

FIGURES

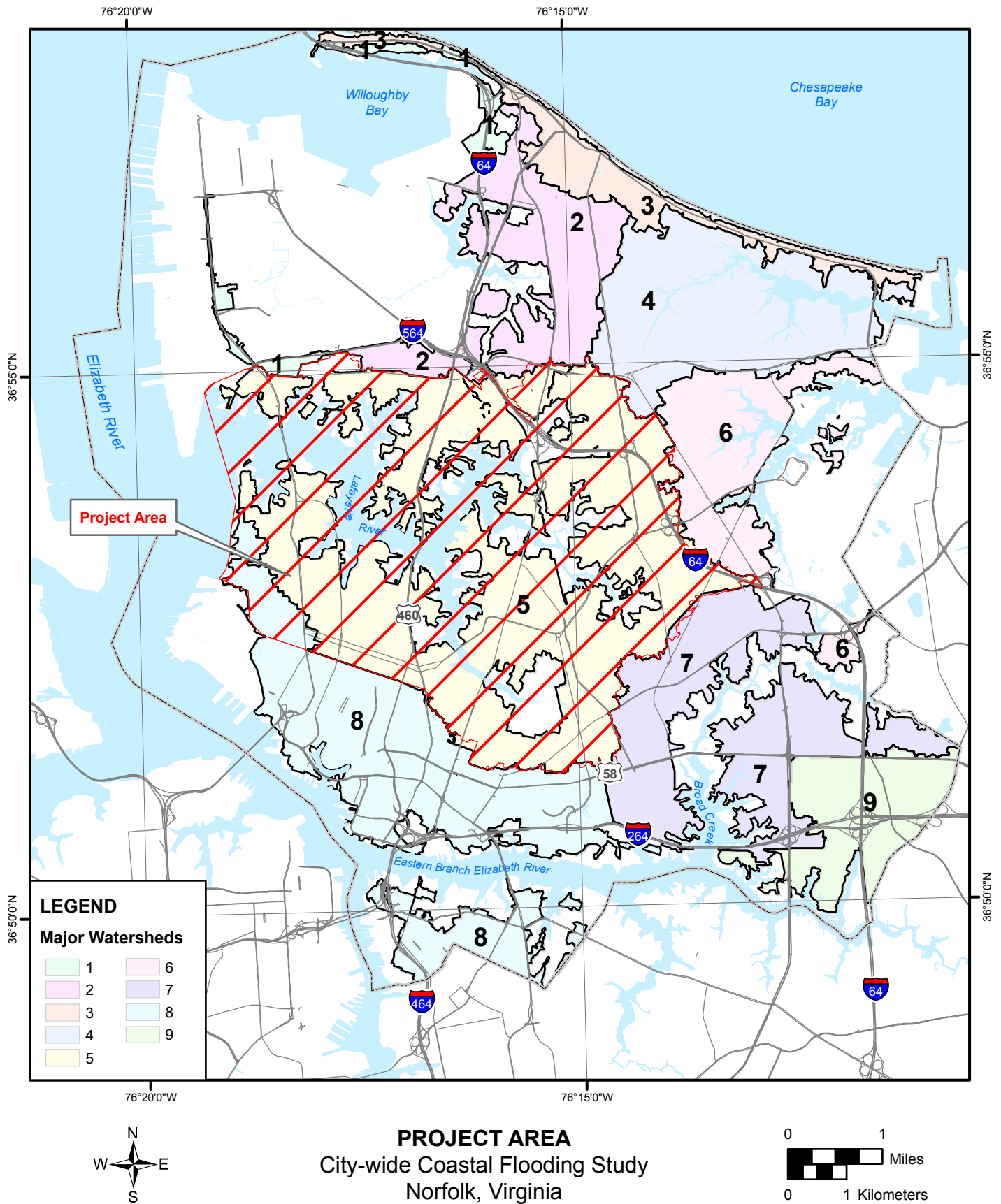


FIGURE 1-1

N:\Projects\3627_City_Norfolk\04_8111_0007_LafayetteRiver\Outputs\2014_10_2_Flood_Mitig_Rpt\MXD\Fig-1_Project_Overview.mxd, 1/13/2016, wcupples



DH - DePaul Hospital
HB - Hampton Blvd Bridge
HM - Hermitage Museum
LRNC - Lafayette River Navigation Channel
NGH - Norfolk General Hospital, Eastern Virginia Medical Center,
and Children's Hospital
NYCC - Norfolk Yacht & County Club
ODU - Old Dominion University
Z - Norfolk Zoo

LEGEND

-  Lafayette River Watershed Boundary
-  Study Area Boundary

PROJECT OVERVIEW

City-wide Coastal Flooding Study

Norfolk, Virginia

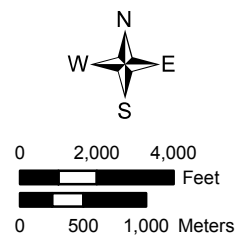


FIGURE 1-2



LEGEND

Conceptual Water Crossing Locations

—— Crossing Location Option

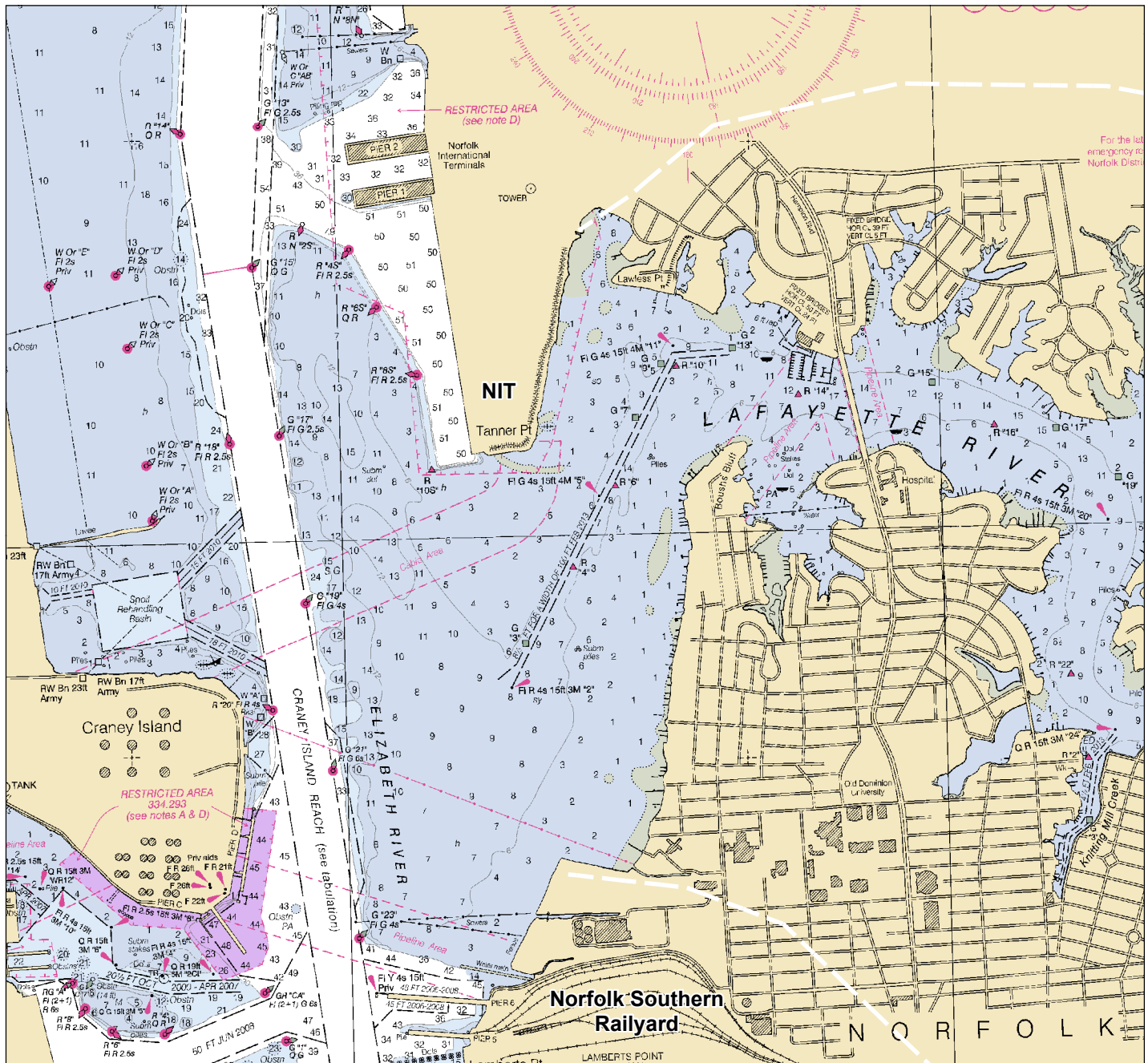
- - - - Alternative Tie-in Location

FLOOD BARRIER CROSSING OPTIONS
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 1-3

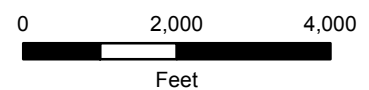


FIGURE 2-1



LEGEND

- Study Area Boundary
- Bathymetric Soundings in Feet (MLLW)**
Source: NOAA Chart 12245 (2013)



BASIN OUTLET
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 2-2

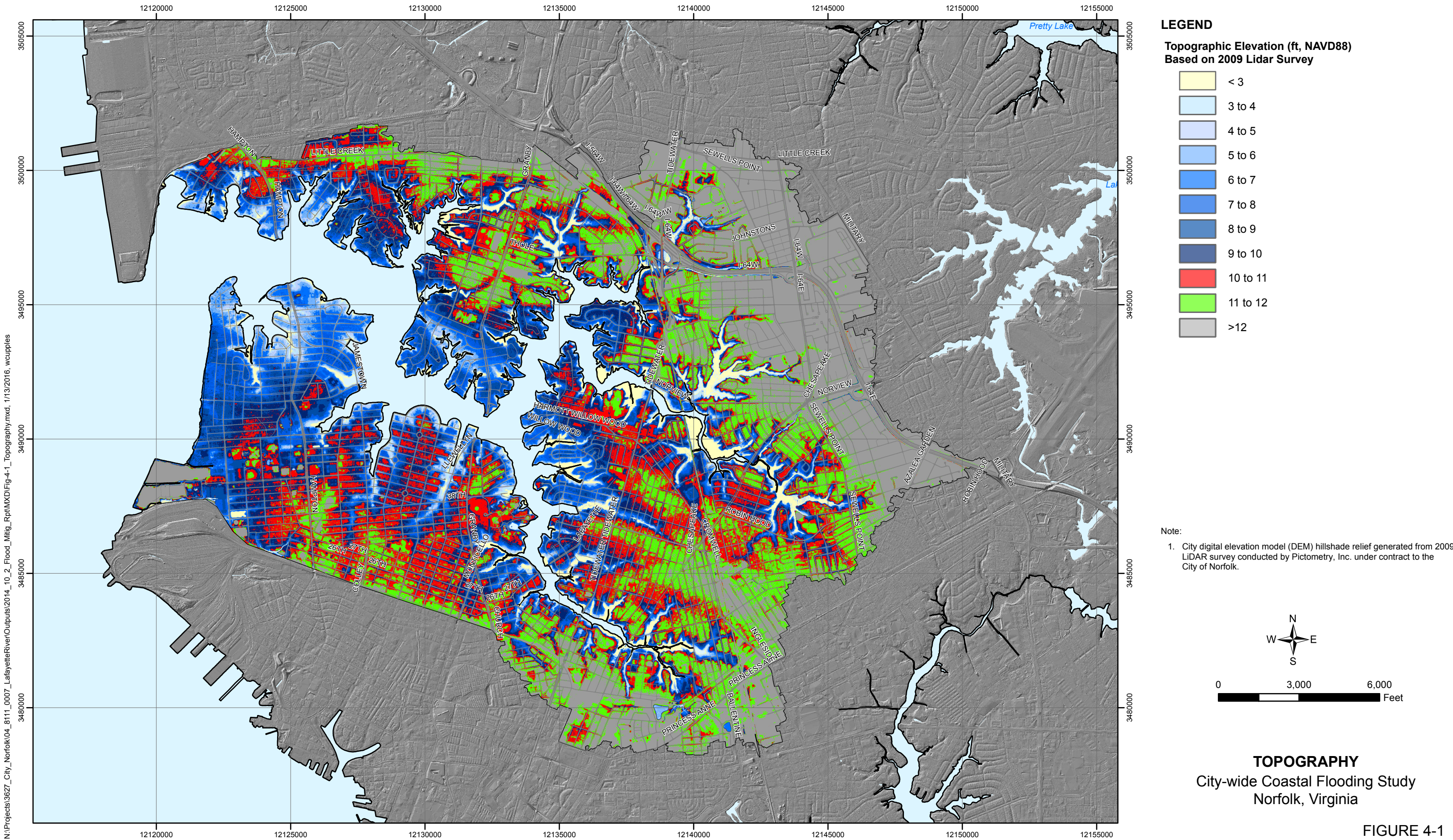
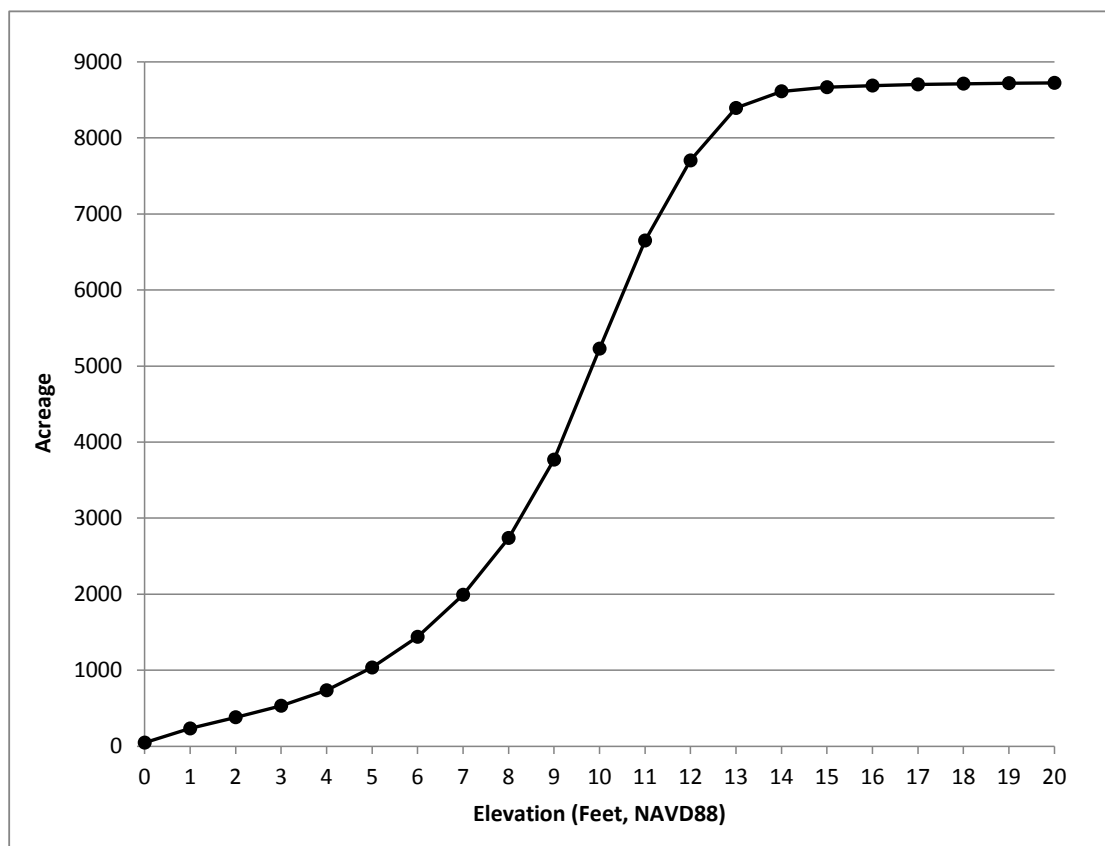


FIGURE 4-1



This graph represents a statistical characterization of the ground surface elevation within the Lafayette River watershed. This cumulative frequency graph is based on the 2009 LiDAR survey data that has a 3-ft by 3-ft bin size (horizontal footprint is 3-ft by 3-ft). The watershed encompasses approximately 8,700 acres. Acreage estimates in this graph do not include the Lafayette River water body.

Examples of how this graph may be interpreted:

- 1) Roughly 1,000 acres of the study area are equal to or below elevation 5 feet (NAVD88).
- 2) Roughly 4,500 acres of the study area are equal to or below elevation 9 feet (NAVD88).

