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

May 2012
Fugro Project No. 04.81110022

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Norfolk, Virginia 23510
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May 2, 2012
Project No. 04.81110022

City of Norfolk
Department of Public Works
City Hall Building, Room 700
Norfolk, Virginia 23510

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

## EXECUTIVE SUMMARY

As part of the comprehensive City-wide Coastal Flooding Study, this study builds upon previous phases of work and identifies flood mitigation options throughout the City. Since 2008, the City of Norfolk has undertaken an effort to evaluate coastal flooding hazards, identify a range of mitigation options, and develop a phased approach for implementing various options. During 2008 and 2009, the City implemented a tide gauge monitoring program that was used to develop an understanding of the relationship of water levels between the tidal tributaries in the City and the long, term tidal station operated by NOAA at Sewells Point. The relationship was used to define water levels throughout the City for a range of tidal return periods (e.g. 2-, 5-, 10-, 25-, 50-, and 100-year). 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 include policy, education, building codes, elevation of buildings and roadways, and infrastructure.

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.

Project areas were defined based on hydrologic boundaries. Therefore, each project represents a stand-alone project. We identified 15 project areas throughout the City as shown on Figure 1-2. A given project area may include several options.

Primary mitigation options focused on in this study include infrastructure-type of projects. Those types of projects generally include items such as floodwalls, earthen berms, gates, pump stations, backflow controls on outfalls, and elevating structures. Figures 4-6, 4-10, and 4-12b show an example of residential flood proofing, an overland flood gate, and a large waterway flood gate, respectively. Projects considered herein are planned to mitigate a 1% annual chance of exceedance storm tide. Estimated project cost and project benefit are based on reduction of flood damages are included herein to help prioritize projects. Project cost estimates are based are design, permitting, easement acquisition, construction, operation, and maintenance costs over a 50-year project lifetime.

Project cost estimates range from approximately $10M to $306M. Project options generally include a flood barrier system across the basin outlet and for areas outside the barrier, elevating structures or flood proofing of structures are considered. We have delineated areas where multiple structures may meet the raising criterion. The most expensive project option is associated with the largest water body crossing – the Lafayette River. The Lafayette River watershed is largest project area considered herein (comprises 46% of the City's land mass).

We have used a GIS-based approach to estimate the predicted damages and flooded roadways from a 1% annual chance storm tide. Figure 3-12b shows an example of how roads centerlines were evaluated for accessibility and restrictions due to flooding. This study focuses solely on tidal flooding and does not incorporate the effects of precipitation. Therefore, flooding extents considered herein likely would be worse during a storm since precipitation typically accompanies the storm events that produce tidal departures.

The Lafayette 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%. Figures 3-6 and 3-7 summarize and illustrate the results of the estimated predicted damages calculated per project area.

This study also considers the potential effects of sea level rise. In terms of predicted flooding damage, the general factor of increase resulting from 1-foot in sea level rise for a 1% annual chance storm tide is 1.9 times. The most vulnerable area is West Ghent where the factor increase is 5.2. Broad Creek, Lambert Point, Eastern Branch-Ingleside, and Eastern Branch Military also are expected to experience increased damage of 2 to 4 times from a 1% annual chance storm tide after a one foot rise in sea level.

This provides a relative comparison of the projects to each other using a scoring procedure based on the 1% annual chance storm event. Scores are based on damage reduction per invested infrastructure dollar and additional points awarded for additional protection of critical or essential infrastructure. West Ghent, Tidewater, Lafayette River, Hague, Pretty Lake, and Mason Creek all had options that appeared provide some benefit.

The Lafayette River and Tidewater projects were identified as potential to tie into other future projects and provide additional benefit beyond flood hazard mitigation. Tidewater – Harbor Park alignment could construct an earthen levee that could be built out as a walking/jogging path along the water front and enhance local use in the area or tie into development projects. Lafayette River project identified a potential crossing option between Lambert Point and the NIT terminal that could be built out as a transportation corridor for Light Rail or access to NIT while providing protection to the Lafayette River watershed.

