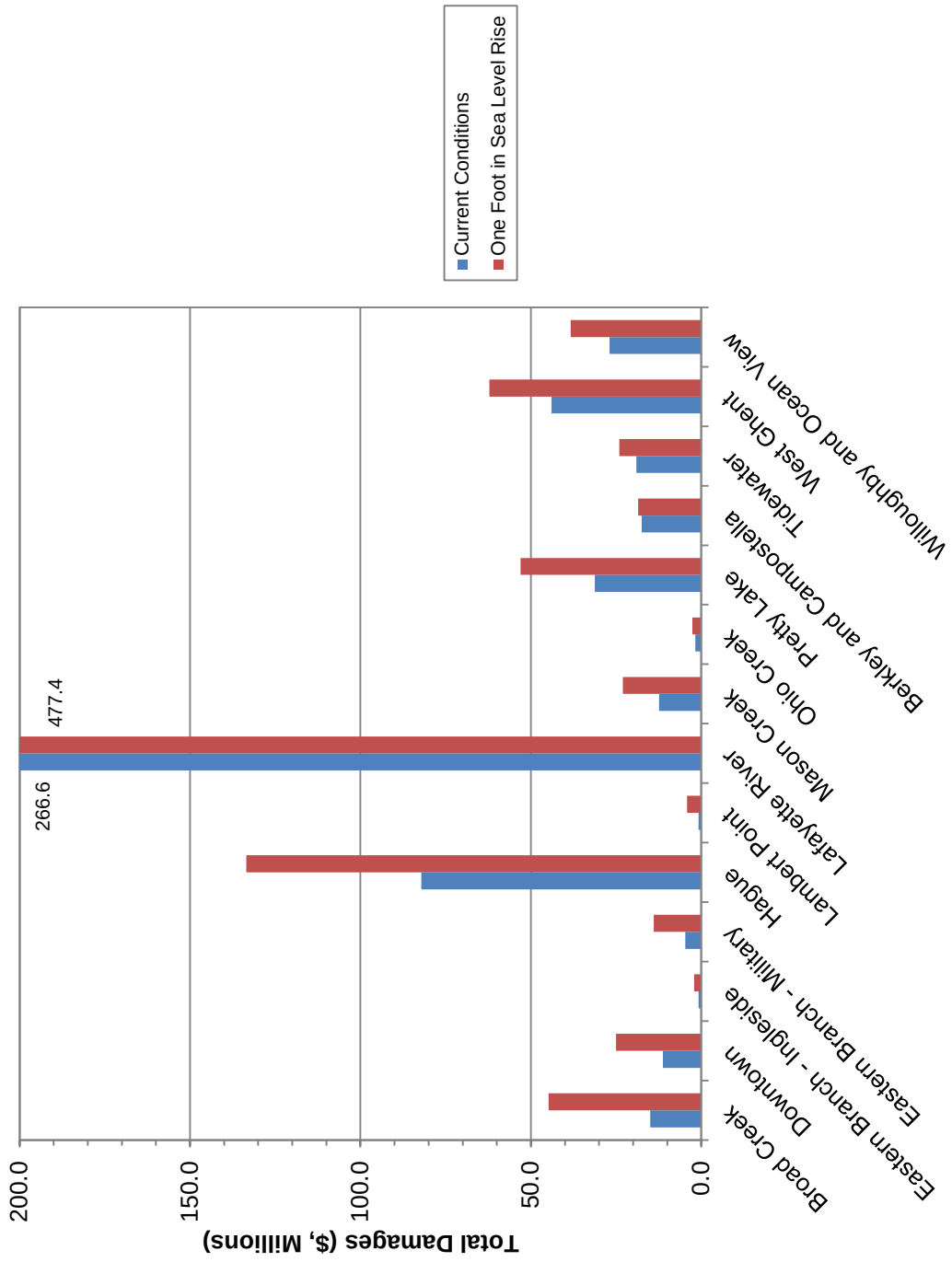
FIGURE 3-4

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-4_NFIP_Severe_RepetitiveLoss_Claims.mxd, 4/26/2012, jfisher



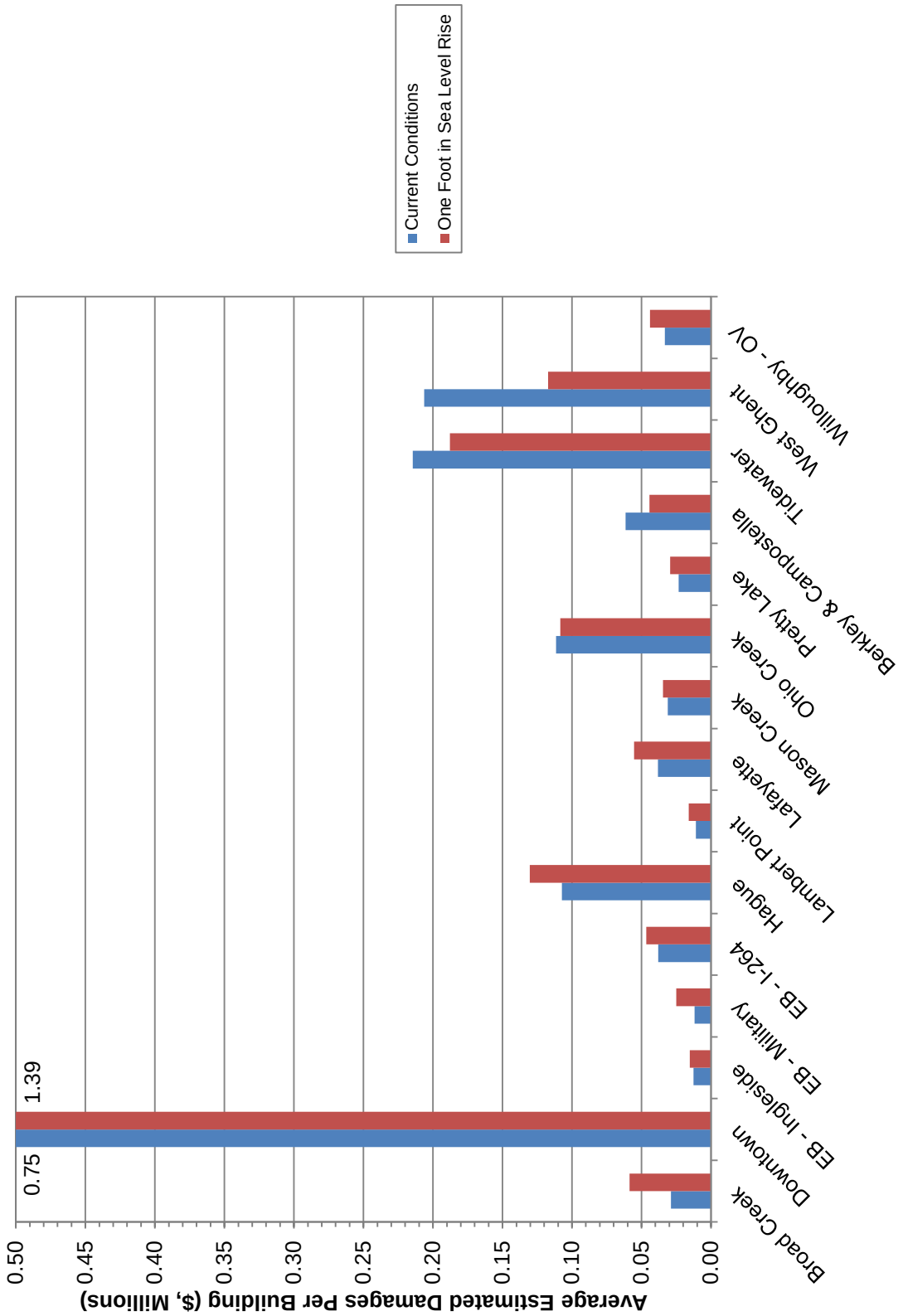
DEPTH DAMAGE FUNCTION CONCEPT
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-5



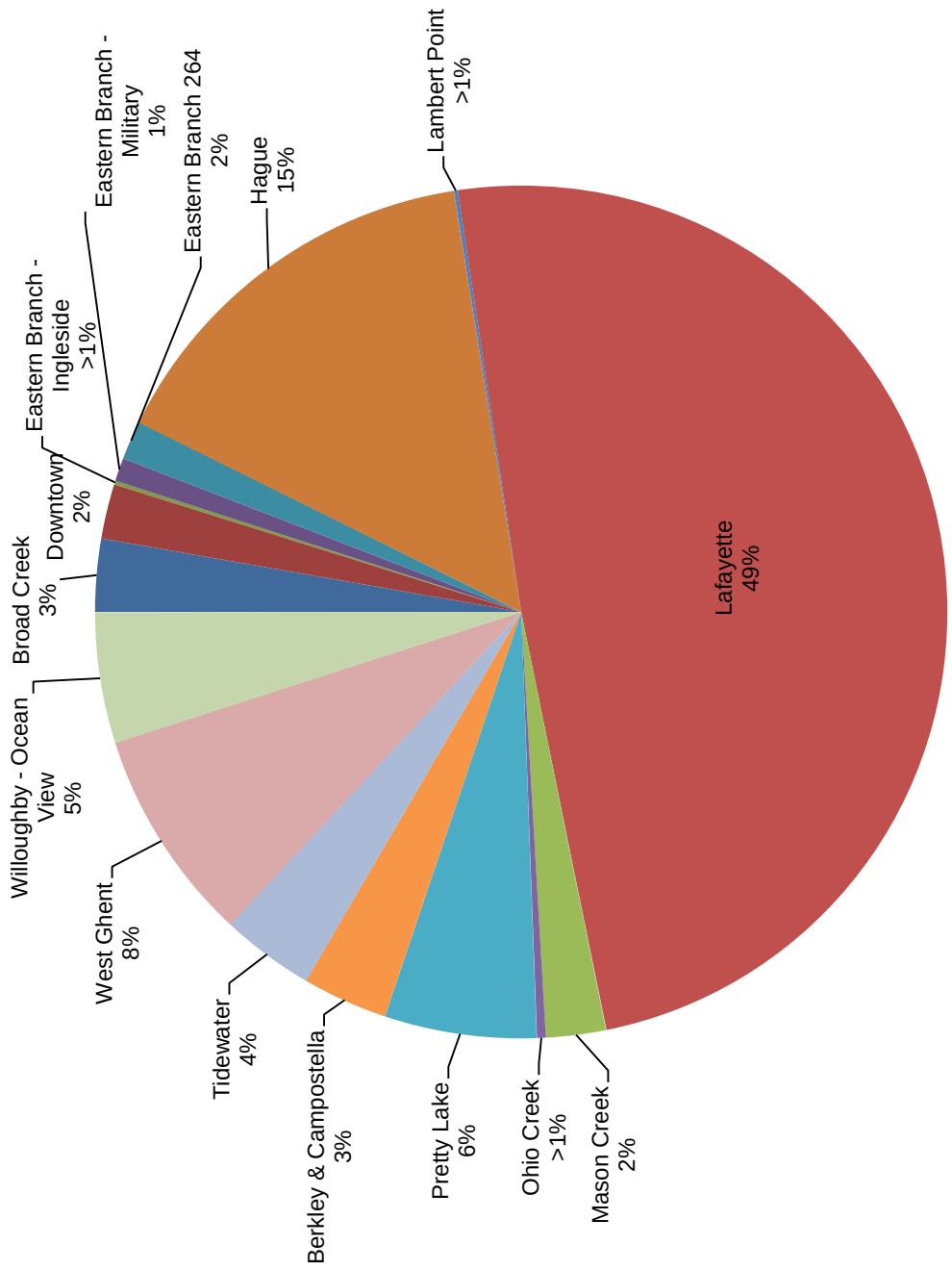
TOTAL DAMAGES FOR BUILDINGS BY PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-6a



AVERAGE DAMAGES PER BUILDING BY PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

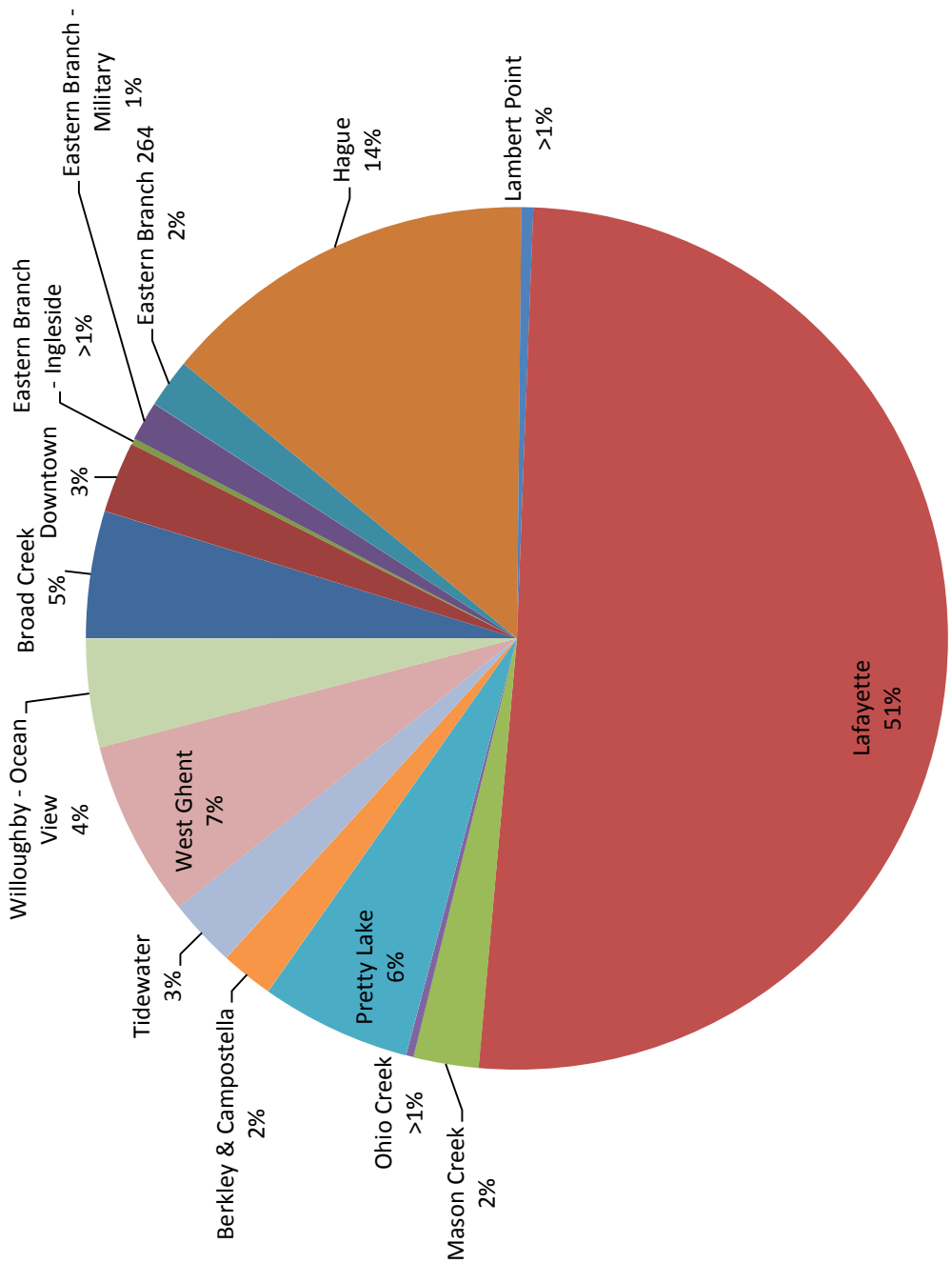
FIGURE 3-6b



RELATIVE TOTAL DAMAGES FOR BUILDINGS UNDER CURRENT CONDITIONS BY PROJECT AREA

City-wide Coastal Flooding Study
Norfolk, Virginia

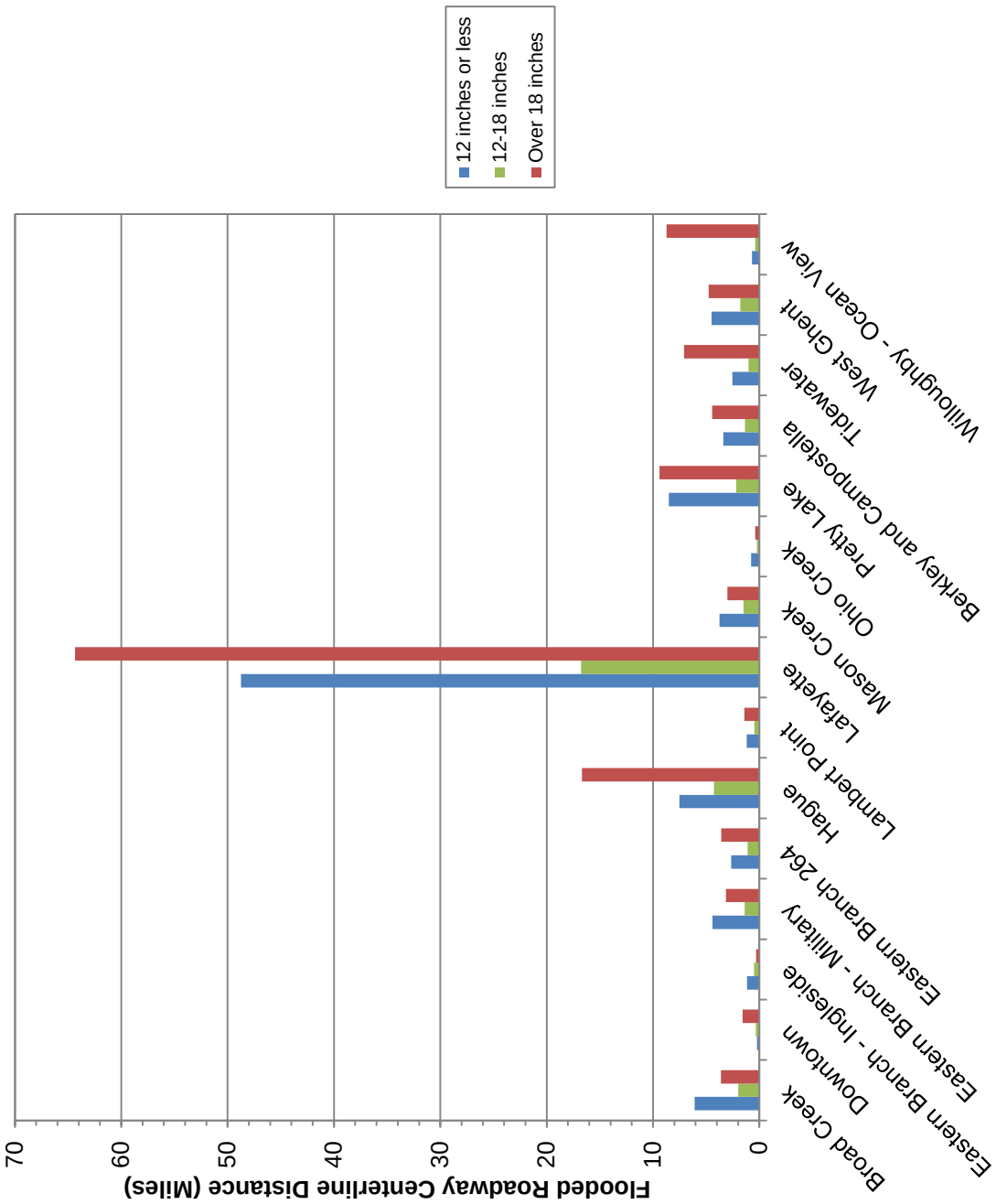
FIGURE 3-7a



RELATIVE TOTAL DAMAGES FOR BUILDINGS WITH 1-FOOT SEA LEVEL RISE BY PROJECT AREA

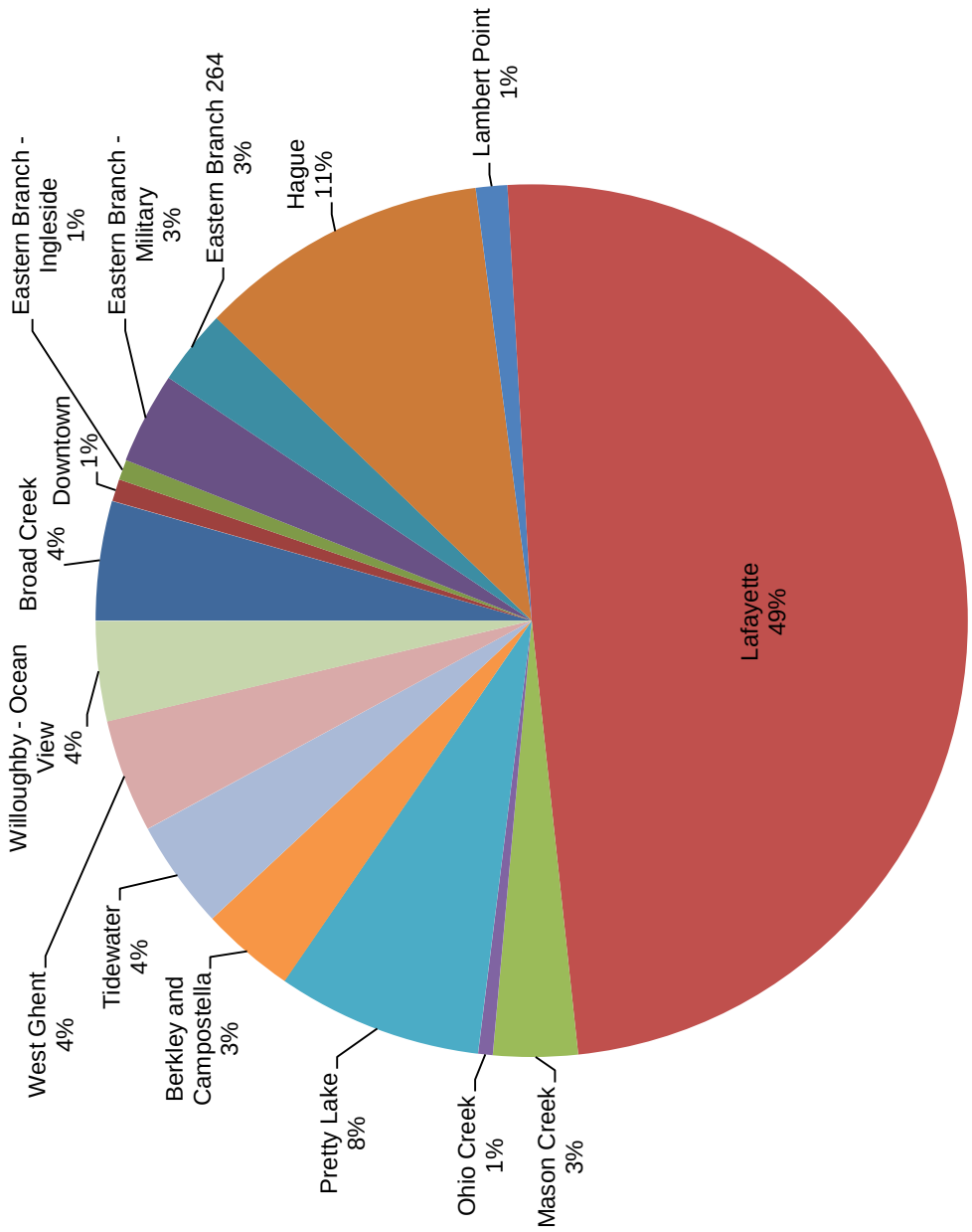
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-7b



FLOODED ROADWAY CENTERLINE MILES
UNDER CURRENT CONDITIONS BY PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

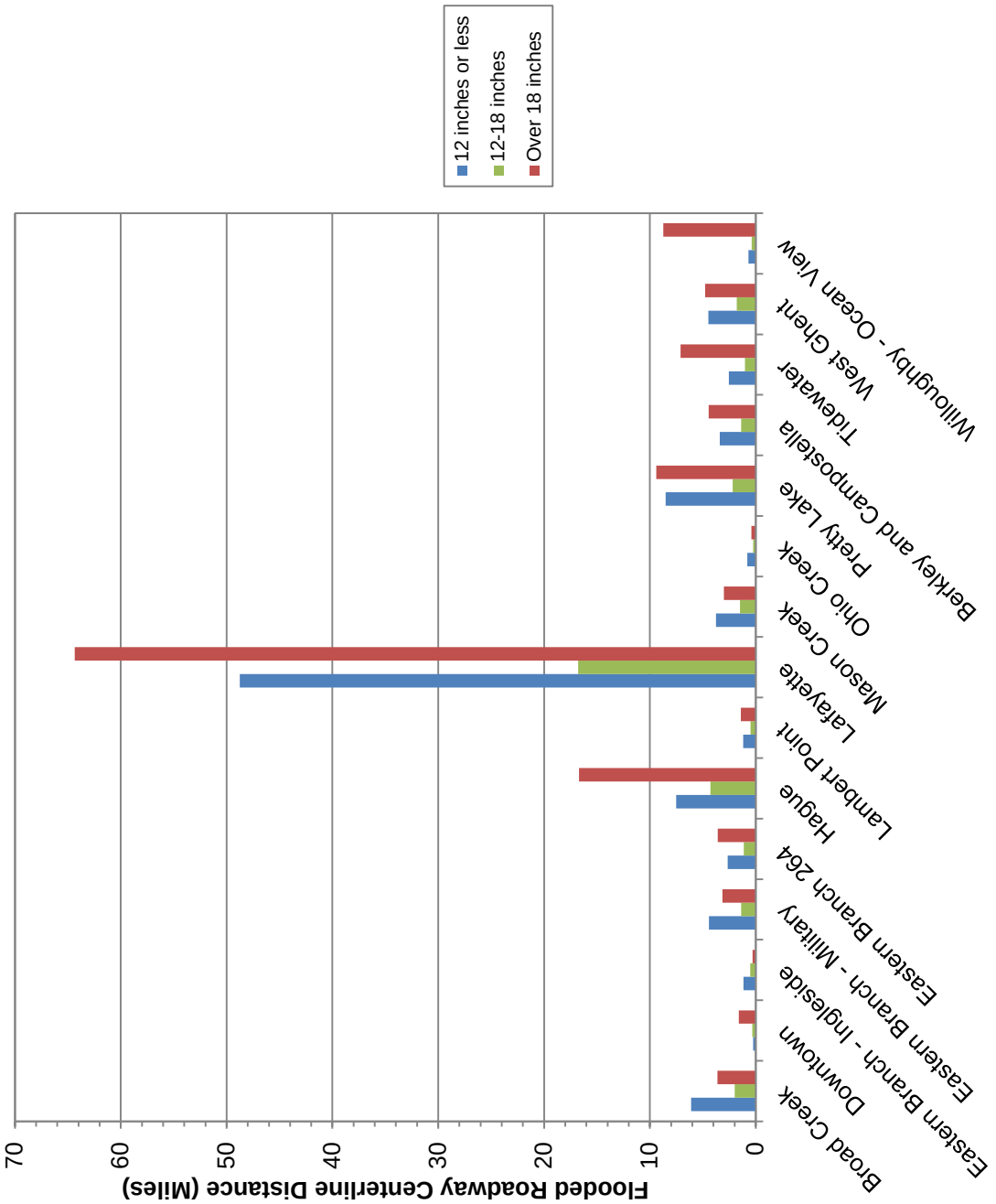
FIGURE 3-8



RELATIVE PERCENTAGE OF FLOODED ROADWAY CENTERLINE MILES UNDER CONDITION CURRENT BY PROJECT AREA

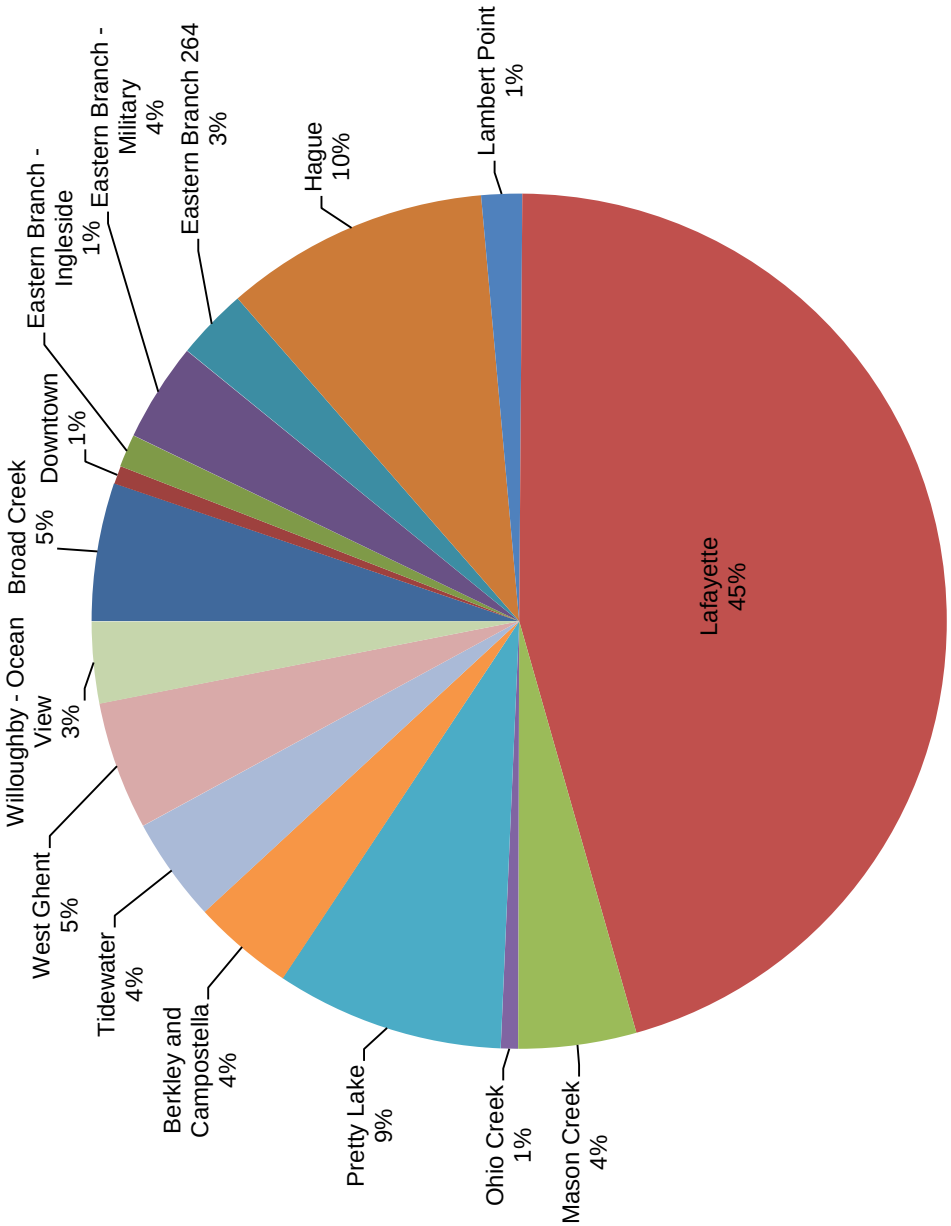
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-9



FLOODED ROADWAY CENTERLINE MILES
WITH 1-FOOT SEA LEVEL RISE BY PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-10

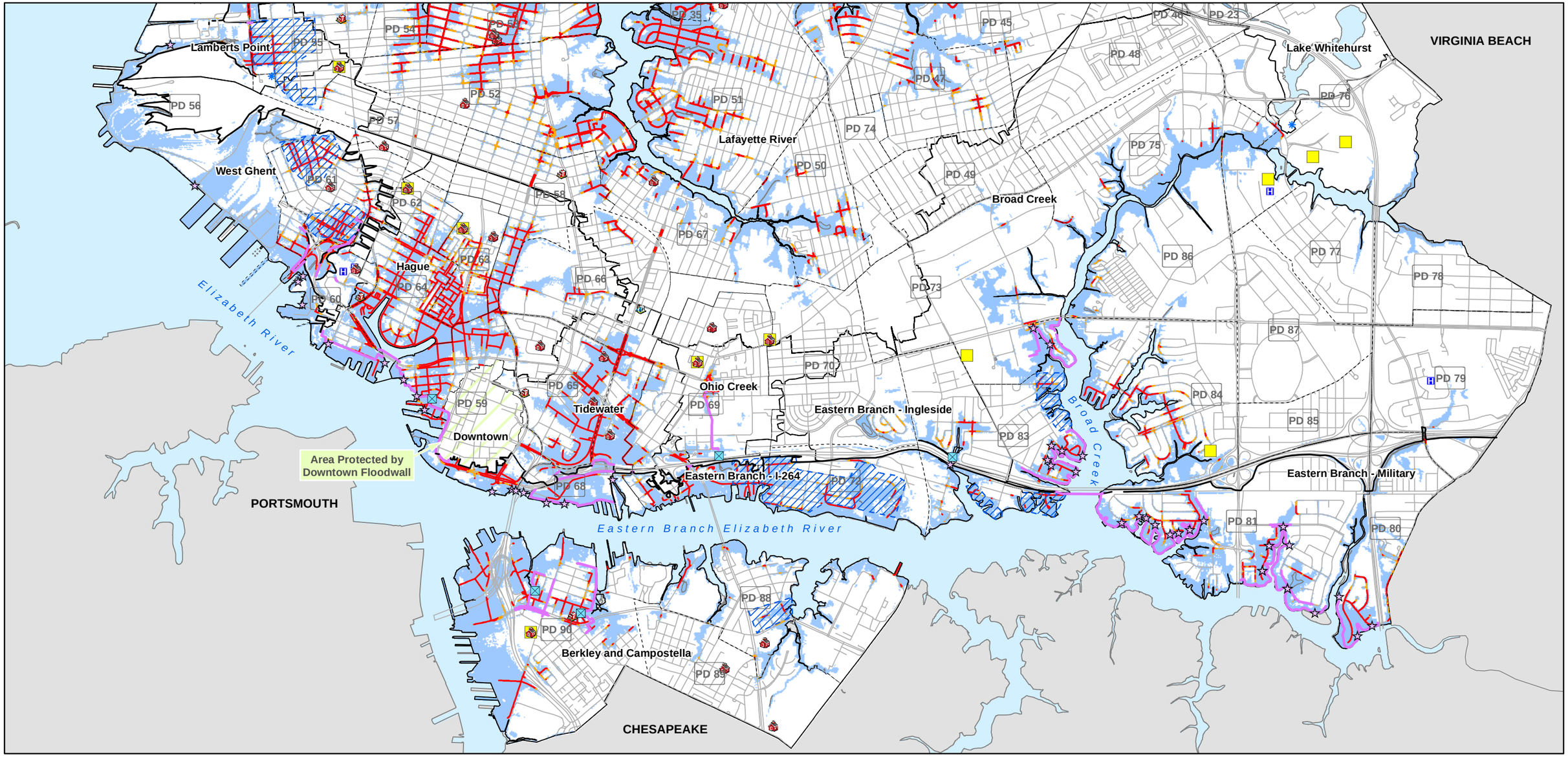


RELATIVE PERCENTAGE OF FLOODED ROADWAY CENTERLINE MILES WITH 1-FOOT SEA LEVEL RISE BY PROJECT AREA

City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-11

City of Norfolk, Department of Public Works
Project No. 04.81110022



LEGEND

- Planning District Boundary
- Street Centerline

Road Accessibility
- Emergency Only (1.0 - 1.5 feet of water)
- Impassable (Greater than 1.5 feet of water)

