MOFFATT & NICHOL

FLOOD MITIGATION ALTERNATIVES EVALUATION - MASON CREEK

City of Norfolk
Underwater Inspection and Engineering Services
Work Order No. 7

Prepared for:
CITY OF NORFOLK
DEPARTMENT OF PUBLIC WORKS

April 2010
Moffatt & Nichol Project No. 7175-07

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Draft Report, 4/29/10

April 29, 2010
Project No. 7175-07

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

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

Subject: **Flood Mitigation Alternatives Evaluation - Mason Creek, City of Norfolk, Underwater Inspections and Engineering Services, Work Order No. 7**

Dear Mr. White:

Enclosed is Moffatt Nichol's report documenting our flood mitigation alternatives evaluation for Mason Creek. This study and report were authorized by Work Order #7, dated December 10, 2010 of the City of Norfolk Underwater Inspection and Engineering Services Contract (City of Norfolk Contract 12481). This report provides our technical assessment of flood mitigation options in Mason Creek and builds upon a previous study completed in 2007. This report incorporates the analysis and findings from the previous report so that this report can stand alone. Our report considers various options for mitigation approach, screens those options relative to their technical merit, flexibility, and projected costs. The report also includes consideration of several different criteria for flood mitigation in terms of severity of storm and potential future sea level rise.

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

Sincerely,

Johnny D. Martin, PE
Associate Vice President/Senior Hydraulic Engineer

Jousha M. Hill, P.E.
Civil Engineer

Enclosure:

Copies Submitted: (#)

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EXECUTIVE SUMMARY

Mason Creek is a water body which flows into Willoughby Bay and is located in Norfolk, Virginia adjacent to the east side of the Norfolk Naval Air Station. Approximately 3,250 acres drain into Mason Creek from surrounding residential developments and the Norfolk Naval Air Station. Mason Creek's hydraulics are characterized by stormwater infrastructure which drains the surrounding area into Mason Creek, twin box culverts installed under Granby Street, and a combination box culvert/semi-circular culvert which runs under the Norfolk Naval Air Station. The major culverts under Granby Street and Norfolk Naval Air Station allow Mason Creek to be influenced by the tidal flow in Willoughby Bay. In addition to these culverts, a tide gate exists at the Norfolk Naval Air Station culvert (on the inland side) at the Mason Creek exit to Willoughby Bay to reduce tidal flooding during storms.

A previous study was completed in 2007 which concentrated on developing gravity-based solutions to improve water quality and flushing within the system. However, the City and Mason Creek residents have indicated the need to review coastal flooding scenarios that could occur during extreme events when the Navy gate is closed to determine if additional flooding relief is warranted and economically justifiable. This study incorporates the findings from the 2007 report in addition to completing a stormwater analysis of the drainage basin for the new flooding scenarios.

This study presents nine (9) alternatives - five (5) mitigating flooding during coincident surge events and four (4) mitigating flooding during rain events only. These flood mitigation alternatives included localized steel bulkheads within low-lying areas, installation of pump stations, property buyouts, culvert upgrades, and open channel construction. Since the drainage area historically has been afforded significant protection from coastal surge events (with the closing of a sluice gate at low tide) relatively few structures appear to be impacted by flood events. The structures that are affected appear to be mainly ancillary structures (garages, sheds, etc.) and are affected from localized flooding when the sluice gate is closed and a significant rain event occurs.

Based on the model results, it was determined that the pumps station alternatives, bulkhead wall alternative and property buy-out alternative be further developed with an opinion of probable cost and benefit-cost ratio analysis so a preferred alternative could be selected based on performance. This study demonstrates that infrastructure improvements such as a pump station can mitigate flooding; however, a significant initial investment of $25.1 Million is required to provide flood protection when the sluice gate is closed. In addition to the significant investment, the benefit-cost ratio is significantly less than 1.0 which indicates that the potential costs outweigh the potential benefits.

From these report findings, none of the alternatives identified in the study provide an economically justifiable solution to mitigating flooding within the Mason Creek area. Since relatively few primary structures appear to be impacted by flood waters, it may be best to modify existing building regulations (placement to shoreline, finish floor elevation, etc.) to limit impacts to ancillary structures and to further investigate if targeted buyouts are justifiable if FEMA

funding can be acquired. However, if the City determines that their main goal is to provide flood relief to the residents of Mason Creek and reduce flooding of Granby Street during extreme events, then Alternative 2 – Culvert, 2 – 60in Pumps is the best alternative at a initial investment of $25.1 Million and an annual operation and maintenance cost of $139K/year.

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1.0 - INTRODUCTION AND BACKGROUND

PROJECT BACKGROUND

Mason Creek is a water body located in Norfolk, VA adjacent to the east side of the Norfolk Naval Air Station which flows into Willoughby Bay. Approximately 3,250 acres drain into Mason Creek from surrounding residential developments and the Norfolk Naval Air Station. Mason Creek's hydraulics are characterized by stormwater infrastructure which drains the surrounding area into Mason Creek, twin box culverts installed under Granby Street, and a combination box culvert/semi-circular culvert which runs under the Norfolk Naval Air Station. The major culverts under Granby Street and Norfolk Naval Air Station allow Mason Creek to be influenced by the tidal flow in Willoughby Bay. In addition, a tide gate exists at the Norfolk Naval Air Station culvert (on the inland side) exit to Willoughby Bay to reduce tidal flooding during storm events.

Historically, the Mason Creek drainage area has been afforded significant protection from coastal surge events with the closing of a sluice gate (at low tide) located at the inlet of a culvert located underneath the Navy property which discharges into Willoughby Bay. Therefore, for the most part, Mason Creek has been mainly impacted by significant rainfall events.

A previous study was completed in 2007 which concentrated on developing gravity-based solutions to improve water quality and flushing within the system. However, the City and Mason Creek residents have indicated the need to review coastal flooding scenarios that could occur during extreme events when the Navy gate is closed to determine if additional flooding relief is warranted and economically justifiable. The City also directed M&N to utilize the previous model and findings to the extent practicable.

In response to flooding concerns, Moffatt & Nichol has been tasked to complete a stormwater analysis of the Mason Creek drainage basin to determine flooding scenarios, and flooding mitigation alternatives. Additional information on these tasks is provided in the Authorization portion of Section 1. The Mason Creek project location map and drainage basin are provided in Figures 1-1 and 1-2, respectively.