N
W E
S

0 4,000 8,000 Feet

**PROJECT AREAS**
City-wide Coastal Flooding Study
Norfolk, Virginia

**LEGEND**
Project Area Boundary
Planning District Boundary

FIGURE 1-2

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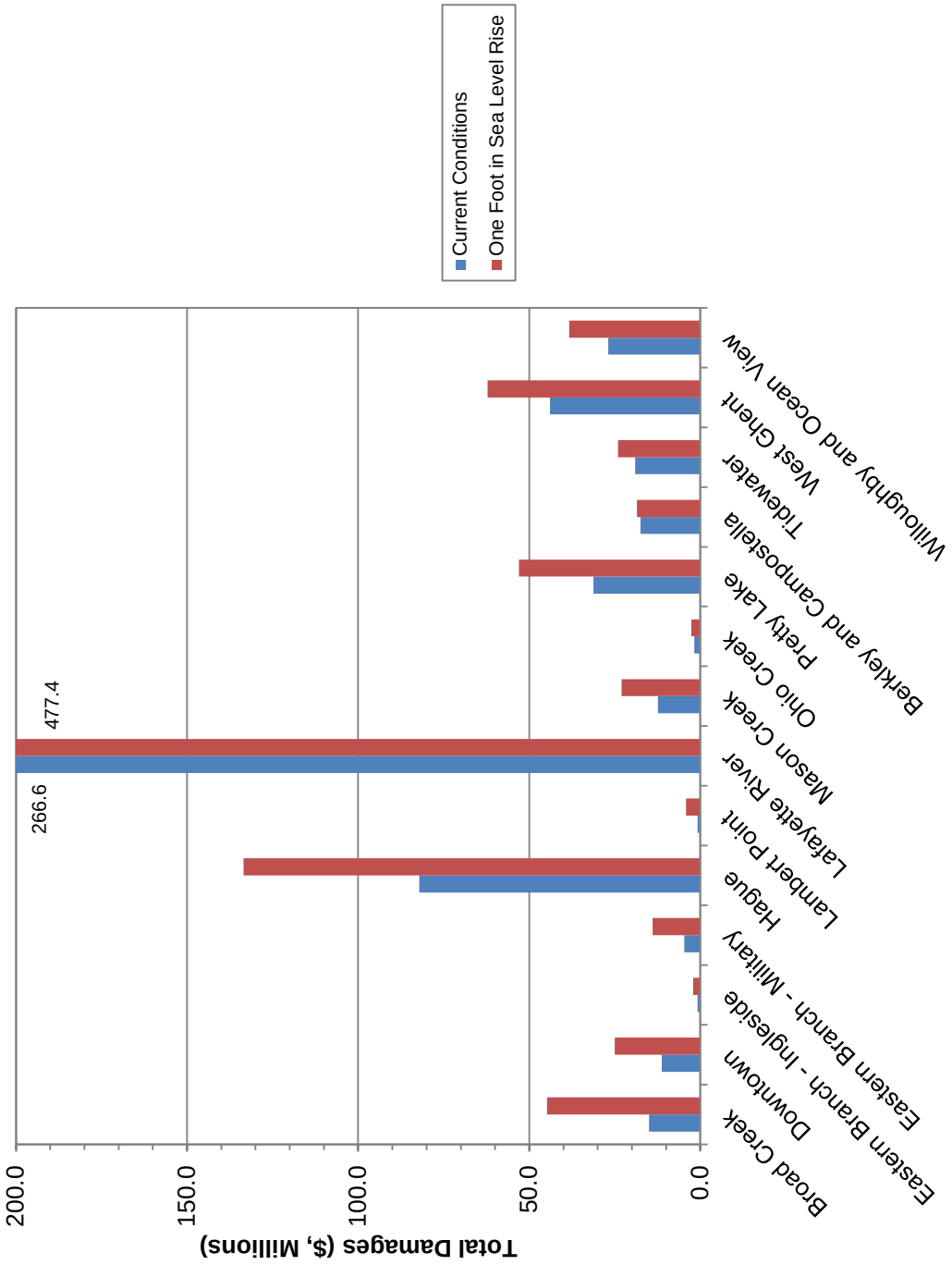
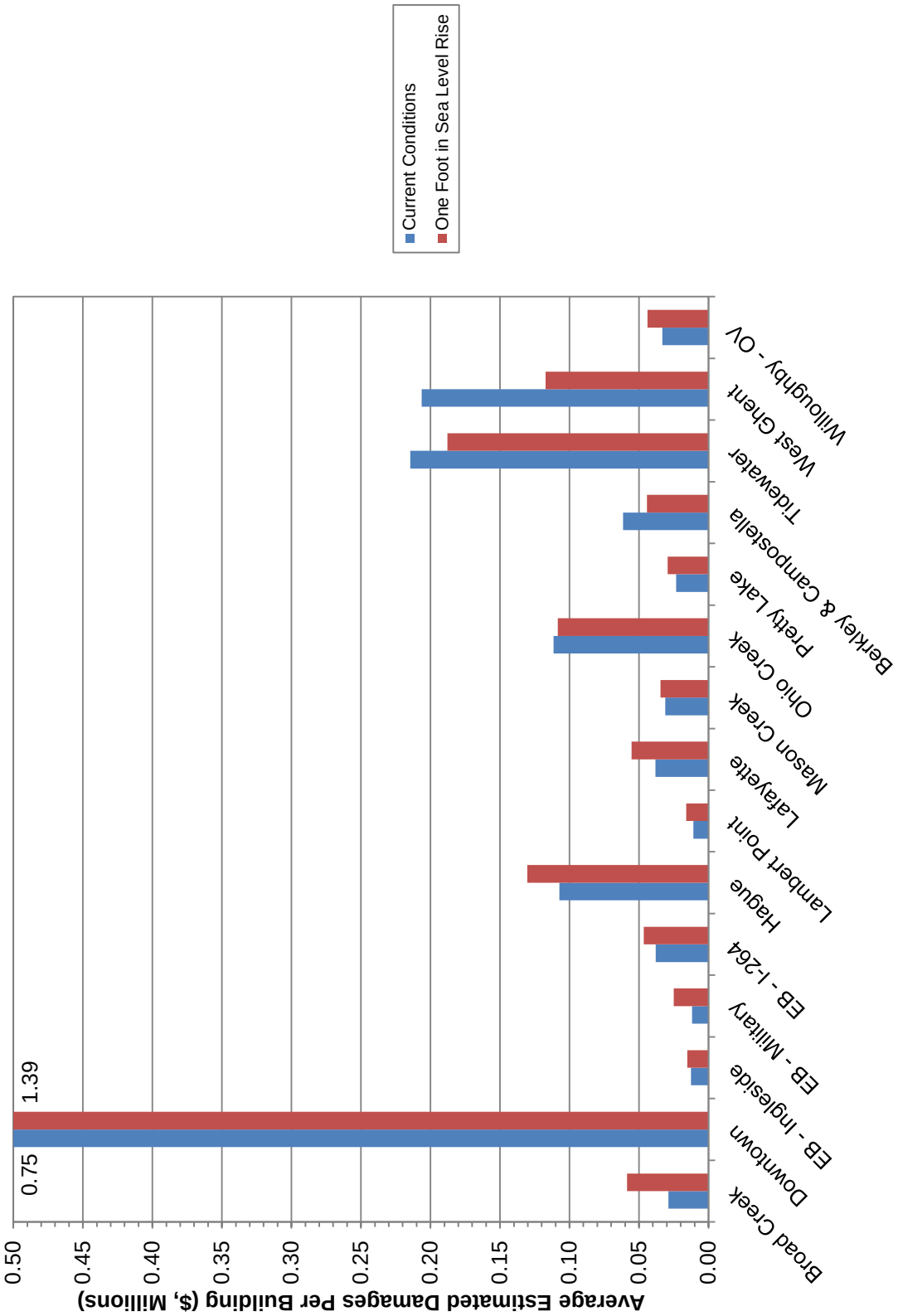