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

N
W E
S

0 3,000 6,000 Feet

CURRENT CONDITIONS IMPASSABLE ROADS
Southern Map
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-12a

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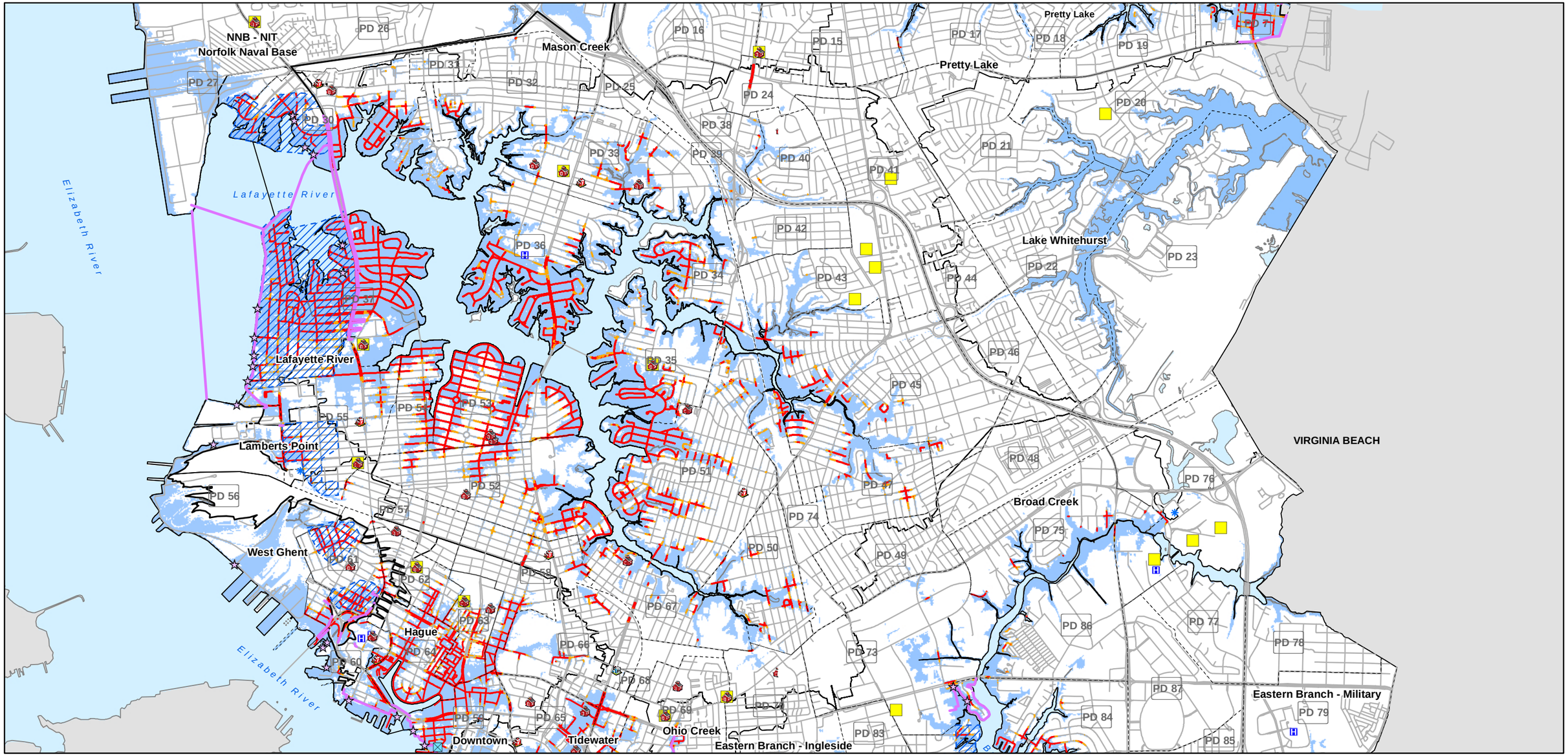
City of Norfolk, Department of Public Works
Project No. 04.81110022



LEGEND

- Planning District Boundary
- Street Centerline

Road Accessibility
- Emergency Only (1.0 - 1.5 feet of water)
- Impassable (Greater than 1.5 feet of water)

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

Eastern Branch

N
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0 3,000 6,000 Feet

Eastern Branch - Military

CURRENT CONDITIONS IMPASSABLE ROADS
Central Map
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-12b

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-12b_RoadImapcts_Central.mxd, 05/16/12, jmchee

Willoughby

Willoughby Bay

Chesapeake Bay

Note:
House Raising is the primary option for this project area.

Norfolk Naval Base

NNB - NIT

Glenwood Park

Mason Creek

Lafayette River

Lafayette River

Elizabeth River

Pretty Lake

Lake Whitehurst

VIRGINIA BEACH

PD 1, PD 2, PD 3, PD 4, PD 5, PD 6, PD 7, PD 8, PD 9, PD 10, PD 11, PD 12, PD 13, PD 14, PD 15, PD 16, PD 17, PD 18, PD 19, PD 20, PD 21, PD 22, PD 23, PD 24, PD 25, PD 26, PD 27, PD 28, PD 30, PD 31, PD 32, PD 33, PD 34, PD 35, PD 36, PD 37, PD 38, PD 39, PD 40, PD 41, PD 42, PD 43, PD 44

LEGEND

- Planning District Boundary
- Street Centerline

Road Accessibility
- Emergency Only (1.0 - 1.5 feet of water)
- Impassable (Greater than 1.5 feet of water)

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

N
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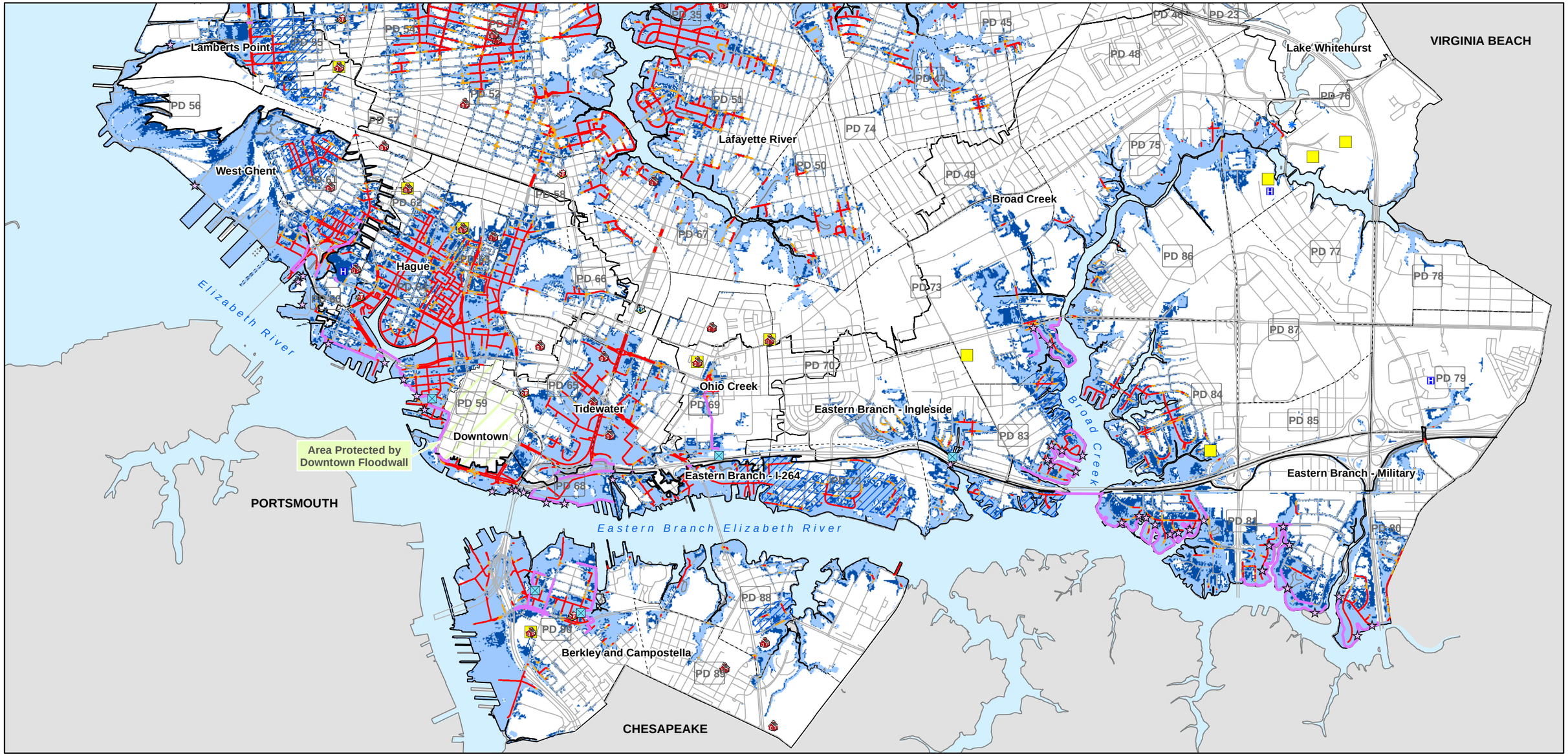
0 3,000 6,000 Feet

CURRENT CONDITIONS IMPASSABLE ROADS
Northern Map
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-12c

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-12c_RoadImapcts_North.mxd, 05/16/12, jmcbee

City of Norfolk, Department of Public Works
Project No. 04.81110022



LEGEND

- Planning District Boundary
- Street Centerline

Road Accessibility
- Emergency Only (1.0 - 1.5 feet of water)
- Impassable (Greater than 1.5 feet of water)

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise (SLR)

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

N
W E
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0 3,000 6,000 Feet

1-FOOT SEA LEVEL RISE IMPASSABLE ROADS Southern Map

City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-13a

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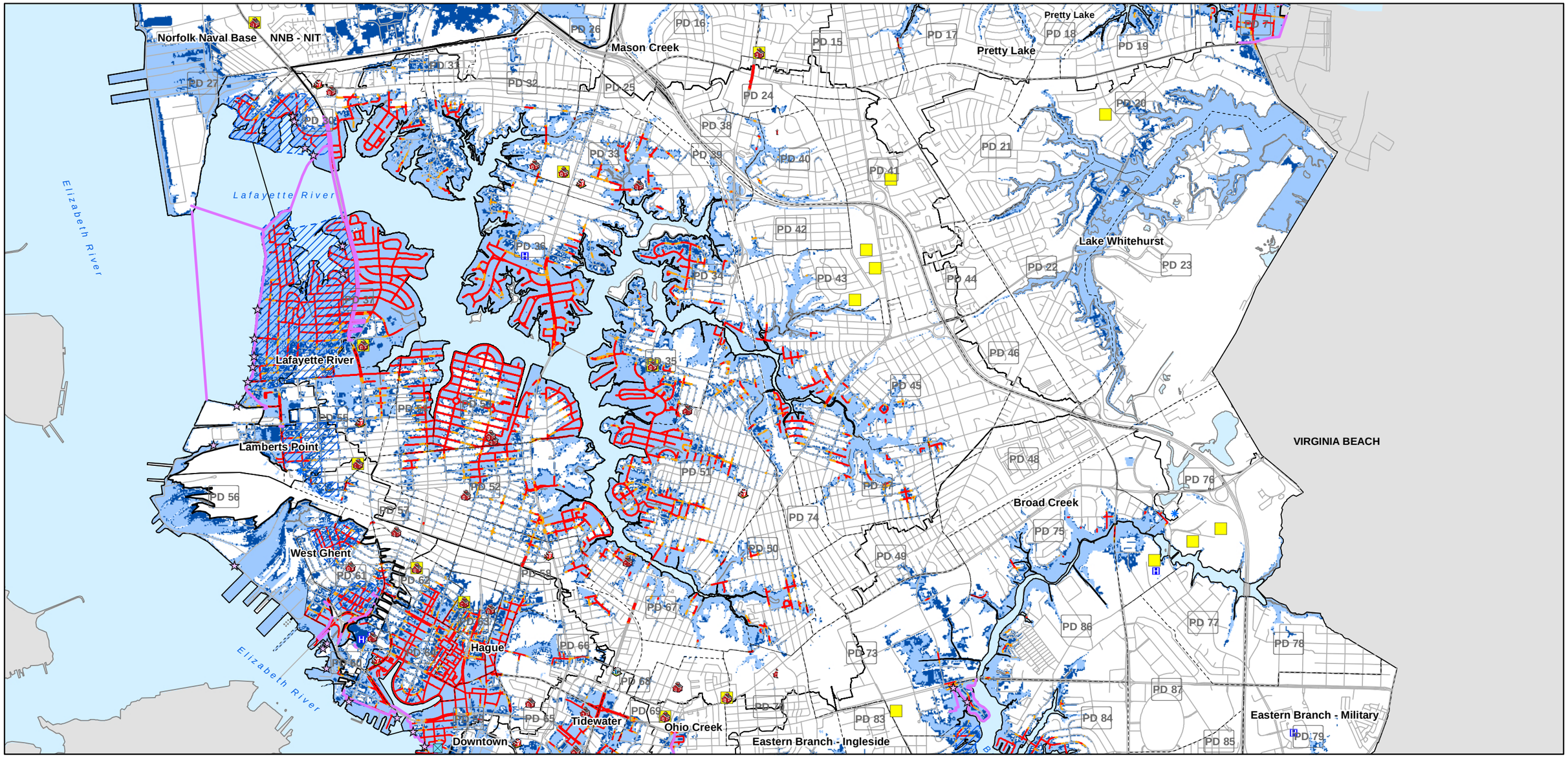

LEGEND

- Planning District Boundary
- Street Centerline

Road Accessibility
- Emergency Only (1.0 - 1.5 feet of water)
- Impassable (Greater than 1.5 feet of water)

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise (SLR)

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

Eastern Branch

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0 3,000 6,000 Feet

Eastern Branch - Military

1-FOOT SEA LEVEL RISE IMPASSABLE ROADS
Central Map

City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-13b

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-13b_RoadImpacts_SLR_Central.mxd, 05/16/12, jmdee

Willoughby

Willoughby Bay

Note:
House Raising is the primary option for this project area.

Chesapeake Bay

Norfolk Naval Base

NNB - NIT

Glenwood Park

Mason Creek

Lafayette River

Lafayette River

Elizabeth River

Pretty Lake

Lake Whitehurst

VIRGINIA BEACH

PD 1, PD 2, PD 3, PD 4, PD 5, PD 6, PD 7, PD 8, PD 9, PD 10, PD 11, PD 12, PD 13, PD 14, PD 15, PD 16, PD 17, PD 18, PD 19, PD 20, PD 21, PD 22, PD 23, PD 24, PD 25, PD 26, PD 27, PD 28, PD 29, PD 30, PD 31, PD 32, PD 33, PD 34, PD 35, PD 36, PD 37, PD 38, PD 39, PD 40, PD 41, PD 42, PD 43, PD 44

LEGEND

- Planning District Boundary
- Street Centerline

Road Accessibility
- Emergency Only (1.0 - 1.5 feet of water)
- Impassable (Greater than 1.5 feet of water)

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise (SLR)

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

Lafayette River

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0 3,000 6,000 Feet

1-FOOT SEA LEVEL RISE IMPASSABLE ROADS
Northern Map

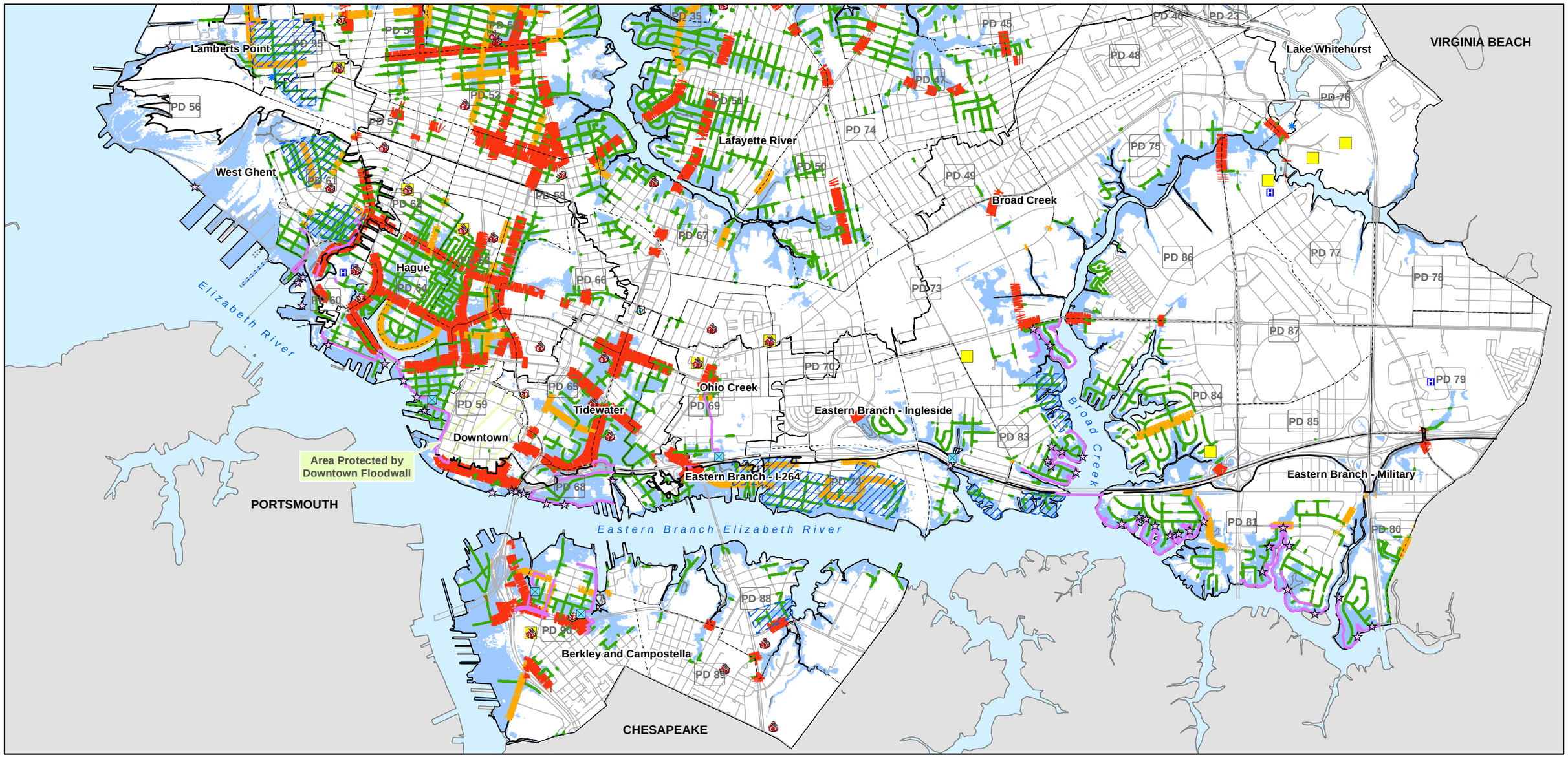
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-13c

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-13c_RoadImpacts_SLR_North.mxd, 05/16/12, jmcbee

City of Norfolk, Department of Public Works
Project No. 04.81110022

Lafayette River



LEGEND

- Planning District Boundary
- Street Centerline

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent

Traffic Volume Impact from Blocked Road
- Severe
- Moderate
- Low

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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0 3,000 6,000 Feet

CURRENT CONDITIONS POTENTIAL TRAFFIC VOLUME IMPACT
Southern Map
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-14a

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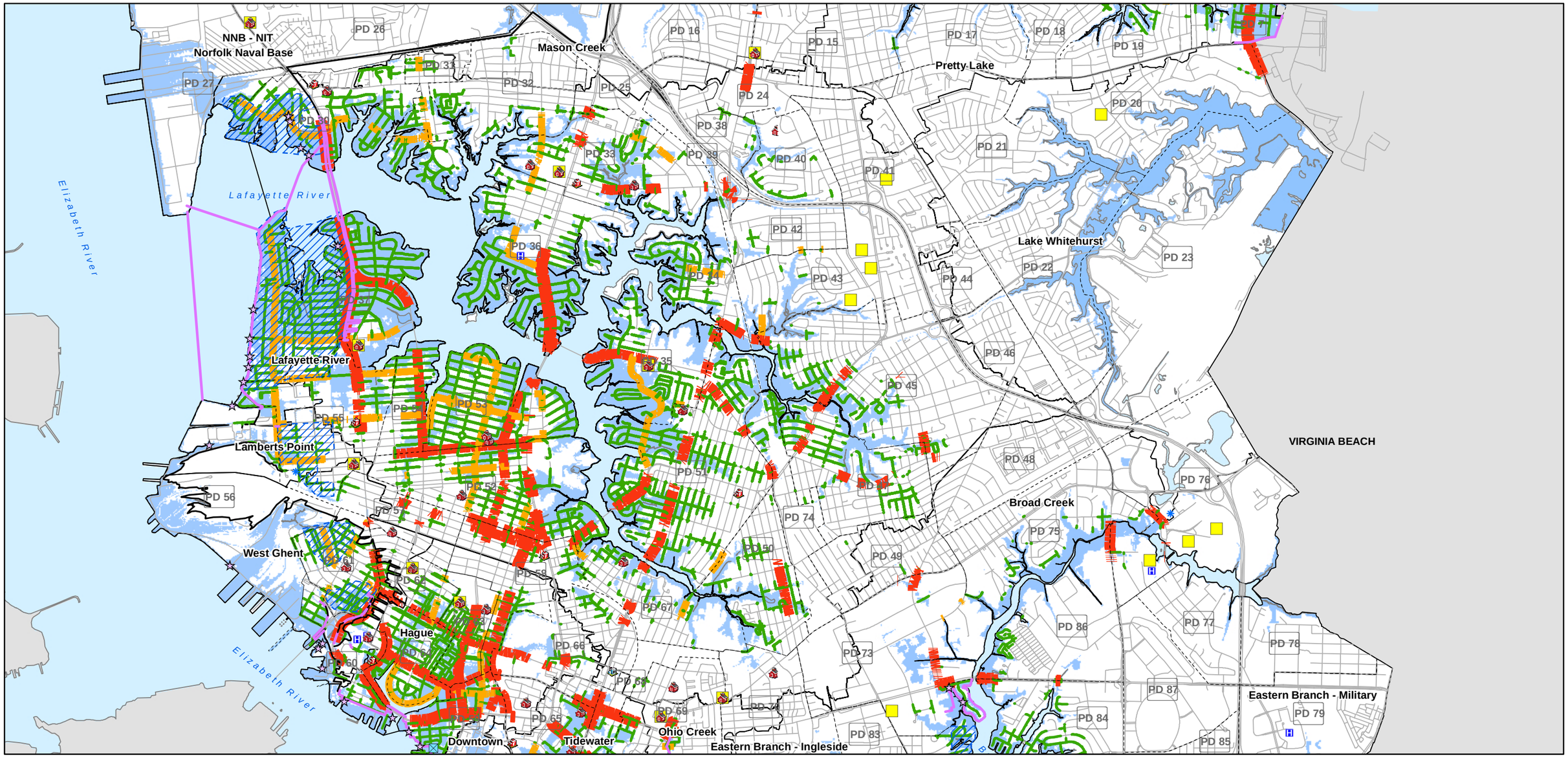

LEGEND

- Planning District Boundary
- Street Centerline

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent

Traffic Volume Impact from Blocked Road
- Severe
- Moderate
- Low

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

N W E S

0 3,000 6,000 Feet

CURRENT CONDITIONS POTENTIAL TRAFFIC VOLUME IMPACT
Central Map
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-14b

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-14b_TrafficImpacts_Central.mxd, 05/16/12, jmcbee

Note:
House Raising is the primary option for this project area.

Willoughby Bay
Chesapeake Bay
Lafayette River
Elizabeth River
Mason Creek
Lake Whitehurst
Pretty Lake
Norfolk Naval Base
NNB - NIT
Glenwood Park
VIRGINIA BEACH

PD 1, PD 2, PD 3, PD 4, PD 5, PD 6, PD 7, PD 8, PD 9, PD 10, PD 11, PD 12, PD 13, PD 14, PD 15, PD 16, PD 17, PD 18, PD 19, PD 20, PD 21, PD 22, PD 23, PD 24, PD 25, PD 26, PD 27, PD 28, PD 29, PD 30, PD 31, PD 32, PD 33, PD 34, PD 35, PD 36, PD 37, PD 38, PD 39, PD 40, PD 41, PD 42, PD 43, PD 44

LEGEND

- Planning District Boundary
- Street Centerline

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent

Traffic Volume Impact from Blocked Road
- Severe
- Moderate
- Low

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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0 3,000 6,000 Feet

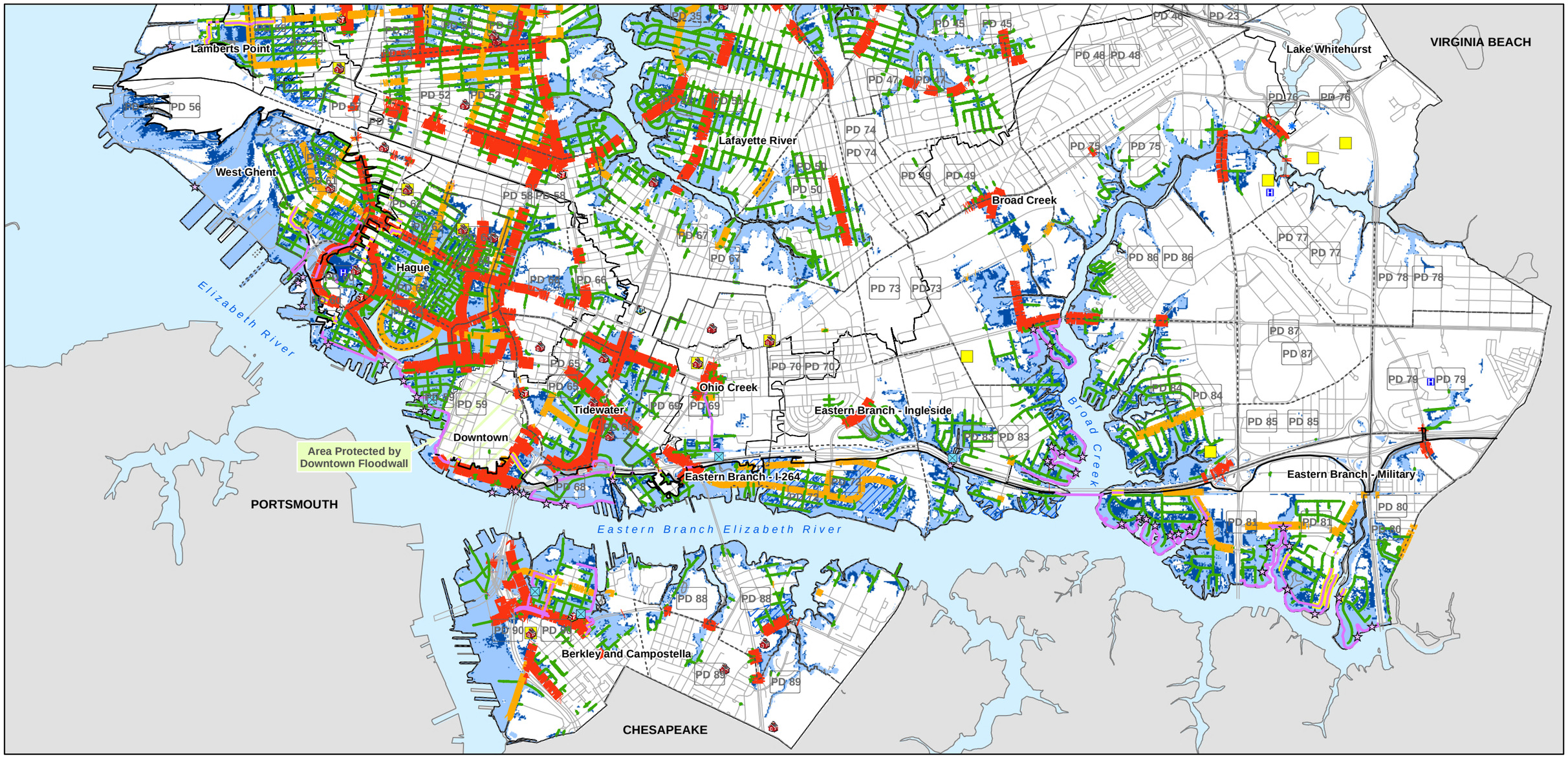
CURRENT CONDITIONS POTENTIAL TRAFFIC VOLUME IMPACT
Northern Map
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-14c

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-14c_TrafficImpacts_North.mxd, 05/16/12, jmcbee

City of Norfolk, Department of Public Works
Project No. 04.81110022

Lafayette River



LEGEND

- Planning District Boundary
- Street Centerline

Approximate Coastal Flooding
Does not include precipitation.
- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise (SLR)

Traffic Volume Impact from Blocked Road (1-Foot Sea Level Rise)
- Severe
- Moderate
- Low

Mitigation Options
- Potential Mitigation Option
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities
- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

N W E S

0 3,000 6,000 Feet

1-FOOT SEA LEVEL RISE POTENTIAL TRAFFIC VOLUME IMPACT
Southern Map

City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-15a

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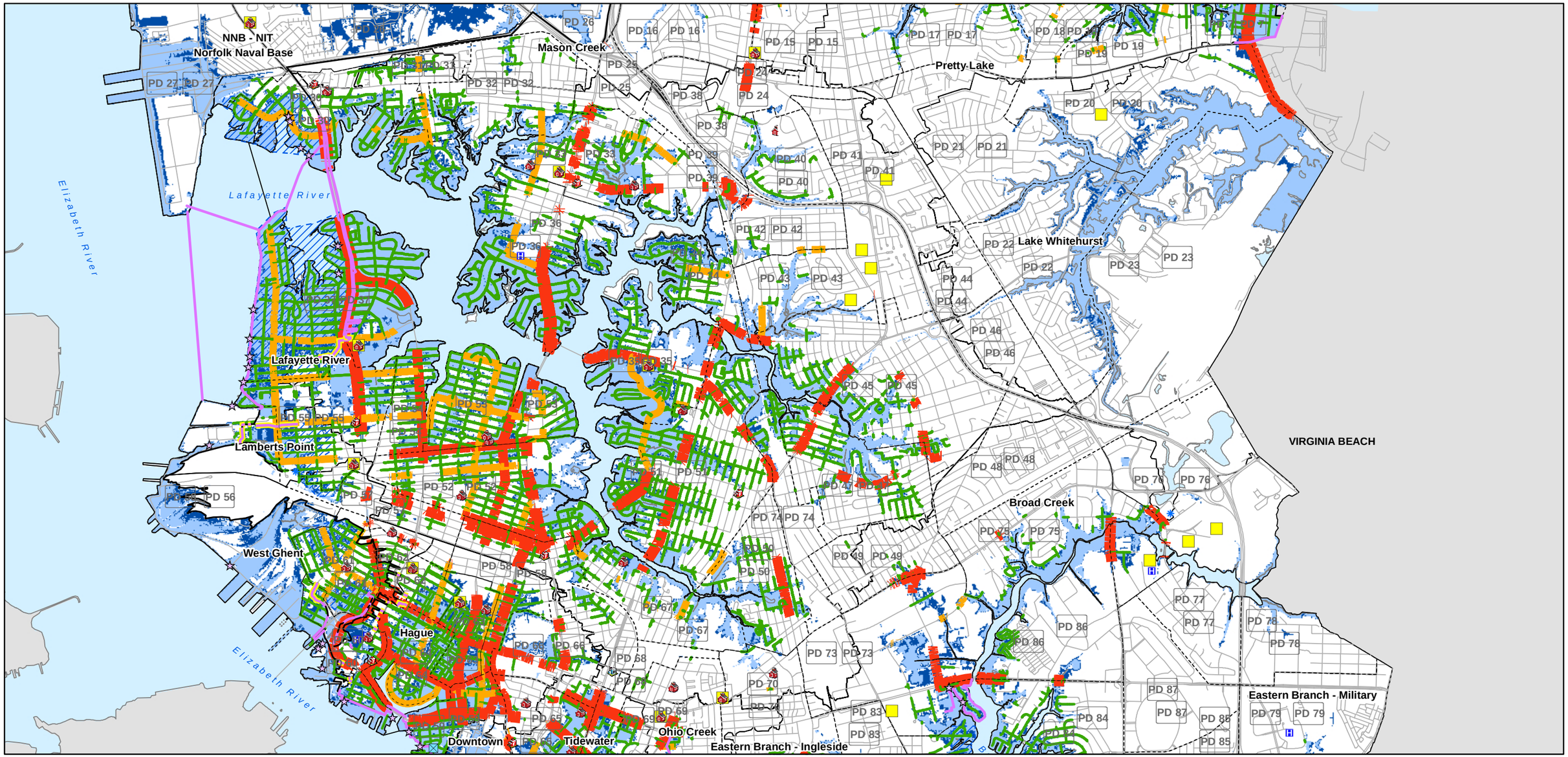
City of Norfolk, Department of Public Works
Project No. 04.81110022



LEGEND

- Planning District Boundary
- Street Centerline

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise (SLR)

Traffic Volume Impact From Blocked Road (1-Foot Sea Level Rise)

- Severe
- Moderate
- Low

Mitigation Options

- Potential Mitigation Option
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

N
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0 3,000 6,000 Feet

1-FOOT SEA LEVEL RISE POTENTIAL TRAFFIC VOLUME IMPACT
Central Map
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-15b

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-15b_TrafficImpacts_SLR_Central.mxd, 05/16/12, jmcbee

Note:
House Raising is the primary option for this project area.