AUTHORIZATION

Work Order No. 7 for the Mason Creek Stormwater Analysis was issued by the City on December 2010. The services under this task order include:

- Analysis of tidal surge events and rainfall events for the 2, 10, 25, 50, and 100 year storm events for the Mason Creek drainage basin,
- Provide Opinion of Probable Cost for mitigation options determined by the study results,
- Establish damage assessments values for the various types of event combinations
- Determine benefit/cost ratios in regards to mitigation options and damage assessments values, and
- Provide a letter report

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PROJECT TEAM

The analysis and this report have been prepared by the Moffatt & Nichol team that includes:

- Mr. Johnny Martin, senior coastal/hydraulic engineer with Moffatt & Nichol is the Project Manager for this task-order and has supervised Moffatt & Nichol's hydrological analyses efforts,
- Nicole Vanderbeke, hydraulic engineer with Moffatt & Nichol conducted hydrological analyses efforts,
- Jousha Hill, civil engineer with Moffatt & Nichol conducted the evaluations for the various alternatives and provided the opinions of probable cost for the various alternatives as reported herein.
- Mr. Kyle Spencer GIS analysts on Fugro Atlantic's staff have developed the GIS-based mapping and prepared the mapping used in the study,

Johnny Martin, Nicole Vanderbeke and Jousha Hill are the primary authors of this report.

2.0 - DATA COLLECTION

WATERSHED DESCRIPTION

The Mason Creek watershed is adjacent to the east side of the Norfolk Naval Air Station. (Figure 1-1). The watershed includes 6,680 parcels within the 3,233 acres of land in the watershed. Data was available for the Mason Creek drainage area from various sources and is outlined below. Aerial photography, topography, drainage basin extents, stormwater infrastructure, bathymetry, tidal data, and rainfall data were used to produce an existing conditions model in EPA SWMM which could be calibrated for normal conditions as well as storm events.

Aerial Photography and Topography

In 2009 Pictometry, Inc., under contract to the City of Norfolk, performed a LIDAR (Light Detection And Ranging) survey which provided aerial photography and topographic data at a 3-ft by 3-ft horizontal resolution. The survey data provide the basis for the 10-ft x 10-ft grid size DEM that was used in the original SWMM model for Mason Creek. The LIDAR survey was also particularly helpful in completing the damage assessments as outlined in Section 8. Figure 2-1 outlines the topographic data for the Mason Creek Drainage Basin.

Bathymetry

Waterway Surveys & Engineering, Ltd. provided bathymetric data for Mason Creek from November and December 2006 with a vertical datum of NAVD88. Data was provided in CADD format and was imported into GIS and converted to a shapefile. Use of this data set in specific

modeling applications will be discussed further in this report. Figure 2-2 shows the bathymetry data used in describing the Mason Creek reservoir.

Tide Data

Waterway Surveys & Engineering, Ltd. Provided water level data within Mason Creek from four Macrotide gages installed throughout Mason Creek which recorded water levels through pressure and temperature sensors. Figure 2-3 presents the approximate tide gage locations. There were two deployments of the gages resulting in a time series of gage data from February 23, 2007 to March 26, 2007 and March 28, 2007 to April 26, 2007. This data was used to calibrate the EPA SWMM model during normal tide conditions.

Tide data from NOAA Station 8638610 (Sewells Point) was downloaded from NOAA Tides and Currents for the same time period as measured data was available. This data was used as the boundary condition at the outfall of the culvert which runs underneath the Norfolk Naval Air Station and discharges into Willoughby Bay for the normal tide conditions calibration. Tide data was also downloaded for this station for the time period surrounding Tropical Storm Ernesto (August-September 2006). This data was also used as the outfall boundary condition for the storm conditions model verification.

Rainfall Data

Rainfall data was downloaded from the National Climatic Data Center NOAA website for Station 446139 (Norfolk International Airport). Data was downloaded for February-April 2007 for use in the normal conditions calibration model. Data was downloaded for August-September 2006 for use in the storm conditions calibration model.

In addition, precipitation frequency estimates were downloaded from NOAA for Norfolk International Airport for use in development of 1, 2, 10, 25, 50, and 100 yr design storms which were used to establish behavior of the watershed under existing conditions as well as evaluate the selected alternatives.

Stormwater Infrastructure

The City of Norfolk provided a shapefile of stormwater pipes for the portion of the Mason Creek drainage area not located on the Norfolk Naval Air Station. The shapefile was in State Plane NAD 1983 Virginia South (ft). Pipe size, shape, and material were included in the attribute table for all pipes. Upstream and downstream inverts were included in the attribute table for approximately 50% of the pipes. The Norfolk Naval Air Station provided CADD drawings of stormwater infrastructure on the base in State Plane NAD 1927 Virginia South (ft). The CADD layers were brought into GIS and converted to shapefiles. Pipe size, shape, and material were included as attributes. Upstream and downstream inverts were included in the attribute table for approximately 50% of the pipes. Use of this data set in specific modeling applications will be discussed further in this report. Figure 2-4 shows the stormwater infrastructure for the Mason Creek Drainage basin.

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Receiving Water Body

Mason Creek is the receiving body of water from the Mason Creek watershed which feeds through a culvert underneath Navy property into Willoughby Bay. Both bodies of water are tidally influenced and subject to storm surge; however, Mason Creek can be controlled by a sluice gate located on the Navy's property which is operated by closing the gate at low tide if a significant tidal event is expected. The operating protocol for the flood gate can be found in Appendix A.

BASIN RIM

The perimeter of the watershed is about 89,232 feet (16.9 miles). The perimeter is delineated by Interstate 564 on the west and Ocean View/Little Creek to the east.

3.0 - BASIN OUTLET

SITE CONDITIONS AT BASIN OUTLET

The basin outlet represents the location of the confluence between Mason Creek and Willoughby Bay. Currently, the outlet passes underneath the Norfolk Naval Air Station. The outlet is approximately 20 feet in width, 11 feet in height and extends ~1800 feet underneath the Naval Air Station.

NAVIGATION REQUIREMENTS

Since Mason Creek is restricted from access to Willoughby Bay, there is no navigable channel within Mason Creek.

4.0 - DESIGN CRITERIA

TAIL WATER ELEVATION AND COASTAL FLOODING CONSIDERATIONS

Historically, the tail water elevation for drainage improvement in the City have been based on various water elevation (e.g., mean high water, mean low water, etc.) at Sewells Point. Table 4.1 below details the recurrence interval tailwater elevations at Sewells Point (Fugro, 2010).