**TOTAL DAMAGES FOR BUILDINGS BY PROJECT AREA**
City-wide Coastal Flooding Study
Norfolk, Virginia



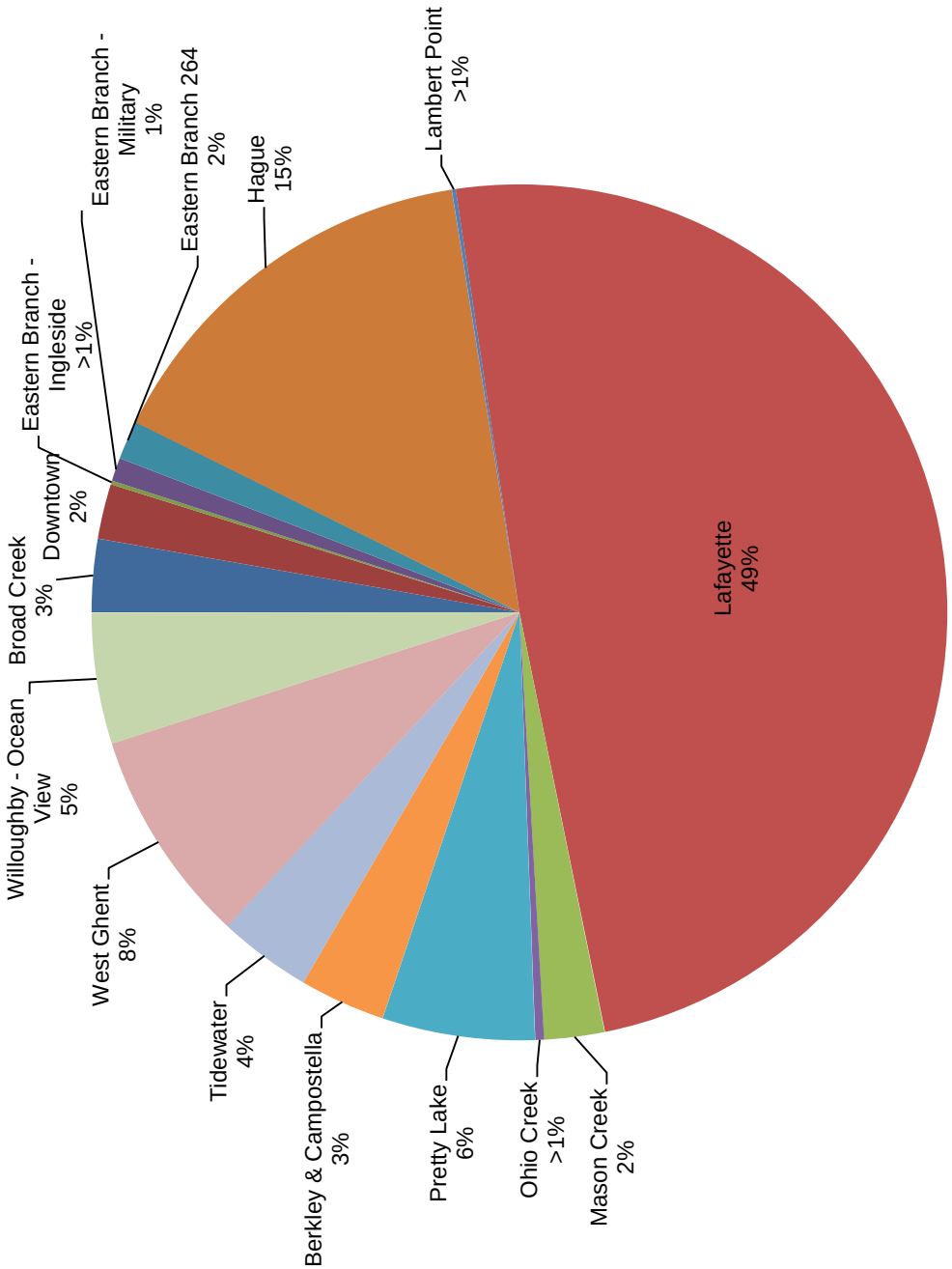
FIGURE 3-6a




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