STATISTICAL DISTRIBUTION OF TOPOGRAPHY
Cumulative Frequency
City-wide Coastal Flooding Study
Norfolk, Virginia

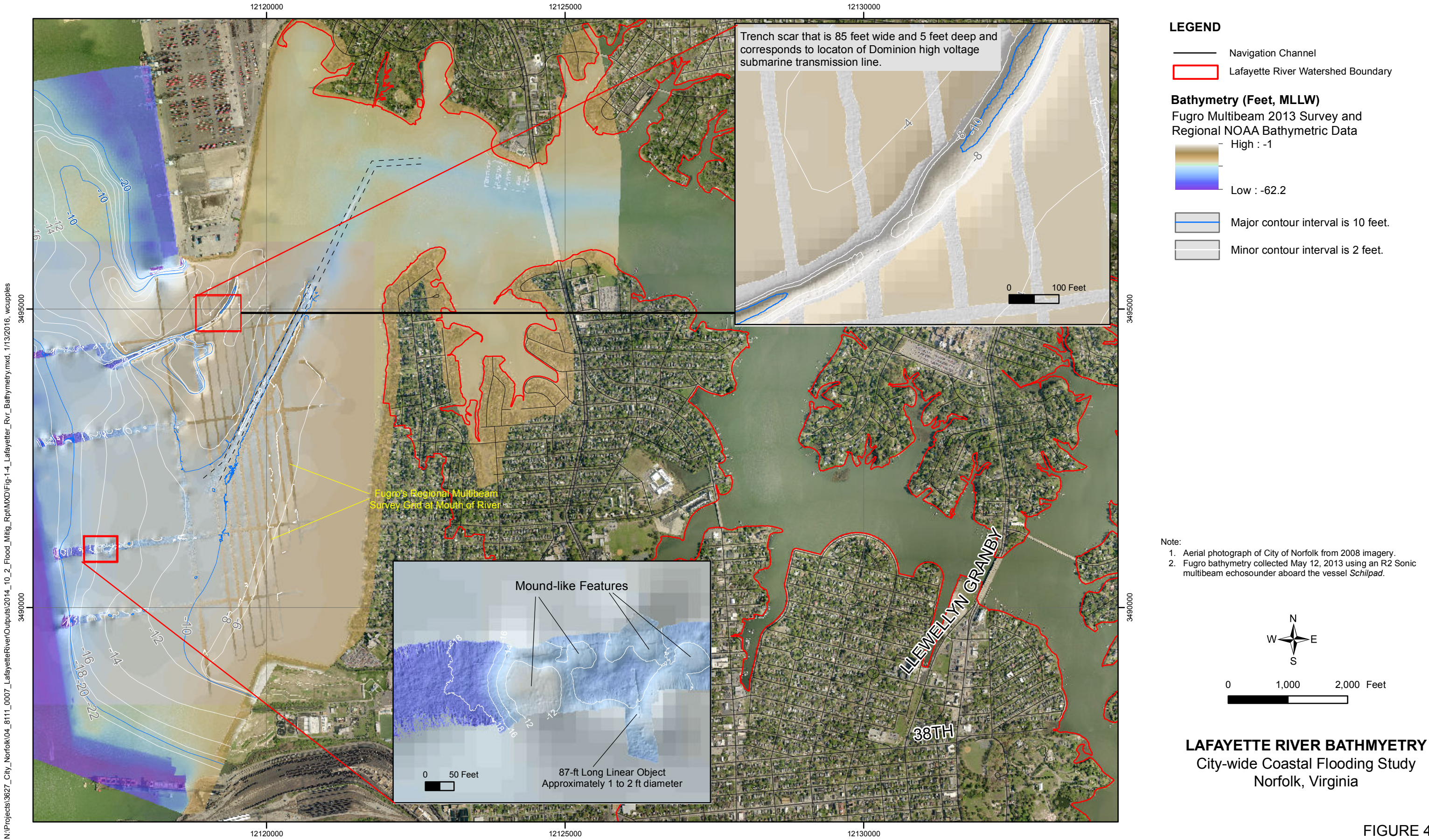
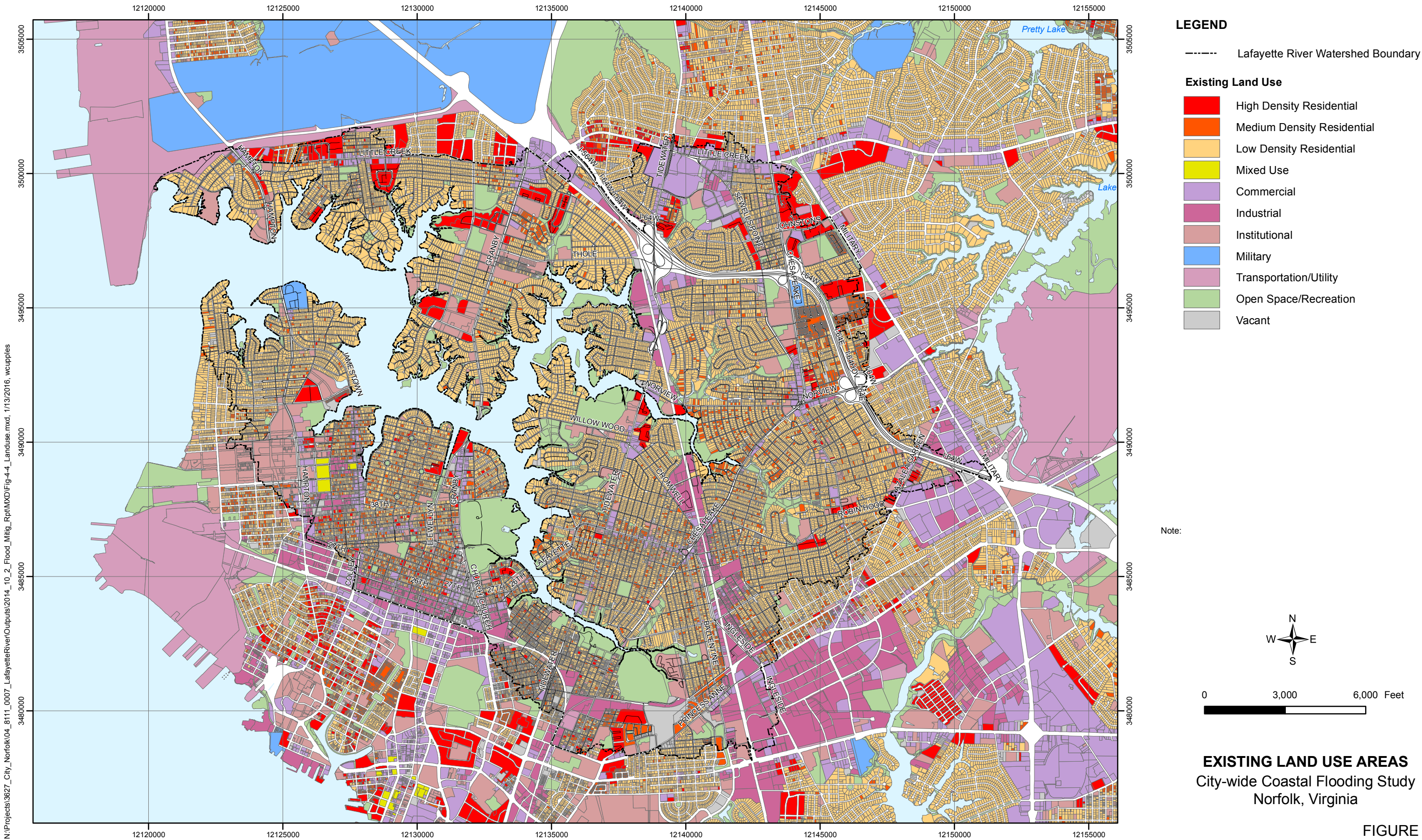
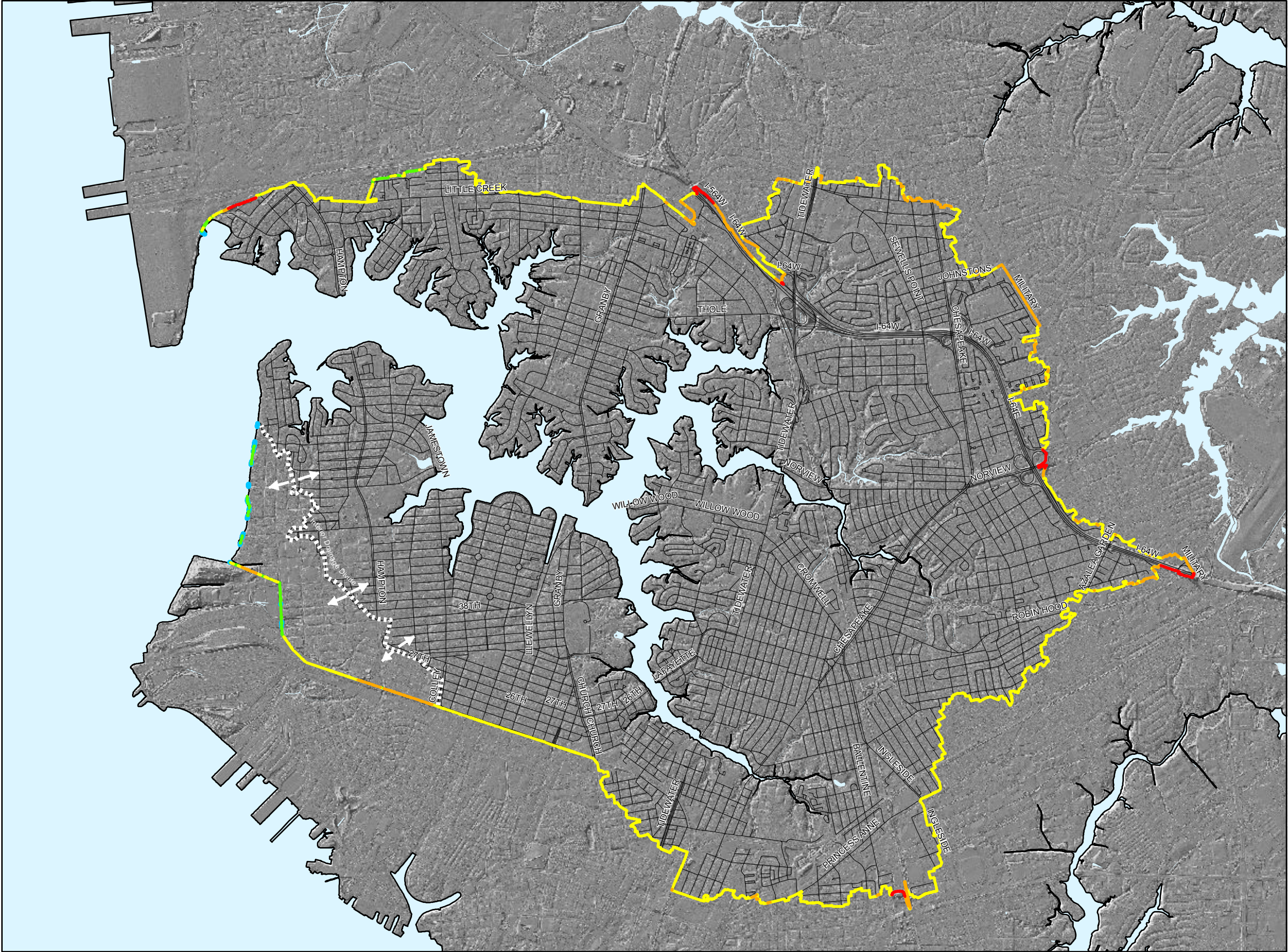


FIGURE 4-3





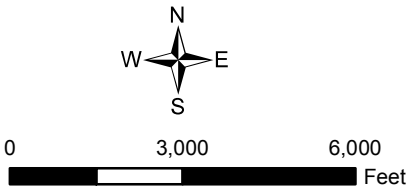
LEGEND

Rim Elevation Segments (feet, NAVD88)

- Less Than 5
- Less Than 10
- Less Than 15
- Less Than 20
- Greater Than 20

Note:

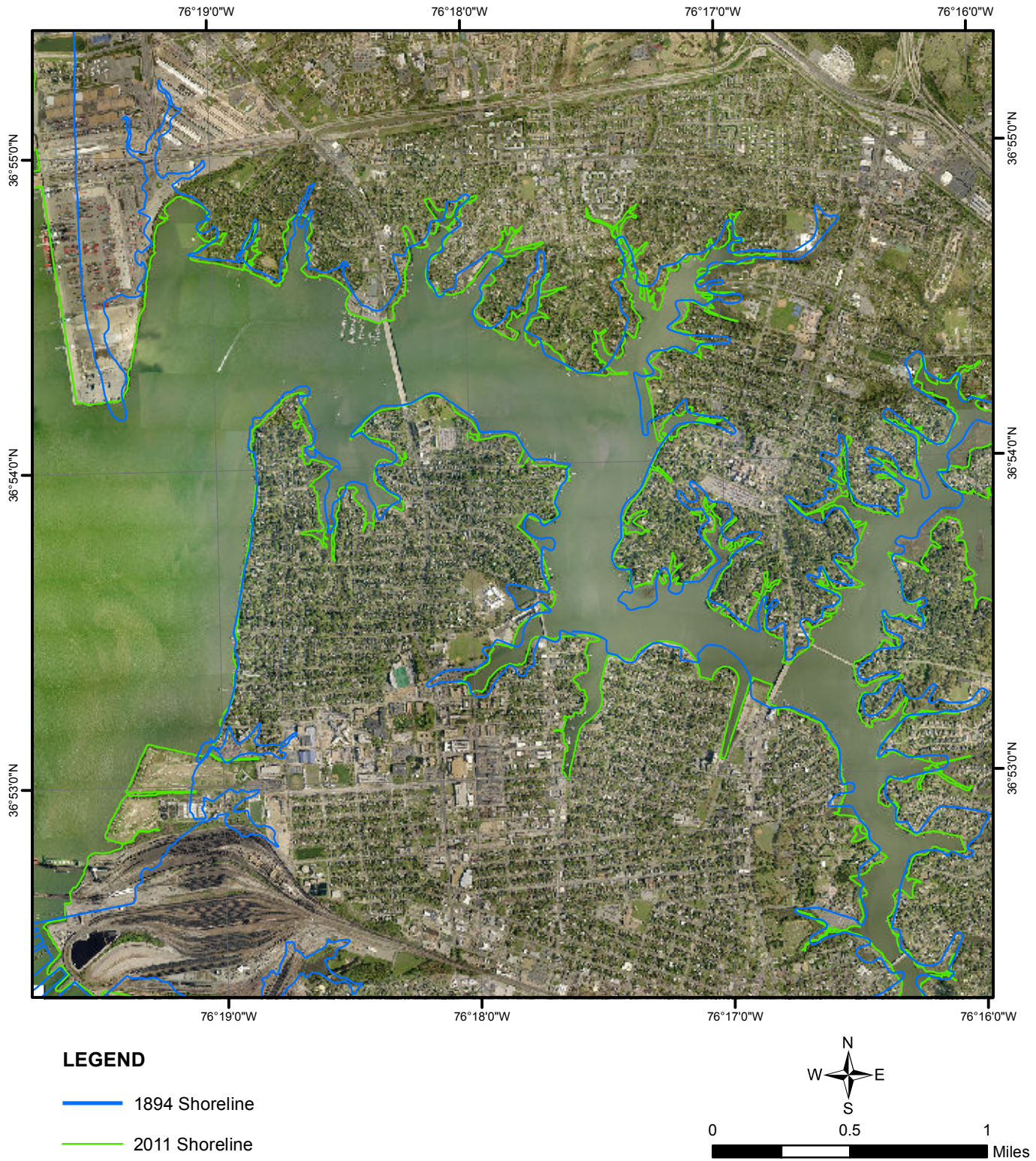
1. City digital elevation model (DEM) hillshade relief generated from 2009 LiDAR survey conducted by Pictometry, Inc. under contract to the City of Norfolk.

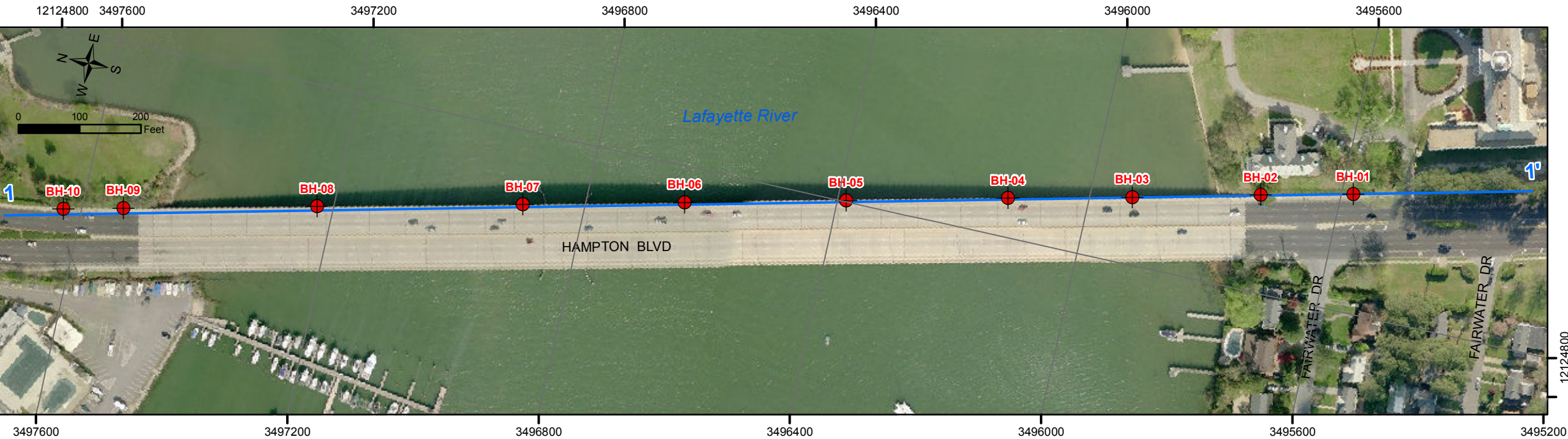


BASIN RIM ELEVATION
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 4-5

N:\Projects\3627_City_Norfolk\04_8111_0007_LafayetteRiver\Outputs\2014_10_2_Flood_Mitg_Rpt\MXD\Fig 4-5_Rim_Elevations.mxd, 1/13/2016, wcupples



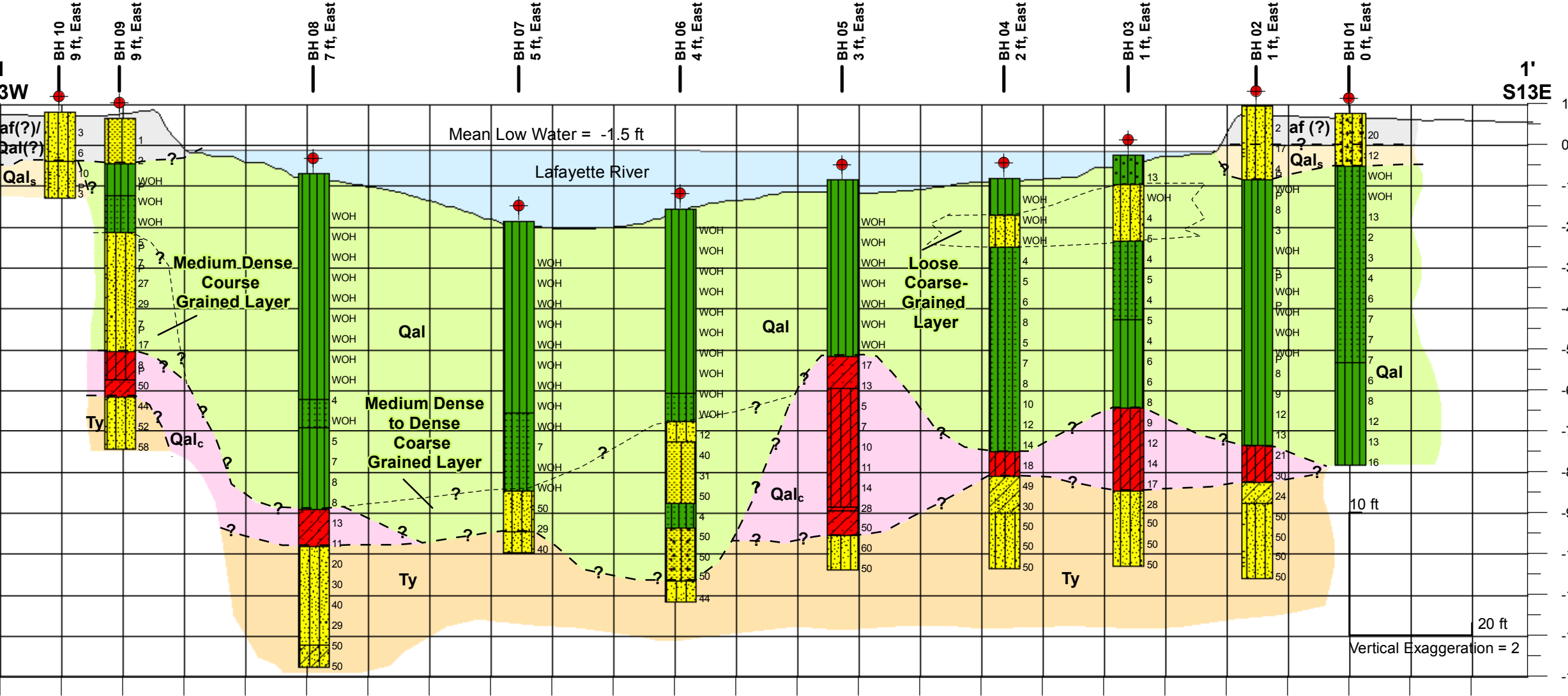


Legend

- 1967 Hampton Boulevard Bridge Borings
- 1-1' Cross Section Line

Notes:

- Coordinate Grid is NAD 83 Virginia State Plane, South Zone, Feet.
- Vertical Datum is not stated in historical borings, but is assumed to be referenced to NGVD 1929 and based on 1960-1978 Tidal Epoch published by the National Ocean Service (NOS). Mean Low Water was observed to be -1.5 feet during the time of drilling operations in 1967.
- Stratigraphic contacts are approximate and are interpreted from borings. Conditions vary both along and perpendicular to the section line.
- Boring logs are projected onto the line of the cross sections. Therefore, stratigraphic contacts may not exactly correspond to the indications (lithology, etc.) in the logs.



af Artificial Fill

Recent Deposits (Holocene)

- Qal_s Quaternary Alluvium (Sand) - Predominately loose to medium dense sand to silty sand
- Qal Quaternary Alluvium - Predominately very soft to medium dense silt to sandy silt with coarse-grained layers generally near the base.
- Qal_c Quaternary Alluvium (Clay) - Predominately stiff to very stiff clay with minor amounts of sand and silt.