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Table 4-1. Tail Water Elevations at Sewells Point

Return Period (years)	Tailwater Elevation (ft NAVD88)
MHHW	1.2
1	3.2
2	3.8
5	4.6
10	5.2
25	6.0
50	6.6
100	7.2

The measurement of water levels using tide gauges throughout the City (Fugro, 2010) has shown that water levels in the various drainage basins within the City are typically elevated over the measurements at Sewells Point; however, Masons Creek is hydraulically connected to the tidally-influenced Willoughby Bay. Thus, there is no basin offset for the difference in water level within the Masons Creek and the tide elevation at Sewells Point. A 0.5-ft allowance has been included to compensate for potential piling off water due to wind effects or cove amplification. The following table documents how those effects have been accounted for in the current storm water and flood mitigation alternatives evaluation.

Table 4-2. Tail Water Correction (re: Sewells Point) and Allowance for Sea Level Rise

Consideration	Offset Relative to Sewells Point, feet	
	Incremental	Cumulative
Wind Direction and/or Cove Offset	0.5	0.5

Therefore the final tailwater elevations to be used in the study are 0.5 ft higher than Sewells Point and can be found in Table 4-3 below.

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Table 4-3. Tail Water Elevations at Mason Creek Outlet

Return Period (years)	Tailwater Elevation (ft NAVD88)
MHHW	1.7
1	3.7
2	4.3
5	5.1
10	5.7
25	6.5
50	7.1
100	7.7

RAINFALL AND PRECIPITATION

As indicated in Section 2.0 - Data Collection, the design rainfall duration-frequency depths were derived from precipitation frequency estimates published by the National Oceanic and Atmospheric Administration (NOAA) for the Norfolk International Airport (NOAA, 2004 – nearest station). These 24-hour rainfall amounts are listed in Table 4-4 below.

Table 4-4. NOAA Return Frequency Rainfall Depths for Norfolk WSO Airport

Average Recurrence Interval (ARI) (years)	24-hr Precipitation Frequency Estimate (inches)
1	2.93
2	3.57
5	4.62
10	5.51
25	6.82
50	7.96
100	9.21

5.0 - EXISTING SYSTEM HYDROLOGIC/HYDRAULIC EVALUATION

SELECTION OF MODEL

XP-SWMM is a software package that utilizes the EPA Stormwater Management Model (SWMM) one-dimensional (1D) analytical engine for running rainfall-runoff simulations for single event or long-term simulations of runoff quantity and quality. SWMM simulates runoff from

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subcatchment areas and routes it through systems of pipes, channels, pumps, and storage devices.

XP-SWMM also incorporates a two-dimensional (2D) analytical module for the routing of surface flood flows, based on the TUFLOW program developed by WBM Oceanics Australia and The University of Queensland. TUFLOW is specifically orientated towards establishing the flow patterns in coastal waters, estuaries, rivers, floodplains and urban areas where the flow patterns are essentially 2D in nature and would be difficult to appropriately represent using a 1D model. A powerful feature of TUFLOW is its ability to dynamically link to the 1D network of the SWMM engine. In XP-SWMM, the user sets up a model as a combination of 1D storm-drain network domains linked to 2D domains, i.e. the 2D and 1D domains are linked to form one model.

The main inputs to the SWMM model for this study include:

- Rainfall-time series of rainfall
- Subcatchment Data-area, overland flow, % slope, % impervious, curve number
- Junction Data-inverts, depth, ponded area
- Conduit Data-shape, size, length, roughness, inverts, loss coefficients
- Weirs-type, height, length
- Storage Units-shape, inverts, initial depth
- Outfall-inverts, tide gate, tidal boundary condition

MODELING SCOPE

The existing EPA SWMM model (completed in 2007) served as the basis for developing an understanding of the existing hydrologic and hydraulic conditions present in the Mason Creek drainage area and evaluating numerous flood control alternatives. To establish appropriate model parameters, the existing EPA SWMM model was calibrated for a February 23, 2007 to April 26, 2007 time period using gage data collected in the field by Waterway Surveys and Engineering, Ltd. Roughness coefficients and allowable ponding were adjusted until the calculated water levels in Mason Creek were comparable to those measured by the macrotide gages.

Once a calibrated model was developed under normal conditions, the model was run using Tropical Storm Ernesto to verify that the chosen calibration parameters performed well under storm conditions. Model performance was based on resident observations of flooding which occurred at Granby Street in which Mason Creek slightly overtopped the road. Flooding was also noted to have occurred in surrounding residential areas as well.

After model verification, the model was run for 1, 2, 10, 25, 50 and 100-year events to determine existing condition behavoir of the watershed under various return period flows. The storm events were also run for a future condition of full build-out based on the City's current land

use plan. This was a carryover from the original 2007 study as far as the return period rainfall events which were run.

Based upon the findings from the existing and future conditions studies, viable solutions to flooding and drainage problems were developed and evaluated. Alternatives were run for existing conditions and future conditions of full build-out. Model results were analyzed and discussed with the City to provide a recommendation of the finalized alternative.

MODEL CALIBRATION: NORMAL CONDITIONS

The EPA SWMM model was calibrated to reflect water level data measured in the field from February 23, 2007 to April 26, 2007. Statistical analysis of the tide and gage data shows that this time period was representative of average conditions in Mason Creek.

Model set-up was started with creating a representative schematic of the Mason Creek drainage area in EPA SWMM. For purposes of this study and conceptual modeling effort, the drainage area was described by nine subcatchments based on tributaires flowing into Mason Creek, two reservoirs, or storage units, on either side of the Granby Street twin box culverts, a simplified but representative pipe network to transport runoff from subcatchments to the storage units, and a box culvert running under the Naval Air Station which discharges into Willoughby Bay, with a tide gate. Figure 5-1 shows a schematic of the model set-up in EPA SWMM. Again, this original model was simplified compared to current efforts in the Hague and Pretty Lake but was deemed accurate enough for this study of potential alternatives. Also, since additional infrastructure in the model would have likely lessened flooding in Mason Creek due to upstream attenuation, it was determined that using the simplified model would be more conservative and provide a “worst case” scenario for flooding within Mason Creek. Model input parameters are explained in detail below.

Rainfall Data

As mentioned previously, rainfall data was downloaded from NCDC NOAA website, for a station located at Norfolk International Airport, for February 23, 2007 to April 26, 2007. An hourly timeseries file was created with rainfall intensity in in/hr. This rainfall timeseries was applied to Gage 1 which was used as the rain gage for each of the nine subcatchments.

Subcatchments

The Mason Creek drainage area was divided into nine subcatchments based on tributaires flowing into Mason Creek. Figure 5-2 shows the division of the drainage area. Each subcatchment was analyzed to determine input parameters for SWMM. Overland flow, percent impervious, and curve number were estimated from aerial photography. Percent slope was estimated from topography. Soil conductivity was estimated from the NRCS for the entire drainage basin. Other values were left as defaults.