Willoughby Bay

Chesapeake Bay

Lafayette River

Elizabeth River

Willoughby

Norfolk Naval Base

NNB - NIT

Mason Creek

Glenwood Park

Pretty Lake

Lake Whitehurst

VIRGINIA BEACH

LEGEND

- Planning District Boundary
- Street Centerline

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise (SLR)

Traffic Volume Impact from Blocked Road (1-Foot Sea Level Rise)

- Severe
- Moderate
- Low

Mitigation Options

- Potential Mitigation Option
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- Outfall Flap Valve
- Pump Station
- House Raising

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

N W E S

0 3,000 6,000 Feet

1-FOOT SEA LEVEL RISE POTENTIAL TRAFFIC VOLUME IMPACT
Northern Map

City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 3-15c

N:\Projects\3627_City_Norfolk\04_8111_0022_Prelim_Fld_Mstr_Plan\Outputs\2012-03_Draft_Prelim_Fld_Mstr\mxd\Fig-3-15c_TrafficImpacts_SLR_North.mxd, 05/16/12, jmcbee

Flood Mitigation Options (by Scale of Protection)	Associated Cost Scale (S)
RESIDENT/LOCALIZED	
Education	Varies
Building Codes	N/A
Flood proofing buildings	N/A
Building Elevation	10 to 100k
Barricades Around Building	10 to 100s k
NEIGHBORHOOD SCALE	
Storm Drainage Improvements	>100k
Pump Stations	>100k
Channelization	>100k
Small floodwall/berm	100sk to >1M
Road Grade Raise	10 to 100k
Beach Nourishment	10k to 100k (Annually)
Permanent Retention Ponds	>100k
WATERSHED SCALE	
Earthen Berms & Levees	>100k
Floodwalls and Gate Systems	>100k
Temporary Dams	>100k
Impoundment & Storage	>100k

TYPES AND SCALES OF
FLOOD MITIGATION OPTIONS
City-wide Coastal Flooding Study
Norfolk, Virginia

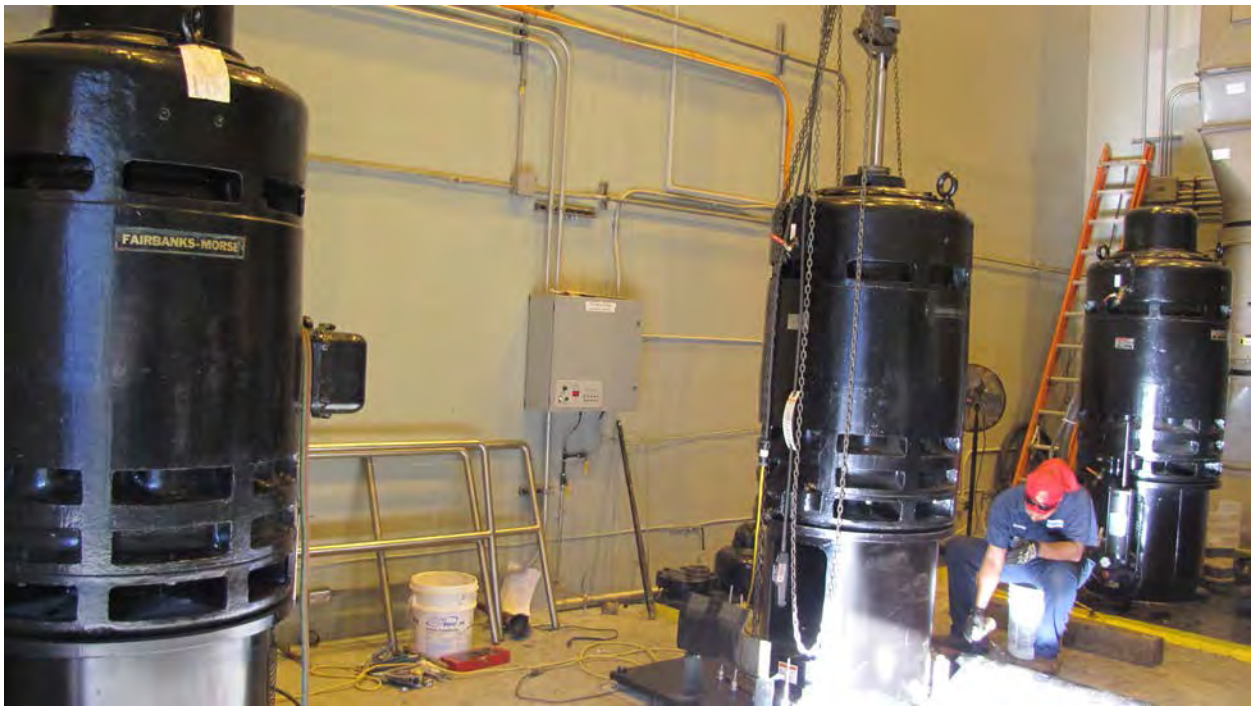
FIGURE 4-1

Open Channel Improvement Project, Raleigh, North Carolina

Existing Open Channel, Rocky Mount, North Carolina

CHANNELIZATION IMPROVEMENTS
Flood Mitigation Concepts
City-wide Coastal Flooding Study
Norfolk, Virginia

City of Norfolk, Pump Station, exterior and pumps

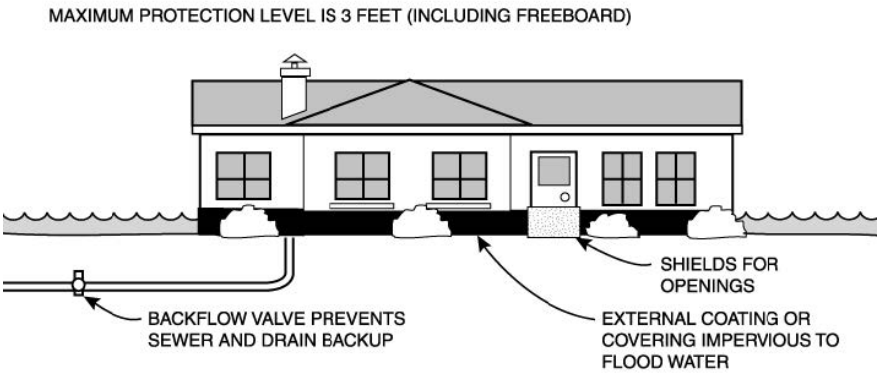


PUMP STATIONS
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

Beach front property with eroded coastal dune is subject to flooding, East Ocean View, Norfolk

Beach front property after beach is widened and dune is stabilized, East Ocean View, Norfolk

COASTAL DUNE STABILIZATION
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia



Utilities are also susceptible to flooding problems. Raising HVAC systems and duct work above flood water levels is possible as shown the upper photograph of a building in the Pretty Lake area of Norfolk (photograph courtesy of K. Spencer). Elevating hot water tanks and moving electrical wiring to higher positions can also prevent damage during flooding. Also, backflow valves can be installed to help reduce the potential for backflow through sewer and drain pipes as shown in the lower image (modified from FEMA, 2007).

UTILITY IMPROVEMENT EXAMPLES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

Inset A

Inset B

Inset C

Inset D

Inset E

Inset F

The structures above have flood-proofed the lower few feet of the building. This type of flood proofing uses the structures walls as part of the barrier system and are therefore more appropriate for slab on grade structures. Since the residential walls are not usually designed to withstand lateral forces from water, they are generally only effective for water depths up to 2 to 3 feet. These barriers are not recognized by FEMA for a flood insurance premium reduction or for funding support. Inset A shows a concrete wall around the base of the house, but the garage door will require sandbagging. The planter box is part of the flood barrier system. Inset B has created a concrete step system to access the house over the flood protection wall. This structure had been tested several times and reportedly worked well. Inset C has uses a thin-facing brick to cover the flood proofing. Inset D shows a swing door with a gasket seal for the home shown in Inset C. Inset E shows permanent shields over the lower 2 feet of the windows. Inset F had the walls flood proofed and removable shields placed over the windows. Photographs are from the New Orleans area in Louisiana and are modified from UNO (2006).

DRY FLOOD PROOFING EXAMPLES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 4-6

The temporary flood barricade is used to protect a municipal garage in Danvers, Massachusetts. It is 125 feet long and is 3.5 feet tall when installed. The horizontal boards are removed during periods of non-flooding to allow vehicles to access the garage. Flood boards for structures of this size can usually be installed in a less than a few hours (www.floodcontrolam.com).

The Norfolk business above has installed a temporary flood barrier system around the building. Prior to the storm, flood boards are places in the steel post brackets (shown above below the arrows) to create a barrier around the structure. Photo on right shows one of the flood boards being installed at the doorway. Coastal engineers should be consulted to help determine the elevation of expected flooding and civil engineer should be consulted to help design the structure to be capable of withstanding forces that floodwaters may apply on the barrier system. Modified from Kobell (2012).

REMOVABLE BARRICADE EXAMPLES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

Example of homes raised in Norfolk. Some house raising efforts may be eligible for funding support from FEMA. Twenty-four houses have been raised in Norfolk in the last ten years that received financial support from FEMA through grant programs. A local contractor interviewed during this study indicated that they had raised at least 50 homes in Norfolk that were not part of a FEMA grant program. Upper photograph is modified from Moheim (2010) and the lower one is modified from Kobell (2012).

HOUSE RAISING EXAMPLES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

Section of downtown Norfolk floodwall that is approximately 2 to 3 feet tall.

Section of downtown Norfolk floodwall that is approximately 1 to 2 feet tall.

LOW FLOODWALL EXAMPLE
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

Regional earthen levee, part of coastal defense system
The Netherlands

City of Norfolk,
Downtown Flood Wall

EARTHEN LEVEE AND FLOODWALL EXAMPLES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

Earthen Levee – New Orleans

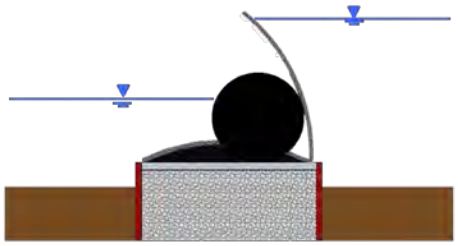
Floodwall – New Orleans

FLOOD LEVEES AND FLOOD WALLS
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

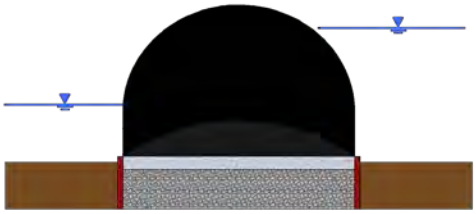
Flood gate within existing flood wall, St. Charles Parish, Louisiana

Flood gate in Norfolk's downtown floodwall system. Vehicles and pass through when the gate is opened.

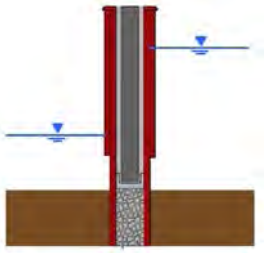
OVERLAND FLOOD GATES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia



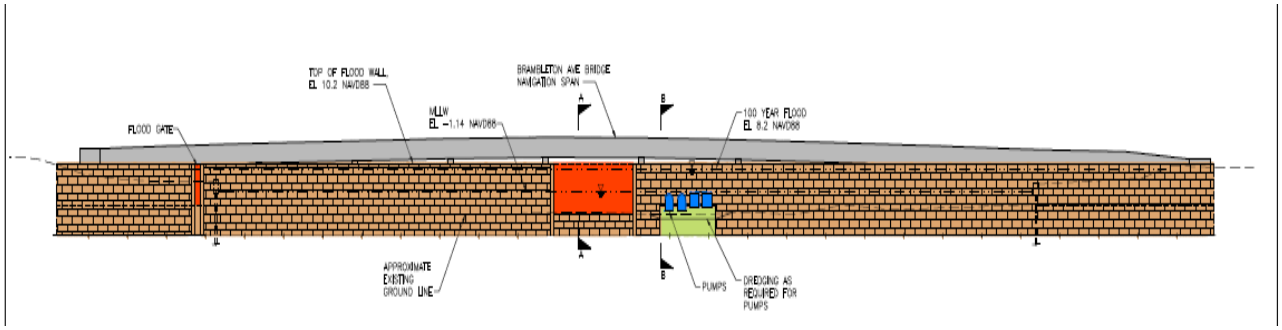
Obermeyer Gate – pneumatic system lifts steel flap up to close off surge barrier. When deflated, the steel flap is lowered and vessels can pass through gate opening.



Inflatable Dam – Rubberized membrane fills with air or water to activate and close off surge barrier. When deflated, vessels can pass through gate opening.

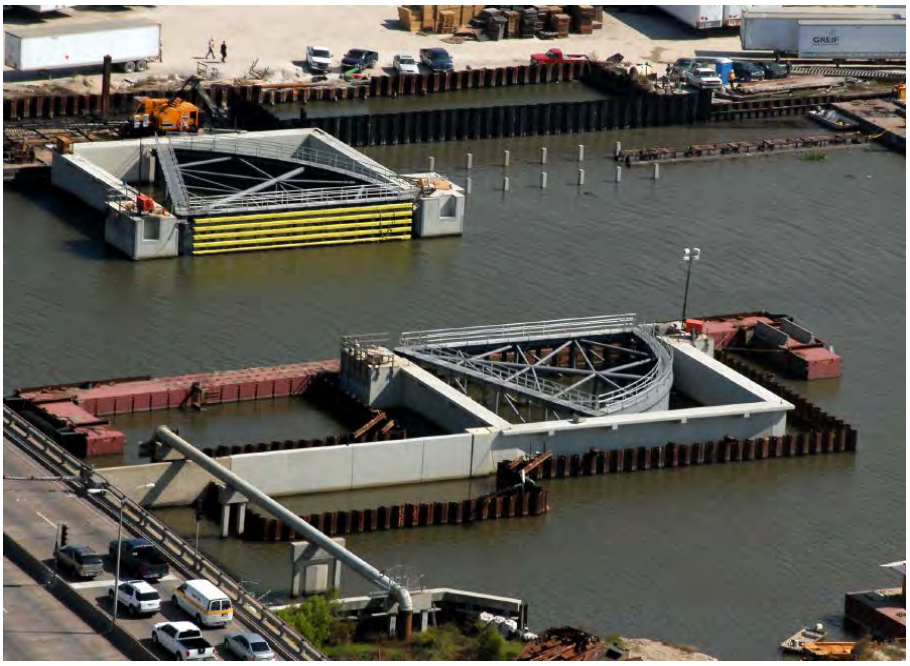


Steel Gate – Steel gate slides horizontally into position to close opening. When in open position, vessels can pass through gate opening.



Schematic illustration showing a gate opening (orange rectangle) in a flood wall. Green rectangle is a pumping station required to rain run-off from the interior of the wall to the exterior. Gray graphic is a bridge in the background and is not part of this wall and gate option.

SMALL WATERWAY FLOOD GATES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia



Sector gate (vertical swing axis) in the Harvey Canal in New Orleans, Louisiana

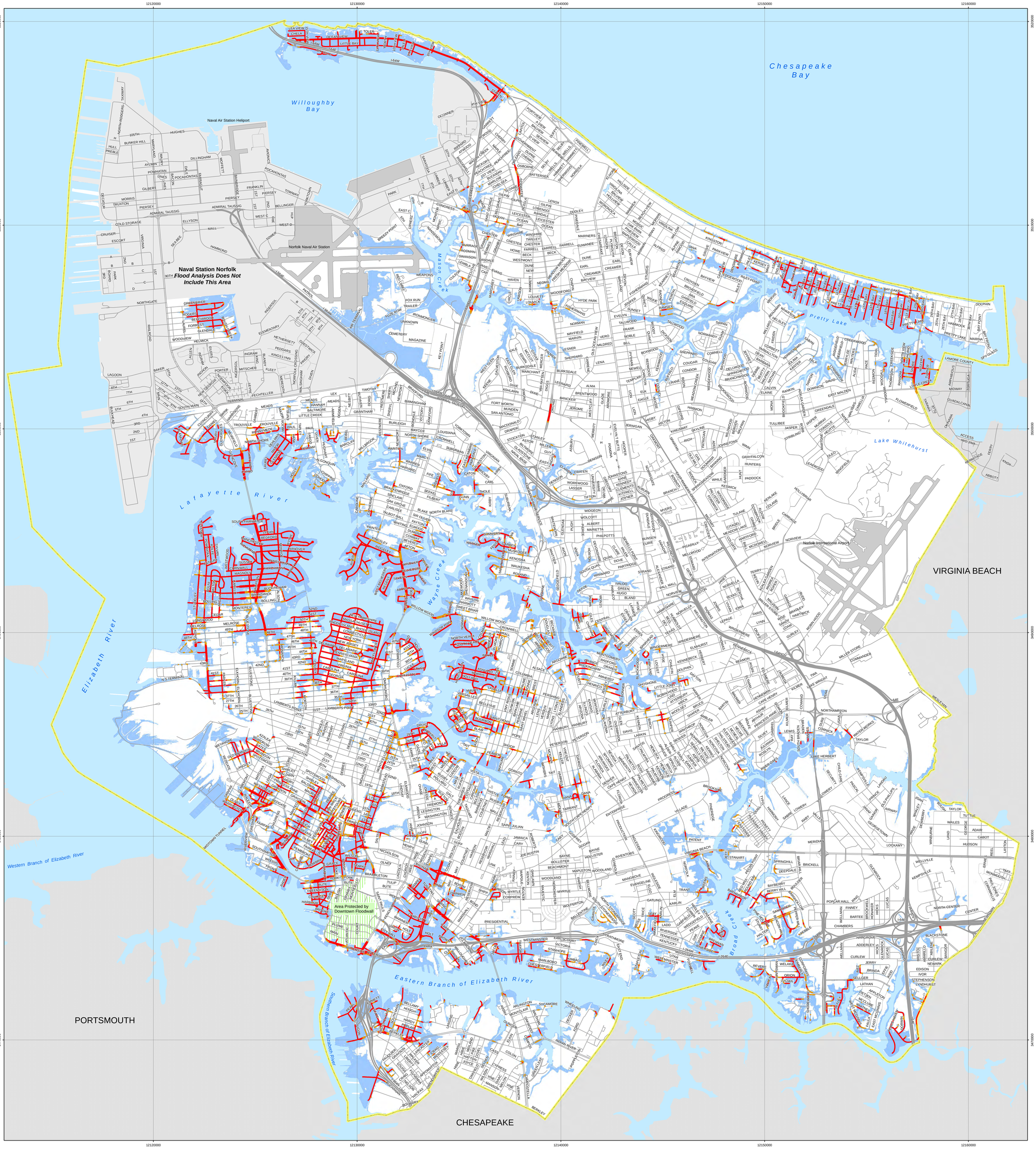
Bayou Bienvenue vertical lift gate in New Orleans.

LARGE WATERWAY FLOOD GATES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia

Conceptual illustration of the Seabrook Floodgate Structure in New Orleans. The illustration shows two lift gates on either side of a sector gate in the closed position (USACE, 2009). When gates are in the open position, normal navigation is permitted through the openings.

Large flood gate, part of Maasland Barrier regional flood defense structures protecting Rotterdam Harbour. The gate structure spans 1,180 feet.

LARGE WATERWAY FLOOD GATES
Flood Mitigation Alternatives
City-wide Coastal Flooding Study
Norfolk, Virginia



LEGEND

- Roads
- Norfolk City Limits

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Event

Impassable Road Centerlines for 1% Annual Chance Coastal Flood Event

- Potentially Impassable For Cars
  Emergency vehicles and large trucks may be able to pass.
  Predicted water depth between 12 and 18 inches.
- Potentially Impassable For All Vehicles (Including Emergency Response Vehicles)
  Predicted water depth greater than 18 inches.

Notes:

1. Ground surface and road centerline elevation used to estimate flooding extent is based on 2009 light detection and ranging (LiDAR) survey.
2. Inland flooded areas (areas not adjacent to tidal tributary) shown are hydrologically connected to a tidal tributary, and potentially may have caused flooding due to backflow. However, elevations of storm water inlets and outlets that would provide insight regarding to backflow potential were not verified during this study.
3. Approximate flooding extents are based on tidal water level relationships between the Sewells Point tide gauge and the City's tide gauge network from data collected during 2009 and 2010. The figure above shows a schematic of how the water levels are related.

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GEODETIC INFORMATION

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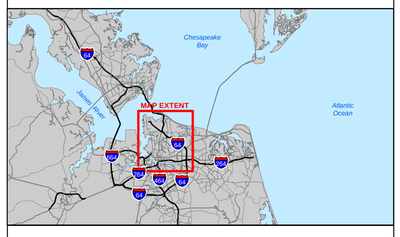
ECCENTRICITY:	0.006694380
PROJECTION:	LAMBERT CONFORMAL CONIC
ZONE:	VIRGINIA SOUTH
LONGITUDE OF ORIGIN:	36.3°
FALSE EASTING:	11,482,916
FALSE NORTHING:	3,280,833

Coordinate Grid: Virginia State Plane South, NAD83, Feet



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IMPASSABLE ROAD CENTERLINES UNDER CURRENT CONDITIONS

City-wide Coastal Flooding Study
Norfolk, Virginia

0 2,000 4,000 Feet
0 500 1,000 Meters

NO:	DATE:	DESCRIPTION:	DRAWN:	CHKD:	APPR:
1	April 2012	Draft City-wide Coastal Flooding Master Plan	JMM	KRS	KRS
2	May 2012	Draft City-wide Coastal Flooding Master Plan	JMM	KRS	KRS
3					

JOB NUMBER: 04.81110022 MAP NO.: 1

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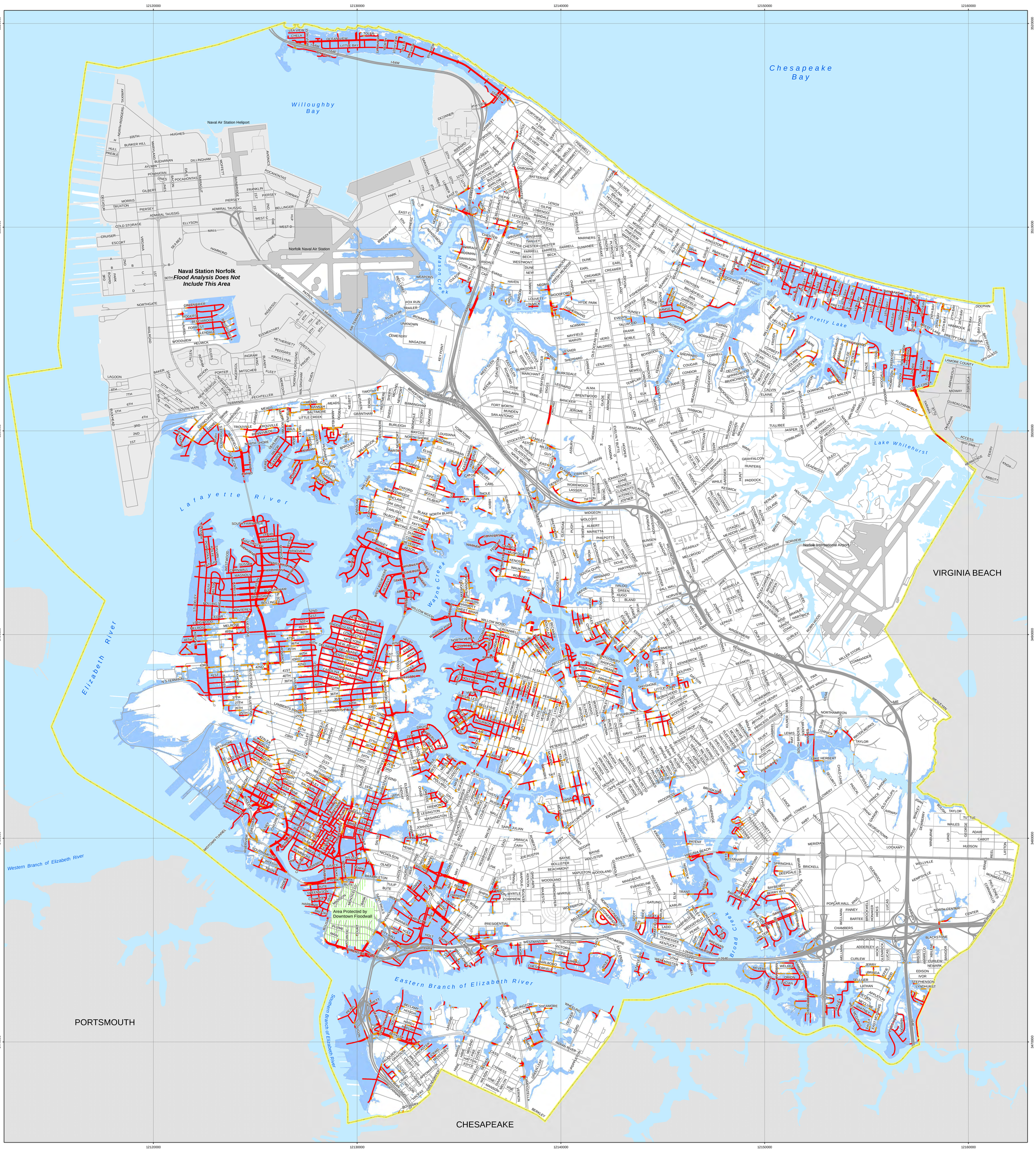

LEGEND

- Roads
- Norfolk City Limits

Approximate Coastal Flooding

Does not include precipitation.

- 1% Annual Chance Coastal Flood Event with 1-foot Sea Level Rise

Impassable Road Centerlines for 1% Annual Chance Coastal Flood Event with 1-foot Sea Level Rise

- Potentially Impassable For Cars
  Emergency vehicles and large trucks may be able to pass.
  Predicted water depth between 12 and 18 inches.
- Potentially Impassable For All Vehicles (Including Emergency Response Vehicles)
  Predicted water depth greater than 18 inches.

Notes:

1. Ground surface and road centerline elevation used to estimate flooding extent is based on 2009 light detection and ranging (LiDAR) survey.
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3. Approximate flooding extents are based on tidal water level relationships between the Sewells Point tide gauge and the City's tide gauge network from data collected during 2009 and 2010. The figure above shows a schematic of how the water levels are related.

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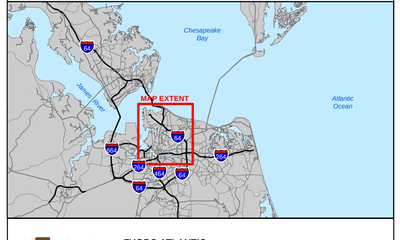
Coordinate Grid: Virginia State Plane South, NAD83, Feet



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IMPASSABLE ROAD CENTERLINES WITH ONE FOOT SEA LEVEL RISE

City-wide Coastal Flooding Study
Norfolk, Virginia

0 2,000 4,000 Feet
0 500 1,000 Meters

NO:	DATE:	DESCRIPTION:	DRAWN:	CHKD:	APPR:
1	April 2012	Draft City-wide Coastal Flooding Master Plan	JMM	KRS	KRS
2	May 2012	Draft City-wide Coastal Flooding Master Plan	JMM	KRS	KRS
3					

JOB NUMBER: 04.81110022 MAP NO.: 2

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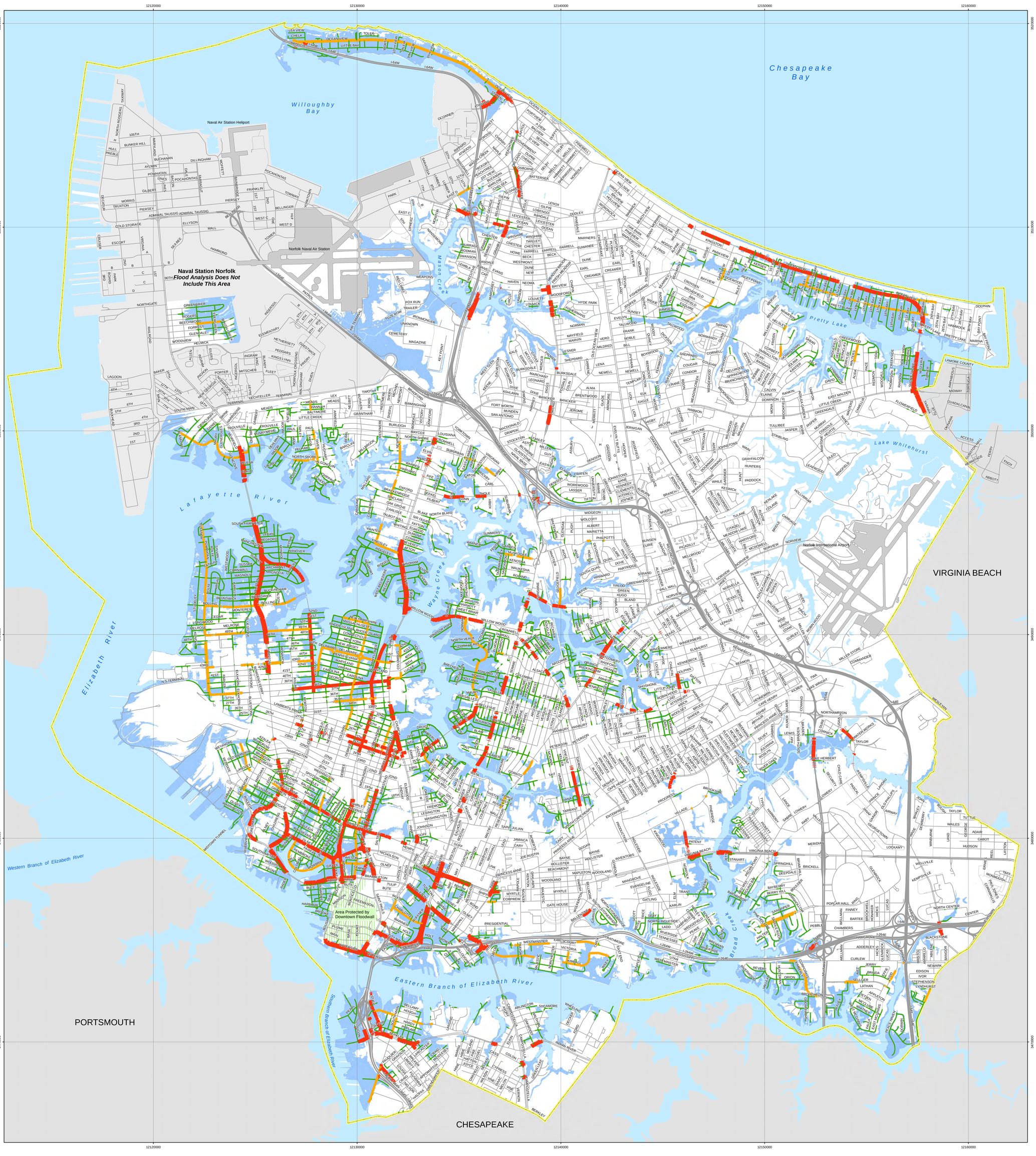

LEGEND

- Roads
- Norfolk City Limits

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Event

Potential Traffic Volume Impact for for 1% Annual Chance Coastal Flood Event

- Severe
- Moderate
- Low

Notes:

1. Ground surface and road centerline elevation used to estimate flooding extent is based on 2009 light detection and ranging (LiDAR) survey.
2. Inland flooded areas (areas not adjacent to tidal tributary) shown are hydrologically connected to a tidal tributary, and potentially may have caused flooding due to backflow. However, elevations of storm water inlets and outlets that would provide insight regarding to backflow potential were not verified during this study.
3. Approximate flooding extents are based on tidal water level relationships between the Sewells Point tide gauge and the City's tide gauge network from data collected during 2009 and 2010. The figure above shows a schematic of how the water levels are related.