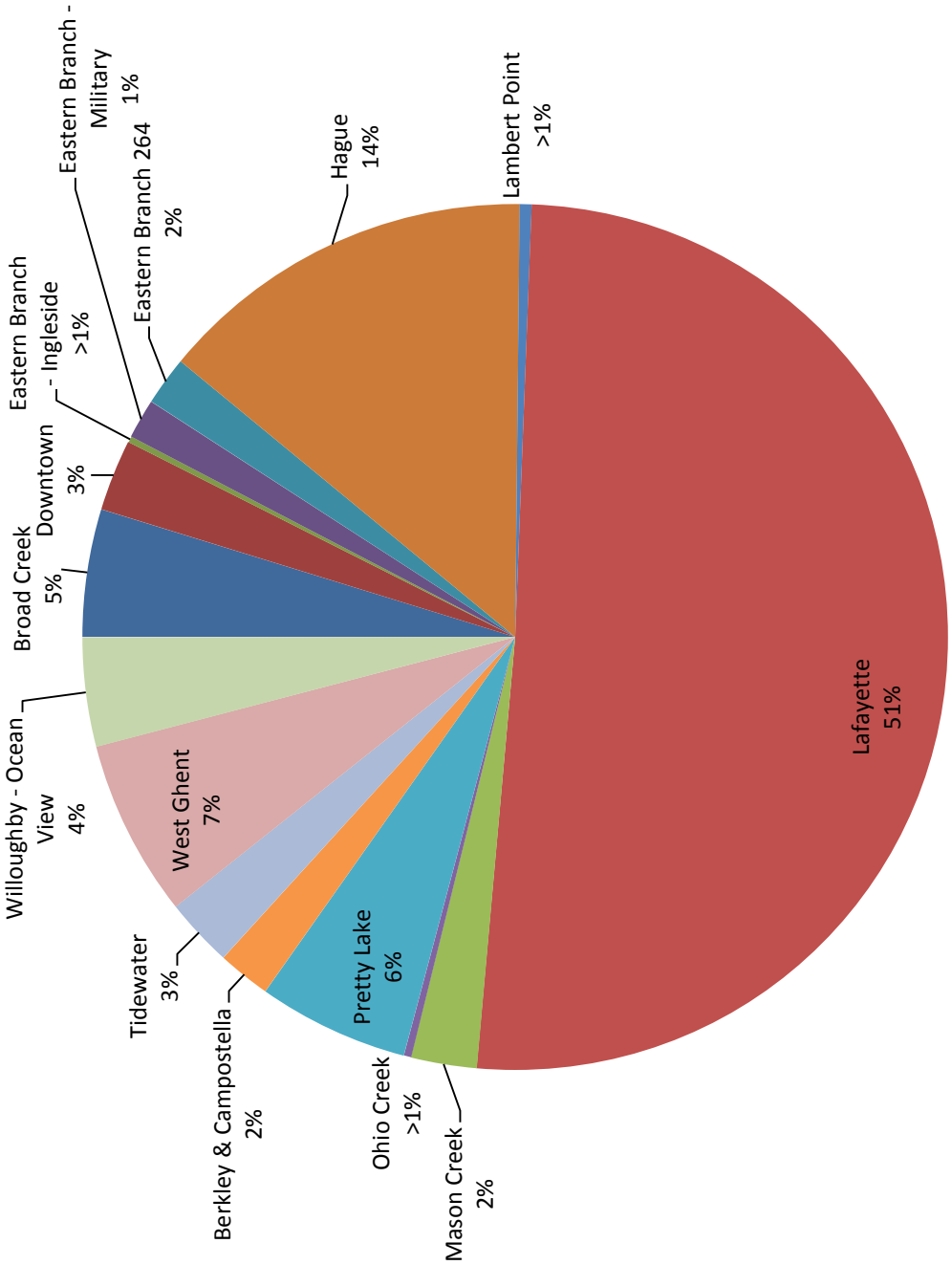
FIGURE 3-6b




**RELATIVE TOTAL DAMAGES FOR BUILDINGS**
**UNDER CURRENT CONDITIONS BY PROJECT AREA**
City-wide Coastal Flooding Study
Norfolk, Virginia