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Junctions

Junctions represent the point where runoff enters the stormwater pipe network in each subcatchment. The topography and stormwater pipe inverts were examined in each subcatchment to determine an average invert elevation and distance to the ground surface for the start of the pipe network leading to Mason Creek. Also, a small ponded area was included at each junction, allowing flooding for larger storm events without losing water mass from the system.

Conduits

The stormwater infrastructure network present in each subcatchment was simplified in SWMM by using one or two stormwater pipes per subcatchment depending on how many major stormwater lines drained into Mason Creek. The length of the main stormwater lines was approximated and the largest pipe size within the system was used to accomodate flow from the entire subcatchment as not to cause significant impoundment within the upstream watershed. It was felt that this assumption would provide a “worst case” scenario for flooding within Mason Creek since flood flows would not be impeded by likely upstream infrastructure undersizing and constraints. Inlet and outlet inverts were approximated at both ends of the main stormwater lines draining to Mason Creek.

The twin box culverts unders Granby Street and the combination box culvert/semi-circular culvert under the Norfolk Naval Air Station were input into SWMM as individual pipes with more detail since changes in these were expected to make the largerst impact when looking at alternative solutions. Entry and exit loss coefficients for the Granby Street culverts were estimated to be 0.5 and 1.0 respectively. The entry and exit loss coefficients for the culvert running under Norfolk Naval Air Station were raised slightly due to the effect of the tide gate on losses to the system and to help calibrate the model to simulate reduction of the tidal range from Willoughby Bay to Mason Creek (~40%). Coefficients of 2.0 and 4.0 were used for entry and exit losses respectively.

The stormwater infrastructure network present in each subcatchment was simplified in SWMM by using one or two stormwater pipes per subcatchment. Conduit sizes and geometries were derived from the stormdrain database provided by the City.

Storage Units

Mason Creek was divided into two reservoirs on either side of the Granby Street box culverts, and represented in SWMM by storage units SU1 and SU2. Stage-storage curves were developed based on topography and bathymetry data for each reservoir. Bathymetry data was used to approximate an average invert elevation for each reservoir. The reservoir on the east side of Granby Street was approxmated to the have an invert of -3 ft while the reservoir on the west side of Granby Street was approximated to have an invert of -3.5 ft. The initial depth of each reservoir was set based on the water level according to the measured gage data at the start of the simulation.

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Weirs

Granby Street has periodically been overtopped with water from Mason Creek during storm events. Therefore, to capture this behavoir, the street was represented in SWMM with a weir. The length was set at 500 ft which is the approximate length of the road running over Mason Creek. The crest height of the weir was set at 8 ft from the invert of the reservoir on the east side of Granby Street which is approximately -3 ft. This is equivilant to the road being at an elevation of +5 ft NAVD88.

Outfalls

The outfall which drains water from Mason Creek into Willoughby Bay was set up with a boundary condition equal to the tide taken from the NOAA Station 8638610 at Sewells Point. The inverts of the outfall were determined from plans received from Norfolk Naval Air Station when the culvert was designed.

MODEL CALIBRATION

Figures 5-3 through 5-7 show results of the February 23-April 26, 2007 calibration. Measured gage data and waterlevels at each reservoir (storage unit) are presented. As can be seen from the figures, the calibrated water levels seem to slightly underestimate the gage data during the first deployment (February 23-March 26). However, the calibrated water levels match well with the gage data from the second deployment (March 28-April 26). Upon examination of the gage data, it appears that there may be a datum issue with the first deployment since the average water level of the gage data is much higher than the average tide level. During the second deployment, the average of the gage data and tide are more similar. Therfore, assuming that the measured gage data is slightly higher than what actually occurred, the calibrated water levels during the first deployment are most likely representative of the actual water level instead of underestimates as it appears in the figures.

6.0 – MODEL VERIFICATION: STORM CONDITIONS

In order to verify that the model provided reasonable results during storm conditions in which flooding occurred as well as under normal conditions and small storm events like that of April 15, 2007, Tropical Storm Ernesto was modeled using the parameters chosen during calibration.

EPA SWMM Input Parameters

The same input parameters decided upon during calibration were used with the exception of rainfall data, tide data, and initial water level of the storage units. Rainfall data for Tropical Storm Ernesto was downloaded from NCDC and an hourly timeseries file was created with rainfall intensity in in/hr. This rainfall timeseries was applied to Gage 1 which was used as the rain gage for each of the nine subcatchments. The tide data from the NOAA station at Sewells Point during Tropical Storm Ernesto was also downloaded and used as the boudary

condition at the outfall. Initial depths for the storage units were chosen based on the tide level at the time when the model run was started. In addition, the tide gate option was used on the outfall since a storm of this magnitude justified closing the gate according to the tide gate operation rules.

Model Results (Storm Conditions Verification)

Model results from the Tropical Storm Ernesto run are presented in Figure 6-1. Based on field observations which noted that Granby Street (elevation +5 ft NAVD88) was slightly overtopped during Ernesto, the plot of the storm conditions model results seems to be representative of what actually occurred, showing a peak water level of 5.68 ft NAVD88. The inundation extents of Tropical Storm Ernesto are presented in Figure 6-2. Also, it was noted during Ernesto that much of the upland drainage area flooded as well. The model results statistics showed flooding at the junctions as well, indicating further that the model performed correctly under storm conditions.

7.0 – EXISTING CONDITIONS STORM EVENT MODEL

Using the parameters set during the model calibration and verification process, storm events of various return intervals were run in the EPA SWMM model to evaluate the behavior of the watershed under existing conditions.

EPA SWMM Input Parameters

The input parameters established during calibration and verification were used for the existing conditions storm event model with the exception of rainfall data and initial water depths in Mason Creek. Design storms were developed for 1, 2, 10, 25, 50 and 100 yr 24-hr return intervals from Norfolk International Airport precipitation frequency estimates which were downloaded from NOAA. These design storms were then imported into Gage 1. The average mean low tide from field data collected in February-April 2007, -0.33 ft NAVD88, was used at the initial water level in each reservoir (storage unit) based on the fact that the Navy would likely shut the tide gate at the low tide before the storm arrived. Consequently, the tide gate option was used at the outfall since the tide gate operation rules state that the gate will be closed during storm events to prevent flooding from elevated tide levels. Tide conditions at the outfall were run at a fixed value for both MHHW (+1.7' NAVD88) and storm conditions, using peak surge values for each of the design storms. Table 4-3 displays the surge values for each of the design storms.