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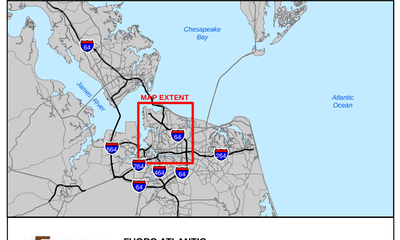
INVERSE FLATTENING:	298.25722101
ECCENTRICITY²:	0.006694380
PROJECTION:	LAMBERT CONFORMAL CONIC
ZONE:	VIRGINIA SOUTH
LONGITUDE OF ORIGIN:	36.3°
FALSE EASTING:	11,482,916
FALSE NORTHING:	3,280,833

N W E S

Coordinate Grid: Virginia State Plane South, NAD83, Feet



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POTENTIAL TRAFFIC VOLUME IMPACT UNDER CURRENT CONDITIONS

City-wide Coastal Flooding Study
Norfolk, Virginia

0 2,000 4,000 Feet
0 500 1,000 Meters

NO:	DATE:	DESCRIPTION:	DRAWN:	CHKD:	APPR:
1	April 2012	Draft City-wide Coastal Flooding Master Plan	JMM	KRS	KRS
2	May 2012	Draft City-wide Coastal Flooding Master Plan	JMM	KRS	KRS
3					

JOB NUMBER: 04.81110022 MAP NO.: 3

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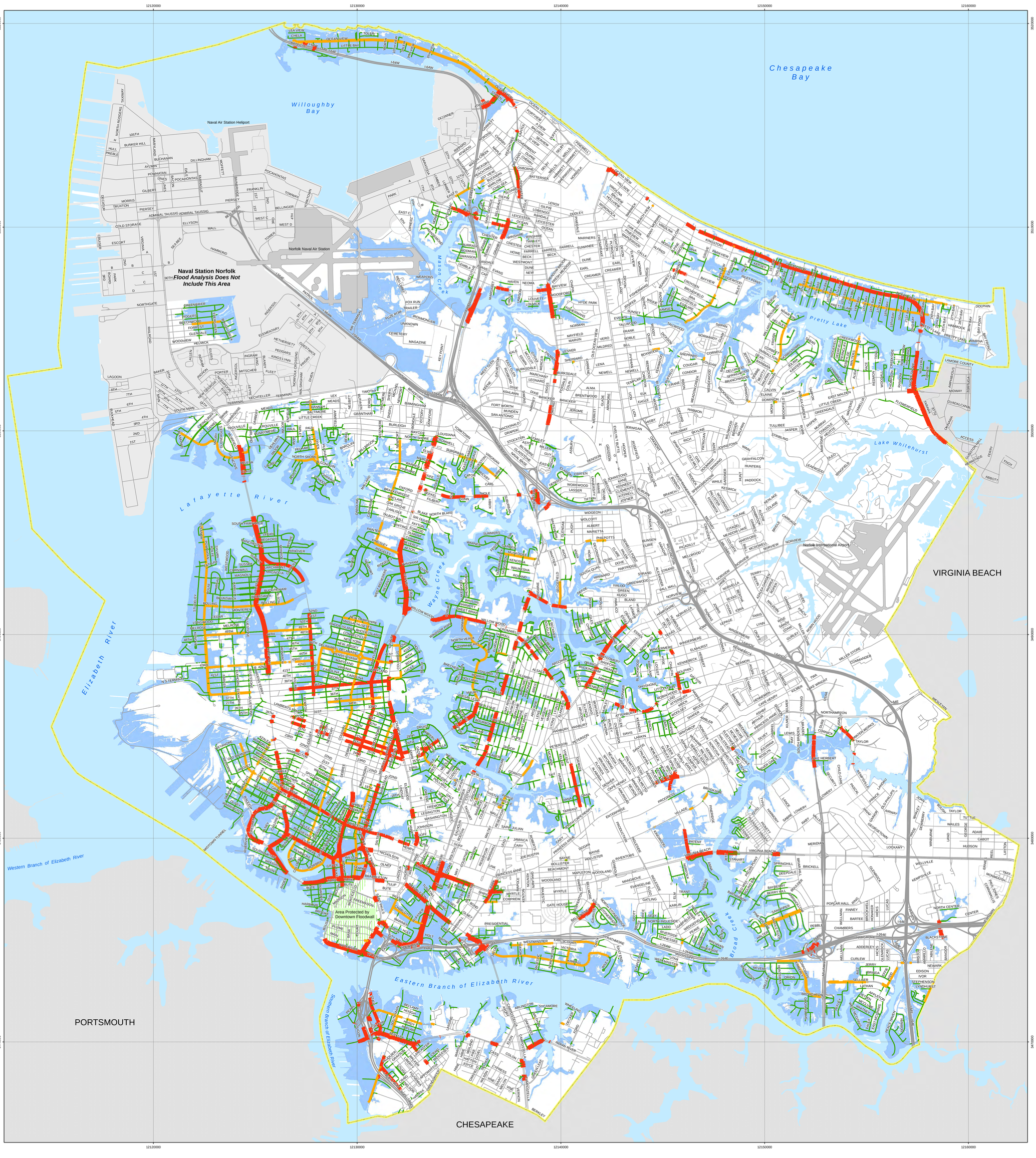

LEGEND

- Roads
- Norfolk City Limits

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Event with 1-Foot Sea Level Rise

Potential Traffic Volume Impact for 1% Annual Chance Coastal Flood Event with 1-foot Sea Level Rise

- Severe
- Moderate
- Low

Notes:

1. Ground surface and road centerline elevation used to estimate flooding extent is based on 2009 light detection and ranging (LiDAR) survey.
2. Inland flooded areas (areas not adjacent to tidal tributary) where are hydrologically connected to a tidal tributary, and potentially may have caused flooding due to backflow. However, elevations of storm water inlets and outlets that would provide insight regarding to backflow potential were not verified during this study.
3. Approximate flooding extents are based on tidal water level relationships between the Sewells Point tide gauge and the City's tide gauge network from data collected during 2009 and 2010. The figure above shows a schematic of how the water levels are related.

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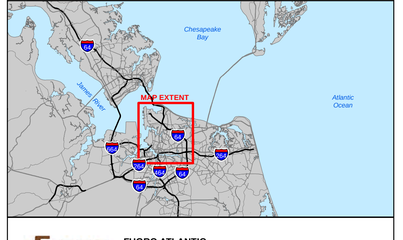
N W E S

Coordinate Grid: Virginia State Plane South, NAD83, Feet



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POTENTIAL TRAFFIC VOLUME IMPACT WITH ONE FOOT SEA LEVEL RISE

City-wide Coastal Flooding Study
Norfolk, Virginia

0 2,000 4,000 Feet
0 500 1,000 Meters

NO:	DATE:	DESCRIPTION:	DRAWN:	CHKD:	APPR:
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2	May 2012	Draft City-wide Coastal Flooding Master Plan	JMM	KRS	KRS
3					

JOB NUMBER: 04.81110022 MAP NO.: 4

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APPENDIX A

BROAD CREEK AND
EASTERN BRANCH – MILITARY PROJECT AREAS

BROAD CREEK AND EASTERN BRANCH – MILITARY PROJECT AREAS

This appendix describes two separate project areas located in the southeastern portion of the City. The project areas are the:

- Broad Creek project area, and
- Eastern Branch- Military project area.

BROAD CREEK PROJECT AREA

The Broad Creek project area encompasses the Broad Creek watershed located in the southeastern portion of the City. Broad Creek is a tidal tributary that connects to the Eastern Branch of the Elizabeth River. The project area is bordered to the north by Interstate 64 and the Lake Whitehurst watershed and to the east by the Eastern Branch – Military project area and City of Virginia Beach. Interstate 264 forms the southern boundary of the project area. The project area is bound on the west by the following three project areas: Eastern Branch – Ingleside, Ohio Creek, and Lafayette River. Figure A-1 shows the Broad Creek watershed in a light green shaded color.

There are 5,599 parcels within the 3,857 acres of Broad Creek project area. The project area consists of 4,528 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $1,309M. The characteristics (e.g. parcels, acreage, number of buildings, etc.) of this project area are summarized in Figures 1-4a and 1-4b. Most of the project area is residential with some commercial and light industrial usage along the main roads. In terms of parcels and acreage, the Broad Creek project area is the third largest in acres and fourth largest in parcels of the 15 project areas considered in this study (Figures 1-4a and 1-4b).

Broad Creek project area is comprised of Broad Creek and numerous tributaries influenced by the tide and storm surges. Broad Creek empties into the Eastern Branch of the Elizabeth River near the I-264 overpass where the mouth of the creek is approximately 1,100 feet wide. The topography is generally flat with the regional ground surface sloping inward toward the creek and south into the river through the outlet beneath the I-264 overpass. Storm water infrastructure in the Broad Creek watershed also conveys collected rainfall into Broad Creek north (upstream) of the I-264 Bridge. Thus, the Broad Creek watershed outlet into the Eastern Branch of the Elizabeth River near the I-264 Bridge represents the outlet for the basin and entry point for storm tides.

EASTERN BRANCH – MILITARY PROJECT AREA

The Eastern Branch – Military project area is located in the southeast corner of the City. The project area is bound to the north by the I-264 (west of I-64) and Virginia Beach Boulevard (east of I-64), to the east by the City of Virginia Beach, to the south by the Eastern Branch of the Elizabeth River, and to the west by Broad Creek. Military Highway is located near the center of the project area. Figure A-1 shows the Eastern Branch – Military project area in light red shaded color.

There are 1,909 parcels within the 1,303 acres of the Eastern Branch – Military project area. The project area consists of 1,265 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of approximately $266M. Most of

the project area is residential with some commercial usage along the main roads. Figures 1-3a and 1-3b provide a summary of the project area characteristics.

Eastern Branch – Military project area's physical characteristics are peninsulas divided by small creeks and inlets that drain into the Eastern Branch of the Elizabeth River. The inlets and Elizabeth River are tidally influenced and susceptible to storm tides. The topography is generally flat, with the exception of the I-64 and I-264 earthen berms, with the regional ground surface sloping south toward the river. The large earthen berms underlying I-64 and I-264 are large topographic features that present prominent, existing hydrologic barriers. Existing storm water infrastructure conveys collected surface run-off to outlets in the river or inlets. Coastal flooding is expected to occur when tidal departures over run the shoreline along the Eastern Branch of the Elizabeth River or back-flow through storm water pipes.

POTENTIAL FLOOD MITIGATION OPTIONS – BROAD CREEK PROJECT AREA

We identified two potential infrastructure projects within the Broad Creek area. The two options considered include:

- Broad Creek Flood Gate Option: Comprised of a flood gate structure across the basin outlet of Broad Creek near the I-264 Bridge.
- Bulkhead Option: Comprised of constructing floodwalls along the shoreline to protect neighborhoods. Elsewhere, includes raising structures where floodwalls are not considered practical.

Broad Creek Flood Gate Option

The Broad Creek watershed drainage basin outlet is located near the I-264 Bridge where the Broad Creek connects to the Eastern Branch of the Elizabeth River. This basin outlet is a location where a floodwall and gate system could be constructed to mitigate storm tides from entering the watershed and inducing flooding. The outlet opening is approximately 1,100 feet wide.

Considering the width of the crossing, the structure would likely consist of a floodwall and gate system. We envision that a wide gate system would be required in order to permit boat access into Broad Creek and minimize flow constriction and impact during tidal flushing or discharge from Broad Creek. For consideration in this study, we have assumed that the gate may be approximately 125 feet wide. Typical gates for wide openings are lift, barge, radial, sector, or hydraulic/pneumatic gates. Considering the width of the opening, water depth, height requirements, relative cost, and viewshed impacts for the Broad Creek project, we have selected a sector gate option as the preferred concept for this area. Vertical axis sector gates operate by closing circular sections supported on a vertical hinge at the center of a circular arc. Sector gates have been installed in Gulf Coast states to protect canals and small rivers from storm surges. Figures 4-12a and 4-12b show examples of sector gates.

We recognize that a structure this large may have potential significant technical, environmental, and funding challenges to overcome. This study has not performed a thorough technical review of various gate types, associated costs, site conditions, or environmental impacts. Thus, we recognize that evaluations of other gate alternatives may identify an alternate preferred concept. Extensive, thorough engineering and environmental analyses will

be required to develop a concept and design that balances optimal protection levels, functionality, cost, and environmental impacts.

The floodwall and gate system option considered herein would cross the mouth of Broad Creek south of the Light Rail and I-264 bridges and tie into high ground near the I-264 (Figure A-2, upper image). The water body crossing is approximately 1,100 feet long. We have assumed that the gate would be approximately 125 feet wide which would be left open to allow boat traffic to enter Broad Creek and tidal flushing and flow to occur.

We have based the cost estimate of this flood wall and gate system on similar structures constructed in the U.S. (e.g. Harvey Canal in New Orleans [Figure 4-12a] and New Orleans Inner Harbor Canal System [Figure 4-12b]). We estimate that the system may cost approximately $112M to design and construct (refer to Tables 1-1 and 1-2). Annual operating and maintenance costs may be between $1M and $2M.

Broad Creek Bulkhead Option

An alternative concept for flood protection in Broad Creek is comprised of constructing a series of floodwalls along the shoreline to protect smaller, flood prone areas. Floodwalls were selected over earthen berm options since the area has extensive residential development along the shoreline and floodwalls would require significantly less easement acquisition (and cost) due to their smaller footprint. We evaluated alignment options throughout the basin compared the floodwall cost relative to benefit in flood damage reduction for a 1-percent annual chance flood event. Several areas along the western shoreline were identified as providing some benefit relative to floodwall cost. Floodwall options along other shoreline areas were ruled out as candidates since they would likely be significantly more expensive relative to their benefit in flood damage reduction.

We also identified eight storm water outfall pipes that may require flap valves to prevent back-flow and flooding behind the floodwalls during storm tides. Figure A-2 shows the locations of the outfall pipes.

For areas not protected by a floodwall, raising structures or dry flood proofing was considered an option. Approximate areas with multiple structures that met the raising criterion (floodwater depth at least 2 feet above the first floor elevation) are delineated in Figure A-2. We note that there may be other isolated houses in the project area that also meet the raising criterion and are not included in the hatched zones on Figure A-2.

Table A-1 lists the infrastructure project elements considered for this option. We estimate that the floodwall (bulkhead) option project cost would be approximately $57.5M. We estimate that it would cost approximately $400k to raise the houses not protected behind the floodwall that meet the structure raising criterion. Refer to Figures 1-3 and 1-4 in the main text of this report for estimated project cost and potential damage reductions.

Table A-1. Broad Creek Bulkhead

Project Elements	Quantities
Flood Wall	12,000 linear ft (typically 4.3 to 8.2 ft above ground)

Project Elements	Quantities
Flood Gate Street Crossings	N/A
Earthen Berm	N/A
Road Raise	N/A
Flap Valves	8
Utility Conflicts	Minimum of 8

POTENTIAL FLOOD MITIGATION OPTIONS – EASTERN BRANCH – MILITARY PROJECT AREA

We identified two flood mitigation options for the Eastern Branch – Military project area. They are:

- Floodwall Option: Comprised of floodwalls in the River Forest West, River Forest Central, and River Forest East areas along the shoreline of the Eastern Branch of the Elizabeth River.
- Floodwall and McGinnis Road Raise Option: Comprised of the same floodwall options as above for the River Forest West and River Forest East areas, and modified floodwall alignment and McGinnis Road raise in the River Forest Central area.

Both options include areas not protected by the proposed infrastructure and may require the raising of structures.

Floodwall Option

The Floodwall Option considered for the Eastern Branch – Military project area is comprised of a floodwall system along the shoreline in the River Forest neighborhoods. There is an area west of Military Highway where raising structures appears to be more cost effective than a floodwall. The floodwalls were broken out into three areas consisting of River Forest East, West, and Central. We also identified a short, low earthern berm that could be constructed at the eastern end of the floodwall in River Forest West, a short section of road raising in River Forest Central. Several low earthern berms or low walls would also be required to extend some of the walls to higher ground to address affects of 1 foot in sea level rise (segments highlighted in yellow on Figure A-3).

Approximately 18 storm water outfalls were identified that may require flap valves to prevent backflow and induce flooding behind the floodwalls.

A floodwall and structure raisings would mitigate most coastal flooding. However there are some structures that would be unprotected and would require dry flood proofing. Figure A-3 (upper image) shows the alignments for Floodwall Option. Tables A-2 through A-5 summarize the approximate quantities of infrastructure elements that would be part of this project. This project cost estimate for current sea level and to account for one foot of sea level rise are approximately $131M and $156M, respectively.

Table A-2. River Forest East

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	3,300 linear ft (typically 3.4 to 7.5 ft above ground)	1,000
Flood Gate Street Crossings	1	N/A
Earthen Berm	N/A	450 linear feet
Road Raise	N/A	N/A
Flap Valves	3	N/A
Utility Conflicts	Minimum of 3	N/A

Table A-3. River Forest Central

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	9,100 linear ft (typically 5.0 to 8.7 ft above ground)	1,000
Flood Gate Street Crossings	N/A	N/A
Earthen Berm	N/A	N/A
Road Raise	630 linear ft	N/A
Flap Valves	7	N/A
Utility Conflicts	Minimum of 11	N/A

Table A-4. River Forest West

Project Elements	Quantities
Flood Wall	10,200 linear ft (typically 4.6 to 8.1 ft above ground)
Flood Gate Street Crossings	N/A
Earthen Berm	600 linear ft
Road Raise	N/A
Flap Valves	8
Utility Conflicts	Minimum of 17

Floodwall and McGinnis Road Raise Option

An alternate project option is considered that includes a variation the floodwall option in the River Forest Central area. In that area, we consider raising McGinnis Road to provide

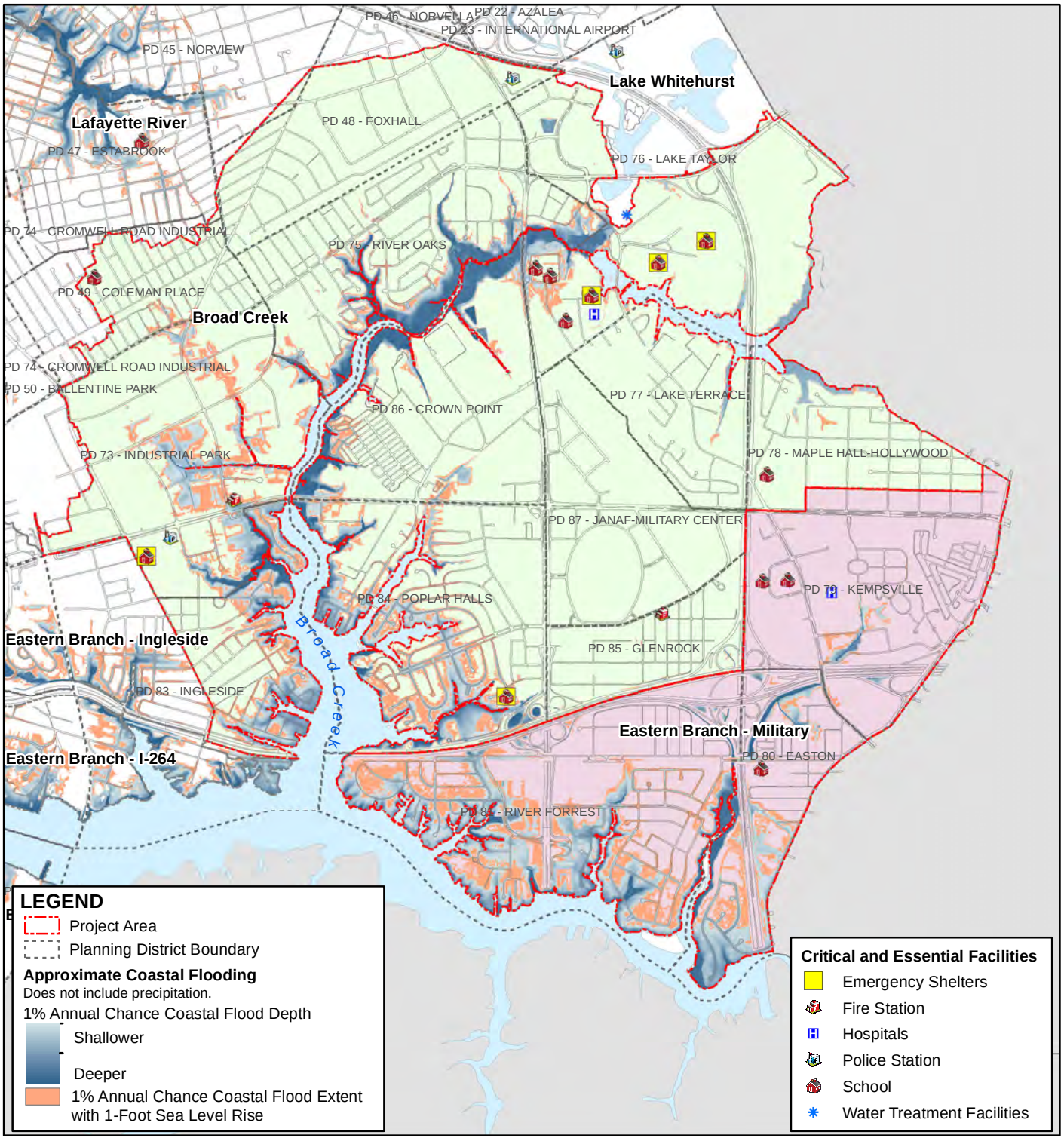
protection on the interior area of the road. Houses susceptible to flooding on the exterior of the road would either require raising or flood proofing. This project option includes the same floodwall options for the River Forest West and East areas and structure raising west of Military Highway as the other alternative (Tables A-2 and A-4). Table A-5 lists the estimated quantities required to raise McGinnis Road and construct the floodwall in the River Forest Central area. Figure A-3 (lower map) shows the proposed locations of the project elements.

Table A-2 through A-5 list the infrastructure project options considered for the River Forest Central area. Refer to Table 1-1 and 1-2 in the main text of this report for estimated project cost and potential damage reductions.

The estimate project cost for this option based on current sea level conditions and to address the affects of one foot of sea level rise are approximately $108.6M and $139.5M, respectively. The project cost estimates and potential damage reductions are also summarized in Figures 1-3 and 1-4.

Table A-5. River Forest Central – McGinnis Option

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	4,120 linear ft (typically 6.3 to 9.1 ft above ground)	1,000
Flood Gate Street Crossings	N/A	N/A
Earthen Berm	N/A	N/A
Road Raise	1,600 linear ft	2,100 linear ft
Flap Valves	N/A	N/A
Utility Conflicts	N/A	N/A



BROAD CREEK AND EASTERN BRANCH - MILITARY PROJECT AREAS

City-wide Coastal Flooding Study
Norfolk, Virginia

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FIGURE A-1

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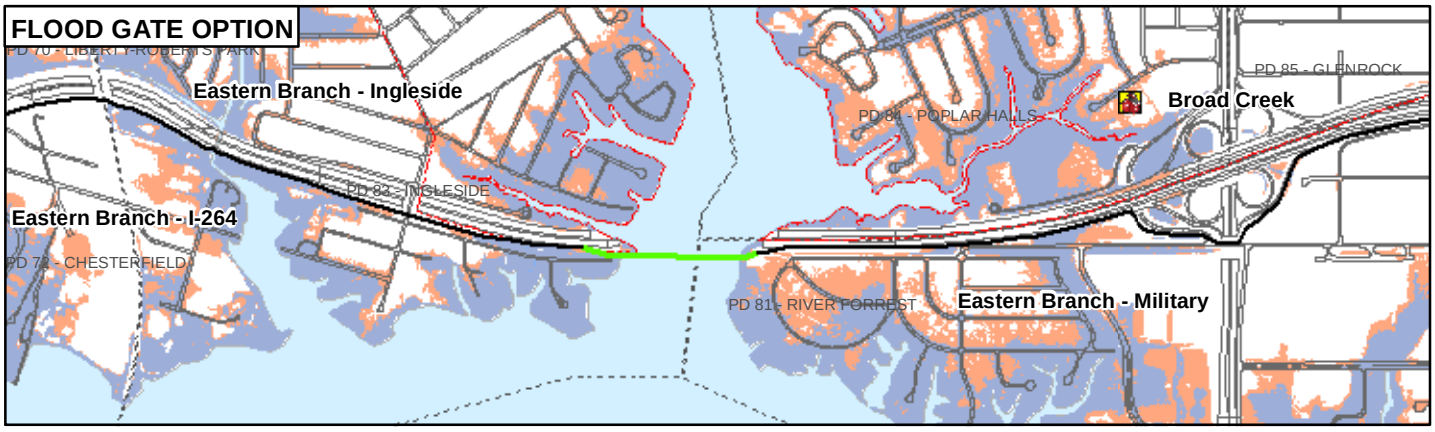

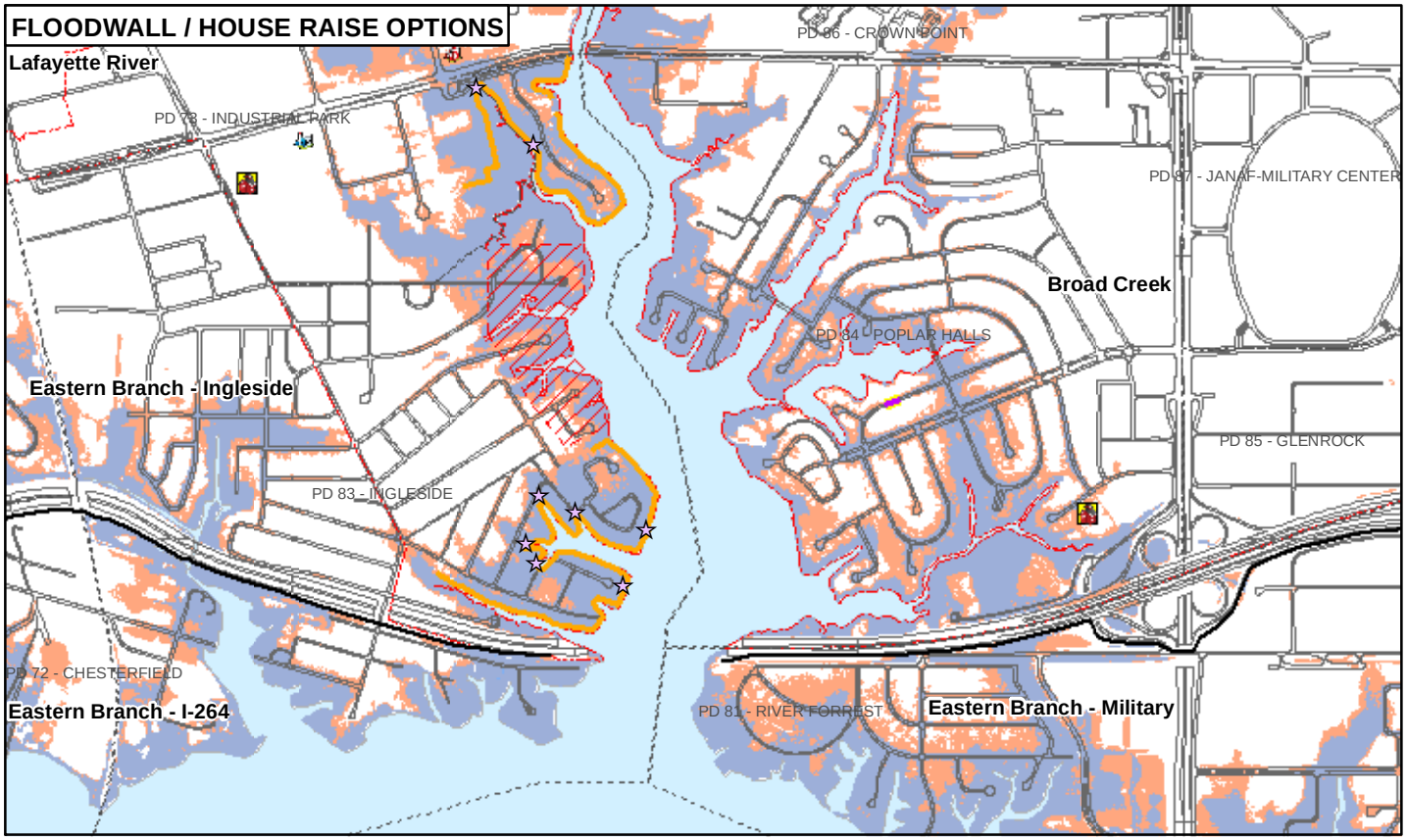

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
Broad Creek Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE A-2

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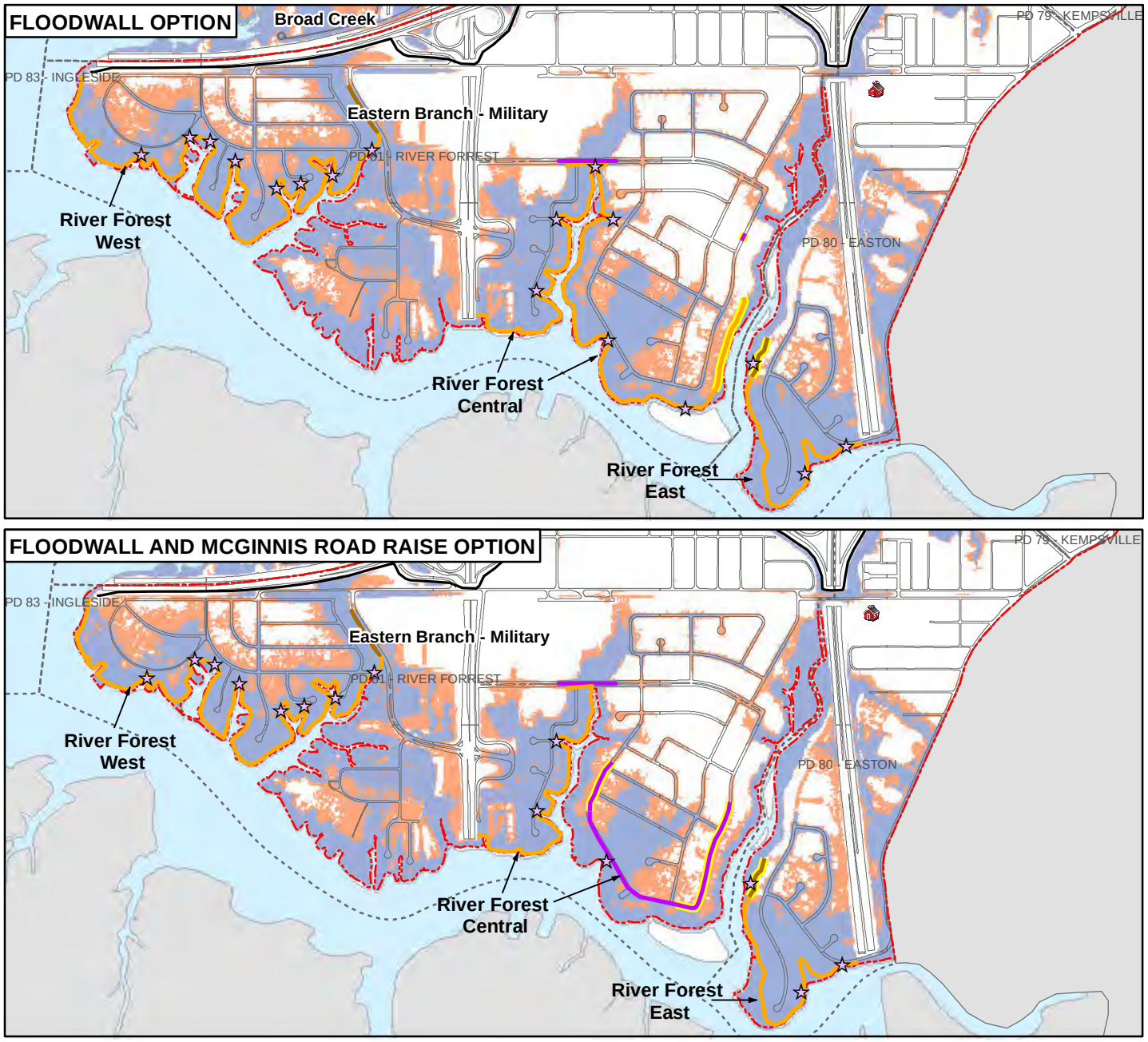

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
Eastern Branch - Military Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE A-3

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APPENDIX B

EASTERN BRANCH – INGLESIDE, EASTERN BRANCH – I-264, AND OHIO CREEK PROJECT AREAS

EASTERN BRANCH – INGLESIDE, EASTERN BRANCH – I-264, AND OHIO CREEK PROJECT AREAS

This appendix describes three separate project areas located along the Eastern Branch of the Elizabeth River including:

- Eastern Branch – Ingleside project area,
- Eastern Branch – I-264 project area, and
- Ohio Creek project area.

EASTERN BRANCH – INGLESIDE PROJECT AREA

The Eastern Branch – Ingleside project area is located in the southern portion of the City. The project area is bordered to the east by the Broad Creek project area, north by the Lafayette project area, west by Ohio Creek project area, and the south by Interstate (I) 264 and the Eastern Branch of the Elizabeth River. Figure B-1 shows the Eastern Branch - Ingleside project area.

There are 979 parcels within the 456 acres of the project area. The project area consists of 871 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $166M. Most of the project area is residential with some commercial and light industrial usage along the main roads. Figures 1-3a and 1-5 through 1-7 summarize the characteristics of the project area.

The project area is a small basin located west of the Broad Creek watershed that drains into the Eastern Branch of the Elizabeth River. The topography is generally flat with the regional ground surface sloping south to the river. Storm water infrastructure collects surface run-off and conveys it to a large culvert beneath the I-264. The basin outlet is through this culvert where it discharges into the Elizabeth River. Numerous flood claims have been filed through the National Flood Insurance Program and several are considered to be repetitive loss claims.

EASTERN BRANCH – I-264 PROJECT AREA

The Eastern Branch – I-264 project area is a narrow strip of land between I-264 and the Eastern Branch of the Elizabeth River in the southern portion of the City. The project areas northern boundary is Interstate 264 and the southern boundary is the Eastern Branch of the Elizabeth River. Figure B-1 shows the Eastern Branch – I-264 project area.

There are 1,210 parcels within the 553 acres of Eastern Branch – I-264 project area. The project area consists of 599 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $138M. Most of the land use is industrial and commercial with some residential use. Figures 1-3a and 1-5 through 1-7 summarize the characteristics of the project area.

Eastern Branch – I-264 project area is mostly low-lying and contains numerous small creeks and inlets that drain southward into the Elizabeth River. Coastal flooding stems from tidal surges of the Elizabeth River that breach the shoreline. The topography is generally flat with the regional ground surface sloping to the south into the river. Historically reported flood

claims have been relatively low to moderate. A few repetitive claims have been located in this project area.

OHIO CREEK PROJECT AREA

The Ohio Creek project area is located in the southern portion of the City north of I-264. The project area is bordered to the north by the Lafayette River project area, to the east by the Eastern Branch – Ingleside project area, to the south by I-264, and to the west by the Tidewater project area. Figure B-1 shows the Ohio Creek project area.

There are 720 parcels within the 275 acres in the project area. The project area consists of 527 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $254M. Most of the project area is residential; however, the project area includes Norfolk State University and Booker T. Washington High School. Figures 1-3a and 1-5 through 1-7 summarize the characteristics of the project area.

Ohio Creek project area is connected to the Eastern Branch of the Elizabeth River by a large culvert under I-264. The topography is generally flat with a low-lying area in the middle of the project area where Park Street and Virginia Beach Boulevard intersect. This area has experienced moderate to severe flood claims and several are considered to be repetitive loss.