Nearshore Marine Deposits (Tertiary)

- Ty Yorktown Formation - Predominately fine silty to clayey sand with shell fragments throughout

SUBSURFACE PROFILE
ALONG HAMPTON BOULEVARD
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 4-7

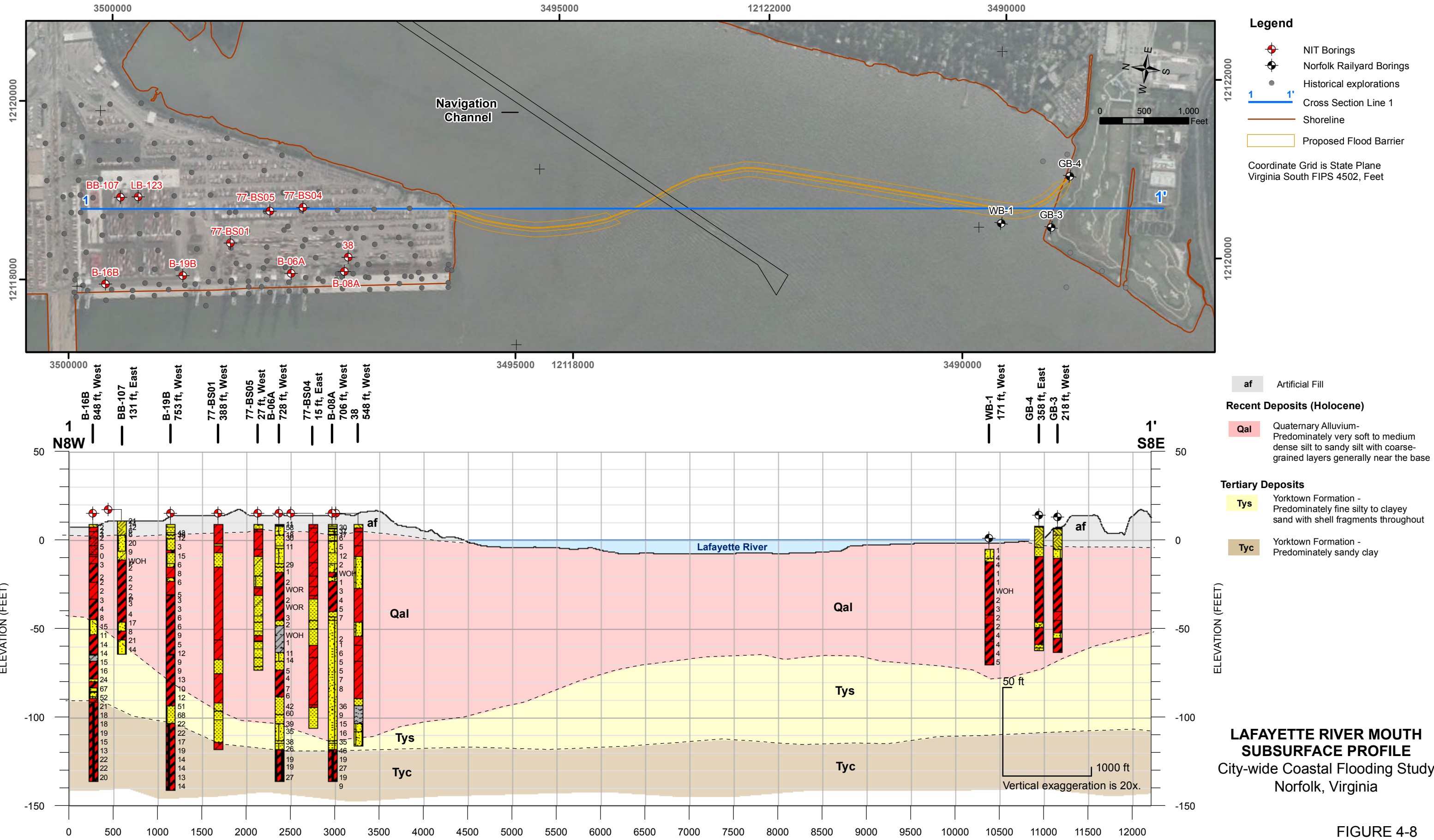
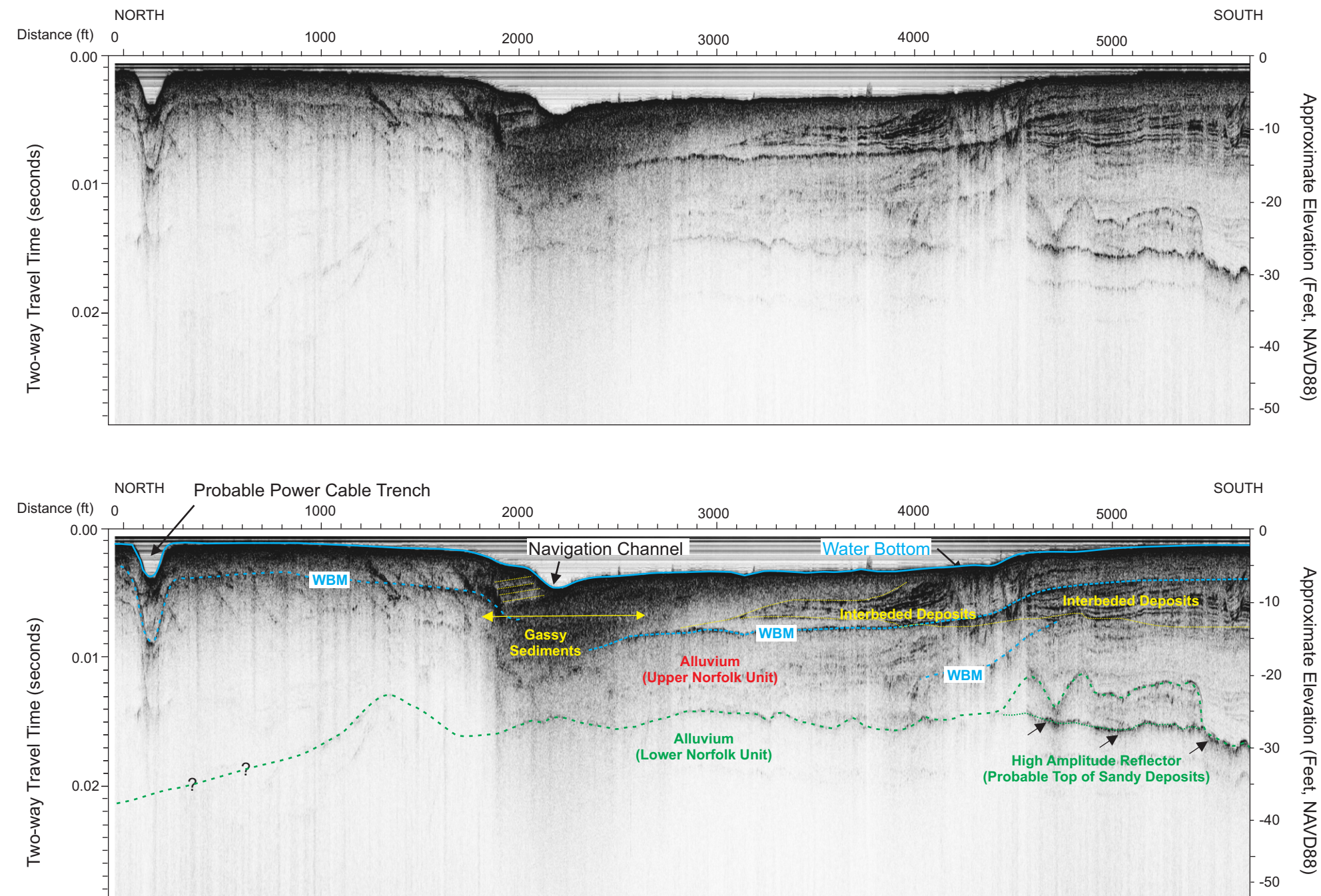


FIGURE 4-8





- Notes:
- 1) Time-to-depth conversions are approximate and calculated using $V_p = 5,000$ feet per second.
 - 2) Seismic data was collected using a Chirp sub-bottom profile by Fugro during survey in 2013.
 - 3) WBM = water bottom multiple

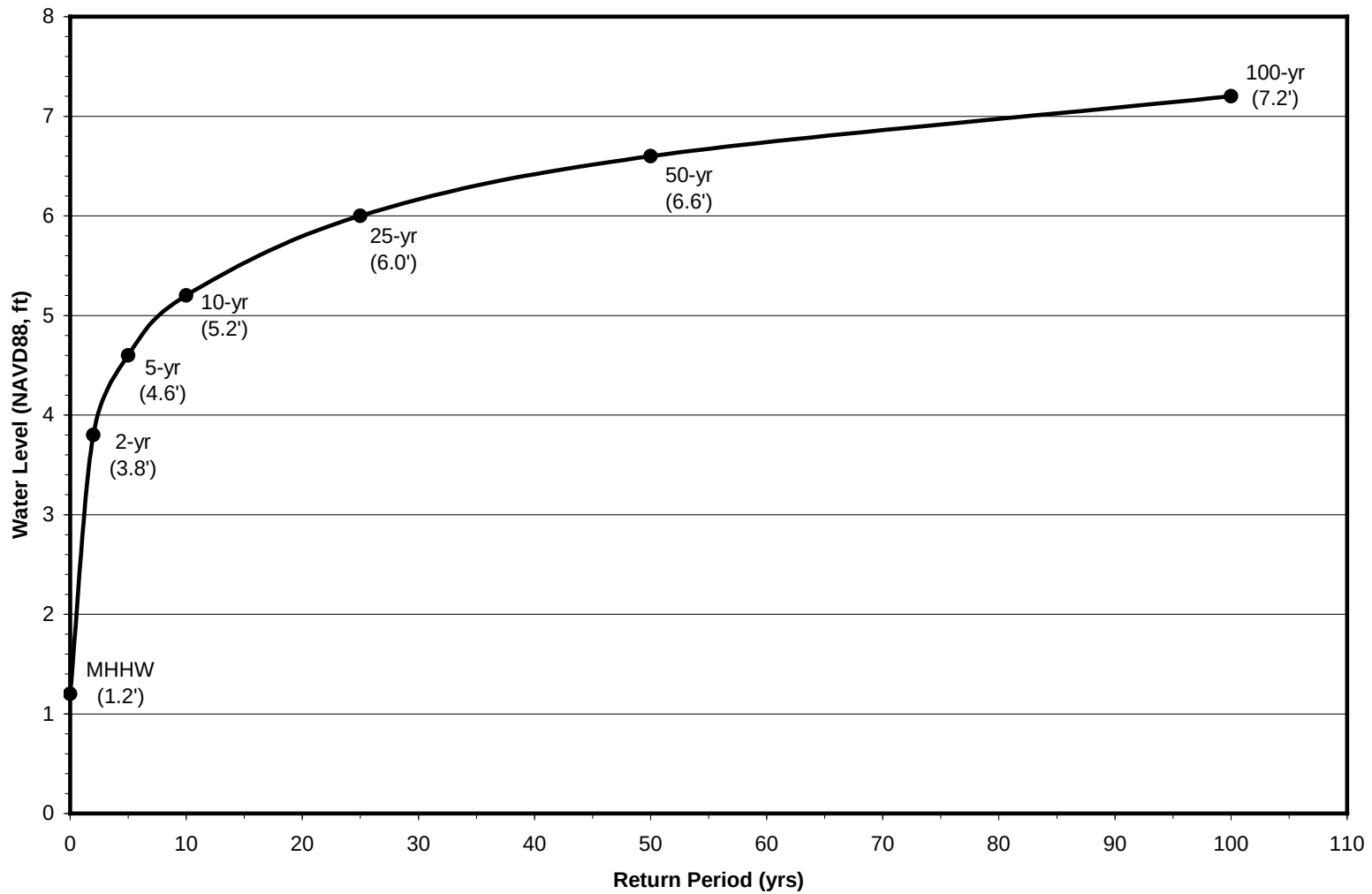
Chirp seismic data collected during the 2013 survey provide high-resolution information about stratigraphic conditions in the upper 30 to 40 feet. Seismic data reveal a high amplitude reflection at approximate El. -30 feet that may represent the sandy deposits of the Lower Norfolk Alluvium unit. The data also reveal two buried channels located at either end of the seismic line. The paleochannel located at the northern end of the line is inferred to have incised into the top of the Yorktown formation as deep as El. -110 ft (see Figure 4-9).

The seismic data also reveal a trench scar likely related to a power cable crossing. Gassy sediments were observed near the navigation channel and likely indicate the presence of soft, organic-rich deposits.

Deeper penetrating boomer seismic data indicate that the top of the Yorktown formation is approximately at El. -50 to -80 ft in the area shown on this seismic record (refer to Figure 4-9 and 4-11).

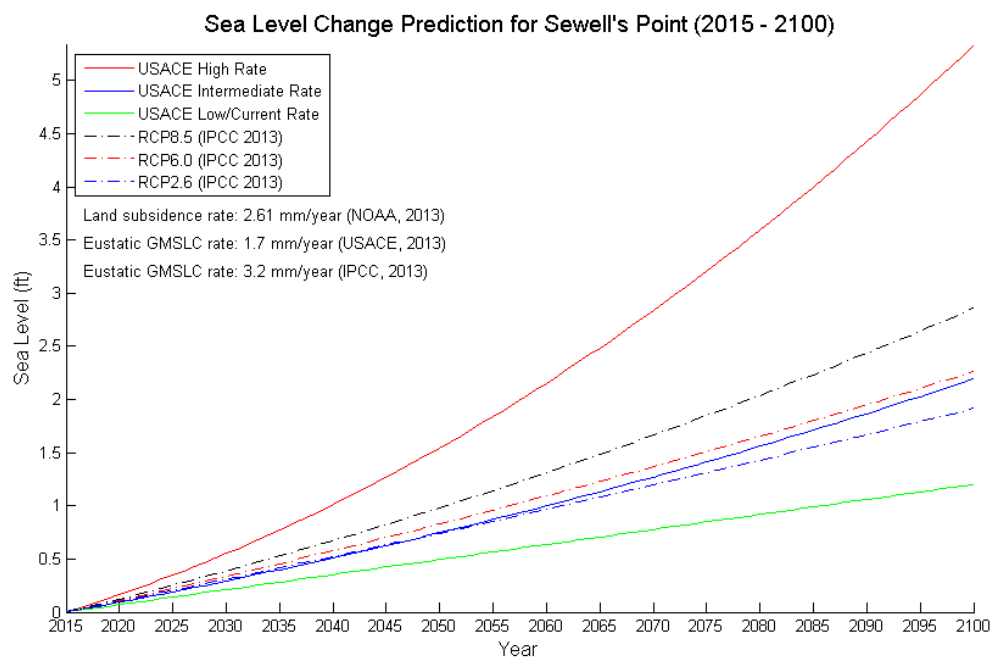
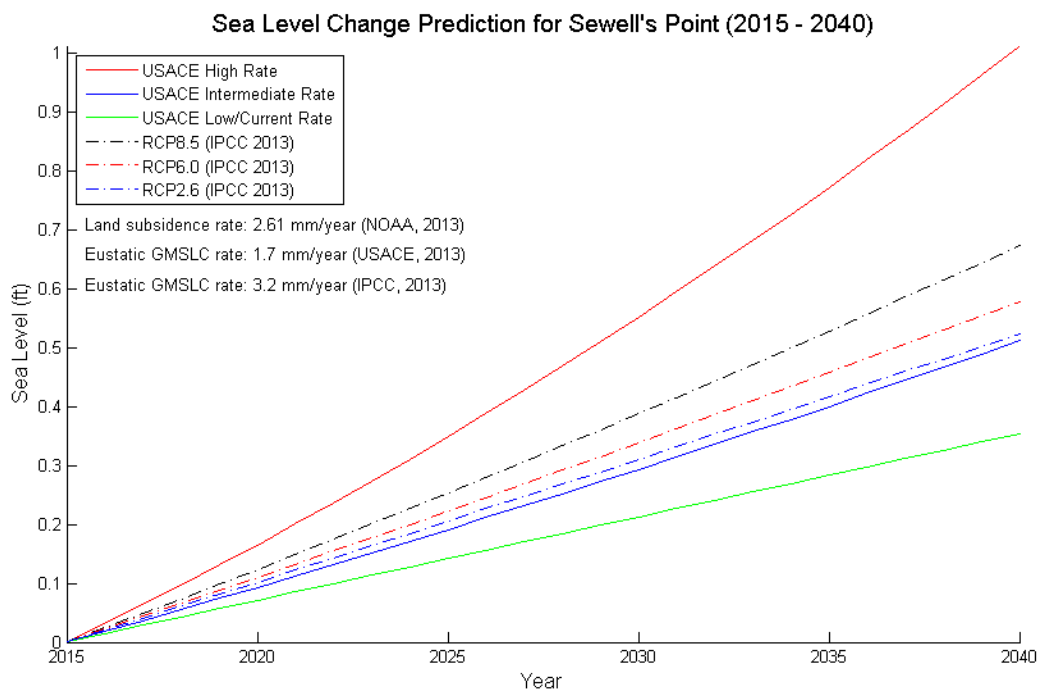
CHIRP SEISMIC RECORD, LINE 102
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 4-10



WATER LEVEL ELEVATIONS AT SEWELLS POINT FOR VARIOUS RETURN PERIODS
Based on Current Sea Level Elevation
City-wide Coastal Flooding Study
Norfolk, Virginia