Model Results (Existing Conditions Storm Event)

Model results for the 10yr and 100yr design storms are presented in Figures 7-1 through 7-4. The model results for each design storm are presented in provided in Appendix B and peak flood values are tabulated in Table 7-1. The results represent the water levels in Mason Creek corresponding to the behavior of the watershed during 1, 2, 10, 25, 50, and 100 yr 24-hr design storms which were started at low tide. The table shows both sets of runs with tail water

set at MHHW as well as the coincident surge level for each. Based on these values, it can be assumed that Tropical Storm Ernesto, which reached a peak water level of approximately 5.68 ft, was between a 50 yr and 100 yr event. Although the total rainfall during Ernesto, which was 9.93 inches, exceeded the NOAA 100 yr, 24 hr event of 9.21 inches, the combined rainfall and surge places Ernesto somewhere between a 50 yr and 100 yr event.

Table 7-1. Existing Condition Peak Flood Elevation (ft)

Design Storm	Tailwater	Peak Flood El. (ft)
1 yr	MHHW	1.78
	1 yr Surge	2.38
2 yr	MHHW	1.95
	2 yr Surge	3.13
10 yr	MHHW	2.75
	10 yr Surge	5.17
25 yr	MHHW	3.43
	25 yr Surge	5.47
50 yr	MHHW	4.05
	50 yr Surge	5.65
100 yr	MHHW	4.74
	100 yr Surge	5.80

8.0 - EXISTING SYSTEM ESTIMATES OF DAMAGE COSTS

METHODOLOGY

Flood damage estimates were assessed for a range of flooding scenarios under existing conditions. However, these analyses would also be completed for many of the flood mitigation alternatives to aid in their assessment. The analysis focuses on direct damage to structures and contents of private and public buildings. The primary focus of this analysis is to estimate the economic damages associated with future flood events in the study area under existing conditions and to provide a basis for performing a benefit-cost comparison of flood 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 resulting from responses to flood warnings.

In general, structure and contents flood damage assessments were based on predicted flood water depth above the first floor in a structure and the value of the structure. Damage estimates were calculated based on a percentage of the building value where the percentage is a function of the flood water depth. The function, referred to as a depth damage function (DDF), generally increases as the flood water depth increases. DDFs have been developed for various types of buildings. This study used a building inventory file developed by the project team with assistance from the City, output flooding results from the modeling analyses, high-resolution LIDAR topography data, and flood water DDF curves. A GIS-based

routine was developed to calculate and compile the damage estimates for the various flooding scenarios and mitigation alternatives. The results of the damage assessment estimates are included in the Alternatives Analysis section of the report and is provided in Section 10.0 and included in Appendix D. A description of the procedure is provided in the following sections.

Building Inventory Methodology

A GIS file of the building footprints was developed for this study and was used to define the spatial locations of buildings in each study area. The project team coordinated with the City to update building footprints based on 2009 aerial photography. Approximately 10,400 buildings were used in the Mason Creek study areas

After building footprints were updated, the buildings were classified by type. The building type was used to determine which depth damage function (DDF) would be used for damage estimates. The building type was based primarily on information provided by the City's assessor's office. The information was further refined using high-resolution aerial photographs and site reconnaissance conducted during the study. Building classifications are summarized in the following table.

Table 8-1. 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			

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Building Values

Building values were assigned to the buildings based on information provided by the City's assessor's office. Where available, the City's 2009 assessed values were used. In some cases, assessment values were not available and had to be estimated.

First Floor Elevations

In order to estimate the flood depth at a building, first floor elevations (FFE) were developed. FFE derived from surveyed results were not available for most buildings. Therefore, FFE were developed for using the following procedure. For buildings outside of the 100-year flood zone or were constructed during in 1979 or earlier, we used the 2009 LIDAR data to estimate the FFE. If a building did not have a crawl space (as defined in the assessor's database), we assumed the FFE is 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 was assumed based on reconnaissance work conducted during the study. During the study, reconnaissance through the study area was conducted to estimate and assign the FFE where crawl space height data was incomplete in the database.

If buildings were 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). Therefore, per the NFIP, buildings constructed within 100-yr flood zones are required to be 1-foot above the 100-year flood elevation.

Depth Damage Functions - Structures and Contents

A depth-damage function 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 depth damage functions 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. Depth damage functions have been developed for various building types based on statistical studies. For residential damages, curves published in the USACE's EGM 01-03 (USACE, 2000) and EGM 04-01 (USACE, 2003) were used in this study. The guidance documents provide a "mean" percentage and a "standard deviation" percentage to use when estimating damage from various flood water depths. Figure 8-1 provides the concept for the depth damage function.

Damage Assessment Estimates

For this study, a GIS-based damage assessment tool was developed. The tool reads the flood water body outputs from the modeling runs described in a previous section of this report and estimates the flood water depth for each building based on the building's FFE and flood model output. Structure and content damages were estimated using the flood water depth and respective DDFs. The distribution of estimated damages for 10yr and 100yr storm events are provided in Figures 8-2 through 8-5 respectively.

RESULTS

The results of the structure and contents damage estimates for existing conditions are summarized in Table 8-2.

Table 8-2. Existing Condition Structure and Contents Flood Damage Estimates for the Mason Creek

Mason Creek Scenario 1st number is return period of rainfall event & 2nd number is return period of tidal surge	**Number of Buildings Impacted**	**Structural Damage**	**Contents Damage**	**Total Damage**
		($)	($)	($)
2yr MHHW	0	0	0	0
10yr MHHW	37	82	317	398
25yr MHHW	54	1,351	2,586	3,087
50yr MHHW	58	6,631	5,191	11,822
100yr MHHW	64	26,290	18,652	44,943
2yr / 2yr	0	0	0	0
10yr / 10yr	37	61,334	38,556	99,891
25yr / 25yr	54	100,011	63,532	163,544
50yr / 50yr	57	131,720	82,400	214,120
100yr / 100yr	64	172,721	111,909	284,630

As can be seen from the above table, the range of damages for Mason Creek for the various storm events is quite low in comparison with other watersheds. While the estimates above did not include ancillary structures, it is apparent that the current operation of the tide gate by closing at low tide does provide considerable flood storage which assists in the mitigation of flooding for primary structures.