POTENTIAL FLOOD MITIGATION OPTIONS

Eastern Branch – Ingleside Project Area

The basin outlet to the Eastern Branch of the Elizabeth River is through a culvert beneath the I-264. Therefore, the flood mitigation option is a tide gate on the outfall to prevent storm surge back-flow through the culvert. However, when the gate is closed during a rainfall event, water will not be able to discharge from the outfall and may collect in the bowl shaped basin and cause flooding. Therefore, a pump station will be required to discharge the rainwater that collects in the basin when the gate is closed. Preliminary estimates indicate a 60-inch diameter impeller pump will be needed for this area. Further hydrologic and hydraulic analyses would be needed to refine this estimate. Figure B-2 shows the potential flood mitigation options the Eastern Branch – Ingleside project area.

We estimate that it will cost approximately $17M for the planning, design, construction, maintenance, and operation of the project. Refer to Figure 1-3a for estimated project cost and potential damage reductions.

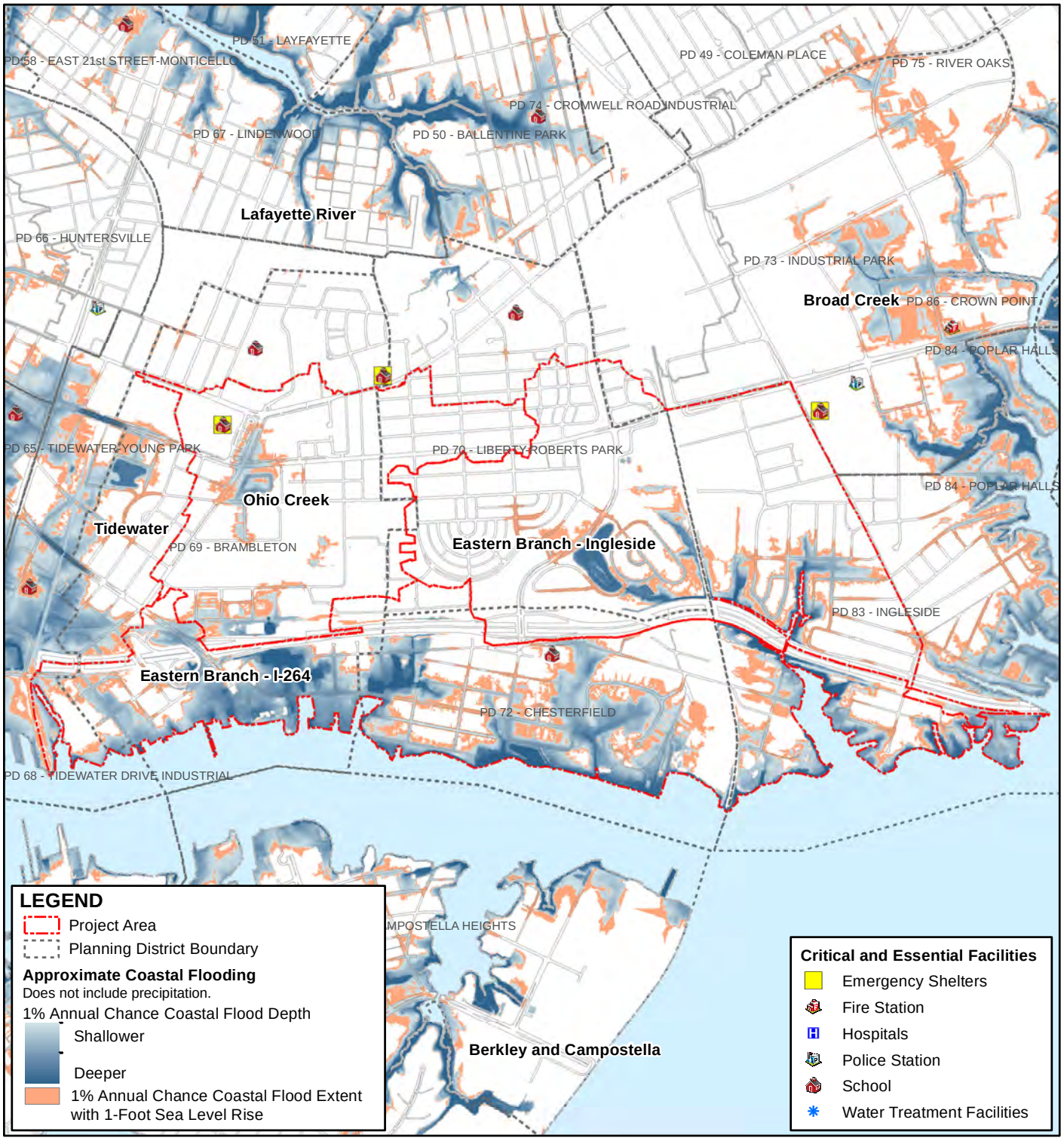
Eastern Branch – I-264 Project Area

The primary flood mitigation options considered for the Eastern Branch – I-264 project area are house raising and flood proofing of structures. Figure B-3 shows the area where multiple structures met the raising criterion. We note that several isolated structures outside the hachured area shown on Figure B-3 also meet the structure raising criterion. We estimate that it will cost approximately $1.7M to raise structures above the one percent annual chance flood level (including one foot above the flood water elevation). We estimate that it would cost approximately 70 percent more or $3.0M to raise structures for a one percent annual chance event if accounting for one foot in sea level rise.

Ohio Creek Project Area

The Ohio Creek project area has an existing tide gate that is closed during storm tide events. However, there is a topographic bowl-shaped depression near the center of the project area that experiences severe flooding during rain events. The bowl-shaped depression is highlighted by the predicted flood extent shown in Figure B-4. Figure B-4 shows the predicted flooding that would occur during a storm tide only event of the tide gate was not closed. Figure 2-3b shows the predicted peak flood extent that would occur during a simulated 24-hour, one percent annual chance precipitation event if the tide gate was closed. The simulated flood extent shown in Figure 2-3b illustrates the need for an improvement of the flood defense system in this project area.

The primary flood mitigation options considered in the Ohio Creek project area include a pump station, culvert, and buy-out of properties with repetitive losses in the Spartan Village area. This mitigation approach for this project area was evaluated in 2010 by the Timmons Group and Fugro (Timmons, 2010) plans for a phased approach to improve the flood defense system. The initial phase is comprised of buying out flood prone properties (e.g. properties with repetitive loss flood damage claims). Subsequent phases include adding a new pump station to discharge rainwater collected in the basin and upgrading to a larger diameter storm water pipe. Figure B-4 shows the proposed alignment of the culvert running under Norfolk State University, the location of the pump station, and the Spartan Village buyout area. The estimated cost for the Ohio Creek project is approximately $20.7M (Timmons, 2010).



EASTERN BRANCH - INGLESIDE, EASTERN BRANCH - I-264, AND OHIO CREEK PROJECT AREAS

City-wide Coastal Flooding Study
Norfolk, Virginia

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FIGURE B-1

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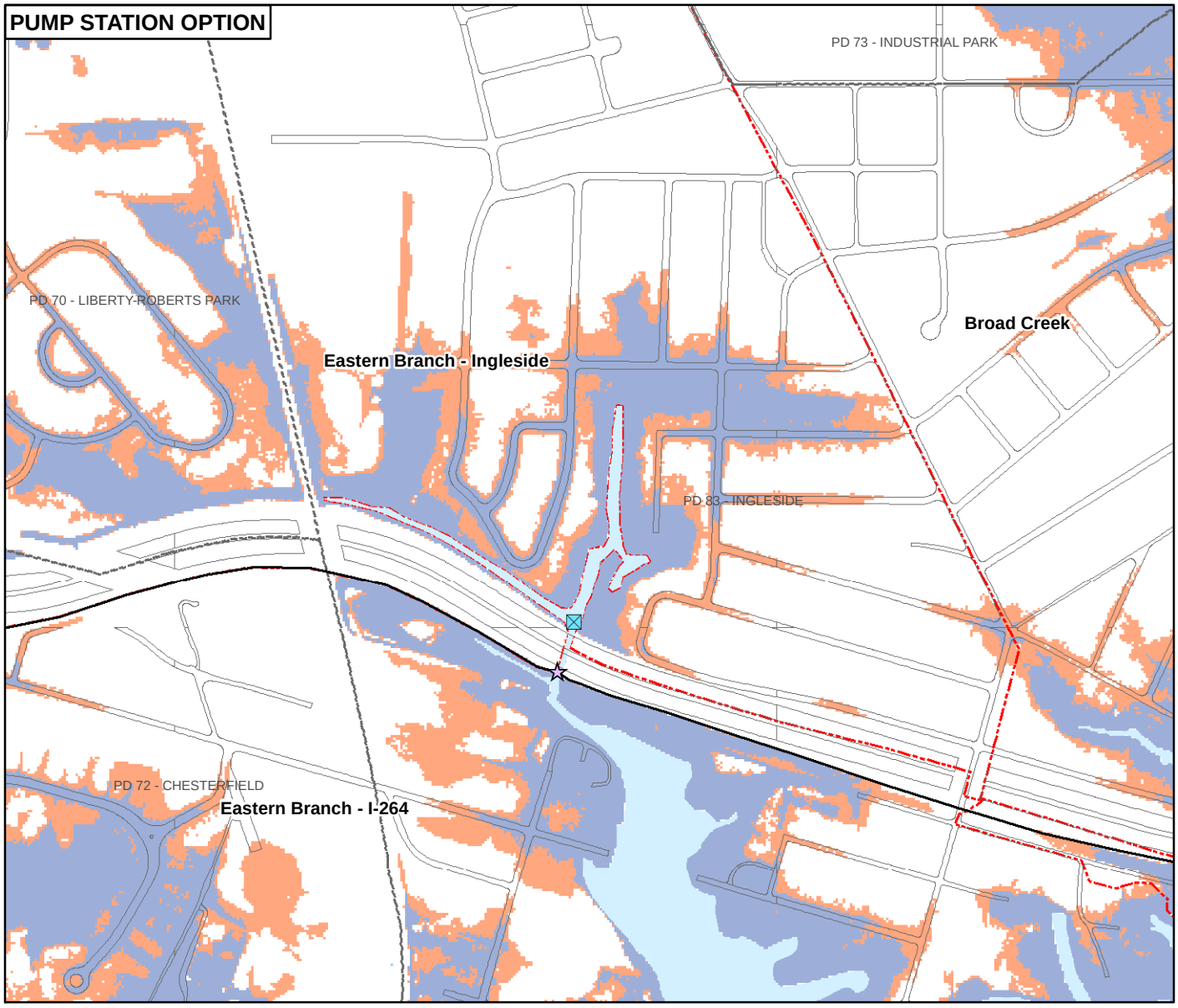

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTION
Eastern Branch - Ingleside Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE B-2

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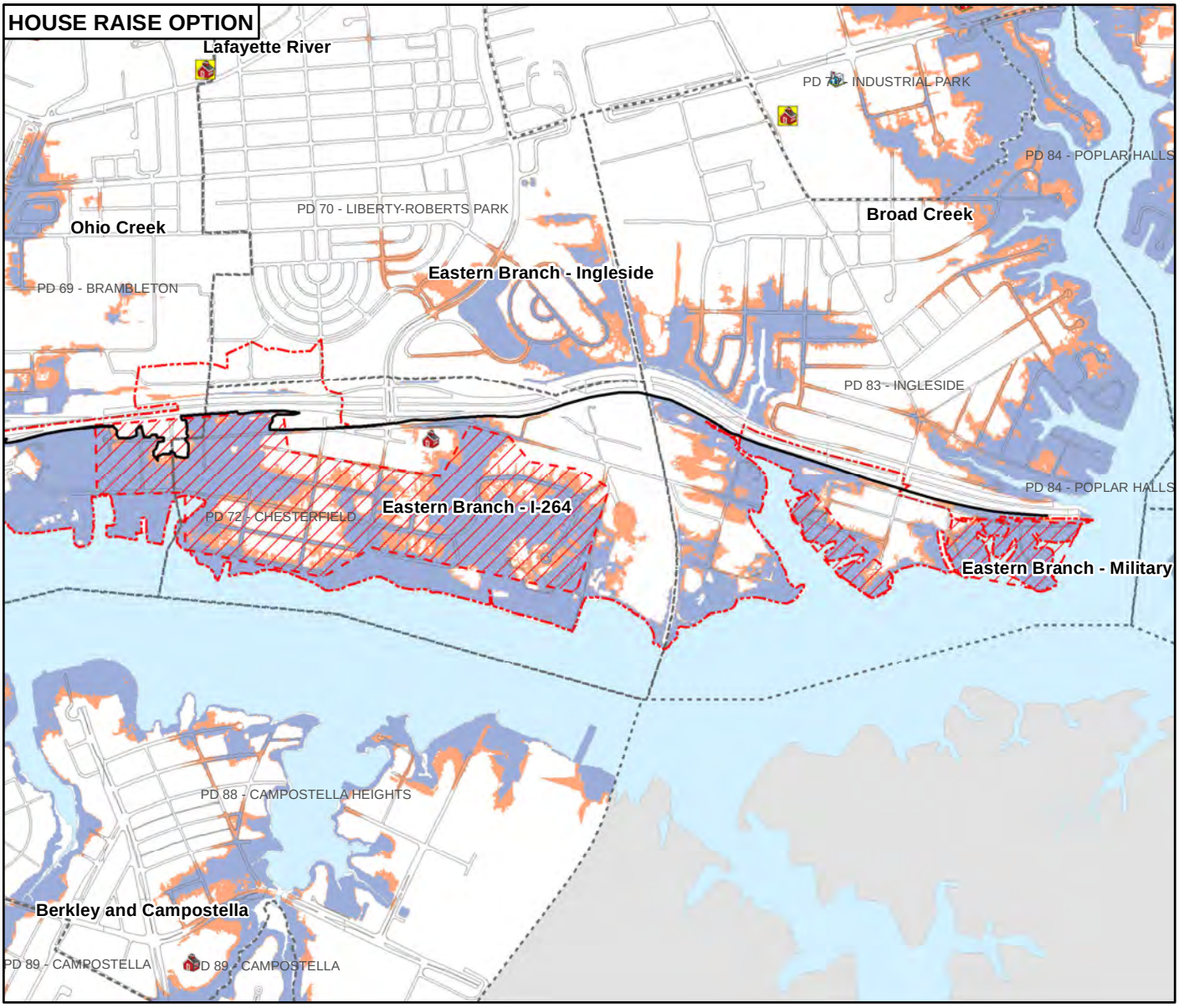

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTION
Eastern Branch - I-264 Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE B-3

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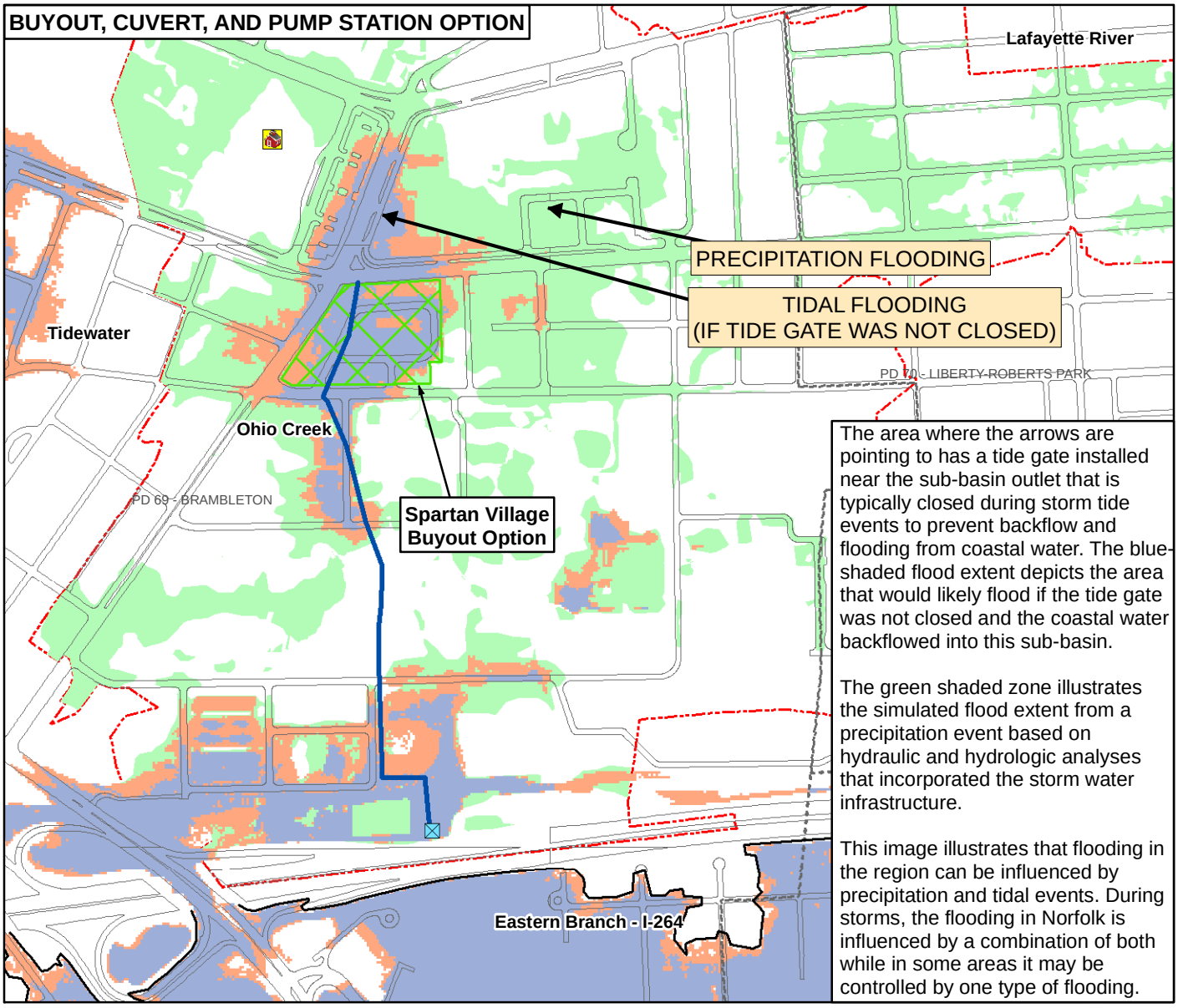

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Approximate Precipitation Flooding
Does not include tidal flooding.

- 1% Annual Chance Precipitation Extent
  Represents peak flood during simulated 24-hr storm.

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTION
Ohio Creek Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE B-4

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APPENDIX C

TIDEWATER PROJECT AREA

TIDEWATER PROJECT AREA

The Tidewater project area is elongated in the north-south direction and is centered on Tidewater Boulevard in the southern portion of the City. The project area is bordered by the Lafayette River project area to the north, Ohio Creek project area to the east, the Downtown project area to the west, and the Eastern Branch of the Elizabeth River to the south. Figure C-1 shows the Tidewater project area.

There are 828 parcels within the 520 acres of the Tidewater project area. The project area consists of 334 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $257M. The project area includes the Harbor Park baseball stadium, the future intermodal yard and Amtrak station, and a section of the Light Rail.

The Tidewater project area has bulkhead along most of the shoreline of the Eastern Branch of the Elizabeth River. The project area is very flat and generally low-lying. Storm water infrastructure system collects rain water and conveys it southward to outfalls near the Harbor Park stadium where the water discharges into the Eastern Branch of the Elizabeth River. The basin outlet area is transected by the I-264 earthen berm system.

POTENTIAL FLOOD MITIGATION OPTIONS

Three alignment options for an overland flood barrier system were considered for this project area. The overland flood barrier system is comprised of floodwalls, earthen berms, and/or flood gates at street crossings where necessary.

Harbor Park Alignment Option

The Harbor Park option primarily consists of either a floodwall or earthen berm along the shoreline of the river. The estimated costs for the floodwall and earthen berm are similar. The earthen berm option may have attributes that make it a more attractive option than a floodwall. For example, earthen berms can be constructed such that a walking/jogging and bike path is created along the top of the berm. This may be considered an enhancement to future development in the area. Other cities have developed bike and walking/jogging paths along waterfront areas that are highly popular and have become icons for cities. Such an enhancement may compliment redevelopment efforts near the Harbor Park stadium, future Amtrak station/multimodal yard, Light Rail area, Waterside, and tie into Town Point Park.

Figure C-2 shows the Harbor Park alignment option in the bottom panel. Table C-1 lists the project elements. As previously indicated, the preliminary cost estimates for a floodwall and earthen berm are similar. For earthen berm options, we compared the cost for a berm with a five-foot wide crest and 10-foot wide crest. The estimated costs for the three options in order of increasing costs under the existing sea level conditions are:

- $16.4M – Earthen berm with 5-foot wide crest,
- $17.6M – Floodwall, and
- $18.1M – Earthen berm with 10-foot wide crest.

Although the earthen berm with a 10-foot wide crest is slightly more expensive, this concept may offer significant value over the other options in terms of providing enhanced use to the area if a the top can provide an alternate use like a walking/jogging path.

Refer to Figures 1-3b and 1-4b for estimated project cost and potential damage reductions. Although the Harbor Park option is estimated to cost more than the other two alignment options, it will be technically less challenging (does not require gate closures of roads and railroad), not require coordination with the railroad company to operate a gate system, and may provide significant additional benefit other than flood hazard mitigation. Moreover, project costs could be offset if integrated into a redevelopment project.

Table C-1. Harbor Park Alignment Option

Project Elements	Quantities
Flood Wall or Earthen Berm	3,150 linear ft (typically 3.8 to 7.8 ft above ground)
Flood Gate Street Crossings	N/A
Road Raise	N/A
Flap Valves	2
Utility Conflicts	Minimum of 10

Holt Street Alignment Option

The Holt Street alignment option primarily consists of a flood wall adjacent to Holt Street that ties into high ground below the I-264. A gate system will be needed at Holt Street and at the railroad crossing. Gate closures for railroads are technically more difficult but are possible. However, additional coordination with the railroad company will be required to operate the gate closure of the railroad and the railroad company will need to be agreeable to allow a closure over their property. A short, low earthen berm will also be necessary beneath a section of the I-264 overpass. This project is estimated to cost approximately $9.6M and is the lower cost of the three alignments. Table C-2 lists the project elements. Figure C-2 shows the Holt Street option in the center panel. Refer to Figure 1-3a and 1-4a for estimated project cost and potential damage reductions.

Table C-2. Holt Street Alignment Option

Project Elements	Quantities
Flood Wall	750 linear ft (typically 3.3 to 7.8 ft above ground)
Flood Gate Street Crossings	2
Earthen Berm	200 linear ft
Road Raise	N/A
Flap Valves	2
Utility Conflicts	Minimum of 4

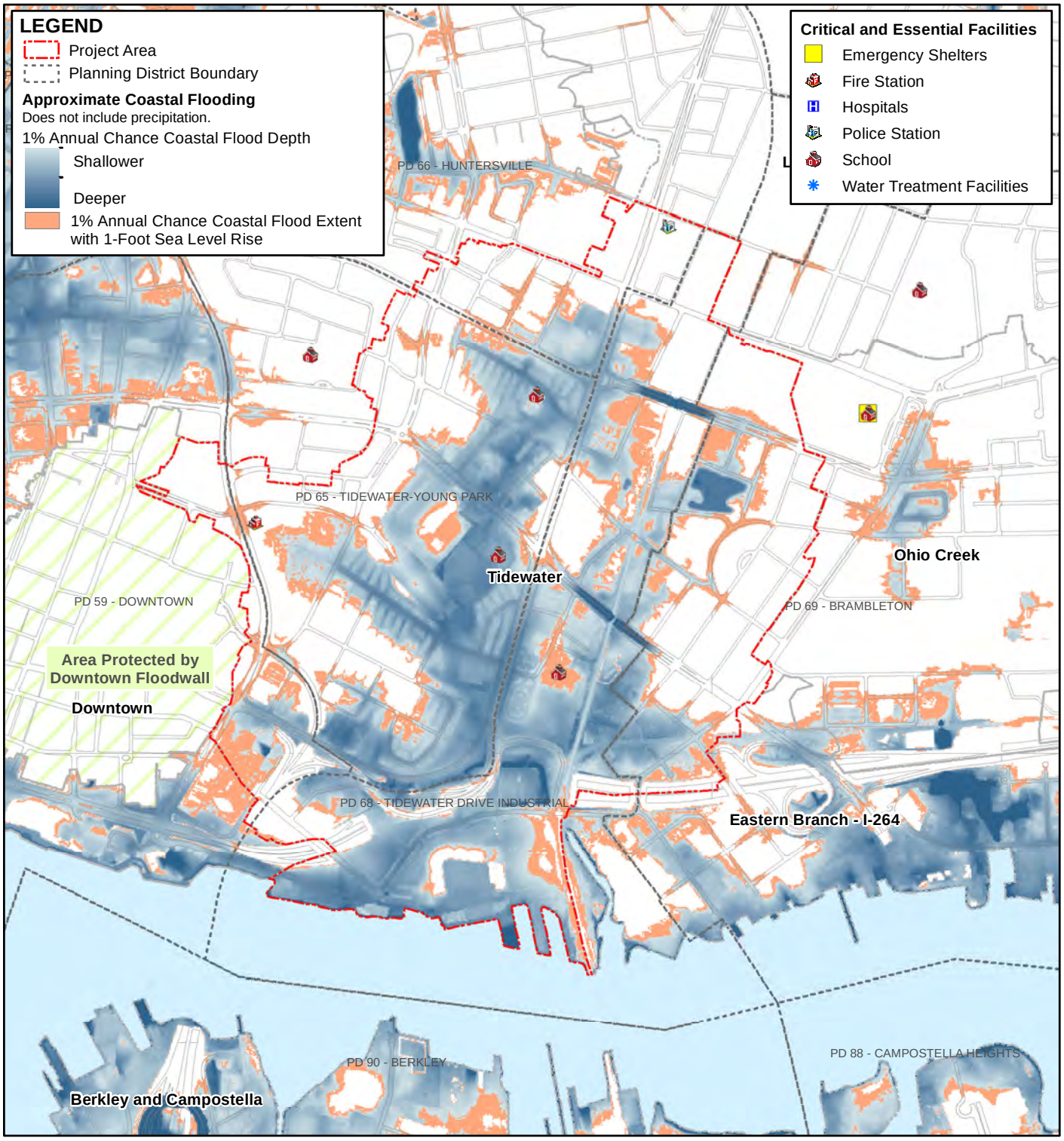
I-264 Underpass Alignment Option

The I-264 Underpass alignment option also consists of a floodwall and gate system that ties into the high ground beneath I-264. A gate system will be required for Holt Street crossing and the railroad. As described in the Holt Street alignment option, gate closures for railroads are technically more difficult but are possible. However, additional coordination with the railroad company will be required to operate the gate closure of the railroad and the railroad company will need to be agreeable to allow a closure over their property. The estimate project cost for this alignment is $11.4M. Project elements are summarized in Table C-1. Figure C-2 shows

the I-264 project alignment option in the upper panel. Refer to Figures 1-3a and 1-4a for estimated project cost and potential damage reductions.

Table C-3. Interstate 264 Underpass Alignment Option

Project Elements	Quantities
Flood Wall	1,600 linear ft (typically 2.3 to 6.5 ft above ground)
Flood Gate Street Crossings	2
Earthen Berm	N/A
Road Raise	N/A
Flap Valves	1
Utility Conflicts	Minimum of 3



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TIDEWATER PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE C-1

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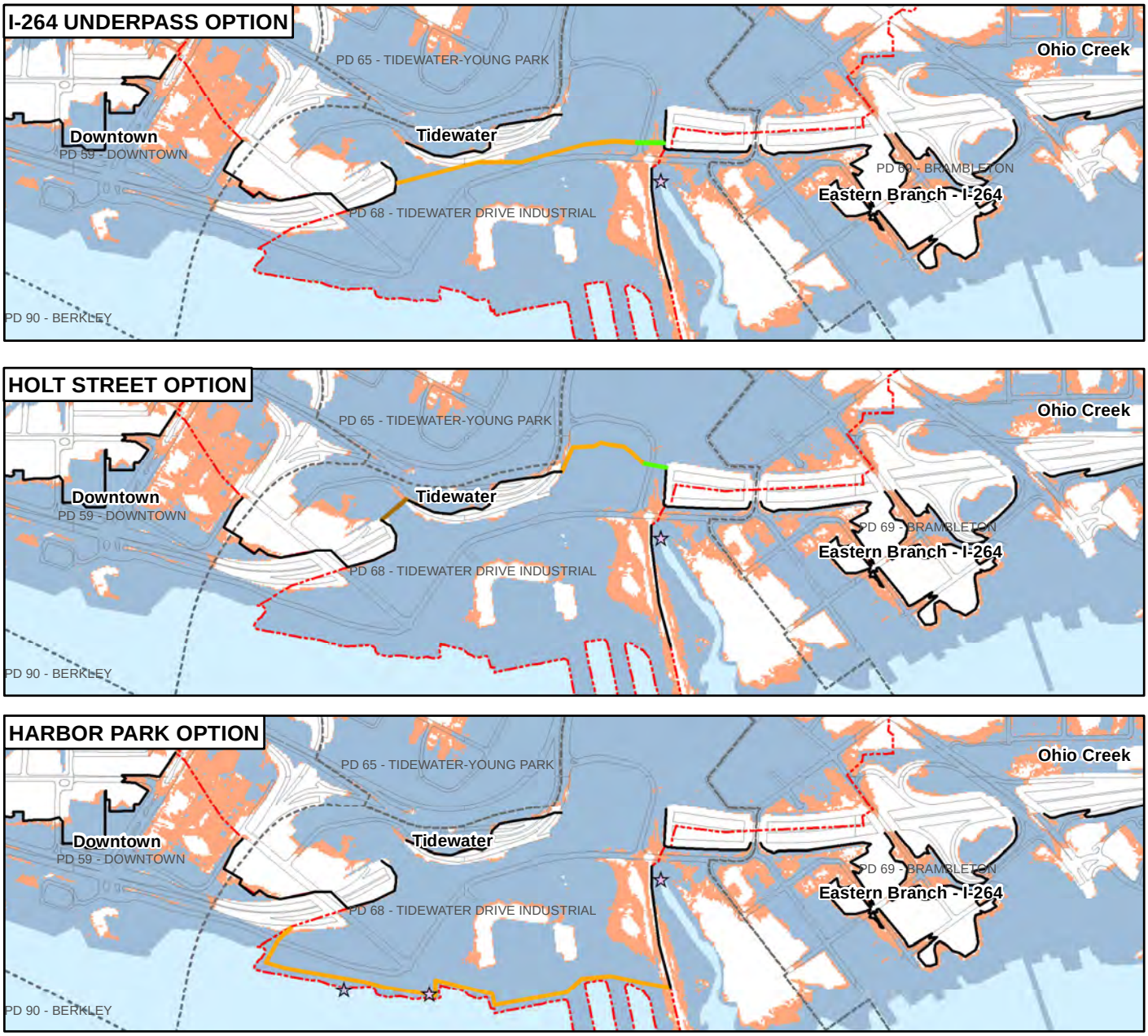

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
Tidewater Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE C-2

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APPENDIX D

DOWNTOWN PROJECT AREA

DOWNTOWN PROJECT AREA

The Downtown project area is in the southern portion of the City along the Elizabeth River. The project area is bordered by the Hague project area to the north, the Tidewater project area to the east, and the Elizabeth River to the south. Figure D-1 shows the location of Downtown project area.

There are 260 parcels within the 136 acres of Downtown project area. The project area consists of 92 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $842M. The project area also includes the Downtown Norfolk Business District and several City of Norfolk municipal buildings (i.e. City Hall).

The Downtown project area has bulkhead along most of the shoreline of the Eastern Branch of the Elizabeth River. The existing Downtown Floodwall protects the majority of the project area from coastal flooding. Several buildings are located outside the protection of the existing floodwall. Those buildings include a hotel, restaurants, the Nauticus, apartment buildings, condominiums, and several miscellaneous structures.

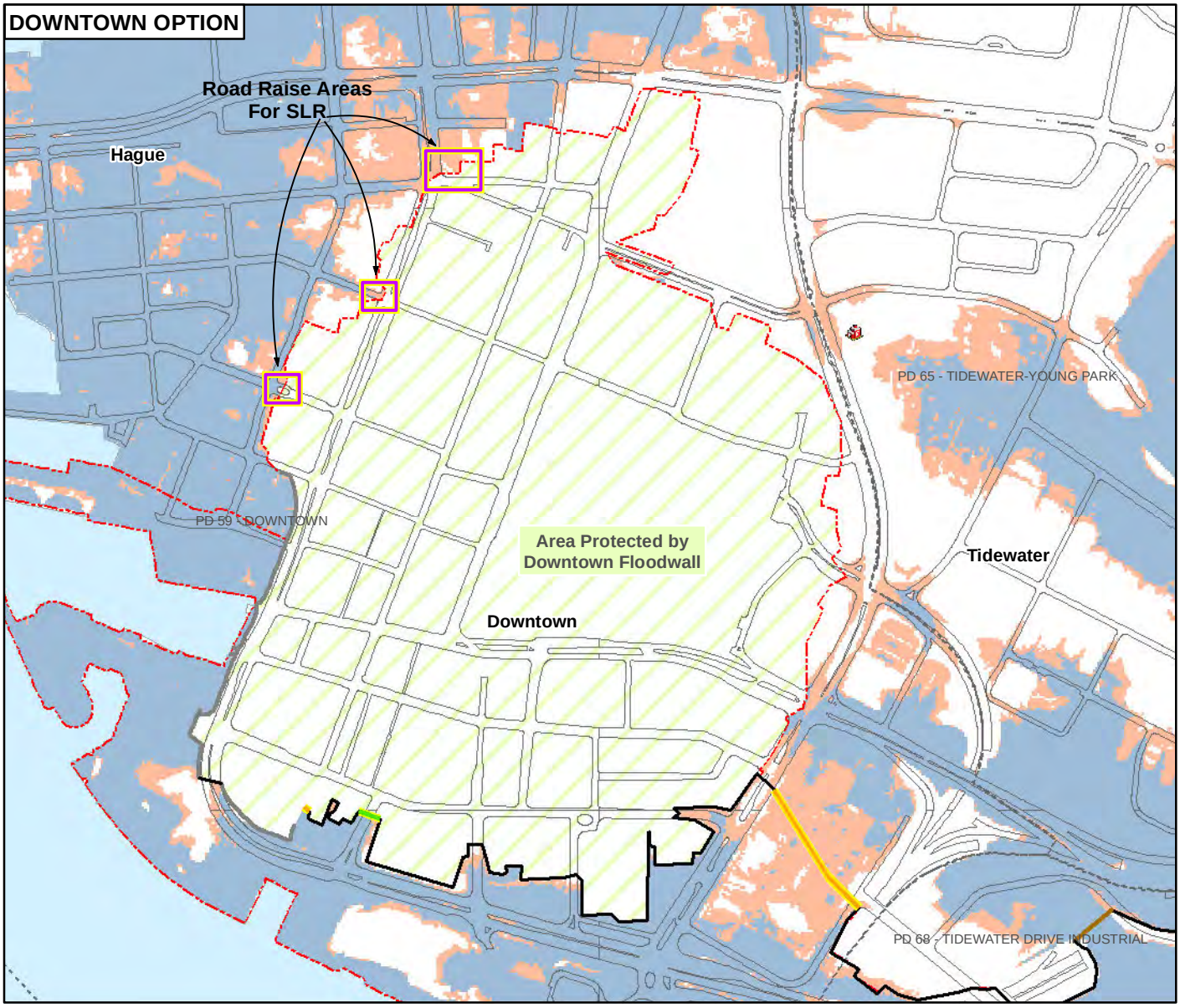
POTENTIAL FLOOD MITIGATION OPTIONS

The existing floodwall protects most of this area and the first floor elevations of most structures outside the floodwall are inferred to be at an adequate elevation to avoid flood damage during. The project options considered for this project area are relatively small and consist of a series of low road grade raises, berms and a flood gate at Martins Lane to mitigate flooding of a 1% annual chance event after one foot of sea level rise. Those small improvements may be required to prevent overland flow into the downtown area after sea level rise during a 1% annual chance event.