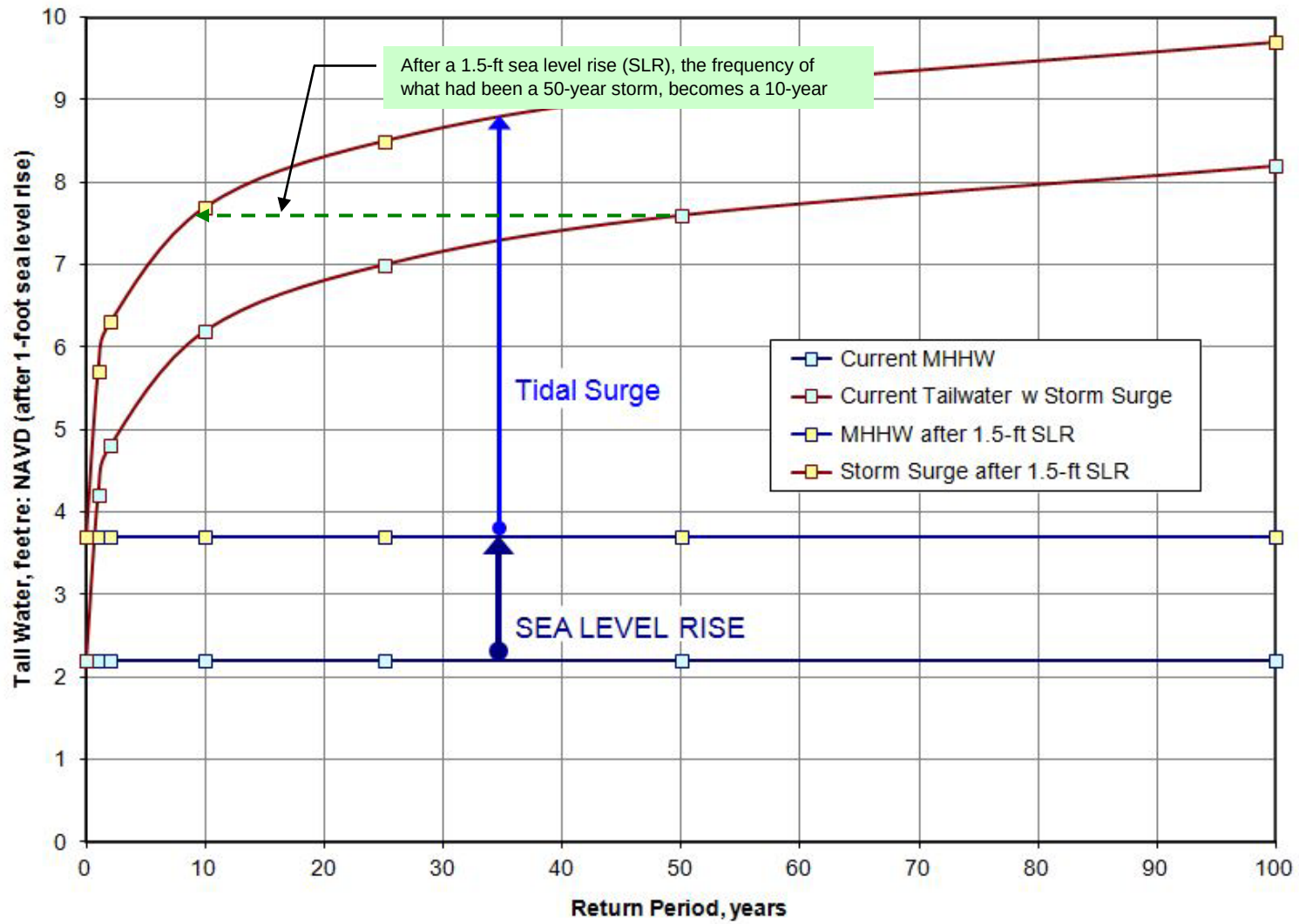
FIGURE 5-1



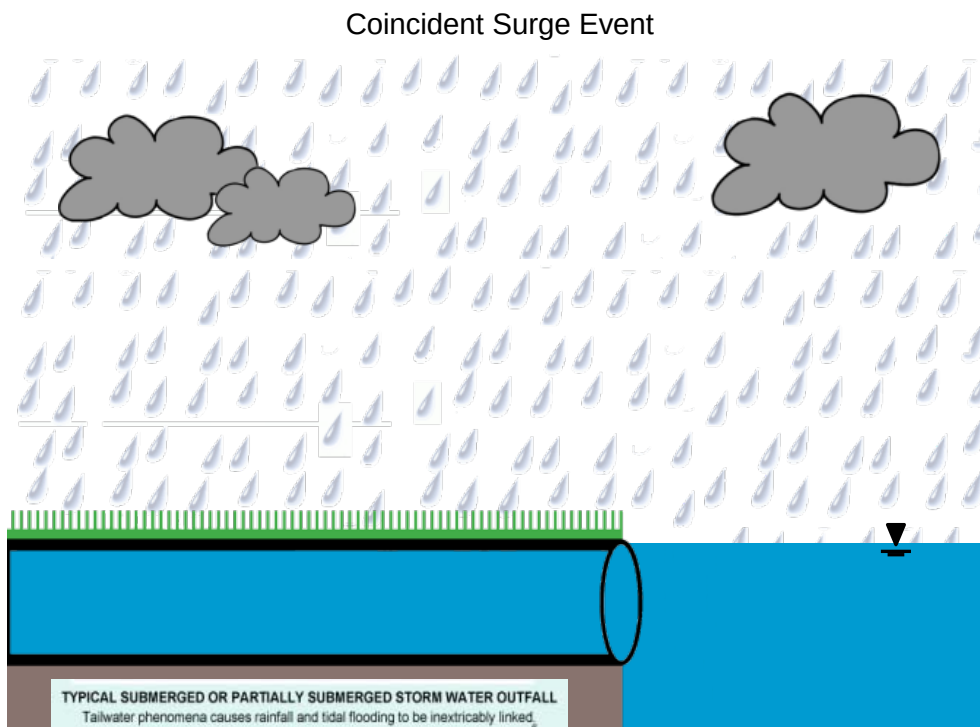
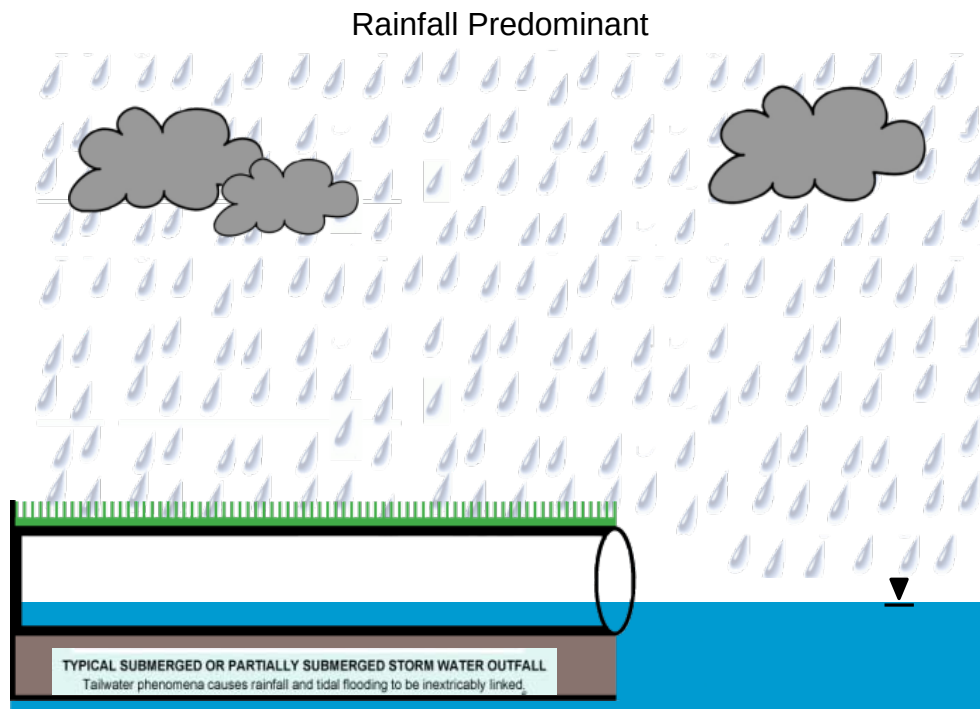
Relative sea level change curves for Sewells Point based on USACE (2011) and IPCC (2013). During a USACE study that reviewed tide gauge data in the Hampton Roads area, land subsidence rates were estimated for the Sewells Point gauge. The RCP curves shown were created by adding the land subsidence rates interpreted by USACE for the Sewells Point to the eustatic (RCP8.5, RCP6.0, and RCP2.6) presented in the IPCC (2013).

SEA LEVEL CURVES

City-wide Coastal Flooding Study Norfolk, Virginia



IMPLICATIONS OF FUTURE SEA LEVEL RISE
City-wide Coastal Flooding Study
Norfolk, Virginia