9.0 - PROJECT DEFINITION OR DEVELOPMENT OF ALTERNATIVES

INTRODUCTION

There are many ways to mitigate the risk, severity, and consequences of flooding. Those approaches can be broadly divided into several categories, such as: 1) drainage and water conveyance system improvements, 2) elevation of the ground surface and structures, 3) construction of barriers to prevent flooding, 4) impoundment and storage of flood waters, 5)

adaptive land use to accommodate flooding, 6) relocation and/or abandonment and 7) public policy actions.

The objectives and priorities for flood improvements will depend on technical considerations, as described herein, that define flood risk (frequency, severity, and extent of flooding) and flood hazards. These technical factors together with the many societal factors that define the consequences (and their acceptability, or not) of flooding, and the costs of flood mitigation measures all must be considered and evaluated when defining and prioritizing flood mitigation approach and priorities.

FLOOD MITIGATION/DEFENSE STRATEGIES AND OPTIONS

The development of a flood mitigation/defense project 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 not), 4) an evaluation of alternatives, and 5) the development and implementation of a mitigation and risk management plans.

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

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

The consequences of flooding are dependent on the potential for loss of life or injury, population and population density, economic losses, disruption of City services, access, and other societal factors. Together the risks and consequences provide the formative information for defining flood mitigation objectives and priorities.

Flood mitigation involves either preventing the flood waters from entering an area, moving the flood waters 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,
- Relocation and/or abandonment,
- Adaptive land use to accommodate flooding, and
- Public policy.

The Mason Creek drainage basin currently utilizes one of the above flood mitigation strategies to assist with coastal flooding. The Mason Creek outlet which is located under the Naval Station Norfolk is constructed with a floodgate to reduce flooding within the Mason Creek Area. This gate remains open during normal weather conditions; however, if a significant

weather event is identified to occur, then the gate is typically closed 24-36 hours prior to the event at the lowest expected tide elevation so that potential flood storage in the reservoir is maximized. Additional information on the Navy's Mason Creek Flood Gate Protocol is provided in Appendix A. In addition to this utilized mitigation strategy, additional strategies have been identified as potential aids in assisting with mitigating flooding with the Mason Creek basin. These additional flood mitigation elements include:

- Drainage and conveyance improvements:
  - Channelization or improved flood conveyance (stream channel improvements) and
  - Storm drainage system improvements;
- Barriers to flooding:
  - Earthen berms and levees,
  - Floodwalls,
- 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/relocation and set aside/abandonment;
- Public policy:
  - Local building and construction code modifications,
  - Zoning and land use restrictions,
  - Education, and
  - Flood warning systems, modeling, and forecasting.

CONCEPTS SELECTED FOR FURTHER EVALUTION

Based on the preliminary evaluation, it was determined that four of the flood mitigation elements could be used collectively to aid in mitigating coastal flooding within the Mason Creek Area. These five flood mitigation elements include:

- Ground Surface Improvements
- Storm Drainage System Improvements, and
- Implementation of Flooding Barriers
- Adaptive Land Use

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- Public Policy

Within these collective elements, several different types of alternatives for flood barriers and drainage improvements were considered to reduce flooding. A total of nine (9) alternatives are presented below and were evaluated under the various storm events. These alternatives are grouped into nine categories and are presented in Table 9-1.

Table 9-1. Mason Creek Alternatives

Alternative	Category
1	Flood Wall
2	Box Culvert, 2-60” Dia. Pumps
3	Box Culvert, 4-60” Dia. Pumps
4	Box Culvert, 4-96” Dia. Pumps
5	Property Buyout
6	Additional Culverts at Granby Street
7	Improvement to Existing Norfolk Naval Air Station Culvert
8	Additional Culverts Under the Norfolk Naval Air Station
9	Open Channel at Norfolk Naval Air Station

Each alternative was evaluated for: 1, 2, 10, 25, 50, and 100 Year storm events. The description of each alternative is provided below. The Opinion of Probable Cost for each the selected alternatives and their respective storm events are provided in the "Opinion of Probable Cost" section of the report (Section 11.0). Figures 9-1 through 9-9 present the concepts that were selected.

Alternatives 1– Floodwall

Alternative 1 includes installing a floodwall along the banks of Mason Creek where floodwater will impact adjacent buildings. The location and elevations for the final height of the wall are dependent on the storm event being analyzed. Figures 9-1 through 9-4 indicate the locations of proposed bulkhead for 10-yr, 25-yr, 50-yr and 100-yr storm events.

The proposed floodwall would consist of steel sheetpiles. The final wall height will be dependent on Mason Creek’s water level plus 1.5 additional feet of freeboard. For instance, the water level in Mason Creek for a 100 year coincident storm event was determined to be at elevation +5.80 (NAVD 88), this would mean that the overall height of the floodwall would to be +7.3 (NAVD 88).

Alternative 2 through 4 Box Culvert with Pumps

These alternatives includes constructing an 8’ x 5’ reinforced concrete box culvert and pump station with pumps to remove excess rainfall runoff during storm events when the sluice gate is closed at the outlet. The culvert will run west, parallel to an existing taxi runway, for approximately 1700 feet then turn north for approximately 2000 feet, draining into the Willoughby Bay. A tide gate structure (only allowing outflow) would be installed where the

culvert drains into the bay to prevent flooding from elevated tides during storm events. The location of the proposed culvert trunk line is provided in Figure 9-5.

The pumps which will be used to discharge accumulated stormwater on the upstream side of the culvert will vary in size and quantity depending on the alternative. The Alternative 2 scenario will utilize three (3) 60-inch diameter pumps (2 operational & 1 back-up), the Alternative 3 scenario will utilize five (5) 60-inch diameter pumps (4 operational & 1 back-up) and the Alternative 4 scenario will utilize five (5) 96-inch pumps (4 operational & 1 back-up). For all three alternative scenarios, the intake lines of the pumps will be located upstream of the culvert and the discharge lines will be tied into the headwall of the concrete box culvert. The pumps will be powered via a substation with electric; however, emergency back-up generators will be located on-site to allow operation during power outages.

Alternative 5 – Property Buyout

Alternative 5 includes purchasing the property with structures that are identified as high damage risks. Since FEMA does not have an established buy-out criteria for this mitigation option, review of the depth damage function was completed to determine the most feasible correlation. Based on this function, it was determined that a depth damage function of 5% would provide the City an optimal characterization of the required property buyout within Mason Creek. This percentage was lower than those used in the Hague and Pretty Lake watershed studies since some protection was already being provided by the current tide gate and the overall number of structures impacted by flooding appeared to be quite less. In addition to buying the property, several other factors were included in the buyout cost. These factors included:

- Legal & processing cost
- Demolition cost of the existing infrastructure on the property
- Restoration of the purchased property to a park or other low-impact use
- Loss of City Property Tax

Alternative 6 – Additional Culverts at Granby Street

Alternative 6 includes installing addition box culverts beneath Granby Street. The proposed culverts are similar in size to the existing boxes beneath Granby Street and would provide additional flow beneath Granby Street from Storage Unit 1 and Storage Unit 2. The location and configuration of this alternative is provided in Figure 9-6.