Figure D-2 shows the potential project options for the Downtown project area. The improvements are estimated to cost approximately $4.4M. Table D-1 lists the project elements. Refer to Figures 1-3a and 1-4a for estimated project costs and potential damage reductions.

Table D-1. Downtown Project Area

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	N/A	700 linear ft (typically 1.2 to 2.0 ft above ground)
Flood Gate Street Crossings	N/A	1
Earthen Berm	N/A	N/A
Road Raise	N/A	3 raised cross walks
Flap Valves	N/A	N/A
Utility Conflicts	N/A	Minimum of 10



LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTION
Downtown Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE D-2

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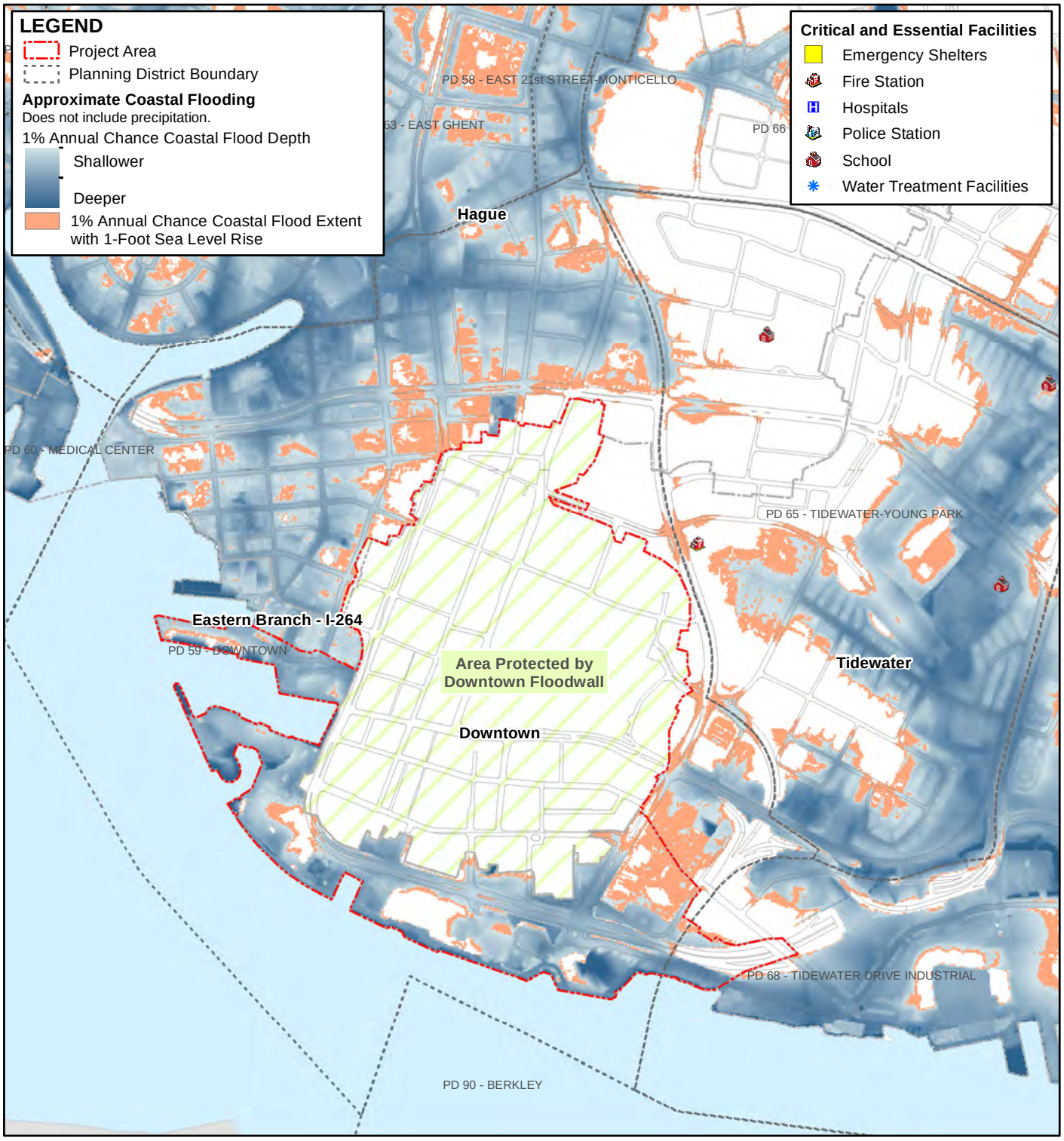

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DOWNTOWN PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE D-1

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APPENDIX E

BERKLEY AND CAMPOSTELLA PROJECT AREA

BERKLEY AND CAMPOSTELLA PROJECT AREA

The Berkley and Campostella project area is located in the southernmost portion of the City on the south side of the Elizabeth River. The project area is bordered by the City of Chesapeake to the south and east. The Eastern and Southern Branches of the Elizabeth River border the project area on the north and west. Figure E-1 shows the Berkley and Campostella project area.

There are 3,272 parcels within the 1,340 acres of project area. The Berkley and Campostella project area consists of 1,710 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $270M. The project area contains several ship yards, industrial areas, and residential neighborhoods along the river front areas.

The project area has bulkhead along a significant portion of the shoreline, however, there are a few small creeks with low lying flat topography surrounding them that flow into the Eastern Branch of the Elizabeth River. Surface drainage is generally to the north toward the Eastern Branch of the Elizabeth River.

POTENTIAL FLOOD MITIGATION OPTIONS

There are two infrastructure project options considered for this project area. The primary structure in both options is a floodwall with overland flood gates at street crossings and road raises. The infrastructure options are located in the Berkley planning district. Several isolated structures met criterion for raising. Numerous structures may benefit from flood proofing.

Clifton Option

The Clifton option consists of a flood wall (with gates at street crossings) on both the east and west sides of the Berkley area. Raising Berkley Avenue is part of the options as well. A pump station will likely be required on the eastern wall to limit flooding due to precipitation. Additional road raising will be needed for one foot of sea level rise. Table E-1 lists the project elements and Figure E-2 shows the Clifton option in the upper panel. The Clifton option is estimated to cost approximately $19.5M and is less than South Main option. Refer to Figures 1-3a and 1-4a for the estimated project cost and potential damage reductions.

Table E-1. Clifton Option

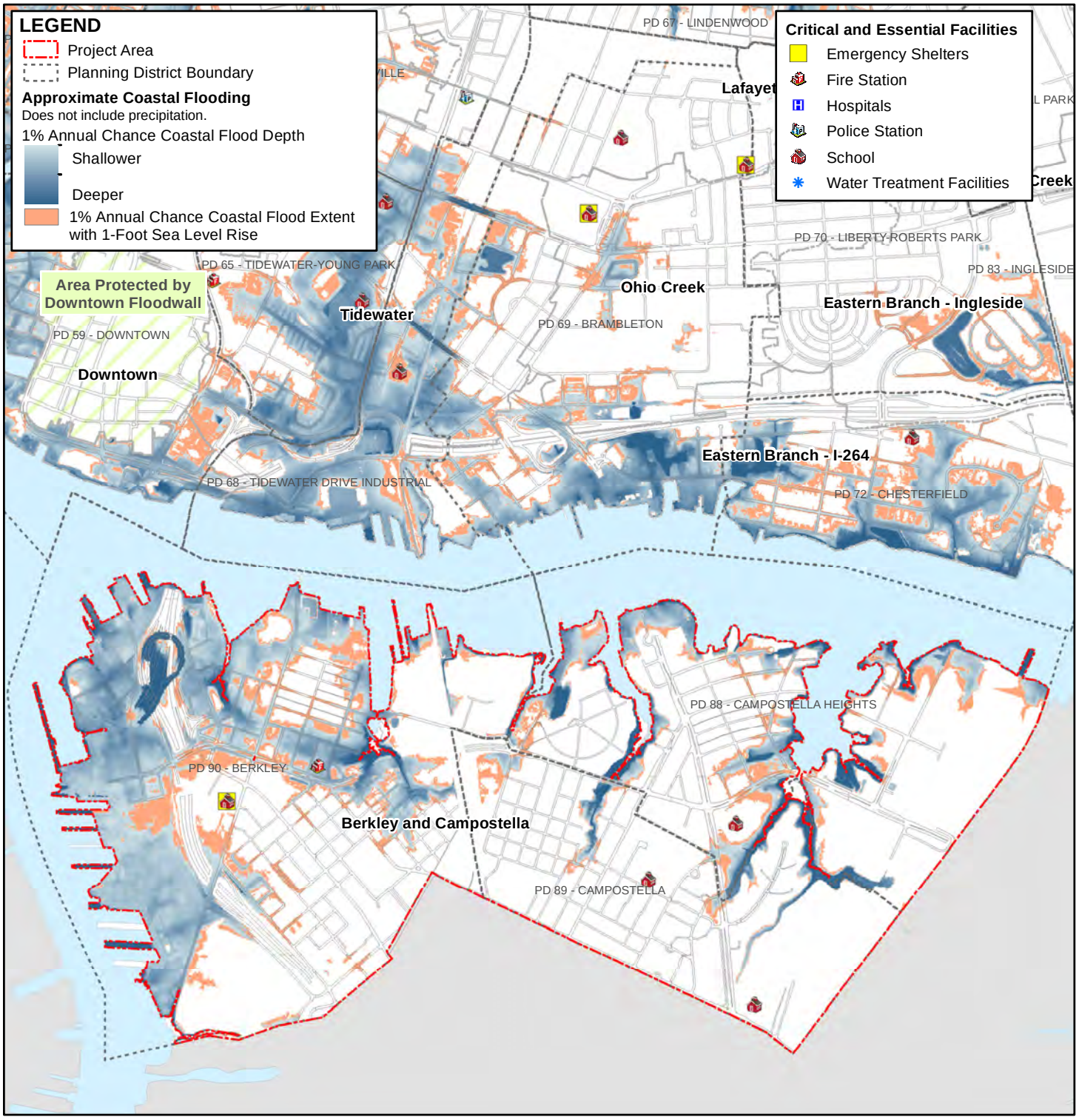
Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	1,500 linear ft (typically 2.2 to 6.2 ft above ground)	N/A
Flood Gate Street Crossings	3	N/A
Earthen Berm	N/A	N/A
Road Raise	2,100 linear ft	400 linear feet
Flap Valves	1	N/A
Utility Conflicts	Minimum of 25	N/A

South Main Option

The South option consists of a flood wall (with gates at street crossings) on both the east and west sides of the Berkley area. Raising South Main Street is part of the option as well. A pump station will likely be required on the eastern wall to limit flooding do to precipitation. Additional road raising will be needed for one foot of sea level rise. Table E-2 lists the project elements and Figure E-2 shows the Clifton option in the lower panel. The cost estimate for this project option is approximately $30.9M. Refer to Figures 1-3a and 1-3b for estimated project cost and potential damage reductions.

Table E-2. South Main Option

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	6,450 linear ft (typically 2.2 to 6.6 ft above ground)	N/A
Flood Gate Street Crossings	1	N/A
Earthen Berm	N/A	N/A
Road Raise	1,200 linear ft	300 linear feet
Flap Valves	1	N/A
Utility Conflicts	Minimum of 20	N/A



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BERKLEY AND CAMPOSTELLA PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE E-1

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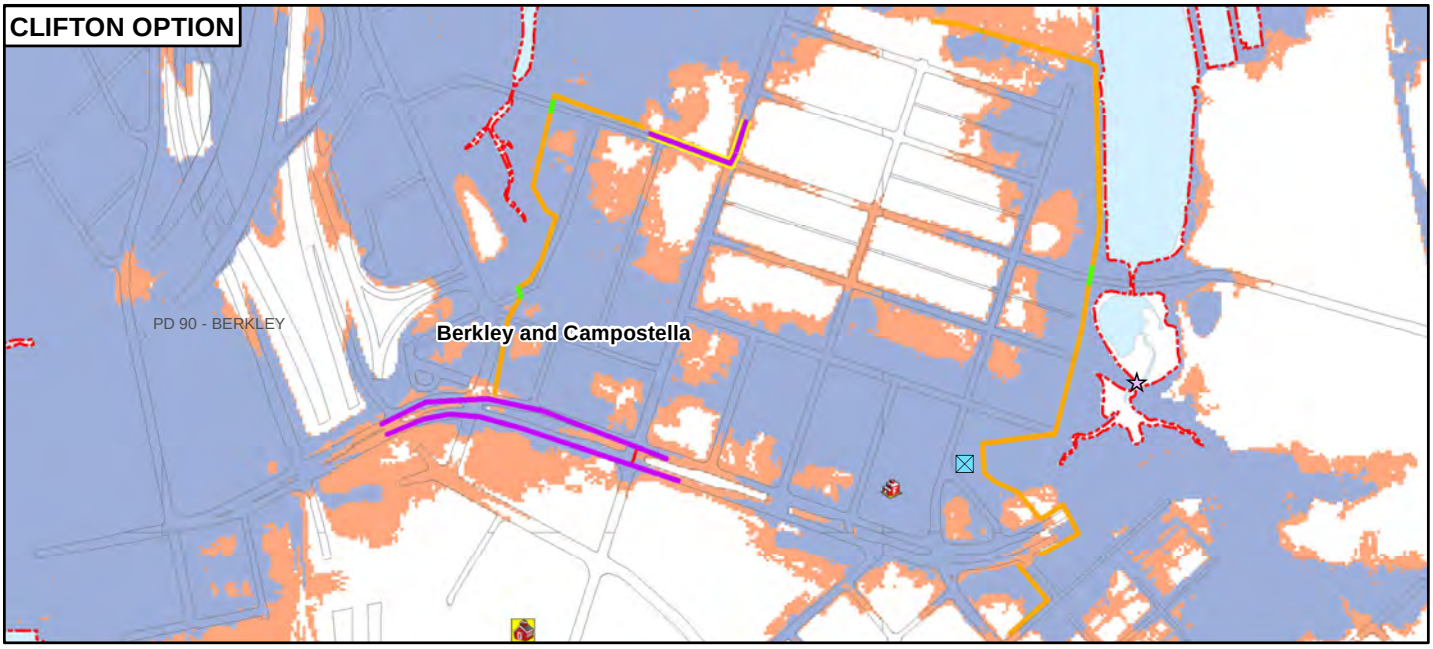

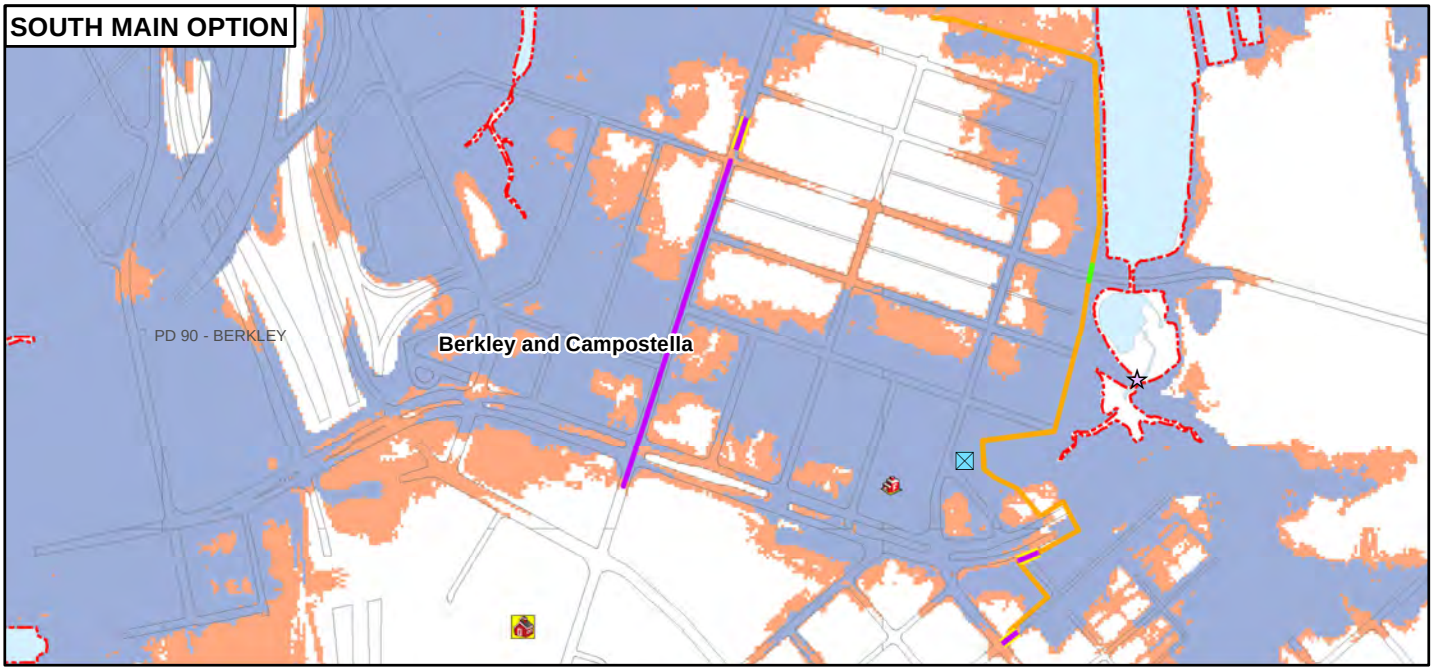

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
Berkley and Campostella Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE E-2

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APPENDIX F

THE HAGUE PROJECT AREA

THE HAGUE PROJECT AREA

The Hague project area is in the southwestern portion of the City. The project area is bordered by the Downtown project area to south and the West Ghent project area to the west. The Lafayette project area borders the Hague to the northeast. Figure F-1 shows the location of the Hague project area.

There are 2,437 parcels within the 971 acres of the Hague project area. The project area consists of 1,564 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $1.1B.

The Hague project area has bulkhead along most of the shoreline of the Hague cove (formally Smith Creek) and the Freemason Historic District. The watershed is bifurcated by to two primary surface drainage systems that trend northeast-southwest and coincide with reclaimed land overlying former streams/low-lying areas. The two primary drainage systems extend up gradient from the two ends of the Hague's "U"-shaped water body. The axis of the western drainage system is roughly aligned with Stockley Gardens and the eastern drainage system is roughly aligned with Virginia Beach Boulevard and Monticello/ Avenue. The eastern branch has two secondary reaches that are roughly aligned with Olney Road and Llewellyn Avenue. The regional slope of the ground surface is toward the southwest.

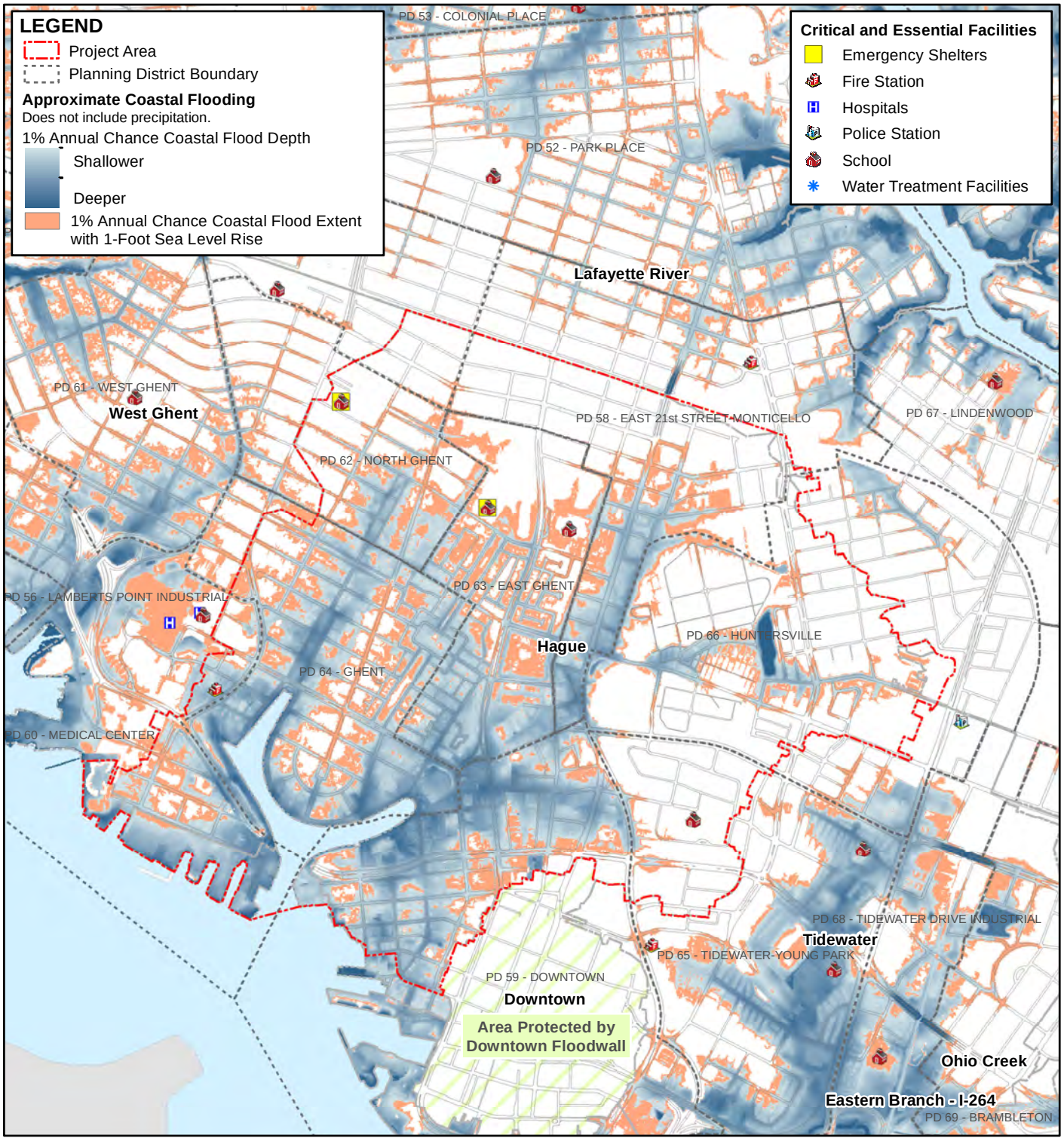
POTENTIAL FLOOD MITIGATION OPTIONS

The project team has evaluated several flood mitigation options during other phases of the City-wide Coastal Flooding Program. The preferred alternative based on the previous studies includes a flood gate across the Hague outlet at the Brambleton Avenue bridge with a tie-in wall to the existing downtown floodwall. A road raise and small berm is needed on the western portion of the project area to accommodate a one foot sea level rise.

The project cost for the Hague area adopts the preferred alternative from the previous studies. The project cost estimate is approximately $58.6. Figure F-2 shows the potential flood mitigation options for the Hague project area and Table F-1 lists the project elements included in the cost estimate. Refer to Figures 1-3b and 1-4b for estimated project cost and potential damage reductions.

Table F-1. Hague

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	2,600 linear ft (typically 2.0 to 6.3 ft above ground)	N/A
Flood Gate Street Crossings	3	N/A
Earthen Berm	N/A	250 linear feet
Road Raise	N/A	1 raised cross walk
Flap Valves	5	N/A
Utility Conflicts	Minimum of 8	N/A



HAGUE PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

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FIGURE F-1

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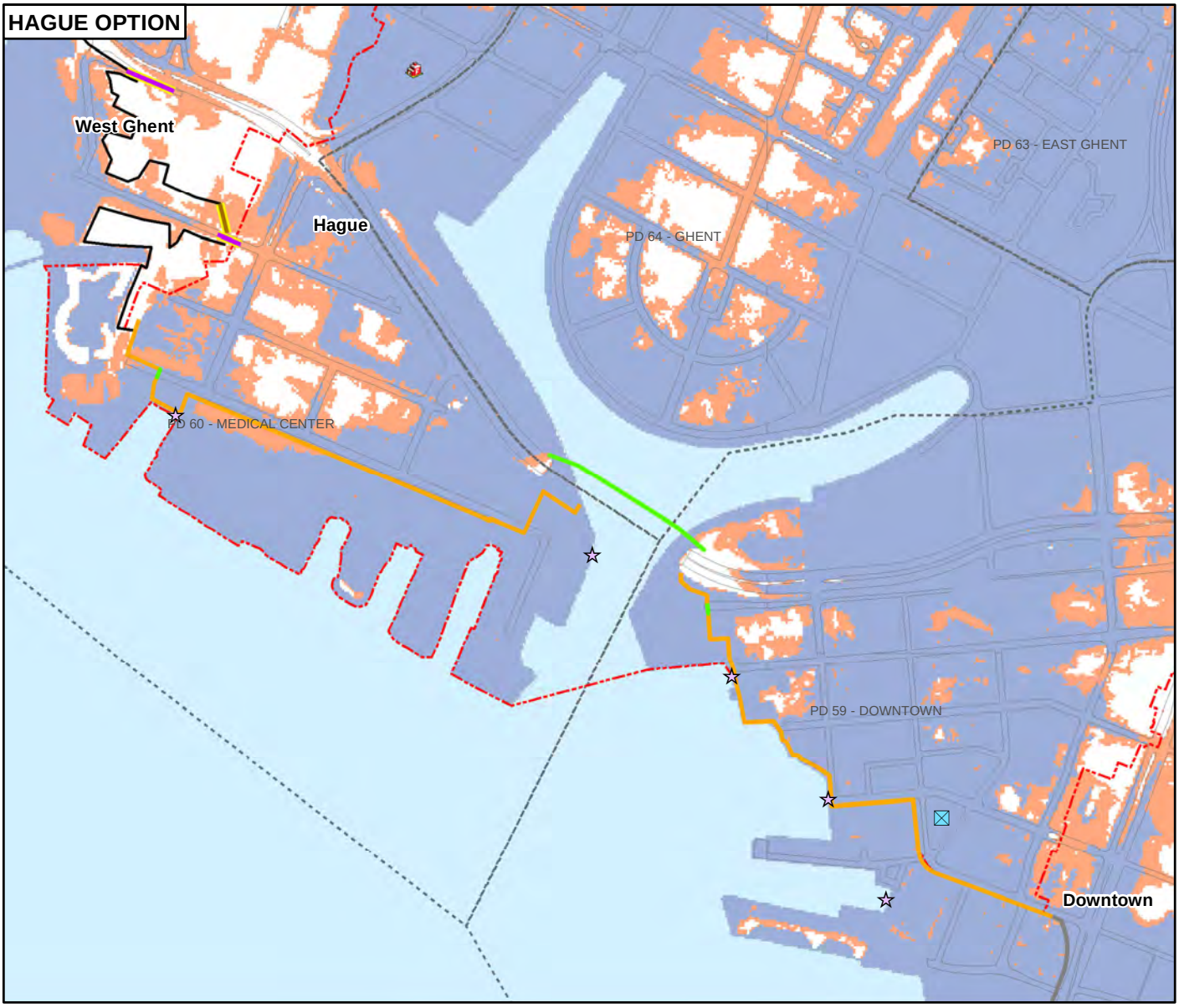

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTION
Hague Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE F-2

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APPENDIX G

WEST GHENT AND LAMBERTS POINT PROJECT AREAS

WEST GHENT AND LAMBERT POINT PROJECT AREAS

This appendix describes two separate project areas located in the southeastern portion of the City. The project areas are the:

- West Ghent project area, and
- Lambert Point project area.

West Ghent Project Area

The West Ghent project area is located in the southwestern portion of the City. The project area is bordered by the Lamberts Point project area to the north the Lafayette River project area to the west and south. The Elizabeth River is the southern boundary of the project area. Figure G-1 shows the West Ghent project area in green.

There are 1,639 parcels within the 959 acres of the West Ghent project area. The project area consists of 1,564 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $257M. The project area includes several large shipping piers and the Norfolk Southern Rail Yard.

The West Ghent project area has bulkhead along most of the shoreline of the Elizabeth River along with the Midtown Tunnel and it's approach ramps. The primary source of coastal flood waters that impacts structures originates from the Midtown Tunnel area. Historically (since entering the NFIP in the late 1970s) the area has experienced severe flooding as evidenced by the numerous flood claims and repetitive loss claims in this area. It is uncertain how many of those claims stemmed from, completely or in part, tidal flooding.

Lamberts Point

The Lamberts Point project area is in the western portion of the City. The project area is bordered by the Lafayette River project area to the west north and west. The Elizabeth River is the eastern boundary of the project area and the West Ghent project area is to the south. Figure G-1 shows the West Ghent project area in red.

There are 544 parcels within the 296 acres of Lamberts Point project area. The project area consists of 415 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $59M. The project area includes Norfolk's water treatment plant in the western portion of the project area.

POTENTIAL FLOOD MITIGATION OPTIONS – WEST GHENT PROJECT AREA

We identify two conceptual flood barrier project alignments in this project area.

West Ghent Norfolk General-Hampton Boulevard Option

The West Ghent Norfolk General-Hampton Boulevard option is comprised of a floodwall and gate system that extends from the Midtown Tunnel area northward along Hampton Boulevard area. The floodwall system will be technically very challenging to site without causing many significant impacts to major existing roadways (e.g. Hampton Boulevard near the Norfolk General Hospital). The alignment may prove to be fatally flawed when looking at roadway impacts and only provides minimal flood relief. The primary flood benefit of this option is derived after looking at a 1 foot sea level rise and then providing significant relief to Norfolk

General and overland flood protection from floodwaters entering into the adjacent Hague project area. Otherwise, the primary benefit of this alignment would be to preserve access on the Hampton Boulevard which would have impact on access to Norfolk General Hospital and transportation on a major transportation route.

Figure G-2 shows the Norfolk/General/Hampton Blvd option in the middle panel. The estimated project cost is approximately $10.5M. Tables G-1 list the project infrastructure elements included in the cost estimates. Refer to Figures 1-3b and 1-4b of this report for estimated project cost and potential damage reductions.

Table G-1. West Ghent – Norfolk General/Hampton Blvd

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	1,700 linear ft (typically 2.2 to 4.3 ft above ground)	N/A
Flood Gate Street Crossings	4	N/A
Earthen Berm	N/A	N/A
Road Raise	N/A	N/A
Flap Valves	1	N/A
Utility Conflicts	Minimum of 14	N/A

West Ghent Midtown Tunnel Option

The West Ghent Midtown Tunnel option is also comprised of a floodwall and gate system that extends from the Midtown Tunnel and extends to the northwest where it eventually ties into high ground. This option provides flood mitigation relief to a wider area than the alternative. Notable features protected include the major transportation arteries of Brambleton Avenue, Hampton Boulevard, their access to Midtown Tunnel, and protection to Norfolk General. It is unclear at this time whether this option will require a pump station. Future hydrologic and hydraulic analyses can be used to evaluate if it will be required and what size of pump system.

Figure G-2 shows the Midtown Tunnel option in the bottom panel. The estimated project cost is approximately $10.2M. Tables G-2 list the project infrastructure elements included in the cost estimates. Refer to Figures 1-3b and 1-4b of this report for estimated project cost and potential damage reductions.