TAILWATER PHENOMENA
City-wide Coastal Flooding Study
Norfolk, Virginia

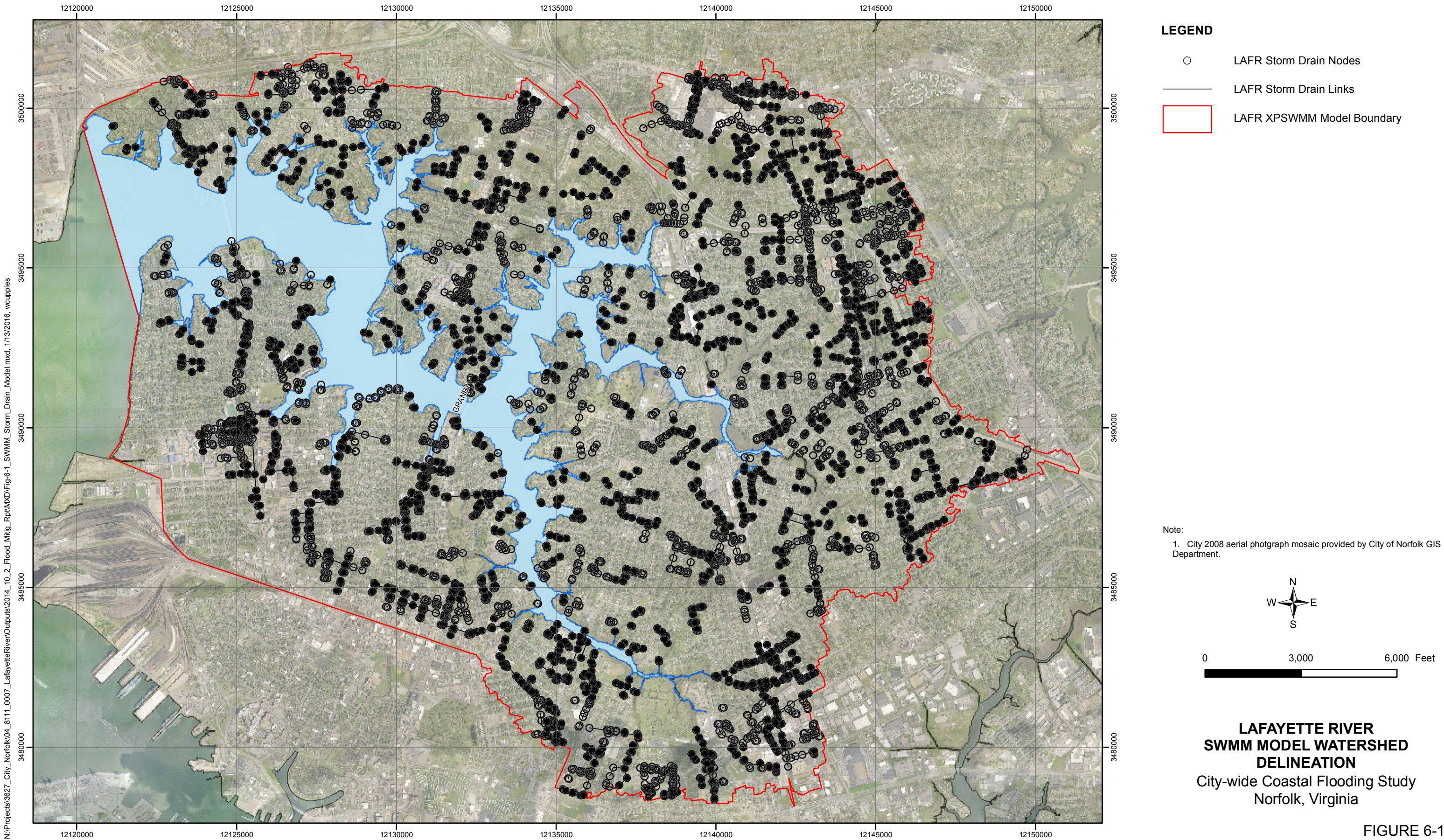


FIGURE 6-1

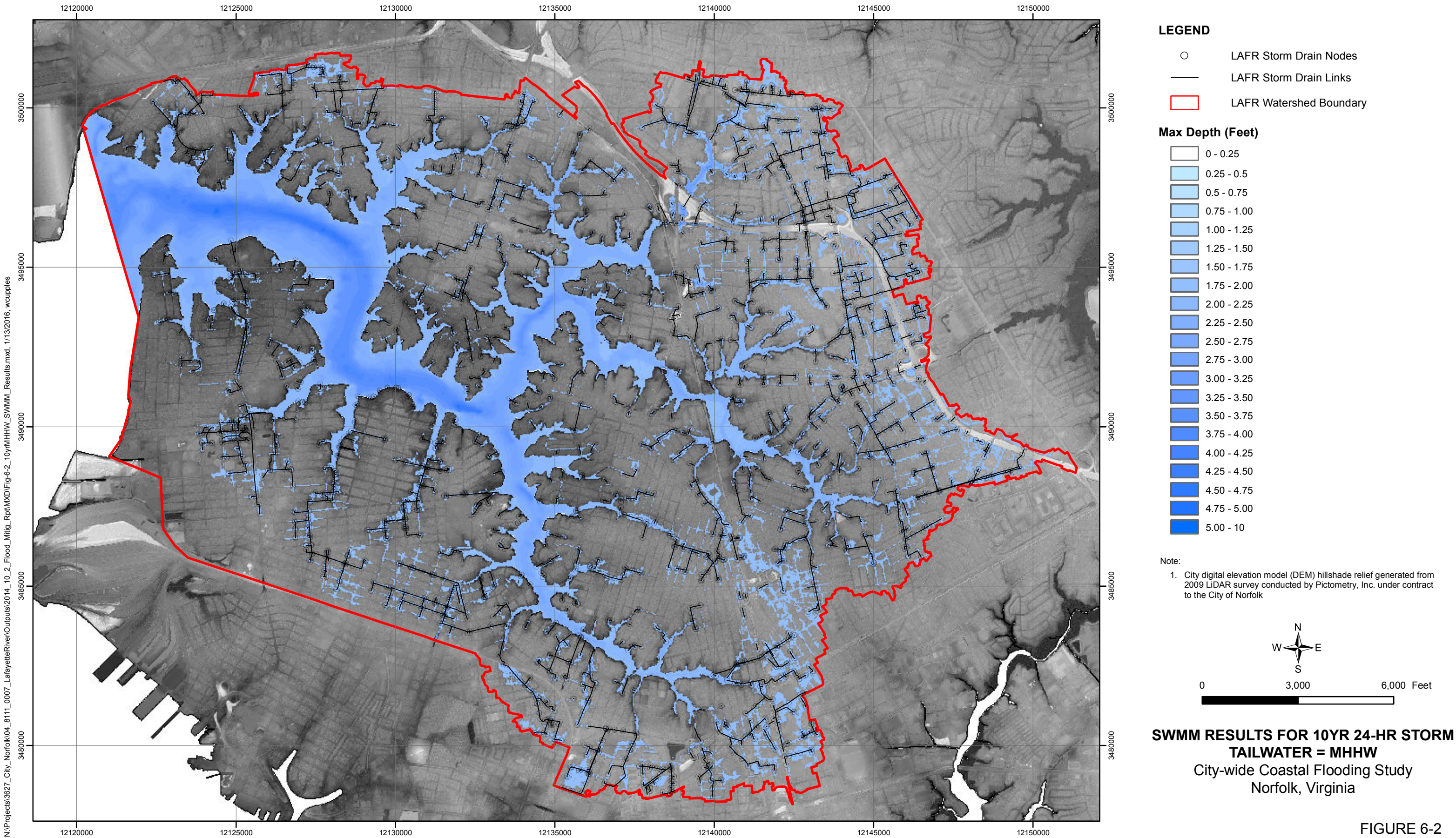


FIGURE 6-2

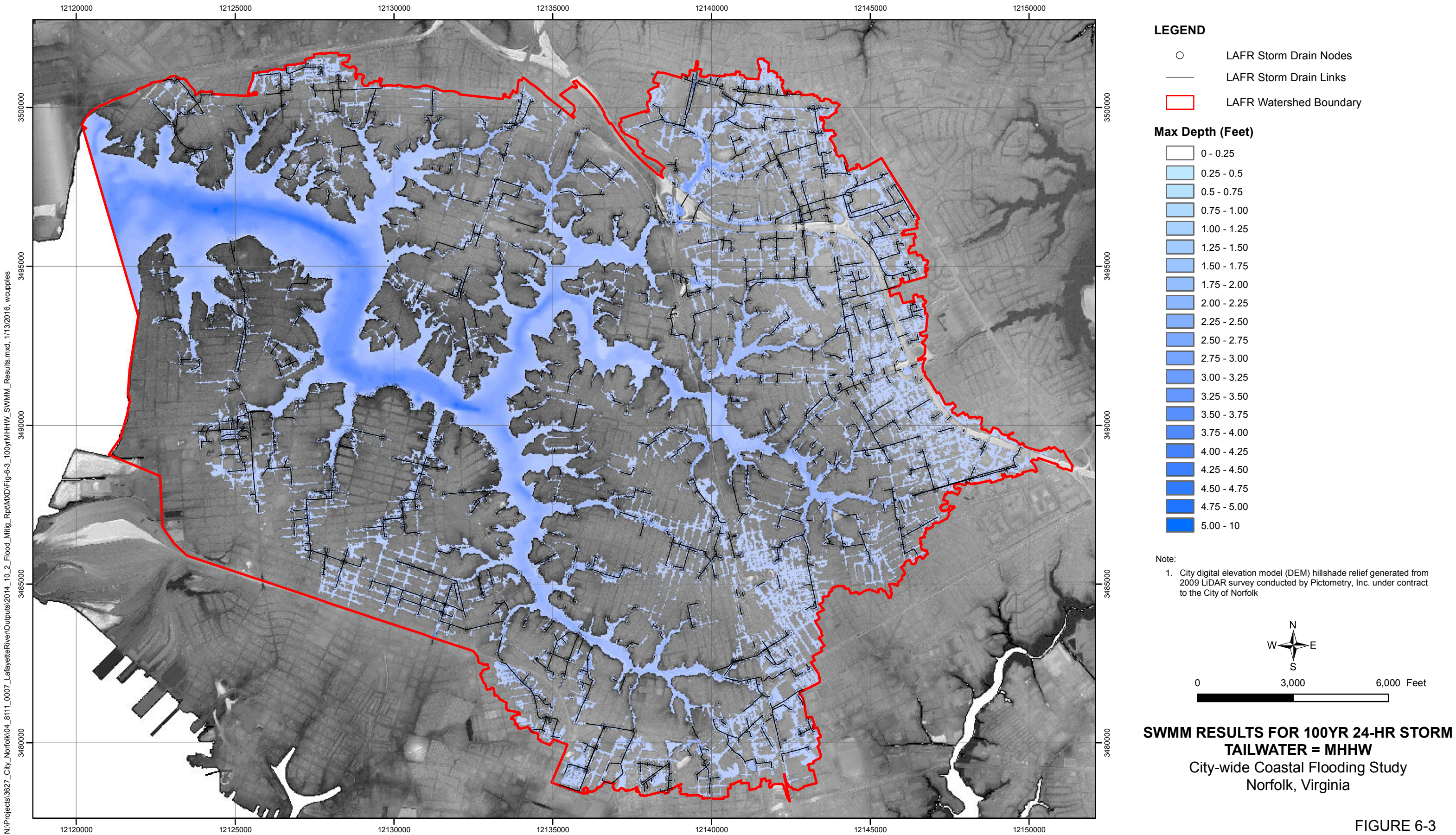


FIGURE 6-3

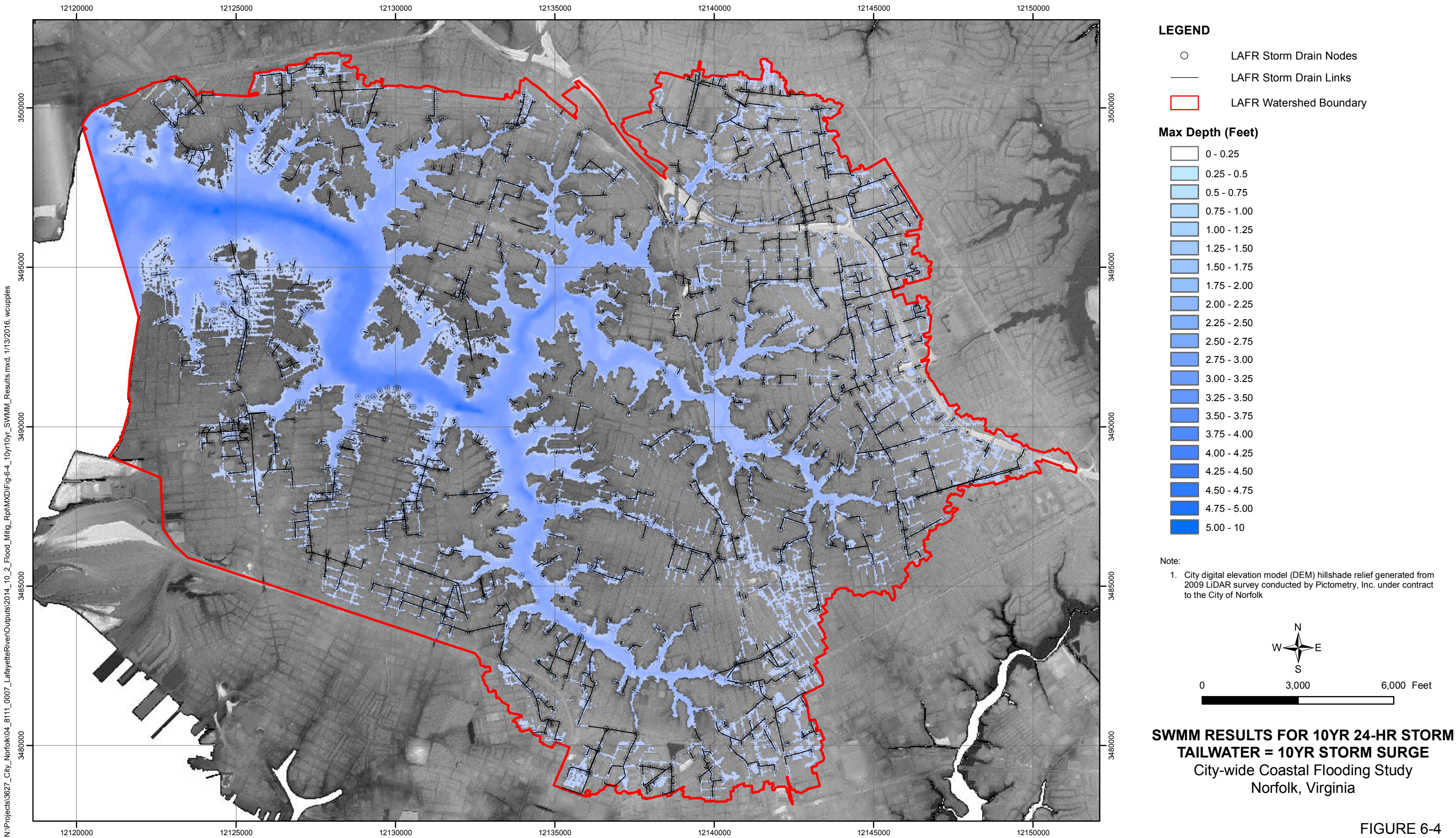


FIGURE 6-4

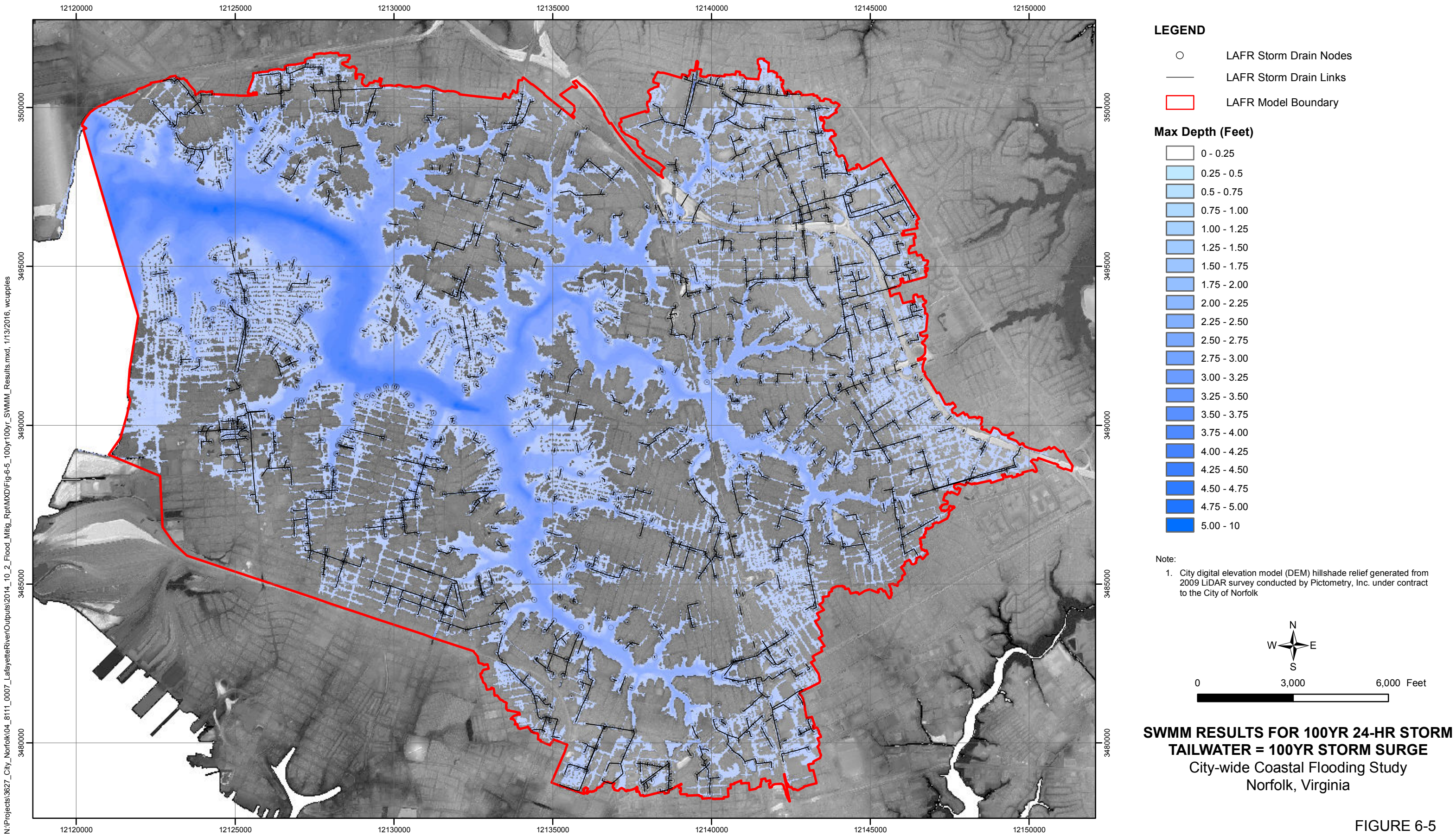
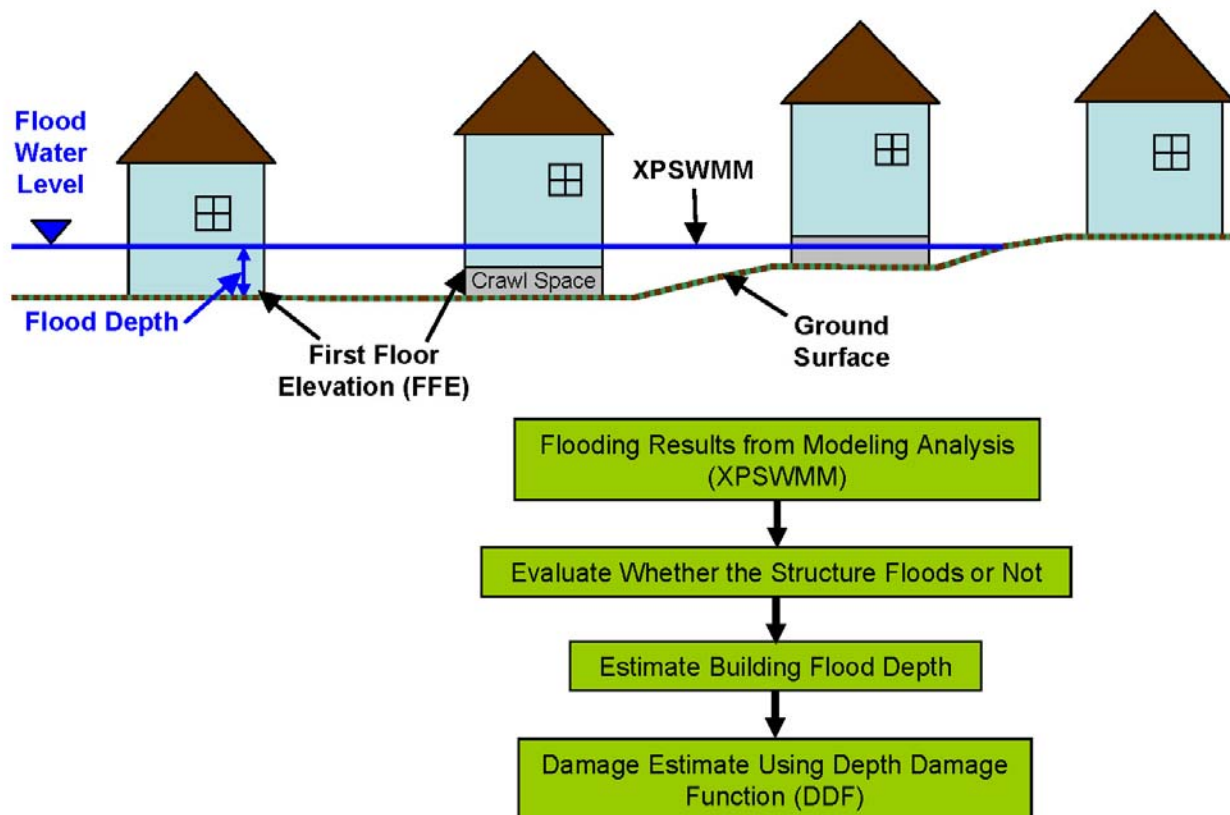