Alternative 7 – Improvements to Existing Norfolk Naval Air Station Culverts

Alternative 7 includes modification to the existing culvert and sluice gate. These modifications would include replacing the existing gate with a more hydraulically efficient gate and creating a smoother entrance into the culvert to allow more flow through the culvert, reducing flooding within the watershed. The locations of improvements for this alternative are provided in Figure 9-7.

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Alternative 8 – Additional Culverts Under the Norfolk Naval Air Station

Alternative 8 includes installing additional culverts under the Norfolk Naval Air Station to assist in reducing the water levels within Mason Creek. At the outlet of the culvert, a hydraulically efficient gate will be installed to prevent additional backflow from the Willoughby area. Figure 9-8 presents the suggested location for the additional culverts under the Norfolk Naval Air Station.

Alternative 9 - Open Channel at Norfolk Naval Air Station

Alternative 9 consisted of constructing an open channel that drains into Willoughby Bay which would handle some (or all) of the flow currently going through the box culvert. This alternative would limit impacts to the Naval base (from operations and utility conflicts) and lessen potential costs for these disruptions. One option would include a channel that would be similar to the channel which currently directs the flow into the box culvert with a bottom width of 20 ft and side slopes of 2:1 (H:V) up to the existing ground level (approximately 10 ft NAVD88). The channel would run west along an existing taxi runway for approximately 2500 ft and then turn north for approximately 1500 ft, draining into Willoughby Bay. A tide gate structure (only allowing outflow) would be installed where the channel drains into the bay to prevent flooding from elevated tides during storm events. For another sub-option, the channel section would be increased to 50 ft so that the current culvert could be abandoned to lessen impacts to Navy operations near the wharf face. This option would require a self regulating tide gate that would allow a muted tide to enter Mason Creek. Figure 9-9 shows the location of the proposed channel alignment.

10.0 - ALTERNATIVES ANALYSES

EVALUATION METHODOLOGIES

Modeling Evaluations

Nine (9) alternatives were considered in order to reduce flooding of the Mason Creek watershed during storm events. The first five (5) alternatives looked at mitigating flooding during coincident surge events (rain and surge) for all storm scenarios. The last four (4) alternatives looked at mitigating flooding events only related to rain events and were studied in detail during the previous 2007 study.

Alternative 1 - Floodwall

This analysis simulated the construction of a bulkhead wall around the Mason Creek shoreline, which prevented storm surges from flooding onto the lower-lying areas adjacent to the shoreline. In this scenario, the shoreline was removed from the 2D model grid and the watershed boundary acted as the 2D grid boundary. Table 10-1 provides general lengths of the proposed floodwalls based on the analysis.

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Table 10-1. Alternative 1 – Floodwall Design Length

Alternative 1 – Floodwall	Length of Floodwall (LF)
2yr / 2yr	0
10yr / 10yr	10,040
25yr / 25yr	11,275
50yr / 50yr	11,605
100yr / 100yr	11,915

The results show that adding the floodwall at the lower-lying areas adjacent to the shoreline would result in reduced flooding. In addition to the construction of the floodwall, this would require Right-of-Way agreements with adjacent property owners and easement acquisitions which could be timely and disruptive to homeowners. Aesthetics and loss of view would also be important considerations.

Alternative 2 through 4 Box Culvert with Pumps

For these alternatives, a culvert was placed in the model for additional drainage of Mason Creek to the Willoughby Bay. Then either two 60-inch pumps, four 60-inch pumps, or four 96-inch pumps were used to drain flood waters out of the basin. These pump sizes were selected based on the magnitude of the pipe flows discharging into Mason Creek and the expected pump flow rates that would be needed to provide some flooding relief. The pump-curves used for the 60-inch and 96-inch pumps are presented in Figure 10-1. Within the XPSWMM model, the pumps started when the water level at the intake exceeded -2 ft NAVD88 and stopped when the water level fell below -6 ft NAVD88. For reference, MLLW at the Sewells Point tide gage is roughly -1.6-ft NAVD88, with a lowest observed water level of -2.7-ft NAVD88.

In the analysis, the 1, 2, 10, 25, 50, and 100 yr 24-hr design storms were run in XPSWMM for each alternative for both the MHHW and coincident surge events. The corresponding design event storm surge was used as the tail water elevation at the pump-outlet. For the purpose of this report, only results for the 10yr and 100yr design storms will be presented in Figures 10-2 through 10-7. As can be seen from the tables below, the addition of pump stations and an additional culvert will provide a significant impact for existing flood levels and volumes. Reductions on the order 1 – 3 feet in peak flooding elevations can be realized (even elimination of flooding on Granby Street for up to a 100-yr event) as well as significant reductions in peak flood volume (40-90%). However, it must be remembered that the current flooding levels appear to only affect a smaller number of residents (especially when compared to other watersheds within the City.

Please also note that it was considered to use the existing culvert under the Naval Air Station to receive the pumped water to lessen costs. However, the Navy is certain that many

drainage systems on base tie directly to the culvert and therefore use of the culvert as a pressurized force main would be prohibited since water would likely backflow into the Navy drainage systems and cause flooding on their property.

Table 10-2. SWMM Peak Elevation Results

Design Storm	Peak Flood Elevation (ft)				Flood Elevation Reduction (ft)			% Reduction		
	Existing Conditions	2x60 Inch Pumps	4x60 Inch Pumps	4x96 Inch Pumps	2x60 Inch Pumps	4x60 Inch Pumps	4x96 Inch Pumps	2x60 Inch Pumps	4x60 Inch Pumps	4x96 Inch Pumps
1	2.38	1.7	1.7	1.7	0.68	0.68	0.68	29%	29%	29%
2	3.13	1.71	1.7	1.7	1.42	1.43	1.43	45%	46%	46%
10	5.17	2.01	1.88	1.88	3.16	3.29	3.29	61%	64%	64%
25	5.47	2.67	2.22	2.21	2.80	3.25	3.26	51%	59%	60%
50	5.65	3.44	2.6	2.54	2.21	3.05	3.11	39%	54%	55%
100	5.80	4.37	3.06	2.91	1.43	2.74	2.89	25%	47%	50%

Table 10-3. SWMM Peak Volume Results (Including Mason Creek "Reservoir")

Design Storm	Peak Volume (acre-ft)				Volume Reduction (acre-ft)			% Reduction		
	Existing Conditions	2x60 Inch Pumps	4x60 Inch Pumps	4x96 Inch Pumps	2x60 Inch Pumps	4x60 Inch Pumps	4x96 Inch Pumps	2x60 Inch Pumps	4x60 Inch Pumps	4x96 Inch Pumps
10	931	128	106	106	804	825	825	86%	89%	89%
100	1,161	675	328	289	486	832	872	42%	72%	75%

Alternative 5 – Property Buyout

No analysis was completed for this alternative, the existing conditions relative to storm conditions and the damage assessments related to these storm events were reviewed. Based on this review, if a structure occurs 5% damage or more on the structure the property was determined a loss and a purchase was required.