Table G-2. Midtown Tunnel

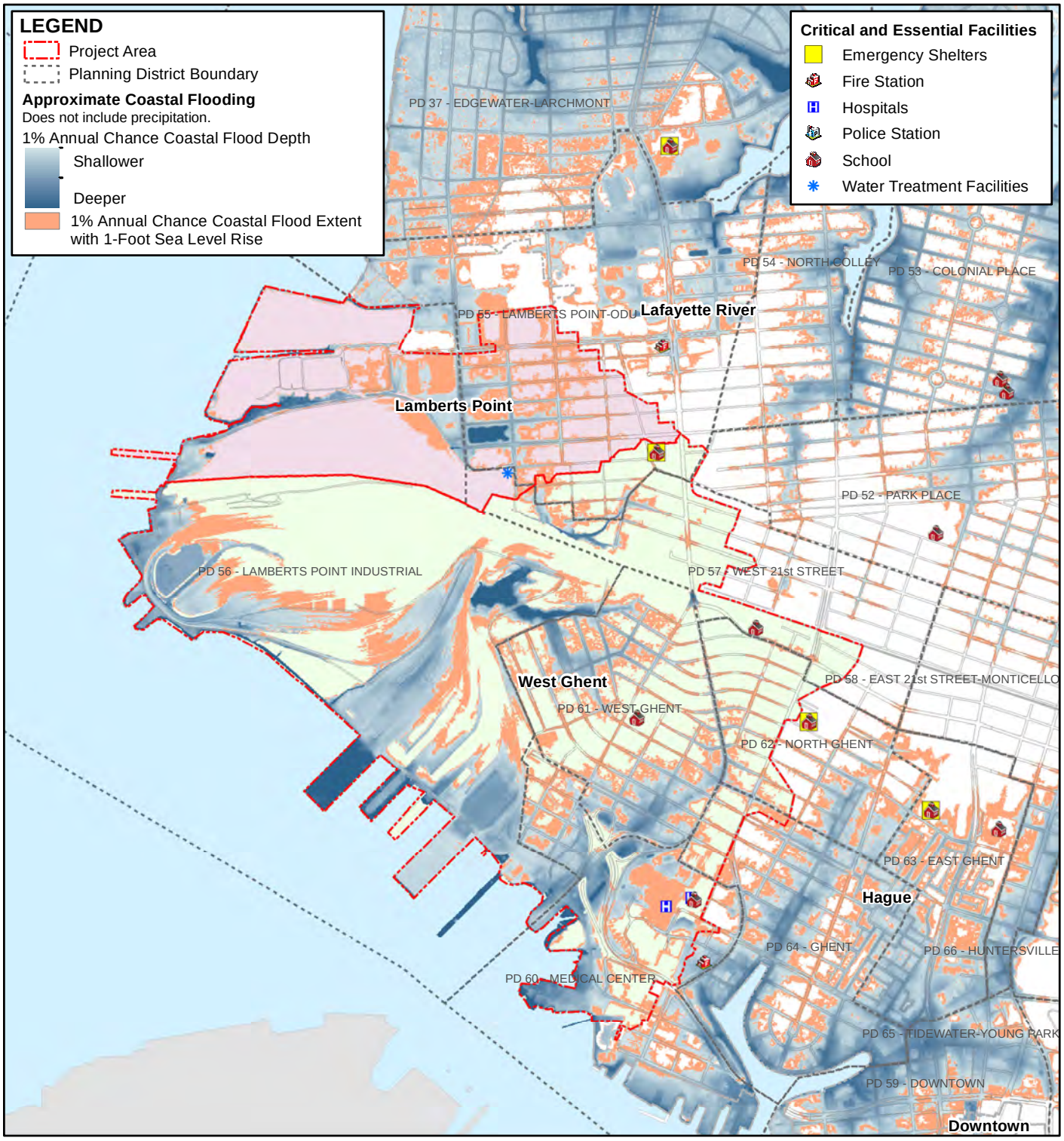
Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	5,100 linear ft (typically 1.6 to 6.0 ft above ground)	N/A
Flood Gate Street Crossings	2	N/A
Earthen Berm	N/A	N/A
Road Raise	N/A	850 linear feet
Flap Valves	3	N/A
Utility Conflicts	Minimum of 3	N/A

POTENTIAL FLOOD MITIGATION OPTIONS - LAMBERTS POINT PROJECT AREA

The Lamberts Point project elements consist of low berms through the water treatment plant, road raises, and a flood gate across Powhatan Avenue. In order to mitigate the effects of 1 foot of sea level rise, about 1,400 feet of a road raise, low berm or floodwall would need to be tied into the Powhatan Avenue flood gate and higher ground. The project would mitigate flooding to a neighborhood area that has historically (since the City has entered the NFIP in the later 1970s) experienced flood damage and repetitive flood damage. Figure G-3 shows the potential flood mitigation option considered for this project area. This project is estimated to cost Table G-3 lists the project infrastructure elements included in the cost estimates (note cost estimates also include planning, design, operation and maintenance). Refer to Figures 1-3b and 1-4b for estimated project cost and potential damage reductions.

Table G-3. Lamberts Point

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	NA	N/A
Flood Gate Street Crossings	1	N/A
Earthen Berm	900 linear feet	N/A
Road Raise	N/A	1,400 linear feet
Flap Valves	1	N/A
Utility Conflicts	Minimum of 7	N/A



WEST GHENT AND LAMBERT POINT PROJECT AREAS
City-wide Coastal Flooding Study
Norfolk, Virginia

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FIGURE G-1

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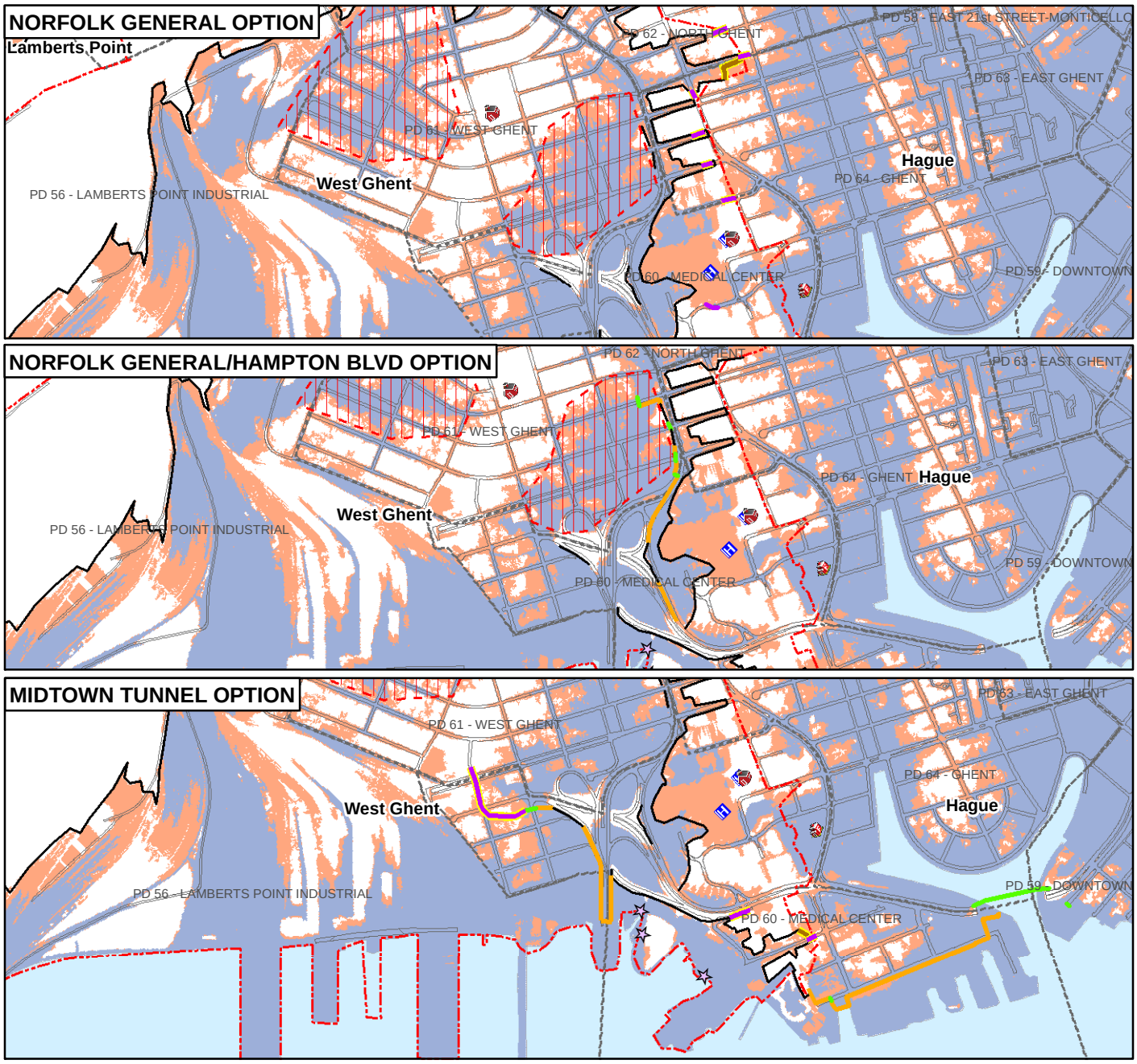

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
West Ghent Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE G-2

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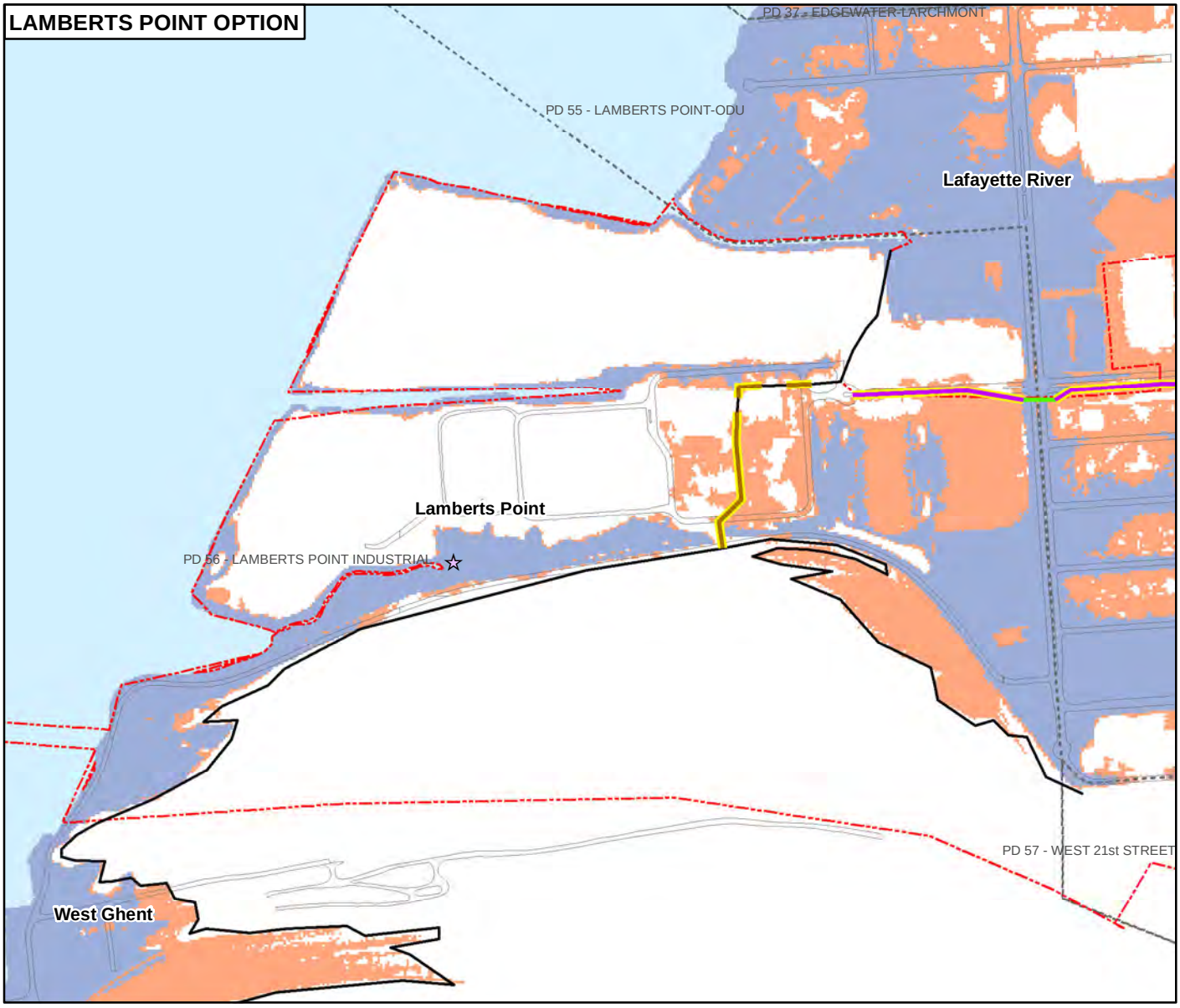

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTION
Lamberts Point Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE G-3

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APPENDIX H

LAFAYETTE PROJECT AREA

LAFAYETTE PROJECT AREA

The Lafayette project area is located in the western portion of the City and encompasses the Lafayette River watershed. This project area is the largest area considered in this study and makes up about 26 percent of the City's total area. Figure H-1 shows the Lafayette River project area outlined in red.

There are 29,503 parcels within the 48,259 acres of project area. The Lafayette project area consists of 22,838 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $4.7B. The project area is primarily made up of residential properties with commercial land use along the main roads. The Lafayette River project area also contains Old Dominion University and Bon Secours DePaul Medical Center.

The project area has historically (since the City entered the NFIP in the late 1970s) experienced severe flooding and has numerous flood claims including repetitive and severe repetitive loss claims.

The Lafayette River and associated tributaries are tidal and have a significant length of shoreline that exposes a considerable percentage of the City to tidal flooding. The Lafayette River itself flows into the Elizabeth River and has a small navigation channel for recreational and fishing boats. The project area has significant amounts of low lying areas, especially in the western portion of the area in the Edgewater-Larchmont planning districts. The shoreline of the Lafayette River has had bulkheads constructed along much of the western portion of the project area. Most of the project area's captured rainwater is conveyed by the storm water infrastructure into the Lafayette River. Most of the rainwater captured west of Hampton Boulevard is discharged through outfalls into the Elizabeth River.

POTENTIAL FLOOD MITIGATION OPTIONS

Flooding hazard in this area is spatially extensive and presents significant challenges to mitigate in terms of technical and financial aspects. Due the large extent of the watershed, a flood barrier system at the basin outlet location along the mouth of the Lafayette River would have far reaching effects in the watershed and replace numerous smaller projects.

The project also presents potential opportunities to combine with other interests (e.g. future extension of a Light Rail spur) that could provide a cost sharing opportunity and additional benefit to the area.

We identified two general conceptual alignments for a flood barrier system. The lower cost conceptual alignment utilizes high ground and is comprised of an overland alignment along Hampton Boulevard and floodwall/gate system crossing of the Lafayette River at the Hampton Boulevard bridge. Although the project cost is lower, it leaves a significant amount of flood prone areas west of the barrier system unprotected. Additionally, this alignment option may have significant impact on traffic patterns and will directly impact a number of residential properties as discussed later.

The second conceptual alignment would include creating a barrier system at the mouth of the Lafeyette River and would provide protection to the entire watershed. We have identified three different overwater alignment concepts. Two alignment options (Larchmont-Eleanor Crossing and Larchmont-NIT Crossing) include a floodwall system along the shoreline in the

Larchmont area and the third alignment (Lamberts Point-NIT Crossing) is located offshore of Larchmont.

The Lafayette River is a large body of water that will require a large flood barrier system to cross. The four water crossings approximate shore-to-shore lengths are:

- At the Hampton Boulevard bridge = 1,700 feet,
- Larchmont-Eleanor Crossing (labeled LR-Eleanor on Figure H-3) = 2,100 feet,
- Larchmont-NIT Crossing (labeled West LR – NIT on Figure H-3) = 2,730 feet, and
- Lamberts Point-NIT Crossing (labeled Lambert – NIT LR Crossing on Figure H-3) = 6,720 feet.

Due to the sizes of the river crossing, large swinging sector gates have been identified as a potential gate closure option. The large gate would permit boating access while open, reduce viewshed impact (compared to a lift gate), and would reduce flow constriction during tidal flushing and river discharge flow.

Hampton Boulevard Option

We considered a floodwall and gate system along Hampton Boulevard. This concept considers three options for routing a floodwall along Hampton Boulevard; down the median, east, and west side of the boulevard.

The Lafayette River crossing would occur at the Hampton Boulevard bridge and then have a wall system continue running north until it ties into high ground.

Hampton Boulevard (Median) Alignment Option

The Hampton Boulevard (Median) project option consists of a floodwall down the median of Hampton Boulevard with flood gates at street crossings where necessary. In order to reduce the number of gates, the wall would cross (and close) some of the existing intersections. During a flood event when the gates system is closed, either the southbound traffic lanes would be closed or the northbound lanes would have to be converted to a two-way traffic pattern to preserve north-south-bound traffic flow.

If a Light Rail spur line is planned in the future along Hampton Boulevard, then it may be an option to elevate the rail line and create a combined rail foundation/flood barrier system.

On the southern end of this project option a low berm is used to tie the wall into the existing topography. The floodwall/gate system across the Lafayette River would be located adjacent to the Hampton Boulevard bridge and is approximately 1,700 feet long.

For the Hampton Boulevard flood barrier option, a considerable number of structures would be unprotected west of the floodwall. Therefore, structure raising would be beneficial in mitigating flooding. We estimate that the combined flood barrier system and structure raising will be approximately $177M. Refer to Figures 1-3b and 1-4b for estimated project cost and potential damage reductions.

Hampton Boulevard (West or East of Boulevard) Alignment Option

An alternate alignment option for the flood barrier system would be located along either the west or east side of Hampton Boulevard (Figure H-2). Both options would significantly

impact residences and their access to Hampton Boulevard. The western alignment appears to have a few more utility and residence impacts than the eastern alignment and thus is slightly more expensive. However, a barrier located on the west side of the roadway would provide protection to the road during a flood event.

At least 12 road gate closures would be required. This many gates will require considerable operation and maintenance costs and may represent significant technical challenges. Impacts on traffic will need to be evaluated to better understand the feasibility of the gate closures.

At the southern end of this project alignment a low berm is used to tie the wall into the existing topography.

The Lafayette River crossing will be located adjacent to the Hampton Boulevard bridge and is approximately 1,700 feet long. This river crossing location is the shortest of all considered for the Lafayette River. Therefore, large swinging sector gates have been identified as a potential gate closure option. This would allow for boat navigation while open, would reduce viewshed impact (compared to a lift gate), and would reduce flow construction during tidal flushing.

For Hampton Boulevard flood barrier option, a considerable number of structures would be unprotected west of the floodwall. Therefore, structure raising would be beneficial in mitigating flooding. We estimate that the combined flood barrier system and structure raising will be approximately $188M. Refer to Figures 1-3b and 1-4b for estimated project cost and potential damage reductions.

Table H-2. Larchmont – Hampton (East or West of Boulevard)

Project Elements	Quantities	Additional Quantities with 1-foot of SLR
Flood Wall	5,400 linear ft (typically 1.7 to 5.5 ft above ground)	N/A
Flood Gate Street Crossings	12	N/A
Earthen Berm	2,000 linear ft	N/A
Road Raise	N/A	2,400 linear feet
Flap Valves	2	N/A
Utility Conflicts	Minimum of 60	Minimum of 5

Larchmont – Eleanor Crossing Option

The Larchmont – Eleanor crossing project option is the first of three alignment options described herein that provides surge protection to most of or the entire Lafayette River watershed. This flood barrier system concept is comprised of a floodwall down the western shoreline of the project area with a large floodwall and gate system crossing the Lafayette River. The floodwall crosses Lafayette River between Larchmont and Eleanor. The river crossing at this location is approximately 2,100 feet long.

The floodwall along the Larchmont shoreline would impact numerous water front properties and access to private docks. Where walls are less than about 3 feet tall, a simple stair system could be constructed provide access over a wall.

House raising would only be needed in the North Shore planning districts with this option. Figure H-3 shows the Larchmont – Eleanor crossing option on the left panel and Table H-3 lists the infrastructure project elements. We estimate that this project option (infrastructure and structure raising) would cost approximately $182M. Refer to Figures 1-3b and 1-4b for the estimated project cost and potential damage reductions.

Table H-3. Larchmont – Eleanor Crossing Option

Project Elements	Quantities
Flood Wall	9,000 linear ft (typically 3.3 to 8.1 ft above ground)
Flood Gate Street Crossings	N/A
Earthen Berm	N/A
Road Raise	N/A
Flap Valves	6
Utility Conflicts	Minimum of 7

Larchmont – NIT Crossing Option

The Larchmont–NIT project option is similar to the Larchmont-Eleanor project option in that it is comprised of a floodwall along the Larchmont shoreline but crosses the Lafayette River in Larchmont and connects to the Norfolk International Terminal (NIT) (Figure H-3). The flood barrier system's water crossing is approximately 2,730 feet long.

One of the advantages of this alignment option over the Larchmont-Eleanor option is that it provides protection to the Lafayette River watershed and does not require structure raising.

Figure H-3 shows the Larchmont–NIT option on the right panel and Table H-3 lists the infrastructure project elements. We estimate that this project cost is approximately $189M. Refer to Figures 1-3b and 1-4b for the estimated project cost and potential damage reductions.

Table H-3. Larchmont – NIT Crossing

Project Elements	Quantities
Flood Wall	7,100 linear ft (typically 1.0 to 2.0 ft above ground)
Flood Gate Street Crossings	N/A
Earthen Berm	N/A
Road Raise	N/A
Flap Valves	5
Utility Conflicts	Minimum of 7

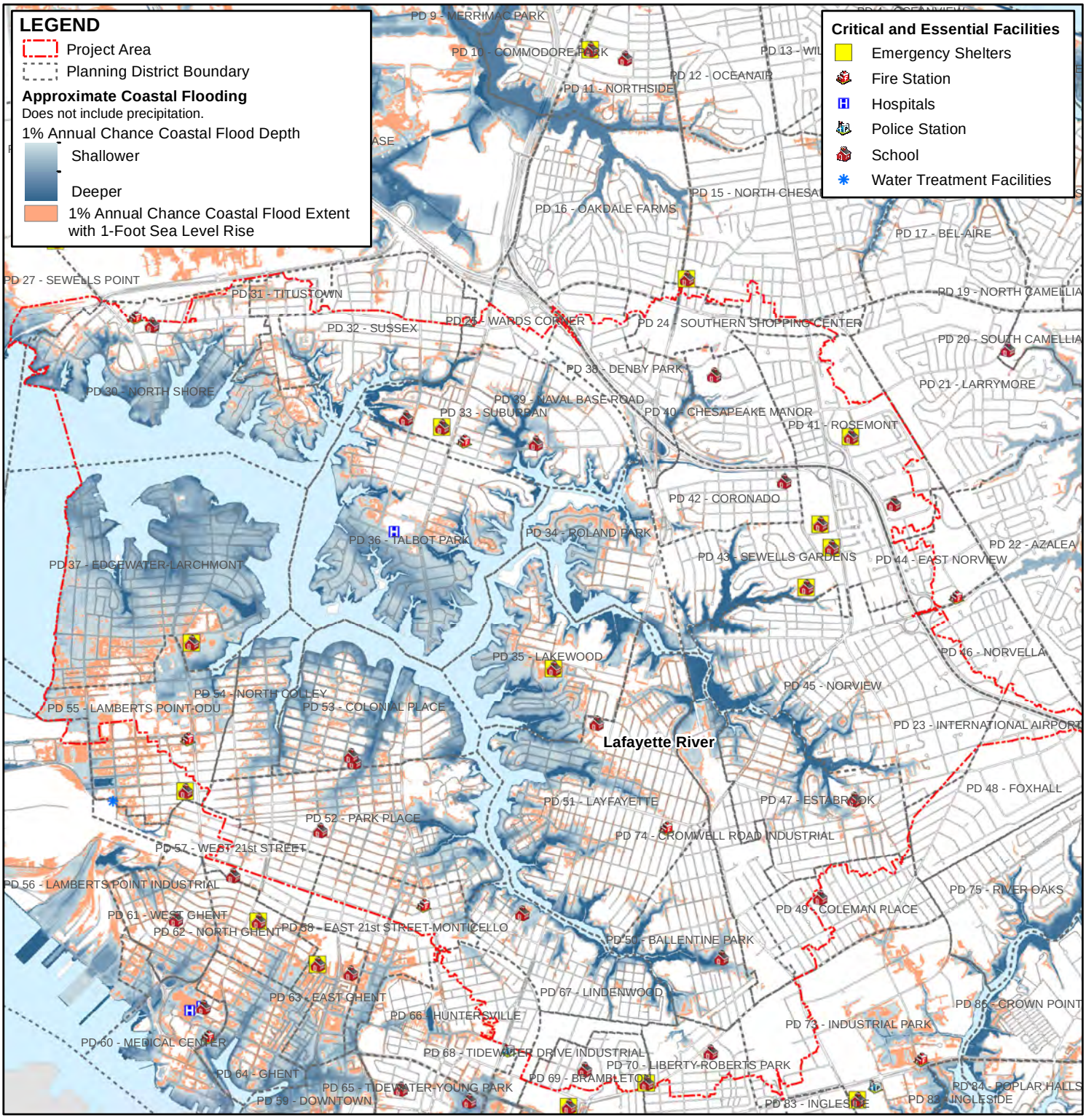
Lamberts Point – NIT Crossing Option

The Lamberts Point – NIT project option is comprised of a flood barrier system that extends from Lamberts Point to the Norfolk International Terminal (NIT). The flood gate would need to be approximately 6,750 feet long and be located approximately 2,000 to 4,000 feet offshore from Larchmont.

Significant advantages of this option are that the flood barrier system would provide protection to the entire Lafayette River watershed and would not directly impact the waterfront properties or access to docks. Additionally, we note that if this flood barrier system were constructed as part of a transportation project, it could offer a means to route Light Rail or traffic to/from the NIT.

Clearly, a structure this large would likely have significant funding, technical, and environmental challenges. However, flood barrier structures this large (and considerably larger) have been constructed in the U.S. and elsewhere in the world.

Figure H-3 shows the Lamberts Point – NIT project option on the right panel. Based on other structures in the U.S. of this size, we estimate that this project would cost approximately $306M to design and construct. Refer to Figures 1-3b and 1-4b of this report for the estimated project cost and potential damage reductions.



LAFAYETTE RIVER PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE H-1

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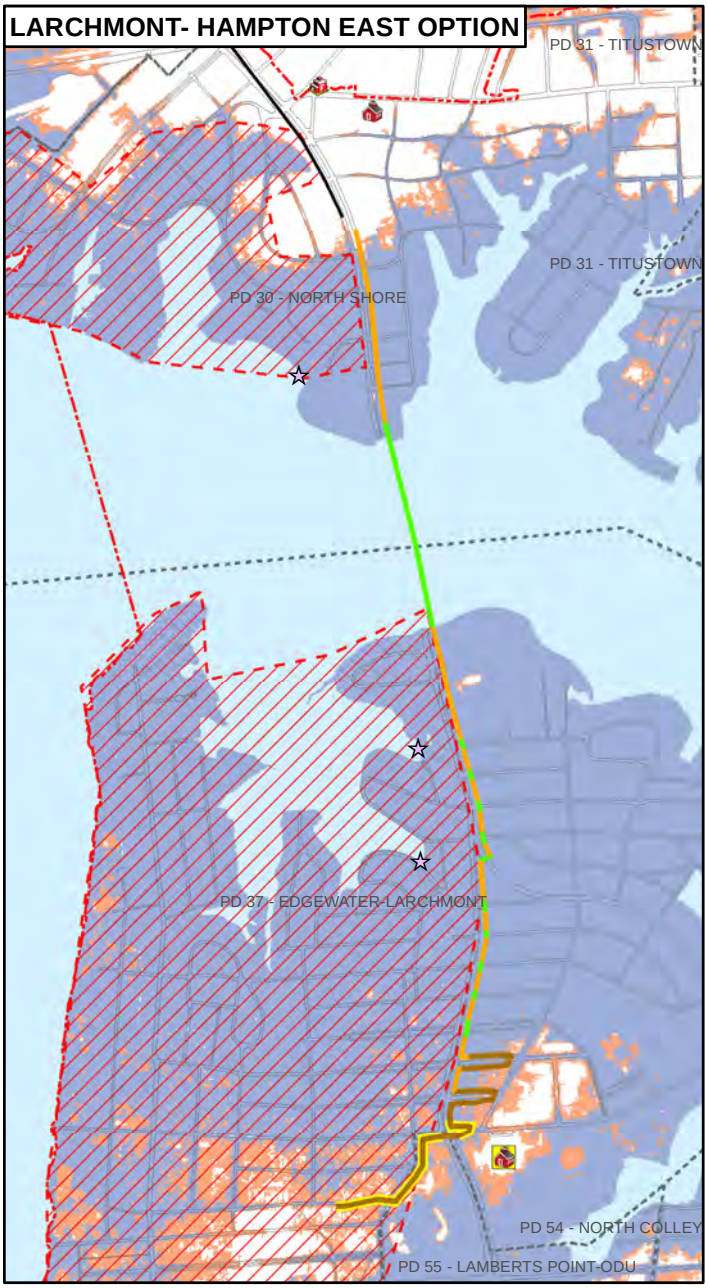
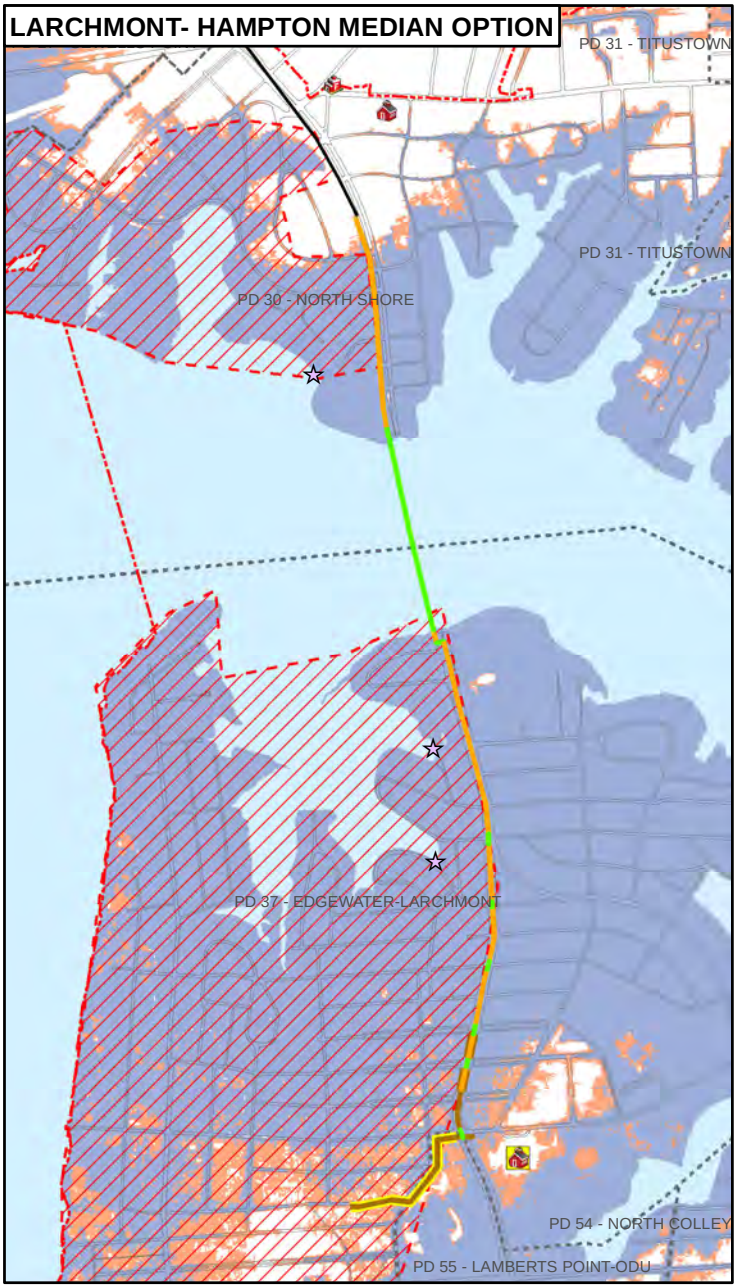
LARCHMONT- HAMPTON EAST OPTION



LARCHMONT- HAMPTON MEDIAN OPTION



LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
Lafayette River Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE H-2

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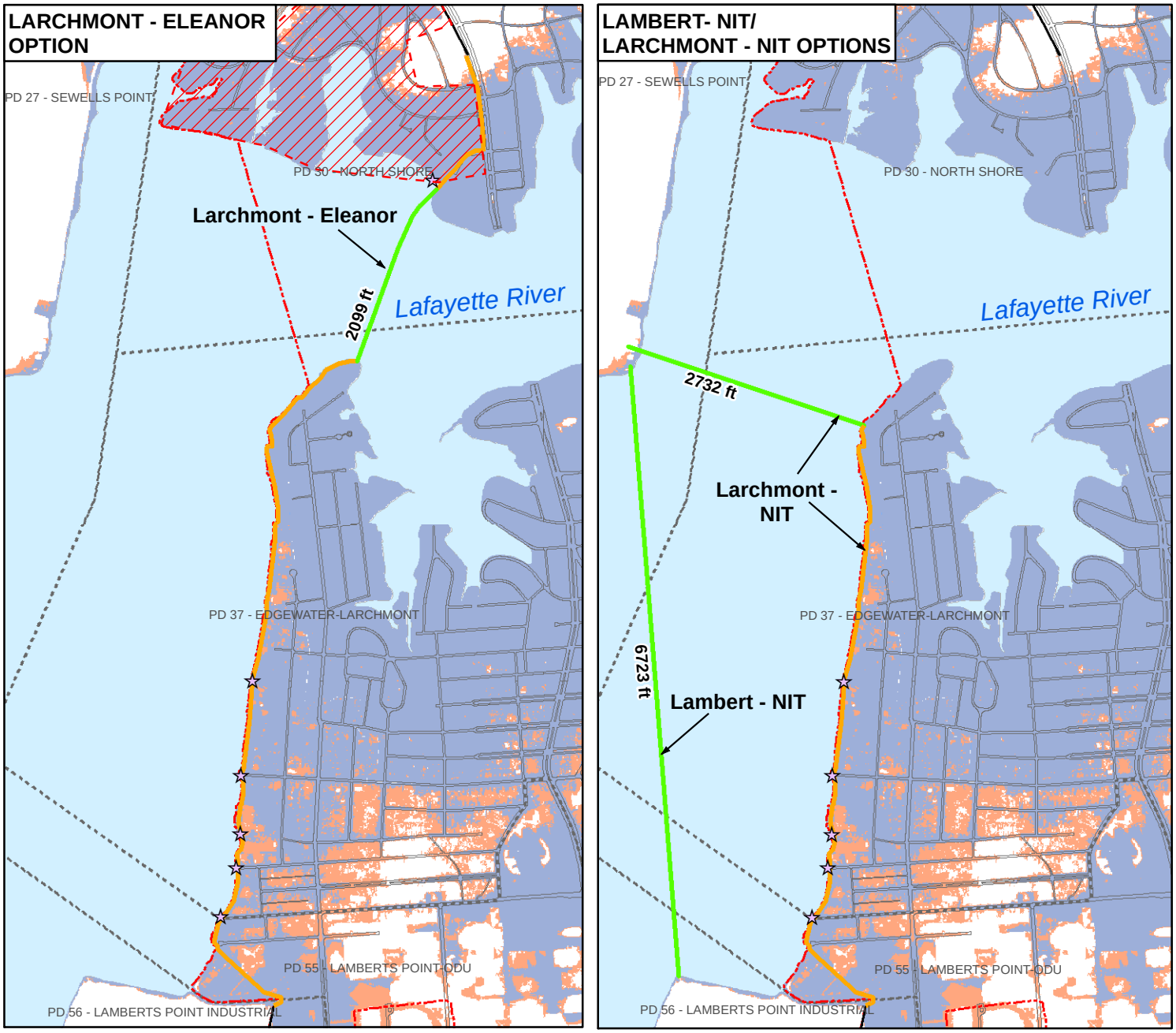

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
Lafayette River Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE H-3

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APPENDIX I

MASON CREEK PROJECT AREA

MASON CREEK PROJECT AREA

The Mason Creek project area is adjacent to the Norfolk Naval Air Station. For the purposes of this study we included the Glenwood Park planning district within this project area. The project area is bordered by the Lafayette project area to the south and Pretty Lake project area to the east. Figure I-1 shows the Mason Creek project area outlined in red.