FIGURE 6-5



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

FIGURE 7-1

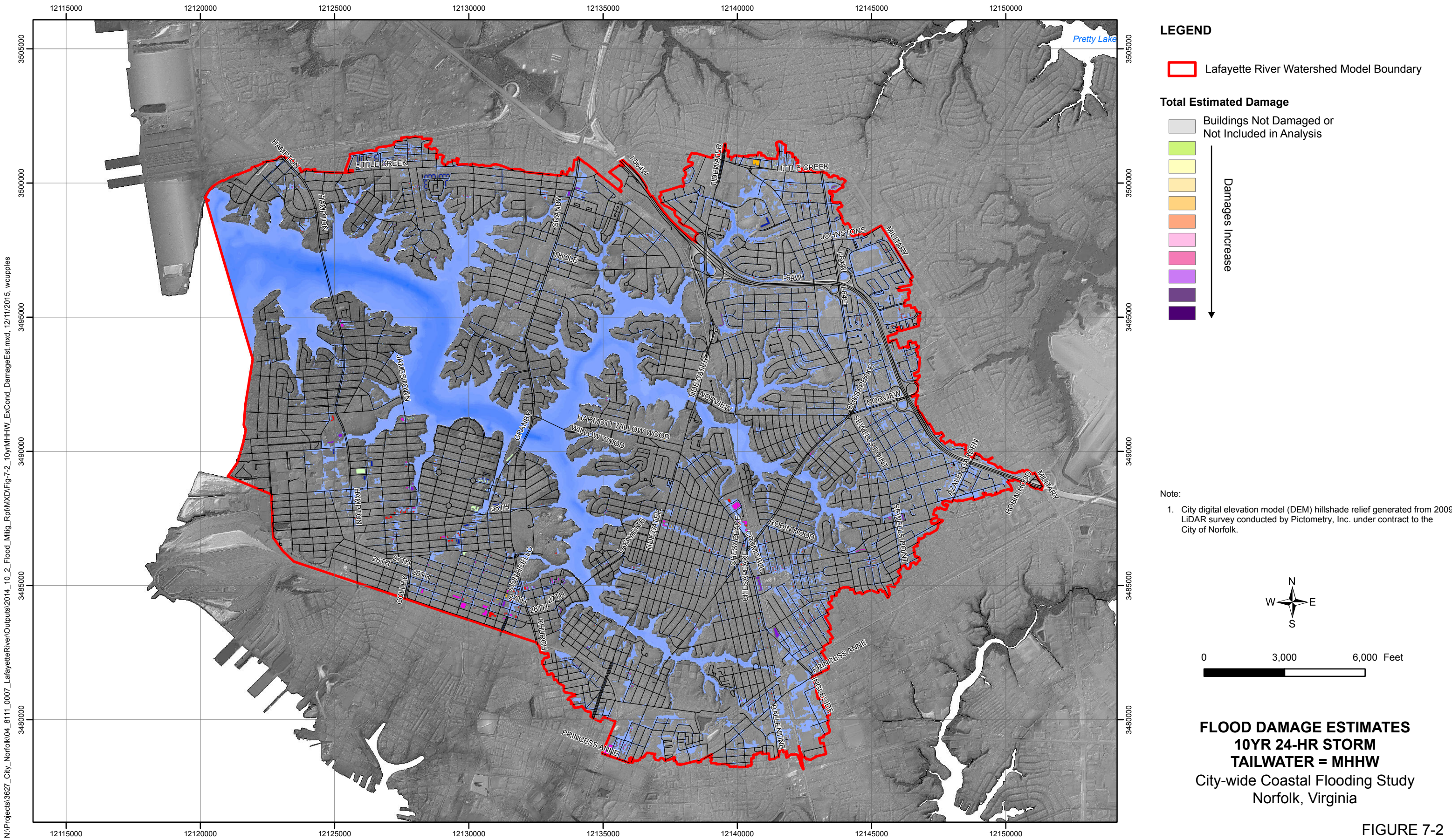


FIGURE 7-2

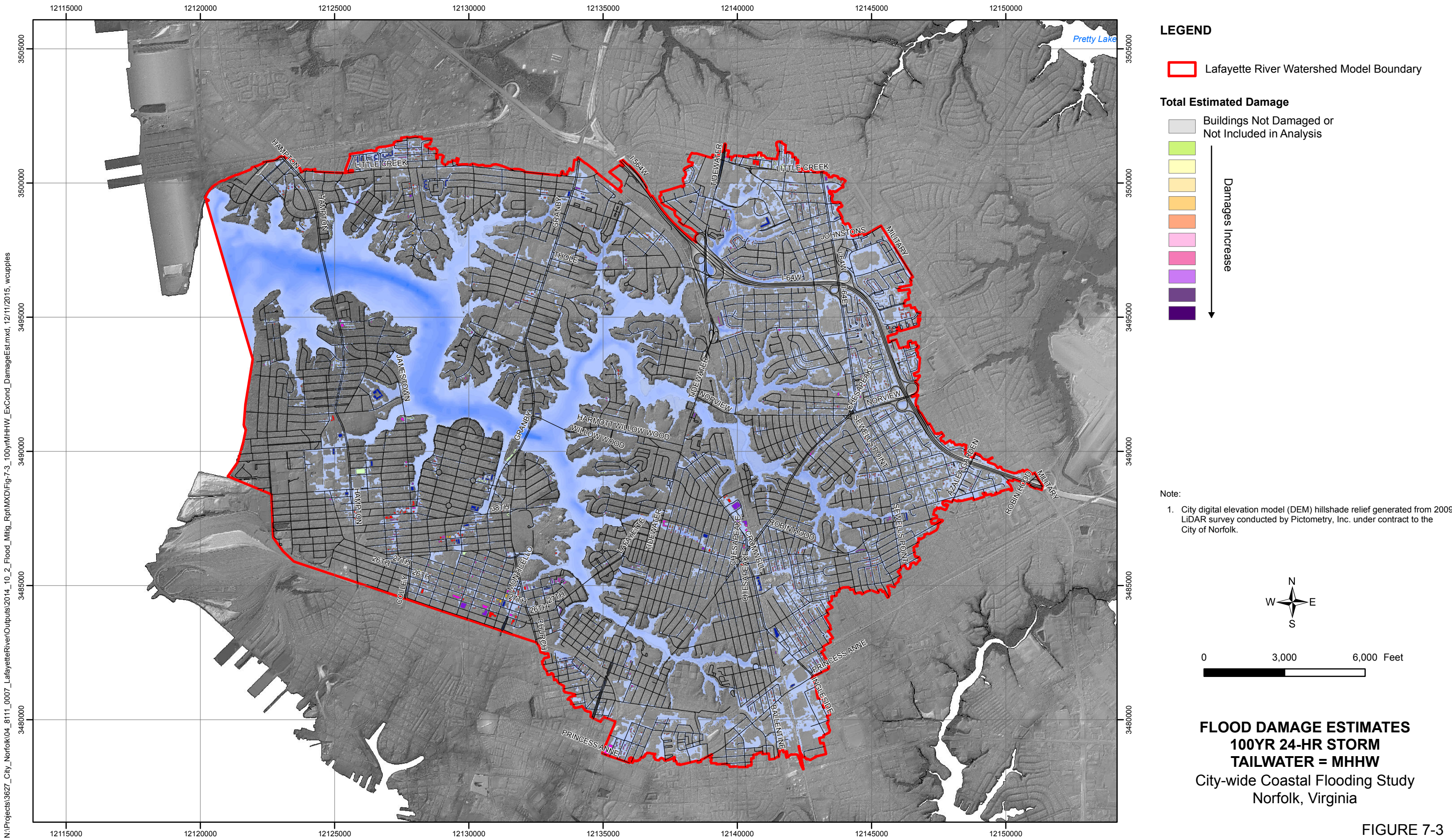


FIGURE 7-3

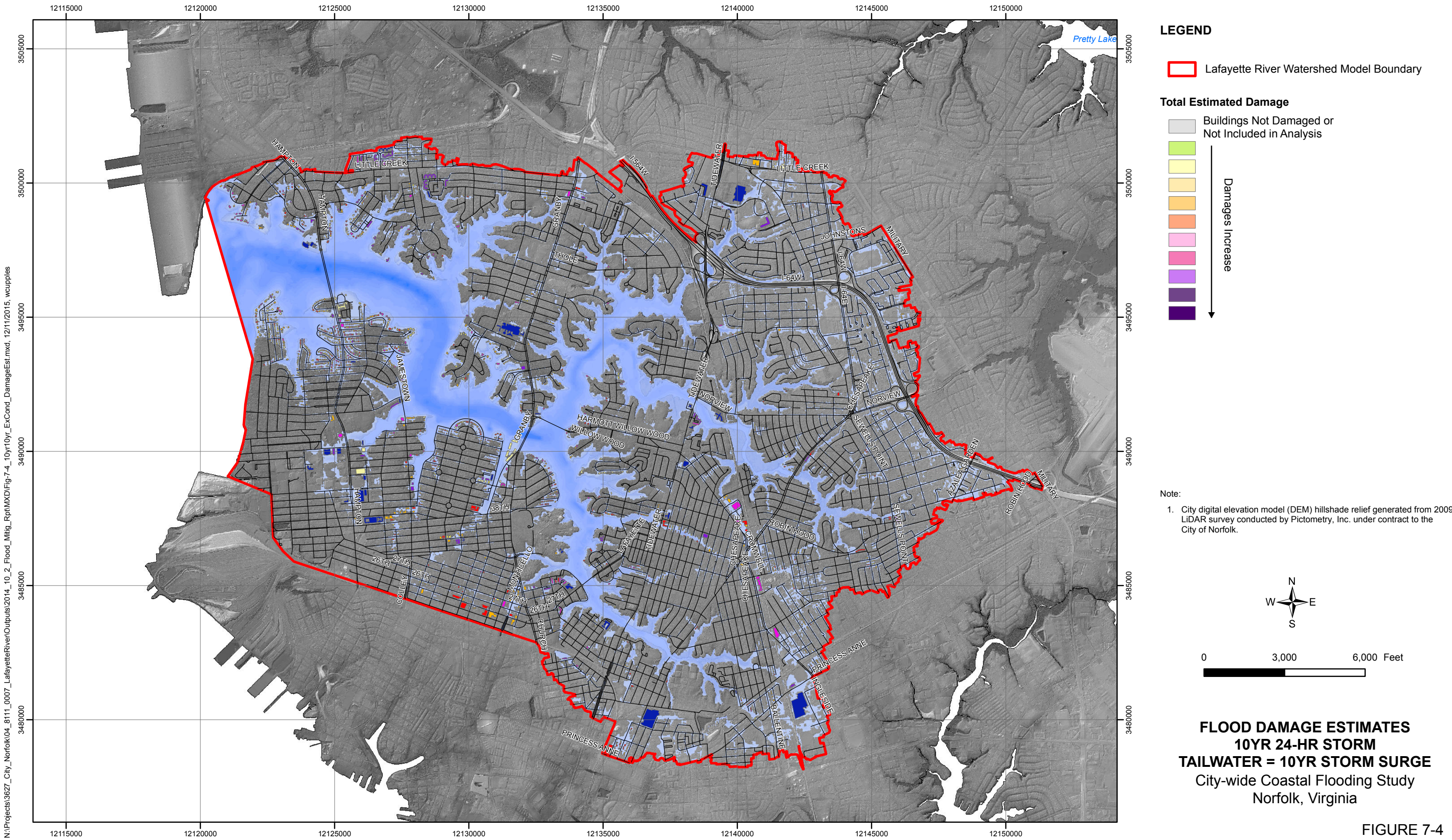


FIGURE 7-4

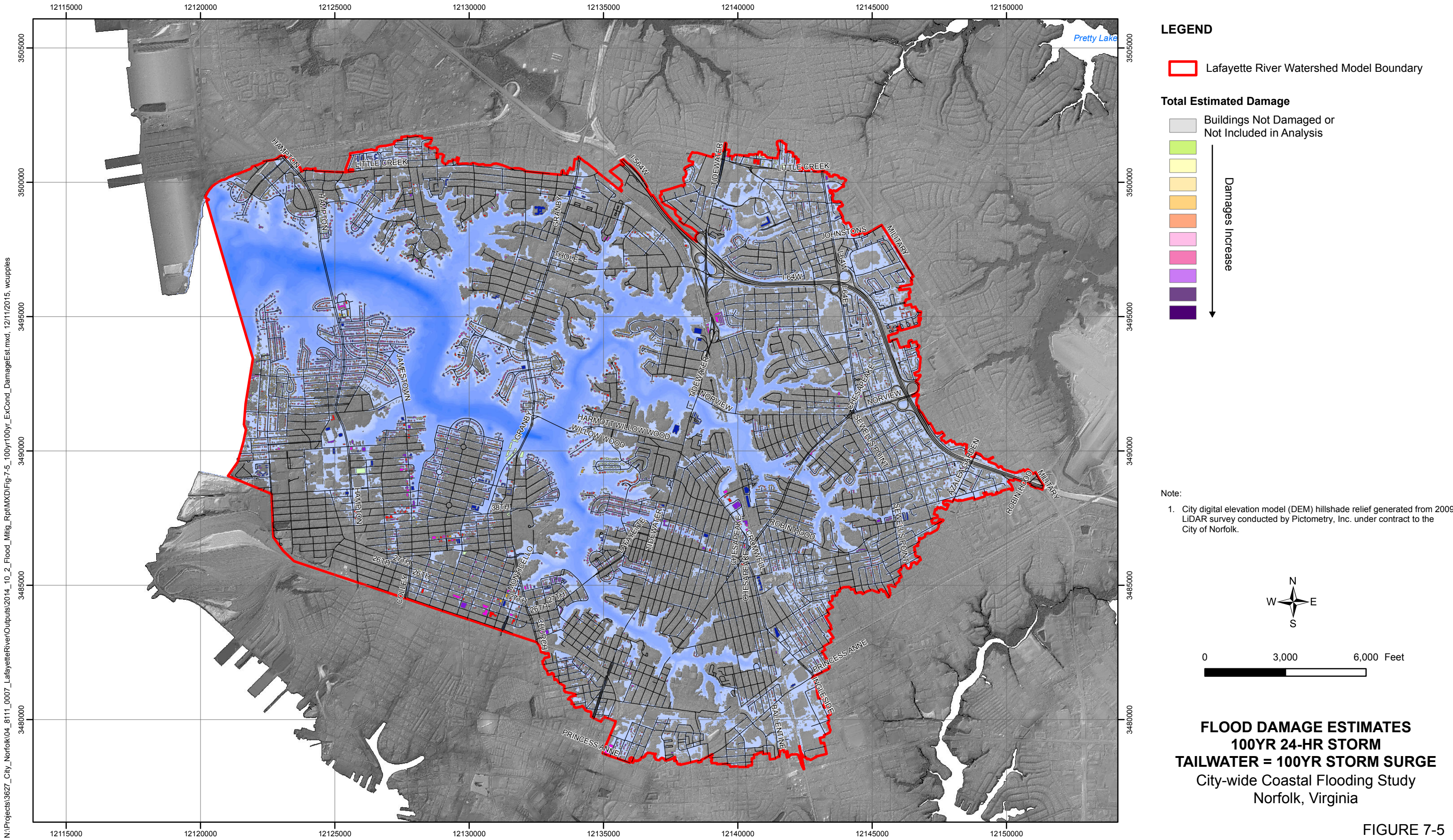
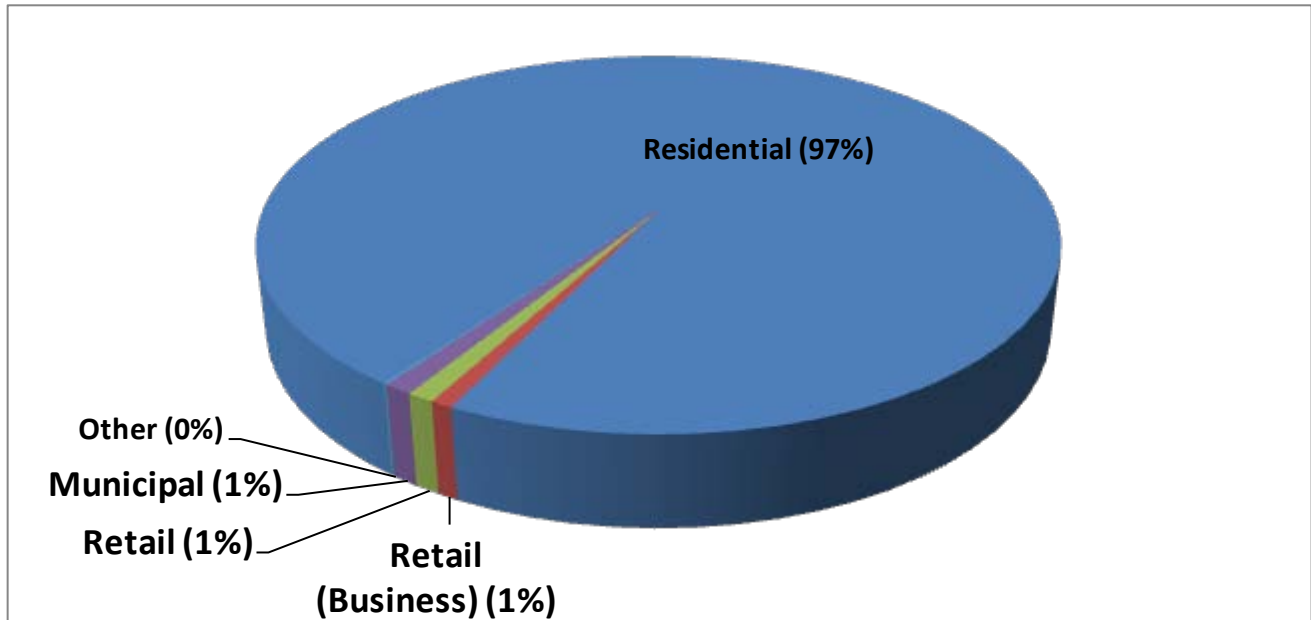
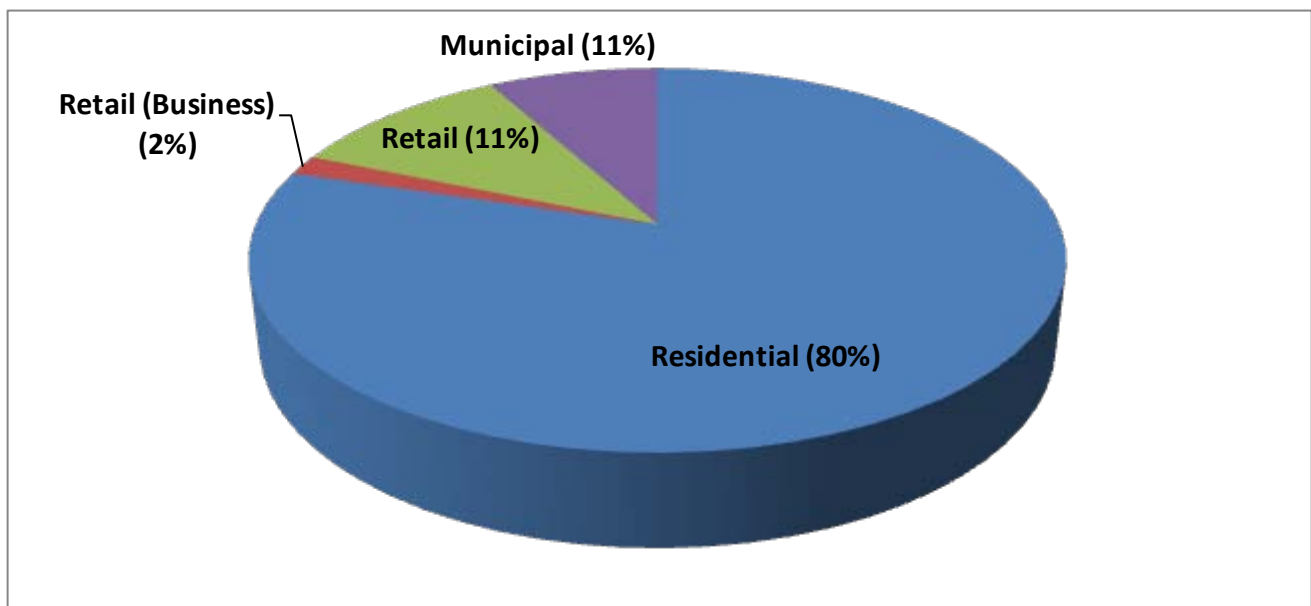


FIGURE 7-5

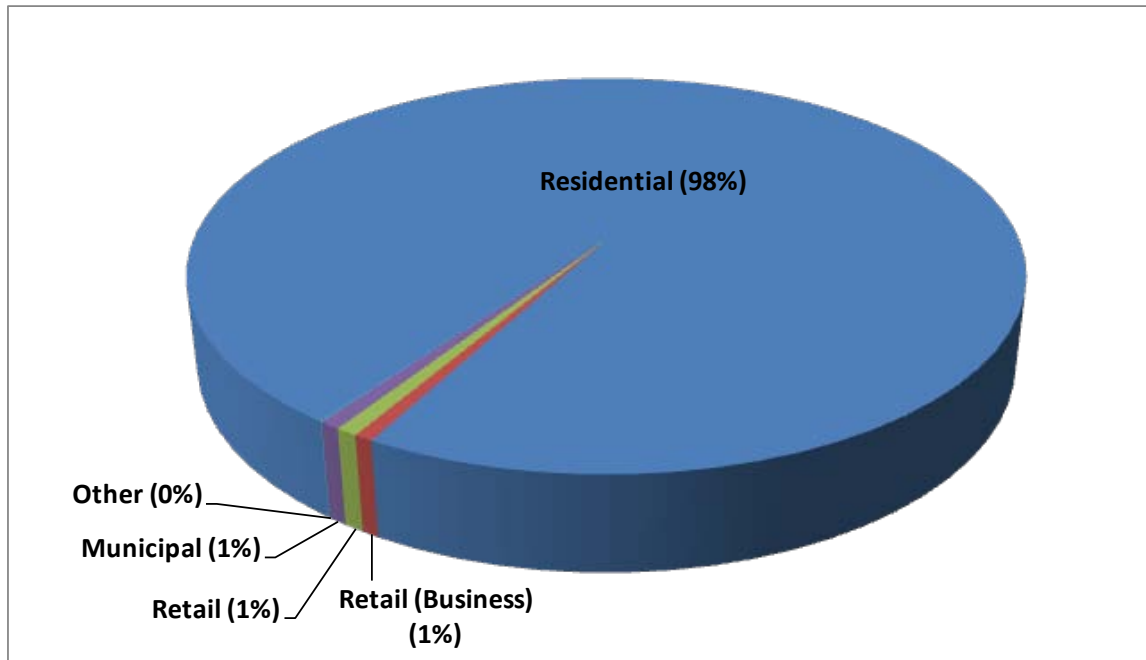


Number of Buildings Damaged by Flood

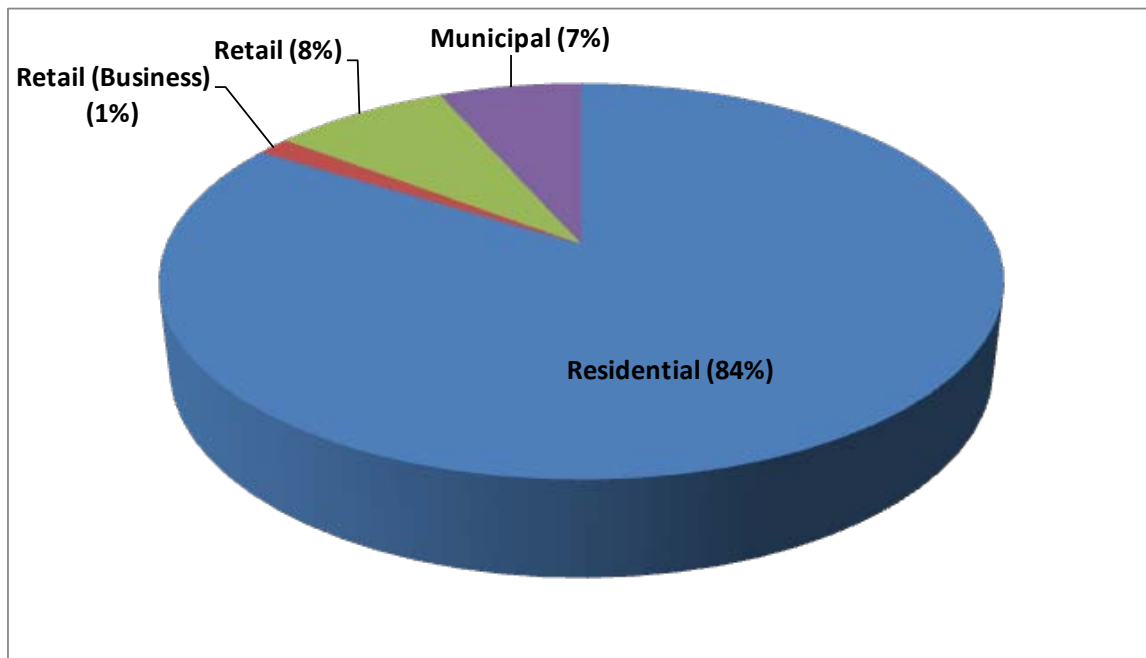


Cost Distribution of Flood Damage

FLOOD DAMAGE ESTIMATES
10YR 24-HR STORM, TAILWATER = 10 YR STORM SURGE
City-wide Coastal Flooding Study
Norfolk, Virginia



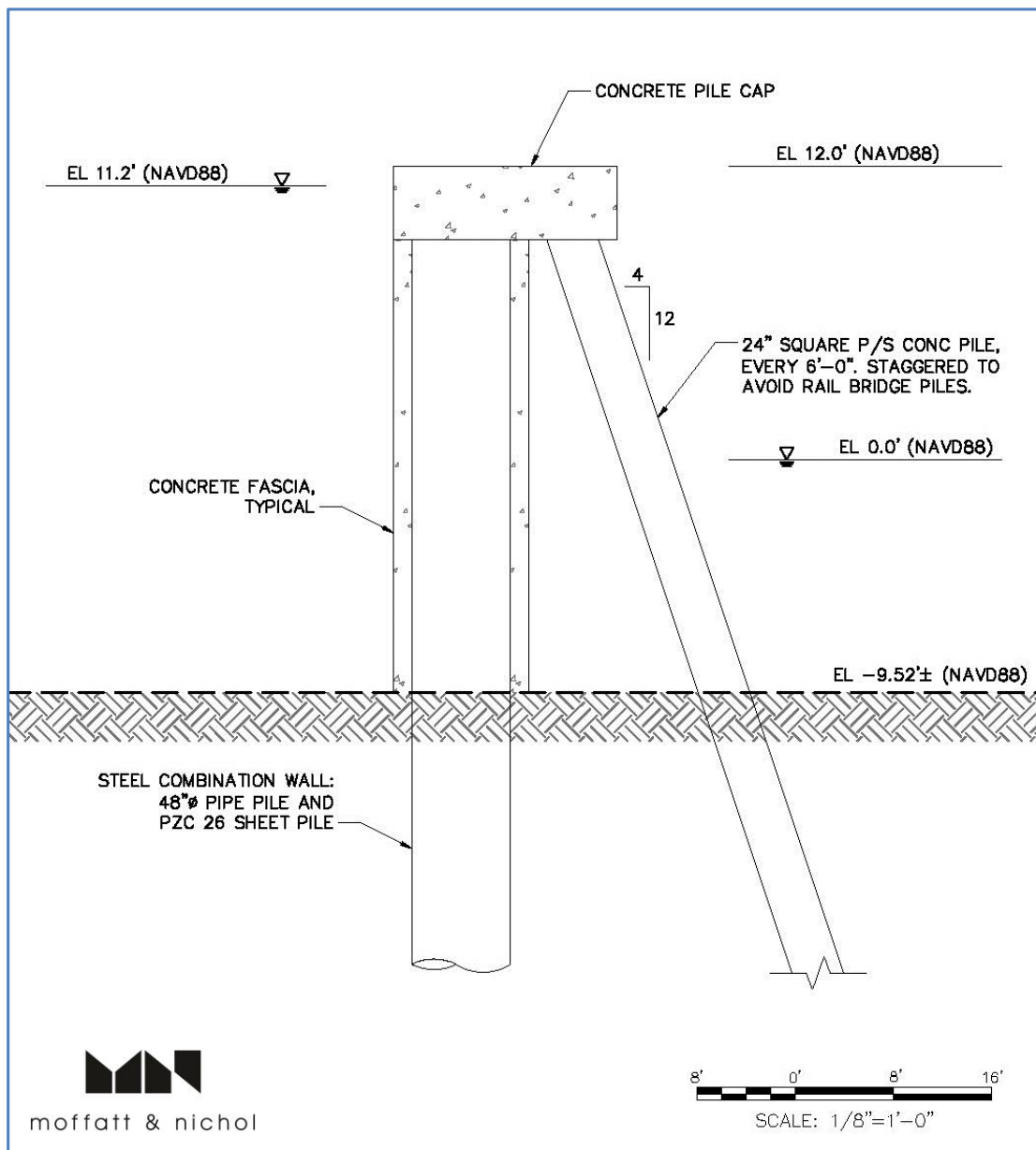
Number of Buildings Damaged by Flood



Cost Distribution of Flood Damage

FLOOD DAMAGE ESTIMATES
100YR 24-HR STORM, TAILWATER = 100 YR STORM SURGE
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 7-7



SOLID WALL BARRIER SEGMENT
City-wide Coastal Flooding Study
Norfolk, Virginia



Ems Barrier, Germany northern aerial view. Constructed between 1998 and 2002, which includes three different gate types:

- a) a rotary segment gate navigable by large vessels, e.g. the “main shipping fairway arch”,
- b) a radial segment gate navigable only by small vessels, e.g. the “inland navigation arch”, and
- c) several non-navigable lift gates (Source: Ralf Schmidt, Panoramio).