FIGURE 3-7a

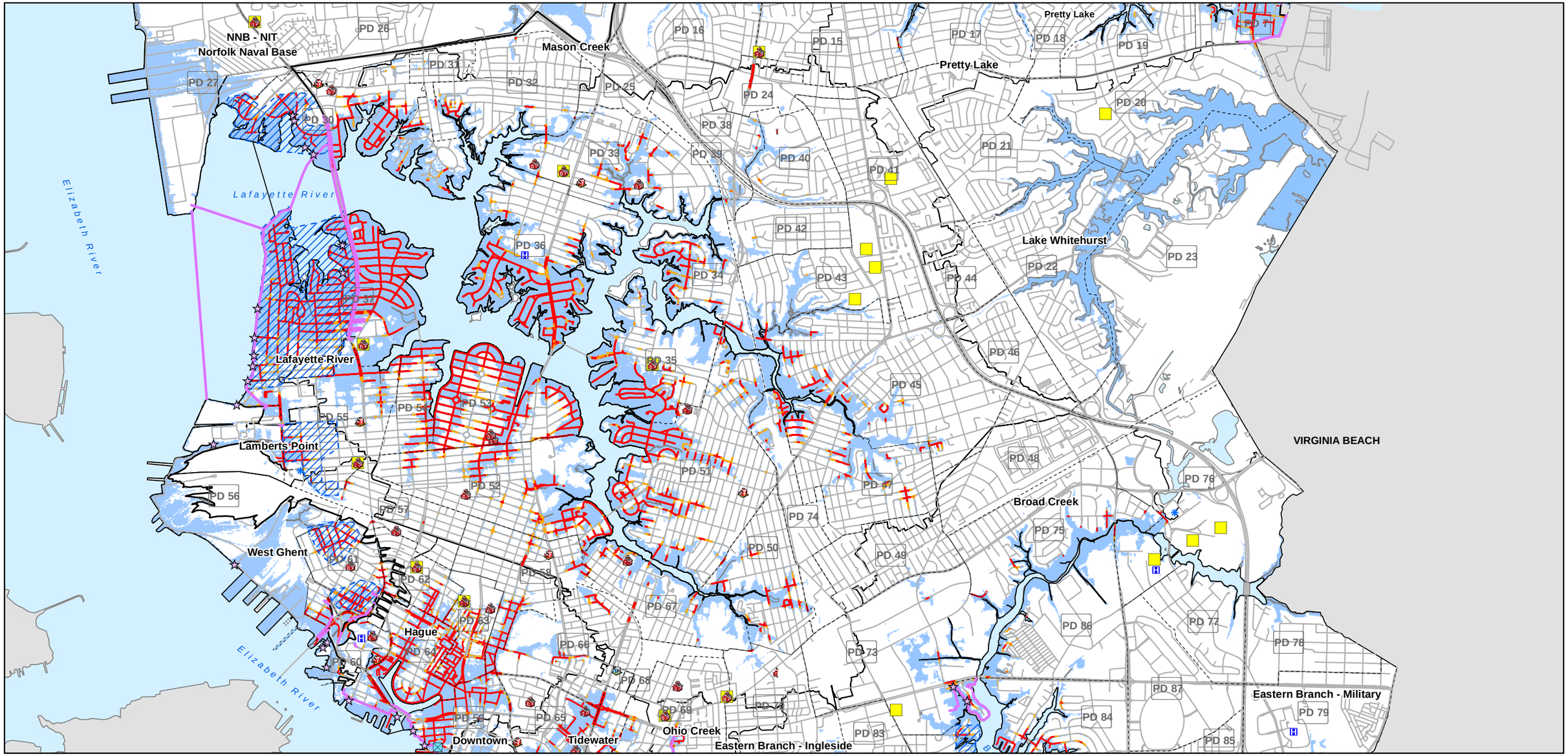



**RELATIVE TOTAL DAMAGES FOR BUILDINGS WITH 1-FOOT SEA LEVEL RISE BY PROJECT AREA**

City-wide Coastal Flooding Study
Norfolk, Virginia



FIGURE 3-7b




## 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
Eastern Branch - Military

N
W E
S

0 3,000 6,000 Feet

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

FIGURE 3-12b

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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

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

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