The project area includes 8,480 parcels within the 4,173 acres of land in the project area. There are 8,327 houses and non-residential buildings (excluding detached garages, sheds, etc), with 2010 assessed value of $1.8B. In terms of the number of parcels and structures, this is the second largest of the 15 projects described in this study. However, this area ranks ninth in terms of predicted flood damages resulting from a 1% annual chance storm event (this assumes that the tide gate operated by the Navy would not have been closed and storm surge flooding would have occurred through the existing culvert into Mason Creek).

Mason Creek has a culvert outlet that connects Mason Creek to Willoughby Bay. Currently, the outlet passes underneath NAS Norfolk (refer to Figure I-2 for location). The outlet is approximately 20 feet in width, 11 feet in height and extends approximately 1,800 feet underneath the Naval Air Station (refer to dashed line on Figure I-2 for Alternative 4).

Both Willoughby Bay and Mason Creek are tidally influenced and subject to storm surge. However, tidal exchange in Mason Creek can be controlled by a tide gate located on the base and controlled by the Naval Air Station. The gate is operated by closing the gate at low tide in advance of predicted significant tidal events.

POTENTIAL FLOOD MITIGATION OPTIONS

The project team is currently evaluating a variety of mitigation options for this area. Since the existing tide gate is operated such that it prevents storm surge flooding from entering through the existing culvert, most flooding stems from rainfall run-off being collected in Mason Creek. Therefore the project team is evaluating concepts that will use a pump system and pipeline to convey water out of Mason Creek during a storm. The project team is evaluating two alignment options. One alignment, referred to herein as Alternatives 2 and 3, is comprised of a new pipeline that will cross Chambers Field (parallel to the Navy's runway), extend beneath Bellinger Boulevard, and discharges into Willoughby Bay. We are considering two alternatives (Alternatives 2 and 3) for this alignment as described below. The second alternative, referred to herein as Alternative 4, will include constructing a new force line inside the existing culvert and use a new pump station to pump water through the pipeline. The alignment options are shown on Figure I-2.

Dredging parts of Mason Creek are also being considered as a way to increase the volume of water the basin can hold during precipitation events.

Alternative 2: Box Culvert Across Chambers Field with Pumps

Conceptual Alternative 2 utilizes a new, large culvert in combination with a high-capacity pump station to reduce peak water levels in Mason Creek during combined tidal surge and rainfall runoff events. The alternative includes constructing one 7 ft x 9 ft reinforced concrete box culvert, with pressurized flow forced by a new pump station (below), to mechanically remove excess rainfall runoff during storm events when the NS Norfolk culvert tide gate is

closed. The culvert would run from the northwest banks of Mason Creek toward the west, parallel to an existing NS Norfolk taxi runway for approximately 1,800 feet, then north for approximately 2,000 feet across Chambers Field and through the NS Norfolk bulkhead into Willoughby Bay. A flap gate structure would be installed at the outfall where the culvert drains into Willoughby Bay to prevent back-flooding from elevated tides during storm events. Figure I-2 shows the location and alignment of the proposed new box culvert(s) under Chambers Field.

The pumps which will be used to discharge accumulated storm water on the upstream side of the tidal barrier consist of three 60-inch diameter pumps (2 operational and 1 backup), forcing flow through the single box culvert.

The intake lines of the pumps would be located upstream of the existing tide gate on the NS Norfolk culvert, and the discharge lines would penetrate through the bulkhead on Willoughby Bay, discharging directly into the Bay. The pumps would primarily be powered via a connection to underground electric service (via Dominion's existing utility lines in the project vicinity). Emergency backup generators would be located on-site to allow operation during power outages.

We estimate that the initial capital investment for this project option is approximately $26.9M. We estimate that the annual operation and maintenance cost would be approximately $139,000 per year and over a 50-year project lifetime would add it up to $1.9M. Therefore, the total project cost would be approximately $28.8M.

Alternative 3: Dual Circular Culverts Across Chambers Field with Pumps

Alternative 3 is very similar in concept to Alternative 2, in that it utilizes a pair of new culverts in combination with a high-capacity pump station to reduce peak water levels in Mason Creek during combined tidal surge and rainfall runoff events. The same general culvert alignment as in Alternative 2 would be used in Alternative 3. However, instead of a single large box culvert requiring extensive open excavation, Alternative 3 utilizes two 42-inch diameter circular culverts, which could be directionally-drilled across Chambers Field. A flap gate structure would be installed at the outfall where the culvert drains into Willoughby Bay to prevent back-flooding from elevated tides during storm events.

Taking the smaller diameter culverts into account, the Alternative 3 pump station consists of three 36-inch diameter pumps (2 operational and 1 backup). The location of the intake and discharge locations and the approach to operational and backup power supply would be the same as in Alternative 2.

We estimate that the initial capital investment for this project option is approximately $21.1M. We estimate that the annual operation and maintenance cost would be approximately $100,000 per year and over a 50-year project lifetime would add it up to $1.4M. Therefore, the total project cost would be approximately $22.5M.

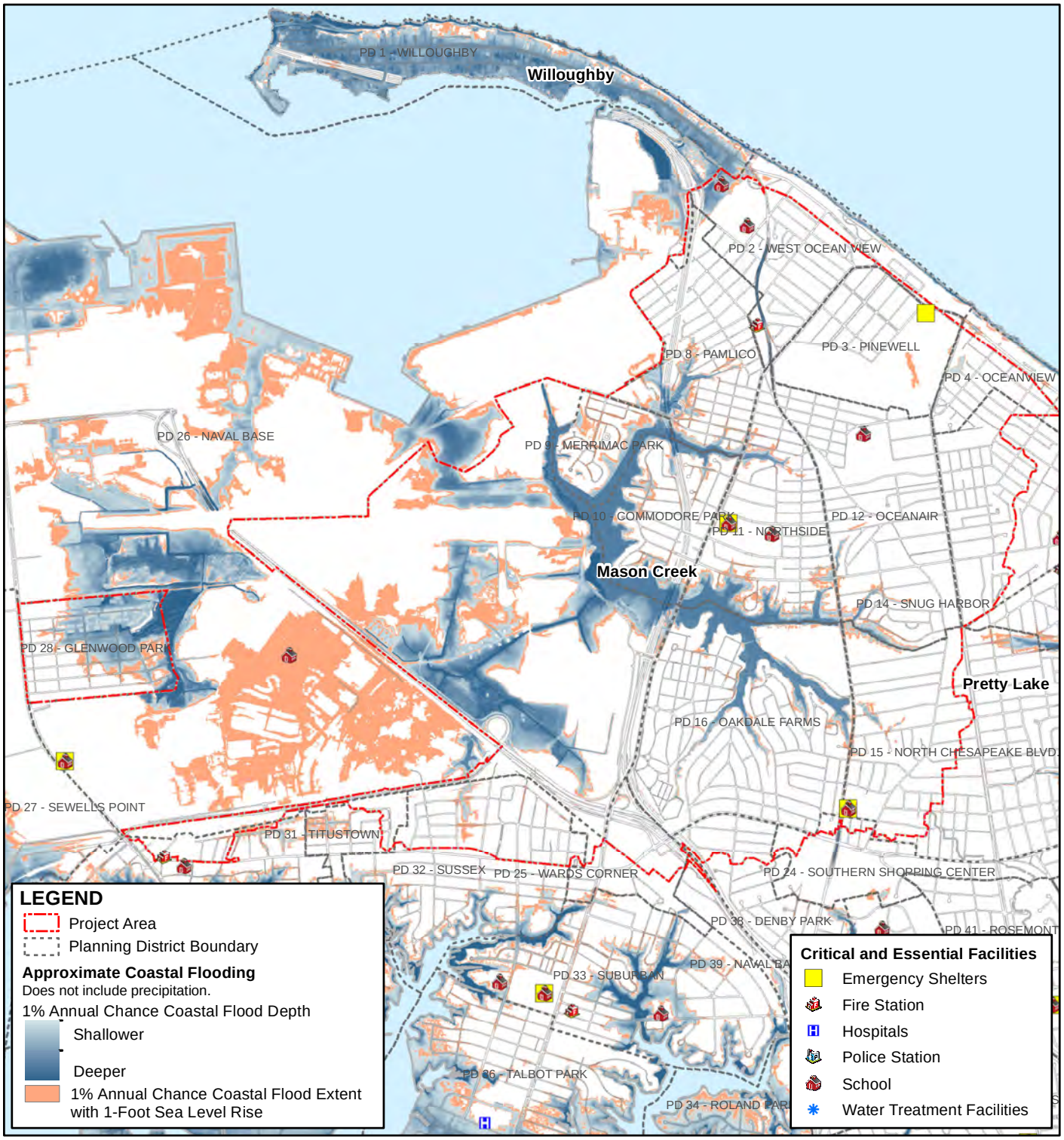
Alternative 4: Force Line Inside NS Norfolk culvert with Single Pump

Alternative 4 provides a means of pumping water from Mason Creek into Willoughby Bay without the need to excavate or directionally-drill a new, long culvert across Chambers Field. Alternative 4 consists of installing a pump station on City-owned property on the northwest arm of Mason Creek (Figure I-2), with the pump discharging through a dedicated pressurized line

running inside the existing NS Norfolk 11 ft x 20 ft box culvert. The separate forced-flow line would be designed to avoid adverse effects on the gravity drainage lines discharging to the NS Norfolk culvert at various points along its length.

The line inside the NS Norfolk culvert would be of a material such as HDPE which would allow a relatively small pipe wall thickness, to mitigate blocking of gravity drainage flow capacity within the culvert. The system would need to be fitted with valves or gates to allow the new line to provide gravity drainage when not in use as a pump discharge line, to maintain much of the present gravity flow capacity. Additional equipment and potentially major modifications of the existing outfall would also need to be considered, to allow the NS Norfolk culvert tide gate to close while still allowing the pumped line to discharge to Willoughby Bay during a coincident rainfall and coastal surge event.

We estimate that the initial investment of this option would be approximately $11.7M. We estimate that the annual operation and maintenance cost would be approximately $80,000 per year and over a 50-year project lifetime would add it up to $1.1M. Therefore, the total project cost would be approximately $12.8M.



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MASON CREEK PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE I-1

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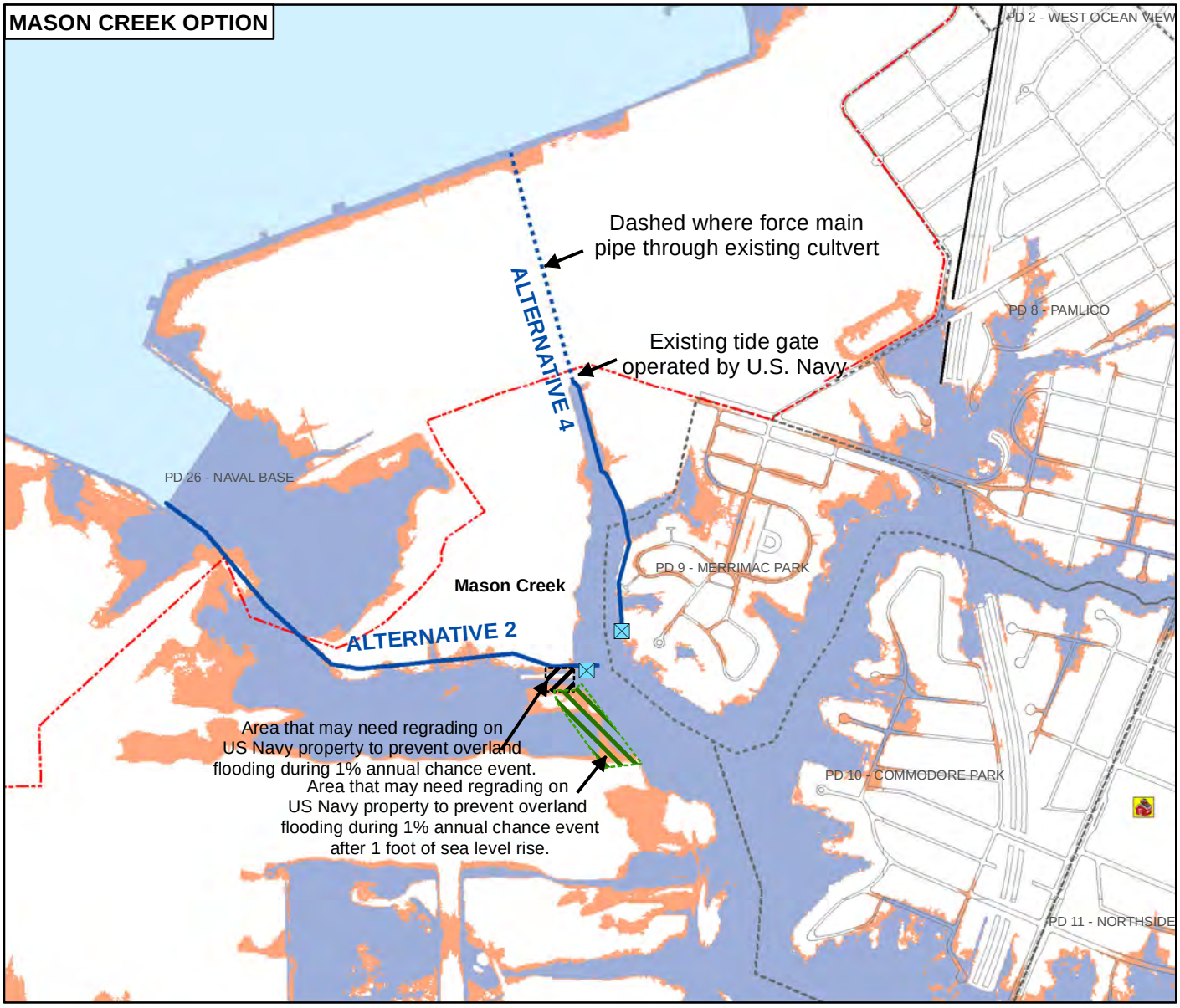

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
Mason Creek Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE I-2

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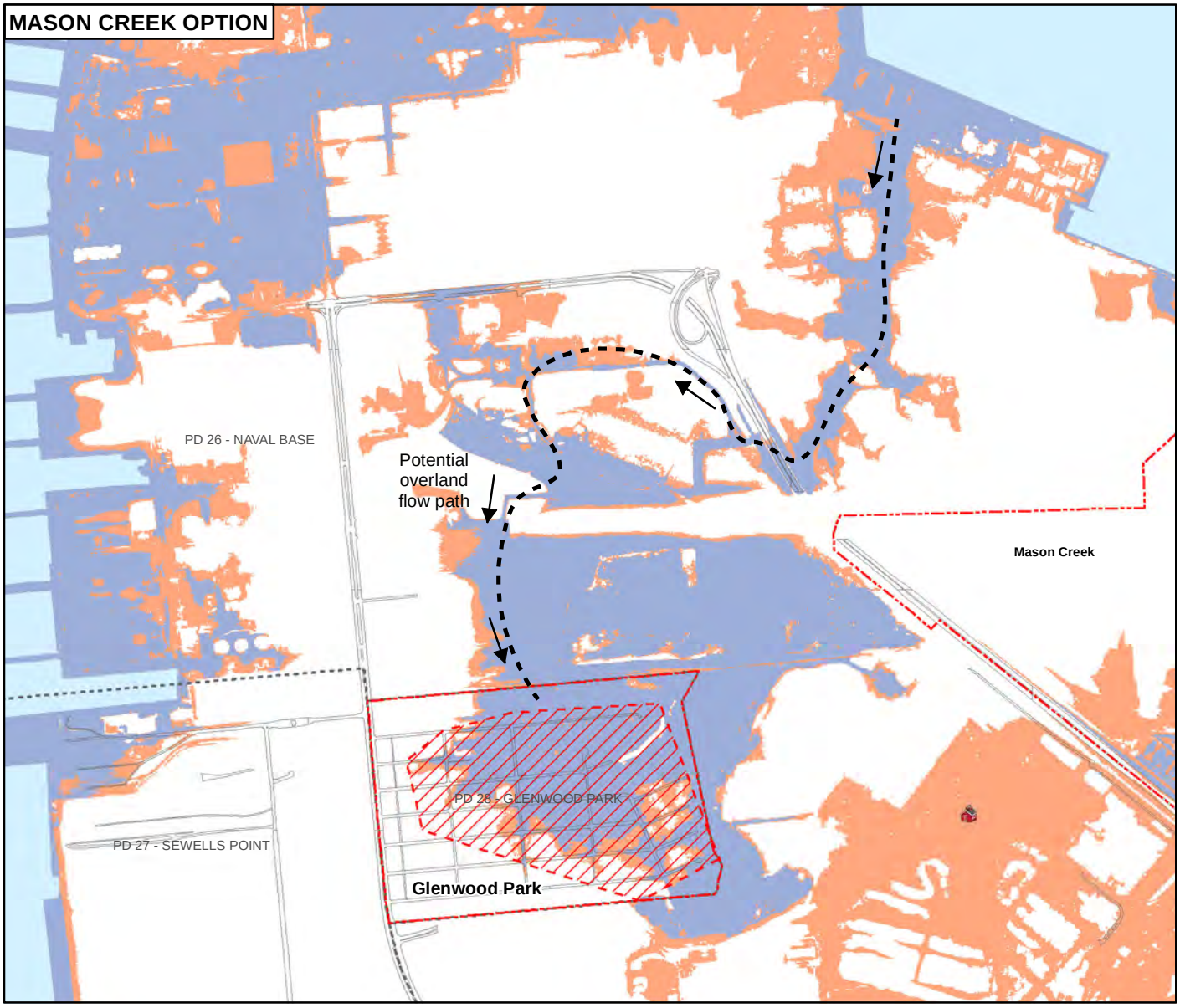

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTIONS
Mason Creek Project Area (Glenwood Park PD)
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE I-3

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APPENDIX J

WILLOUGHBY AND OCEAN VIEW PROJECT AREA

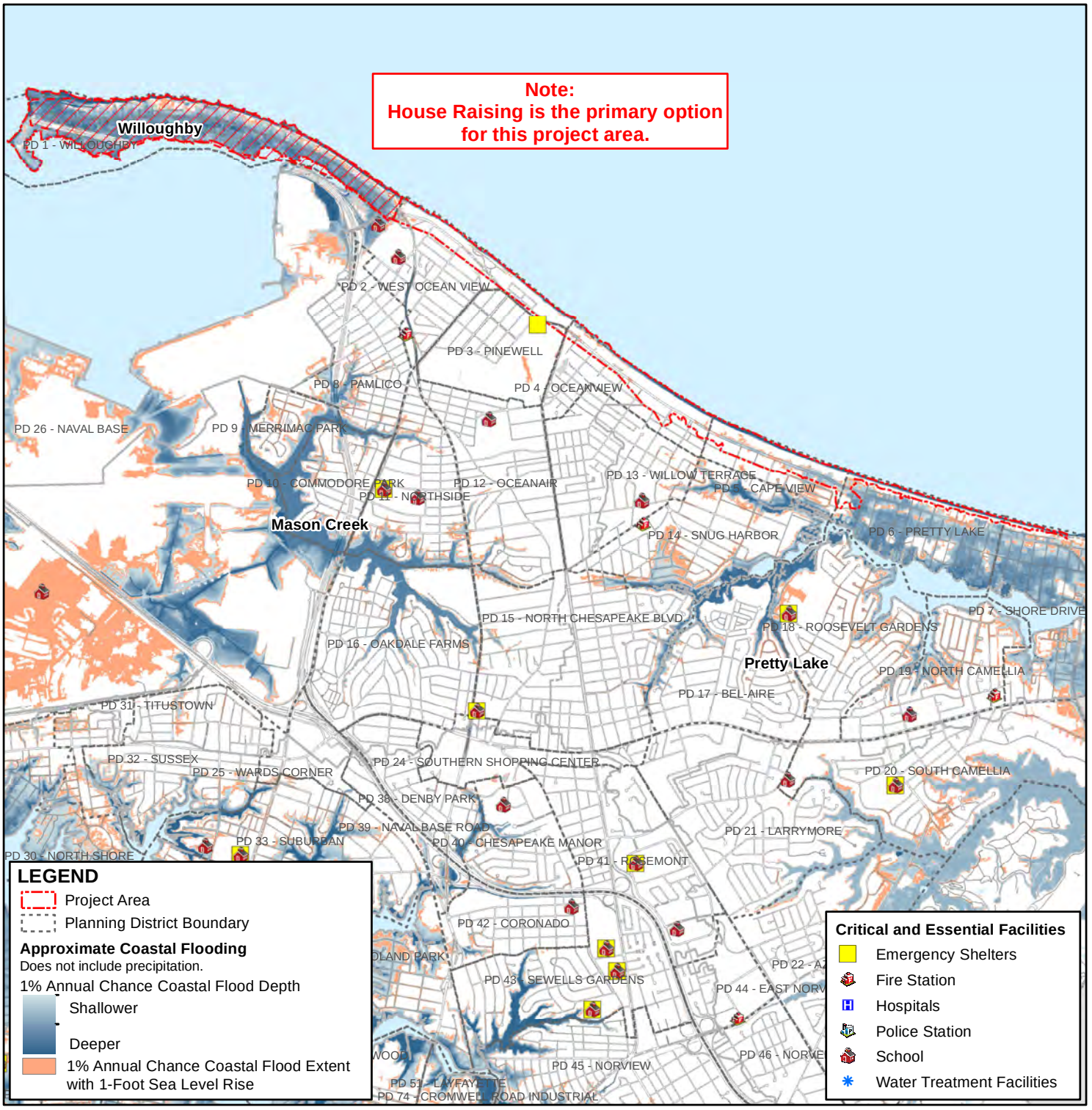
WILLOUGHBY AND OCEAN VIEW PROJECT AREA

The Willoughby and Ocean View project area is in the northwestern corner of the City. Willoughby spit is surrounded by water on three sides and the Ocean view portion is exposed to the Chesapeake Bay to the north. Figure J-1 shows the project area outlined in red.

The project area includes 1,392 parcels within the 554 acres of land in the project area. There are 1,284 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $293M.

POTENTIAL FLOOD MITIGATION OPTIONS

The Willoughby and Ocean View project areas geography and topography limits the type of potential flood mitigation options. Although existing shoreline protection structures reduce erosion rates and preserves dunes, they do not fully mitigate flooding hazards. The primary option to mitigate flooding for a 1% annual chance event is to raise structures. We estimate it would cost approximately $28M to raise structures in this project area. Refer to Figure 1-3b and 1-4b for estimated cost of raising houses susceptible to flooding in this project area and potential damage reductions.



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WILLOUGHBY PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE J-1

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APPENDIX K

PRETTY LAKE PROJECT AREA

PRETTY LAKE PROJECT AREA

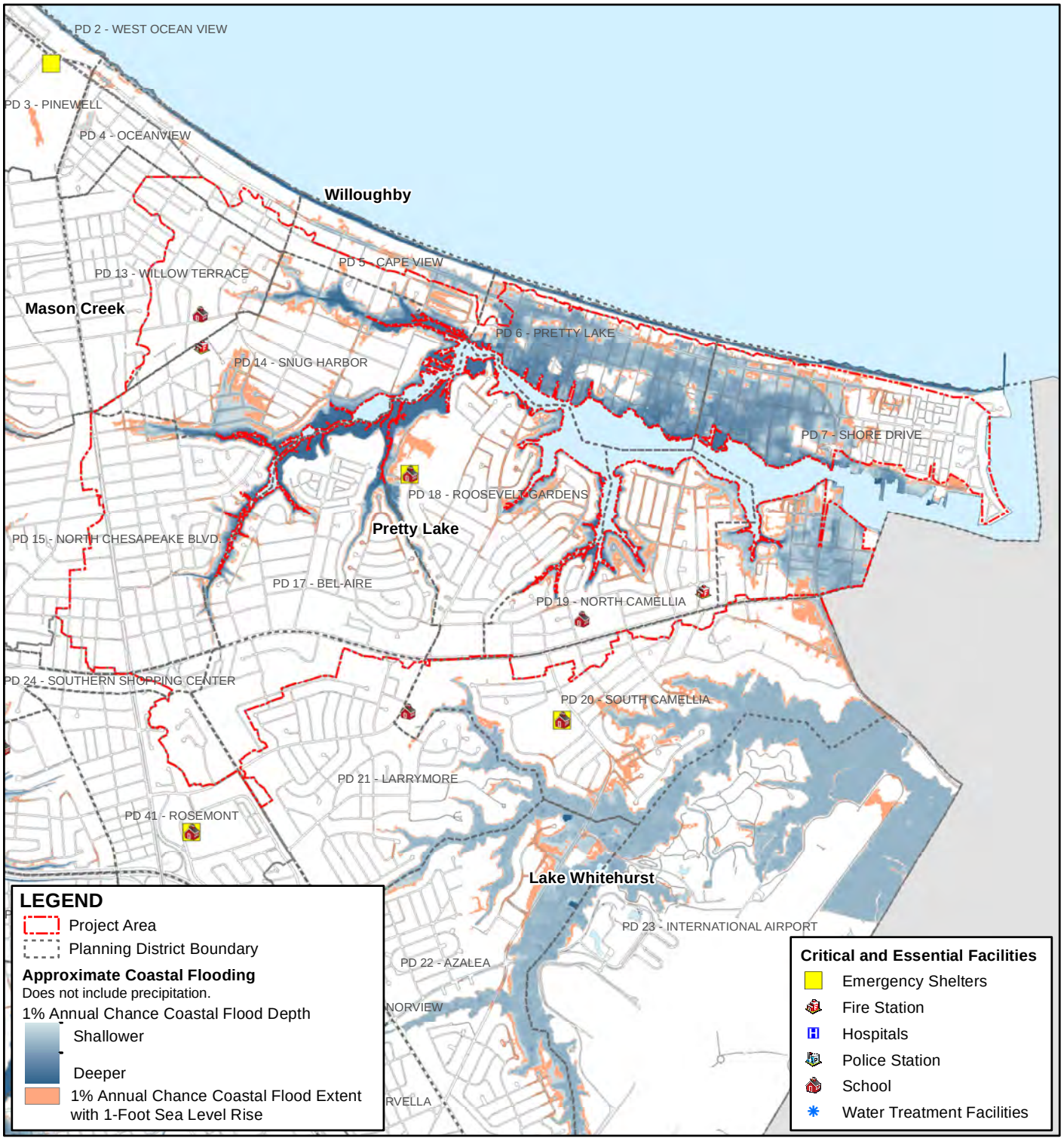
The Pretty Lake project area is in the northeast portion of the City of Norfolk. The northern portion of Pretty Lake is bordered by the Ocean View project area which is just a then band of land adjacent to the Chesapeake Bay. The southern portion of Pretty Lake is bordered by the Lake Whitehurst watershed which is not tidally influenced. Figure K-1 shows the Pretty Lake Project area outlined in red.

The watershed includes 8,345 parcels within the 2,714 acres of land in the project area. The project area consists of 7,875 houses and non-residential buildings (excluding detached garages, sheds, etc), with a 2010 assessed value of $1.2B.

The Pretty Lake, formally known as Little Creek, is the receiving body of water which subsequently feeds into the Chesapeake Bay. The topography of Pretty Lake is very flat, especially in the northern portion along Ocean View Road. The southern portion of the project area is generally higher in elevation then the northern area. Most of the shoreline in Pretty Lake is wetlands with some bulkheads around the marina to the east.

POTENTIAL FLOOD MITIGATION OPTIONS

The project team has evaluated several flood mitigation options during other phases of the City-wide Coastal Flooding Program. The preferred alternative from the previous studies includes a flood gate across the Pretty Lake outlet into the Little Creek Inlet at the Shore Drive bridge. An overland floodwall is needed to the south in order to tie into the existing topography. The northern tie into the existing topography would only require a small berm along Pretty Lake Road. The project cost for the Pretty Lake project area adopts the preferred alternative from the previous studies. To accommodate a 1 foot sea level rise a low 3,000 foot berm is needed to prevent water from the Chesapeake Bay flowing into the Pretty Lake project area from the north. Figure K-2 shows the potential coastal flood mitigation options considered in the Pretty Lake project area. Refer to Figures 1-3b and 1-4b for estimated project cost and potential damage reductions.



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PRETTY LAKE PROJECT AREA
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE K-1

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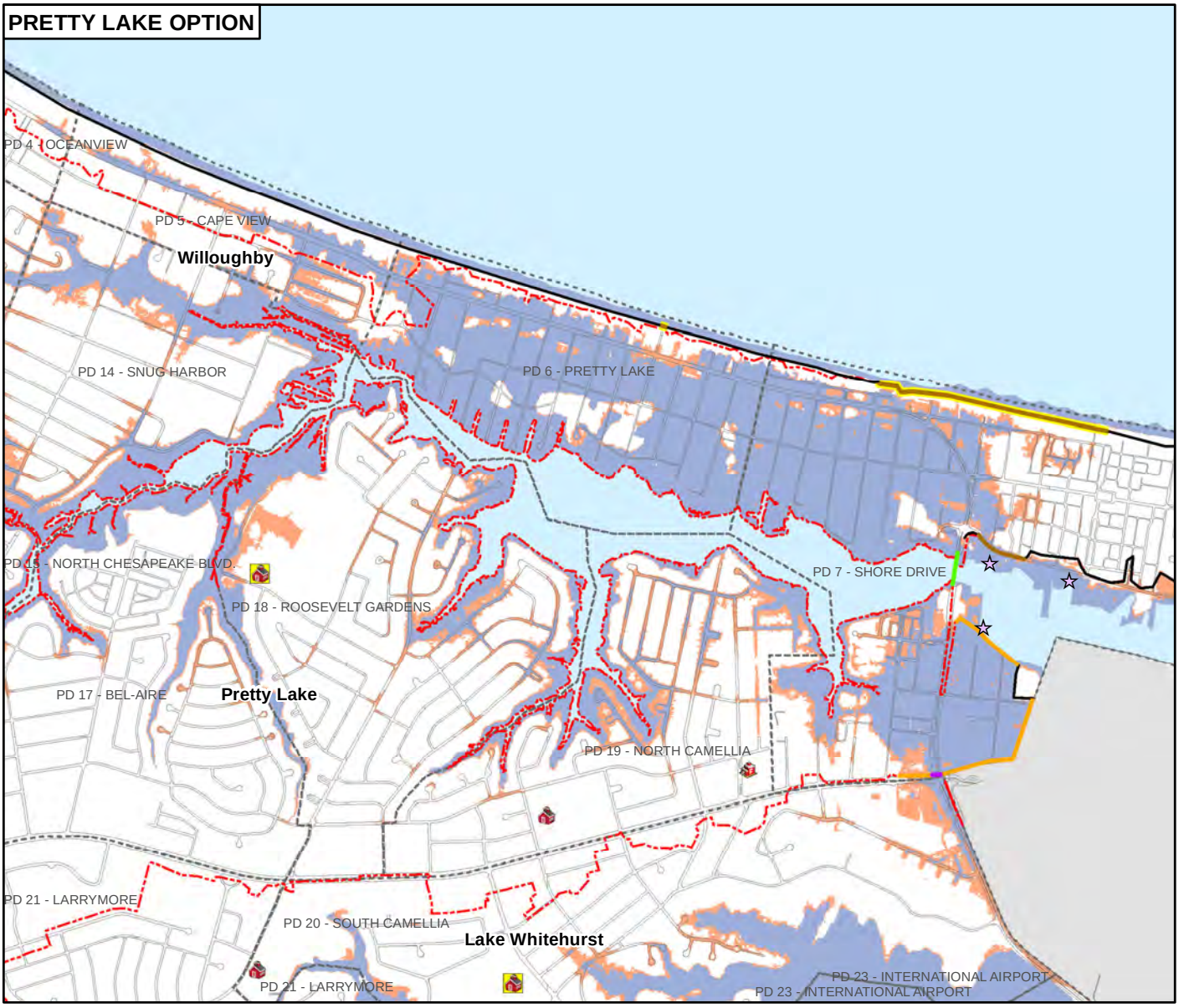

LEGEND

- Project Area
- Planning District Boundary

Approximate Coastal Flooding
Does not include precipitation.

- 1% Annual Chance Coastal Flood Extent
- 1% Annual Chance Coastal Flood Extent with 1-Foot Sea Level Rise

Mitigation Options

- Road Raise
- Berm
- Flood Gate
- Floodwall
- Culvert
- Existing Floodwall
- Existing Topography
- Feature with Yellow Highlight Required for 1-foot of Sea Level Rise
- House Raising
- Outfall Flap Valve
- Pump Station

Critical and Essential Facilities

- Emergency Shelters
- Fire Station
- Hospitals
- Police Station
- School
- Water Treatment Facilities

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POTENTIAL FLOOD MITIGATION OPTION
Pretty Lake Project Area
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE K-2

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