Ems Barrier southern aerial view (Source: Bin im Garten, Wikimedia Commons)

EMS BARRIER
City-wide Coastal Flooding Study
Norfolk, Virginia



Ems Barrier gates (Source: Bin im Garten, Wikimedia Commons)



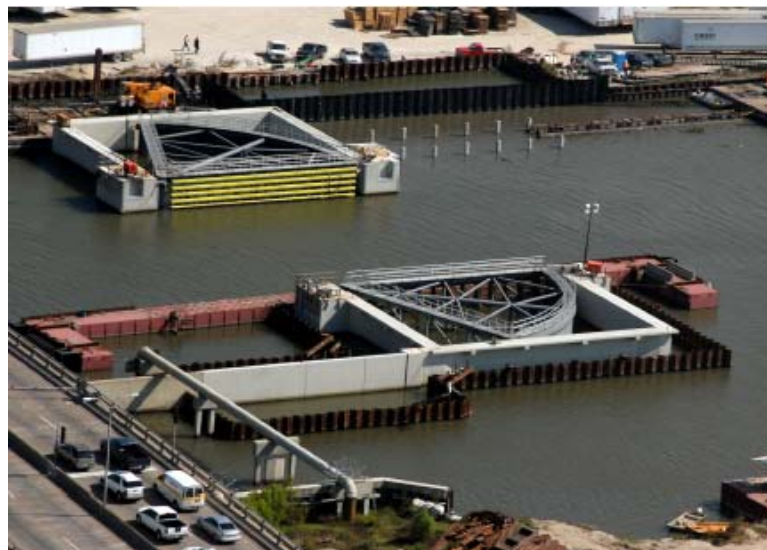
Ems Barrier lift gate (Source: Hein Mück, Wikimedia Commons)

EMS BARRIER
City-wide Coastal Flooding Study
Norfolk, Virginia



This conceptual illustration of the Seabrook Floodgate Structure shows the sector gate and the lift gates in the closed position, as it would look during a storm event. (USACE conceptual illustration)

Navigation sector gate and lift gates from USACE project at Seabrook in New Orleans, LA



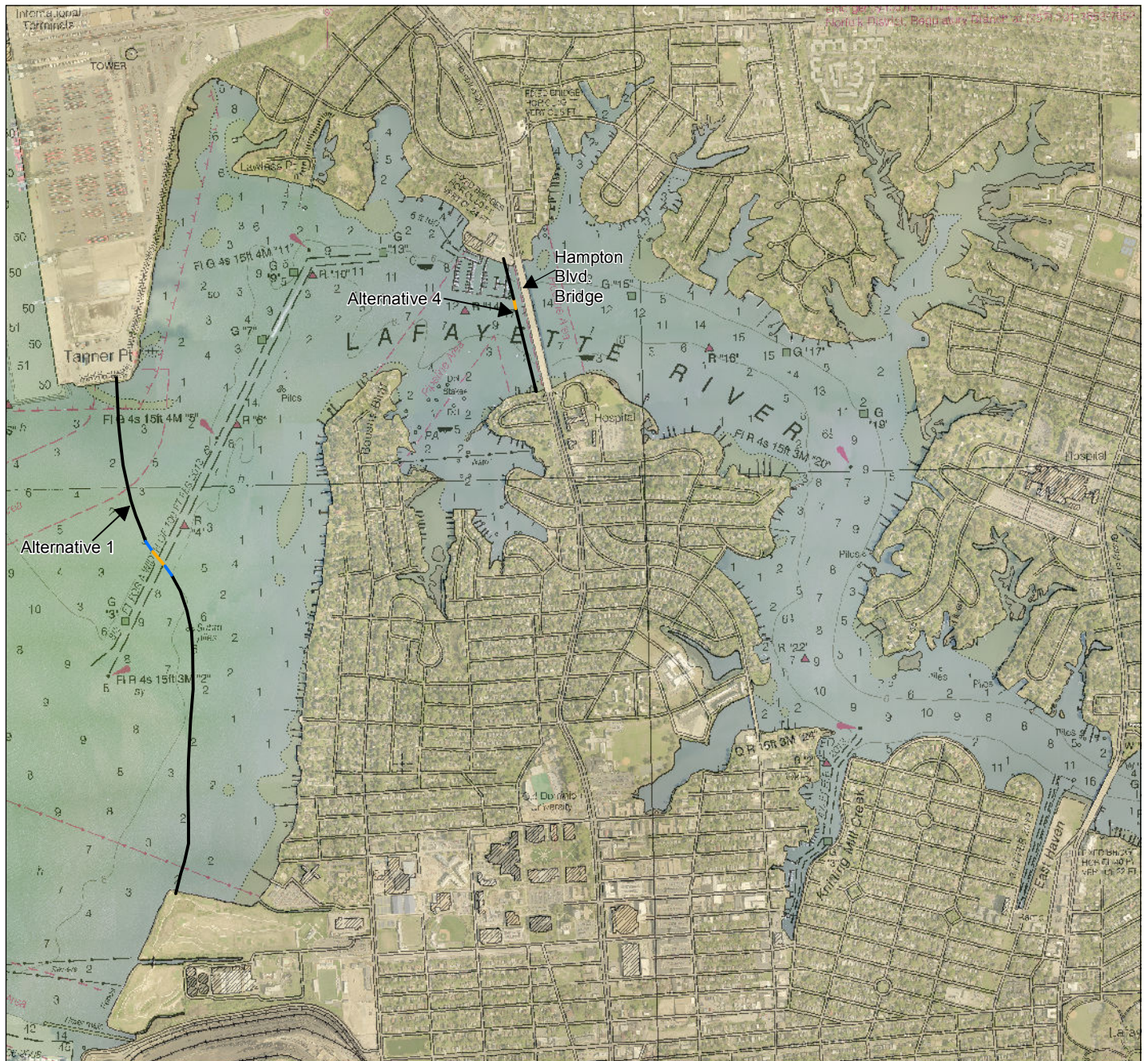
Navigation sector gate USACE project on Harvey Canal in New Orleans, LA

NAVIGATION GATE EXAMPLES

City-wide Coastal Flooding Study

Norfolk, Virginia

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Barrier Section Type

- Gate "Island"
- Solid Wall/Earthen Abutment
- Navigation Gate

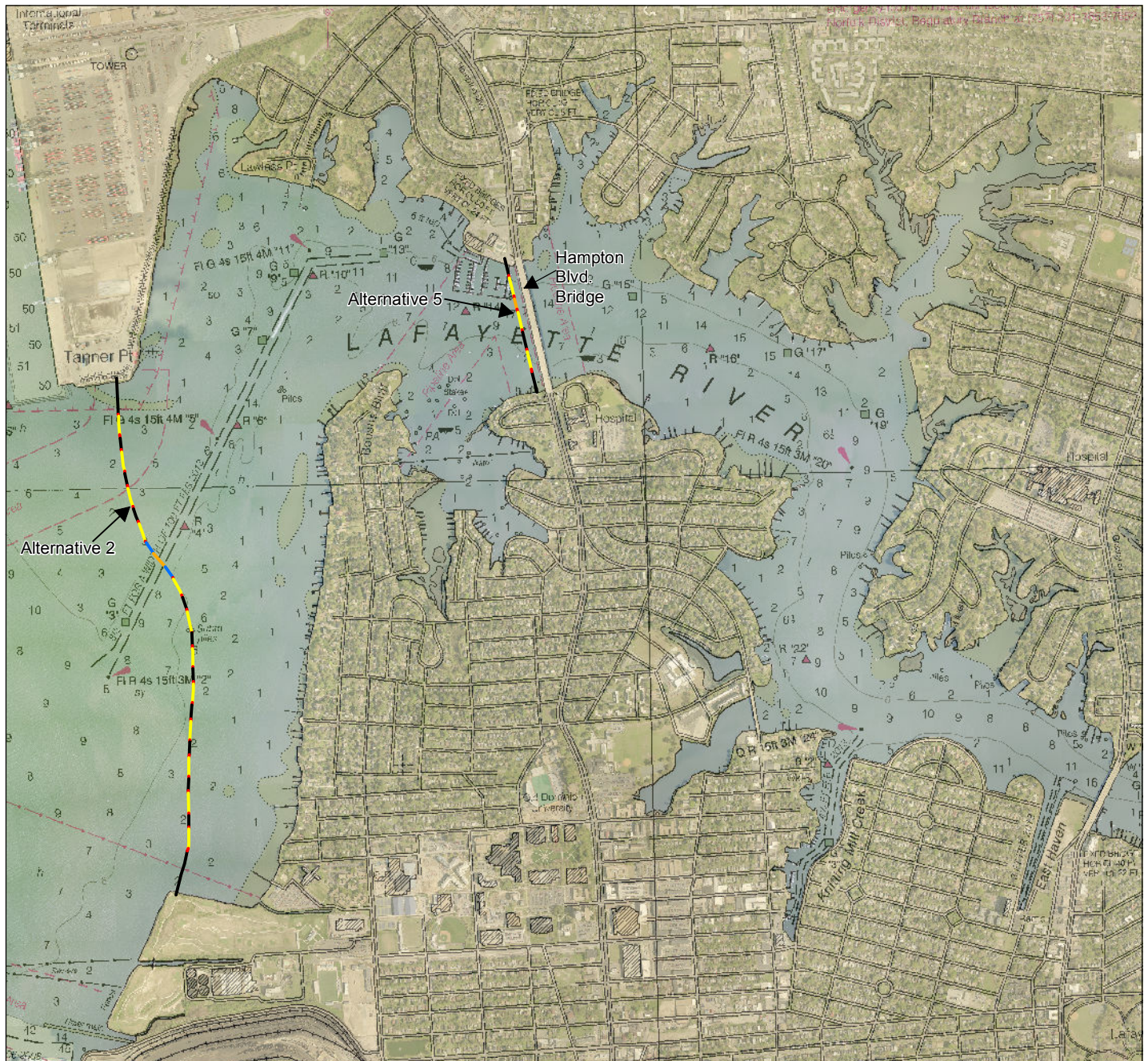


0 1,000 2,000
Feet

ALTERNATIVES 1 AND 4 BARRIER CONFIGURATIONS
City-wide Coastal Flooding Study
Norfolk, Virginia

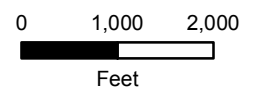
FIGURE 8-4

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Barrier Section Type

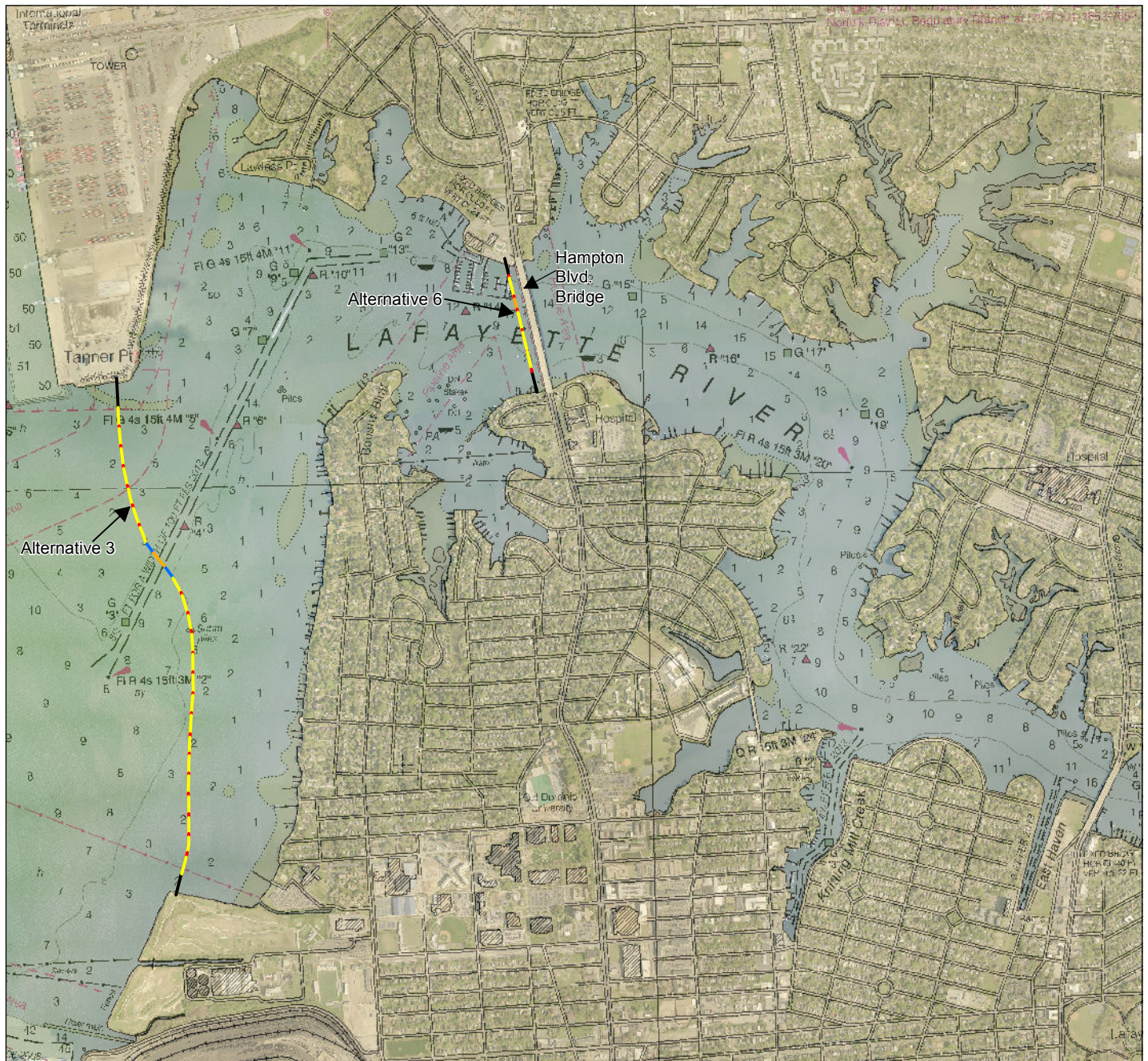
- Gate "Island"
- Solid Wall/Earthen Abutment
- Radial/Lift Gate
- Navigation Gate
- Gate Pier



ALTERNATIVES 2 AND 5 BARRIER CONFIGURATIONS
City-wide Coastal Flooding Study
Norfolk, Virginia

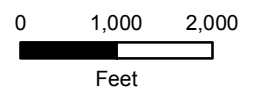
FIGURE 8-5

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Barrier Section Type

- Gate "Island"
- Solid Wall/Earthen Abutment
- Radial/Lift Gate
- Navigation Gate
- Gate Pier



ALTERNATIVES 3 AND 6 BARRIER CONFIGURATIONS
City-wide Coastal Flooding Study
Norfolk, Virginia

FIGURE 8-6

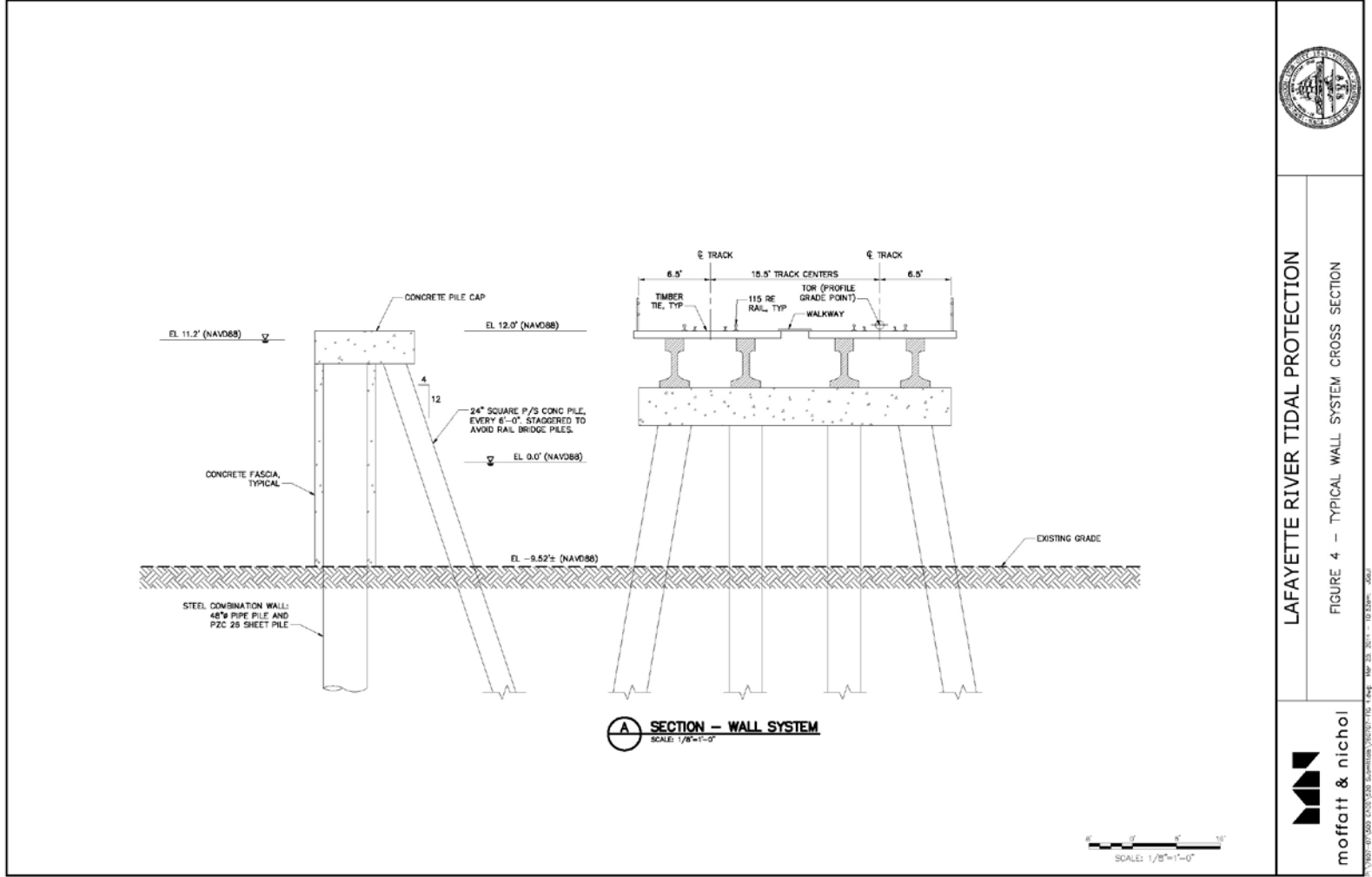
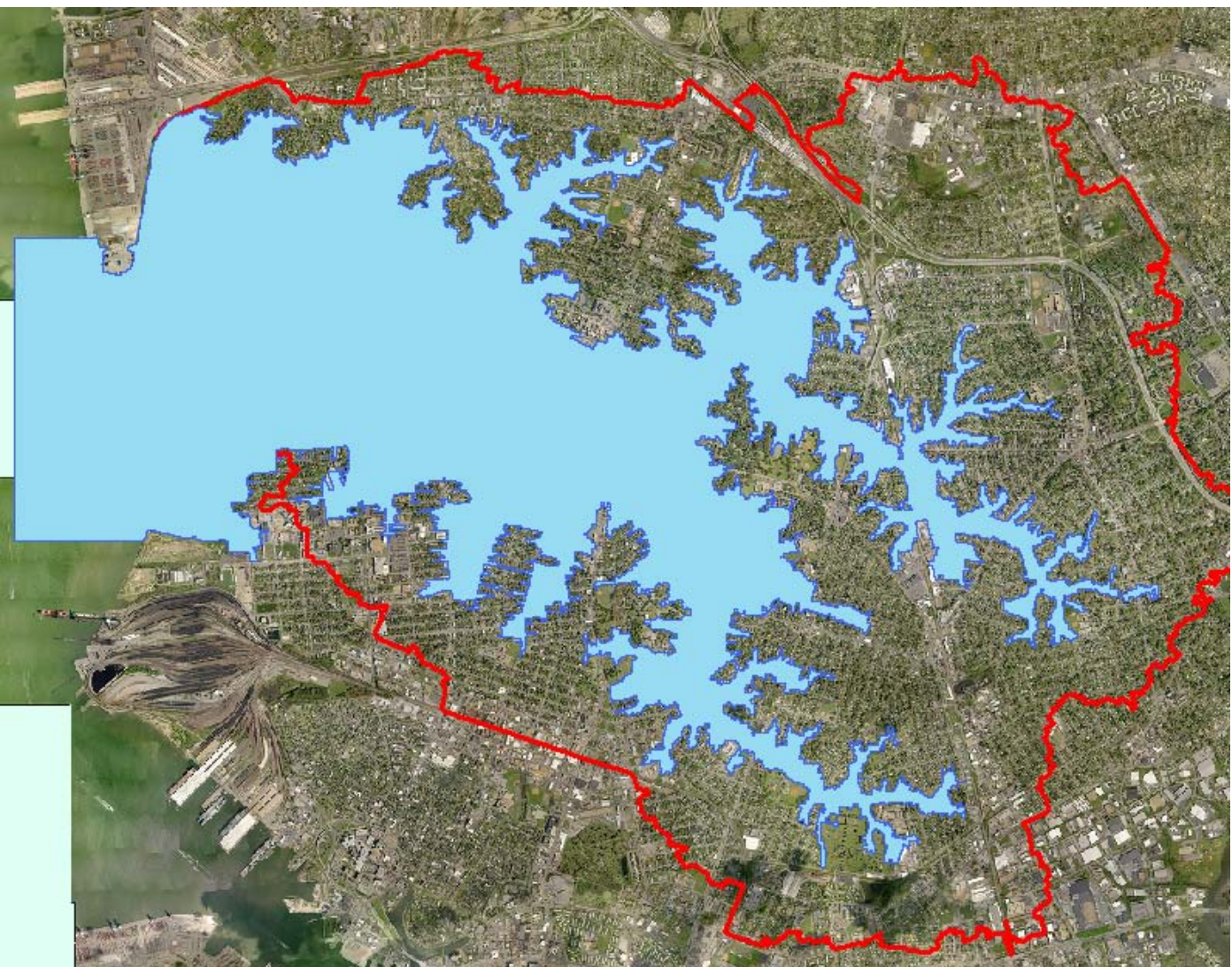
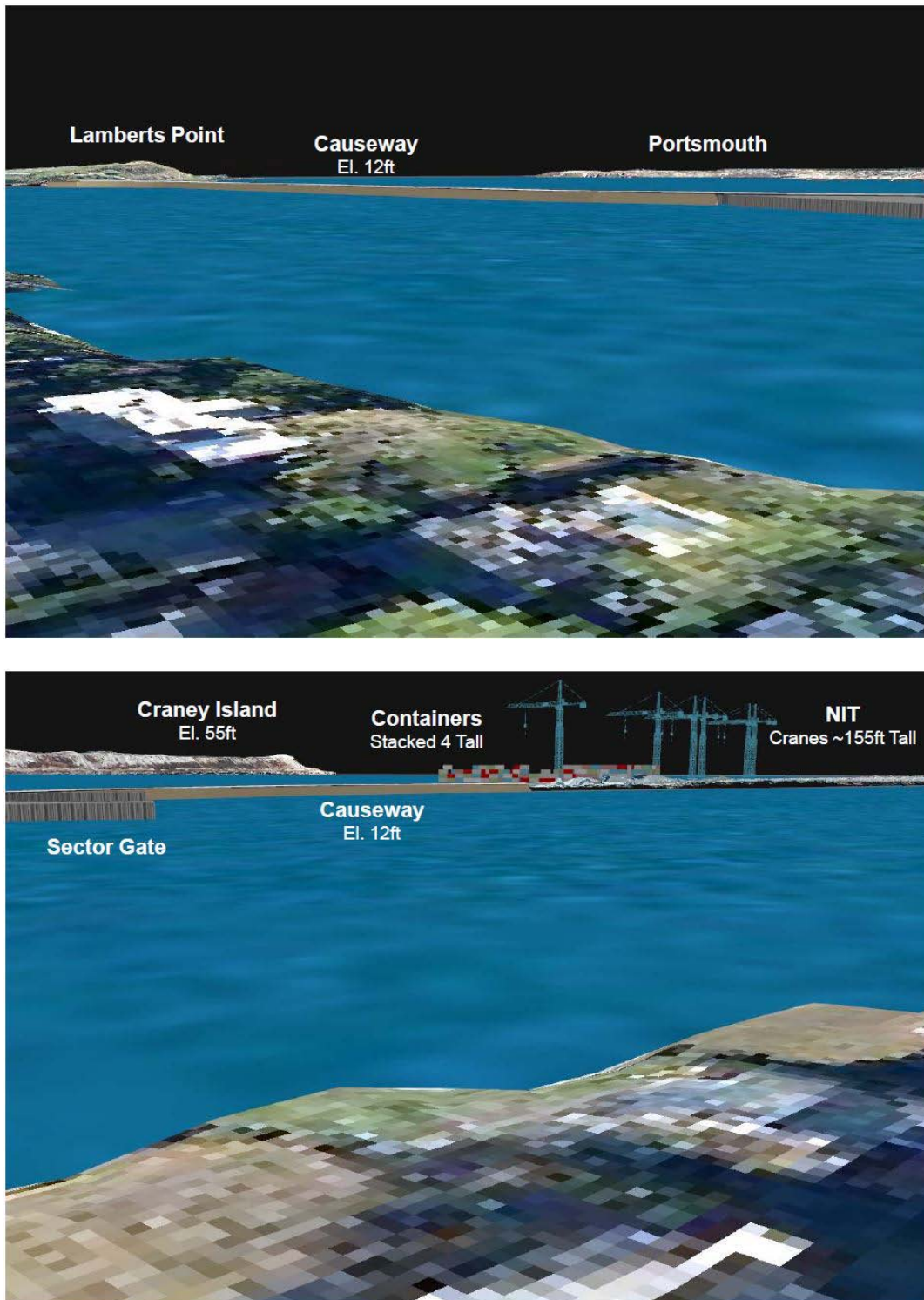


FIGURE 8-7

LIGHT RAIL TRESTLE CONCEPT
 City-wide Coastal Flooding Study
 Norfolk, Virginia



XPSWMM MODEL EXTENT
City-wide Coastal Flooding Study
Norfolk, Virginia



HORIZONTAL SECTOR GATE VIEWSHED
City-wide Coastal Flooding Study
Norfolk, Virginia



CONCEPTUAL DRAWING (SEABROOK FLOODGATE STRUCTURE)
City-wide Coastal Flooding Study
Norfolk, Virginia



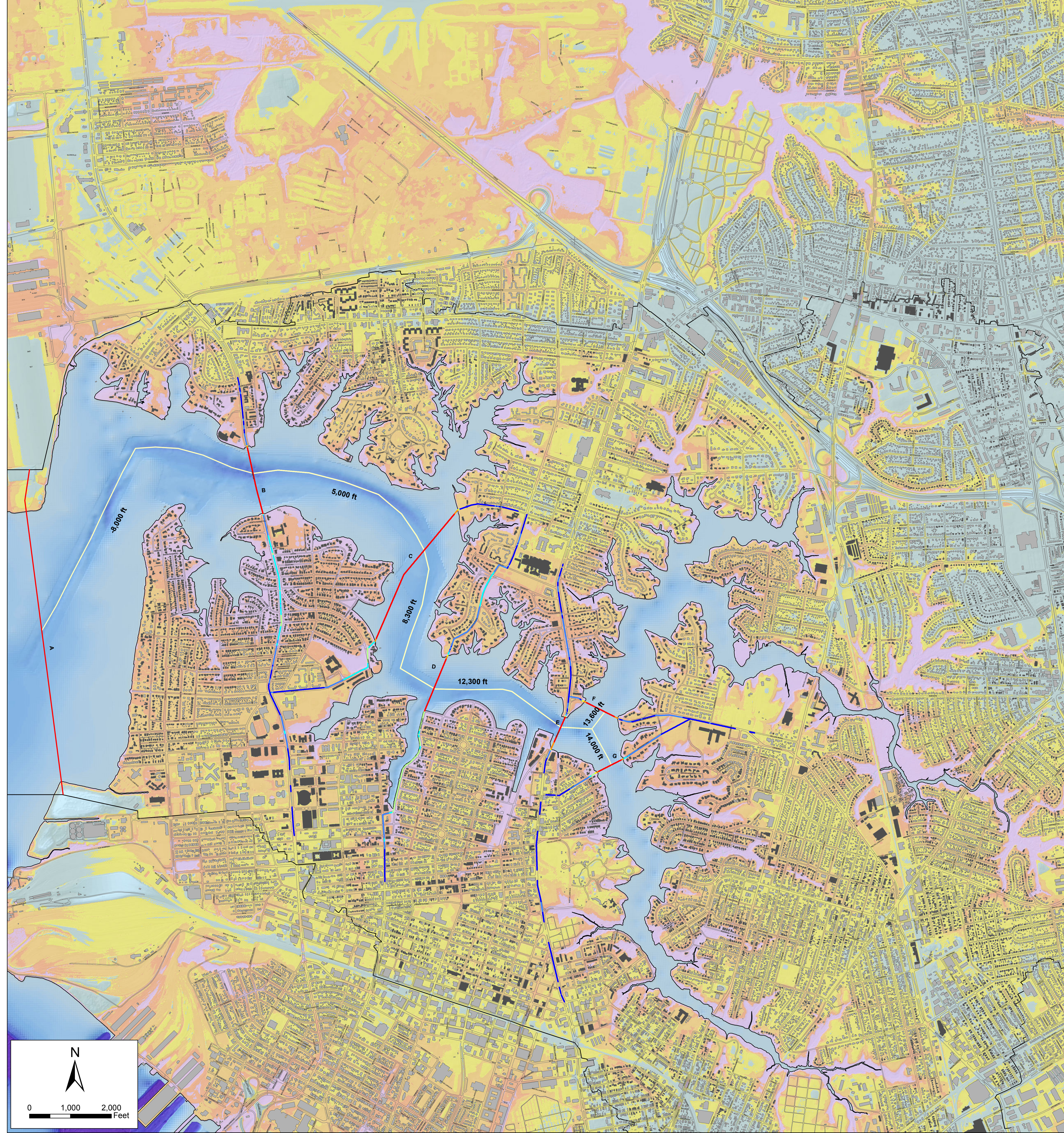
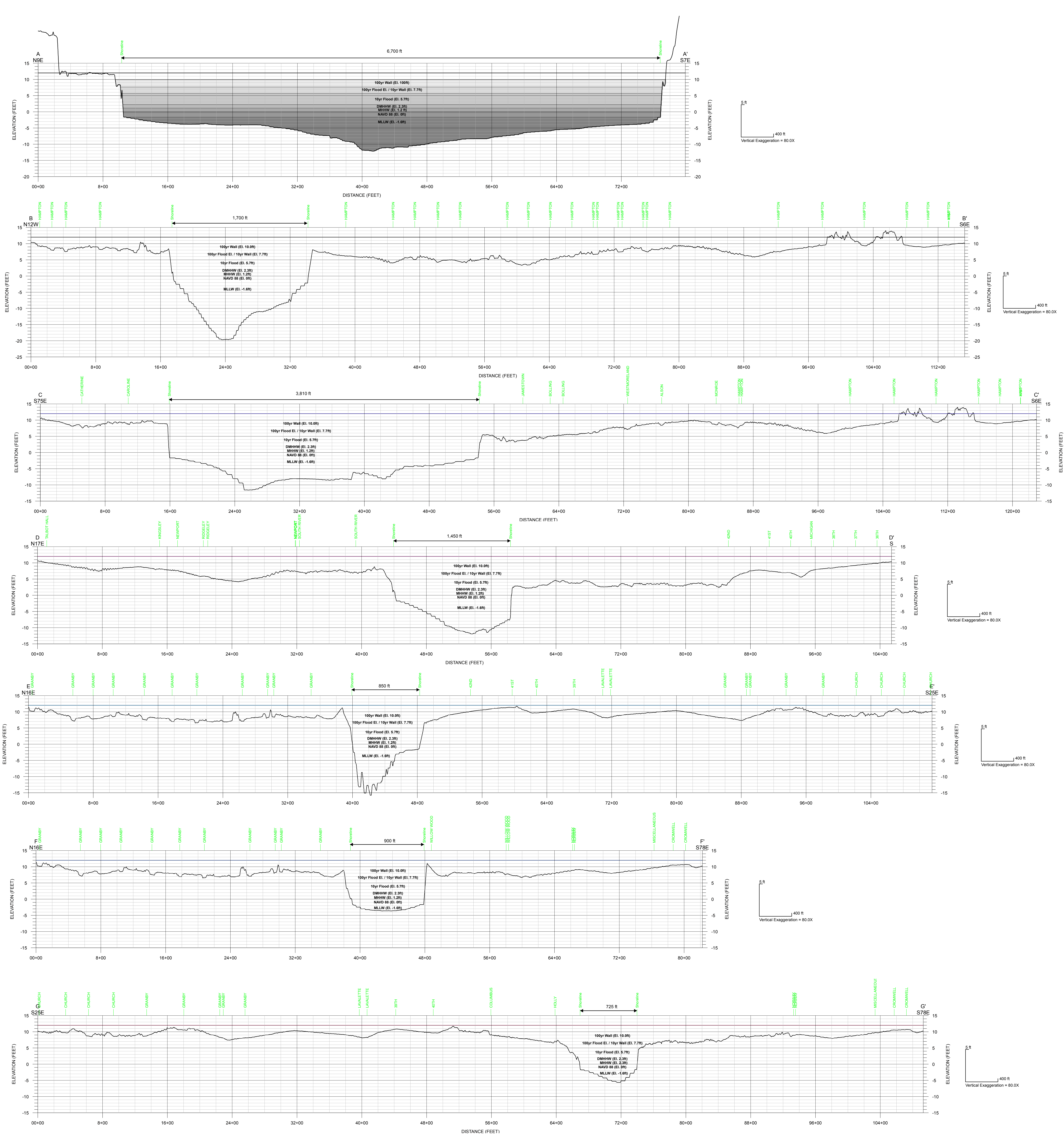
EXAMPLE BARRIER GATES (EMS RIVER, GERMANY)
City-wide Coastal Flooding Study
Norfolk, Virginia



LIGHT RAIL TRESTLE CONCEPT

City-wide Coastal Flooding Study
Norfolk, Virginia

CHARTS



Barrier Alignment	Location	Acres Protected (ac)	Percent of Watershed Protected	Buildings Protected	Property Value (\$)	Population Protected	Overland Distance to +10 Elevation (ft)	River Crossing Distance (ft)
A	NIT-Lamberts Point	10,773	100	13,162	7,200,000,000	81,000	165	6,700
B	Hampton Blvd Bridge	9,310	86	12,050	6,200,000,000	75,000	11,533	1,650
C	Jamestown Crescent/Talbot Park	8,132	75	11,013	5,300,000,000	67,000	10,323	3,800
D	Knitting Mill Creek- Riverpoint	7,583	70	5,739	4,800,000,000	62,000	10,450	1,600
E	Granby Street Bridge	6,531	61	4,921	3,800,000,000	52,000	11,594	850
F	Willow Wood Drive Bridge (Wayne Creek)	4,216	39	3,378	2,500,000,000	33,000	10,910	900
G	Riverview-Rosso Ct/Veaux Loop	2,314	21	1,543	1,300,000,000	19,000	8,297	700

Barrier Alignment	OLFW Average Exposed Height (ft) (Typical Range of Exposed Wall Height, ft)	OWFW Max Exposed Height (ft)	OWFW Average Exposed Height (ft)	Overland Floodwall Cost Score*	Overwater Floodwall Cost Score*	Total Floodwall Cost Score	Flood Damages Prevented for Combined 100yr tidal + 100yr precip (\$)	Alignment Score
A	2.1 (1 to 4)	22	18	500,000	16,800,000	17,300,000	370,000,000	21
B	2.9 (2 to 6)	20	21	8,400,000	19,700,000	28,100,000	280,000,000	16
C	2.2 (1 to 6)	22	16	5,300,000	19,900,000	25,200,000	270,000,000	11
D	4.0 (2 to 7)	22	18	11,200,000	8,300,000	19,500,000	240,000,000	12
E	1.5 (2 to 3)	26	18	3,800,000	4,800,000	8,600,000	140,000,000	16
F	2.0 (1 to 3)	14	13	4,300,000	3,800,000	8,100,000	90,000,000	11
G	1.7 (1 to 3)	16	14	4,200,000	3,200,000	7,400,000	50,000,000	7

OLFW = Overland Floodwall
OWFW = Overwater Floodwall
* = Based on Wall Area (square feet) Exposed Above Ground/Riverbottom
Refer to Chart 1 for wall alignment profiles

LEGEND
Exposed Floodwall Height 10ft - Design Elev

No Exposer

0.0 - 2.0

2.1 - 4.0

4.1 - 5.9

6.0 - 8.0

8.1 - 10.0

10.1 - 12.0

12.1 - 29.6

Building Impacted by 100yr/100yr EC

Building not Impacted (accessory structures)

LiDAR Elev (NAVD88)

0.1 - 5.7

5.8 - 7.7

7.8 - 10

10.1 - 12

12.1 - 69.6