Alternative 6 – Additional Culverts at Granby Street

In this analysis, the model was run with adding a third and fourth culvert underneath Granby Street. These additional culverts had minimal impacts on the Mason Creek water levels "upstream" and "downstream" of the bridge and indicated that the flood levels in the reservoir are most likely influenced by the Naval Air Station culvert.

Alternative 7 – Improvements to Existing Norfolk Naval Air Station Culvert

During the calibration and verification process, it was established that the entry and exit loss coefficients to the Norfolk Naval Base culvert were much higher than those used in the Granby St culverts and in the culverts representing the stormwater infrastructure which drains the surrounding area into Mason Creek. Reducing these losses by replacing the existing baffle plate at the tide gate and creating a smoother entrance to the culvert would allow more flow through the culvert, reducing flooding of the watershed. Therefore, the loss coefficients established during calibration for the Norfolk Naval Air Station culvert were lowered to simulate replacing the existing baffle plate on the tide gate with something more efficient.

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Based on the results, this option appears to lower the peak water level in Mason Creek approximately 2”-6” depending on the size of the storm, having a greater effect on larger storms. These results are based on a rain event only and this option would provide no relief during coincident surge events. It also lessened the duration of flooding currently experienced. However, great care would be needed in the redesign of the entrance and exit to be sure that the tide would still be muted to ~40% of the bay tide under normal conditions but allow more efficient flow out to the bay. This would also require more field investigation to accurately measure the current headlosses through the existing system so that the proposed design would provide the desired hydraulic behavior. It may be that the dominant headlosses are within the culvert itself and entrance/exit improvements may provide marginal benefit.

In addition to the hydraulic improvements to the entrance and exit, Moffatt & Nichol also reviewed the current protocol used in operation of the gate structure. Based on the protocol provided, it appears that the gate is being operated optimally for flood abatement. Closing the gate at the low tide provides the maximum available flood storage capacity, and the gate will open and allow flow to pass if the water levels in Mason Creek are higher than Willoughby Bay. Again, the only improvement possible may be to replace the current gate structure with a more hydraulically efficient one (if flow studies show the existing gate structure is actually the choke point).

Alternative 8 – Additional Culverts Under the Norfolk Naval Air Station

For this alternative, additional culverts were added under the Norfolk Naval Air Station since it appears that the Norfolk Naval Air Station culvert controls the water level in Mason Creek. Four different options were tested: 1) One 48” circular culvert, 2) One 72” circular culvert, 3) One 6’x10’ box culvert, and 4) Two 6’x10’ box culverts. Please note that these options were run assuming that valves/gates would be installed to prevent additional backflow.

The results show that adding 2-6’x10’ box culverts would lower the water levels in Mason Creek the most, ranging from a 3 in reduction during the 2-yr 24-hr design storm to a 1.35 ft reduction during the 100-yr 24-hr design storm. However, these improvements would not provide any additional relief during coincident events. Discussions were also held with the Navy and their staff stated that between the potential for utility conflicts and disruptions of operations that this alternative would be almost if not impossible to construct. They strongly suggested that this alternative be dropped from additional consideration.

Alternative 9 – Open Channel at Norfolk Naval Air Station

For this alternative, an open channel was placed in the model for additional drainage of Mason Creek to the Willoughby Bay. The results show that the first open channel option performs similar to adding a 6’x10’ box culvert, lowering water levels anywhere from 2 in to 11 in depending on the size of the storm. The second open channel option, which abandons use of the Naval Air Station culvert completely, performs slightly better than the previous open channel option however, the channel width has more than doubled. However, these improvements would not provide any additional relief during coincident events. It is also very important to note that in discussions with the Navy, their staff felt that current FAA regulations would not allow the

construction of an open channel with standing water within the air station due to potential conflicts with birds. They strongly suggested that this alternative be dropped from additional consideration.

Based on the above findings and discussions with City staff, it was decided that Alternatives 6-9 would be dropped from any further consideration. The main reasons were that none of these alternatives provided benefits for events with coincident surge which is significant given the level of investment that would be required. The other reason for dropping Alternatives 8 & 9 consisted of the fact that the Navy stated that these alternatives would be viewed as non-starters and would be strongly opposed by the Navy, Therefore, only Alternatives 1 -5 were studied further.

FLOOD DAMAGE ESTIMATES

Flood damage estimates were assessed for the flood mitigation alternatives previously described. The procedures followed to estimate the flood damages were exactly the same as used to determine the existing condition damages. The results are summarized in Table 10-3.

Table 10-4. Estimated Flood Damages

Alternative	Estimated Structure Damages				
	2-year Storm	10-year Storm	25-year Storm	50-year Storm	100-year Storm
1 - Floodwall	$0	$0	$0	$0	$0
2 - Box Culvert, 2-60” Dia. Pumps	$0	$0	$0	$0	$11,287
3 - Box Culvert, 4-60” Dia. Pumps	$0	$0	$0	$0	$0
4 - Box Culvert, 4-96” Dia. Pumps	$0	$0	$0	$0	$0

The flood damage estimates provided in Table 10-3 indicate that Alternatives 1, 3 and 4 are the most effective alternatives to reduce flooding for the varying storm events. Alternative 2 incurred minor structure damage during the 100yr storm event. Please note that these damages are only for the primary structures and ancillary structures were note evaluated under this project.

11.0 OPINION OF PROBABLE COSTS - FLOOD MITIGATION OPTIONS

A total of five (5) alternatives were evaluated under the various storm events. These alternatives are defined in Section 9 and are presented in Table 9-1 as Alternatives 1 through 5.

Capital Costs

A conceptual opinion of probable costs was developed for each of the modeled alternatives. Unit costs were based on available data from local contractors, RS Means, vendors, VDOT and other sources as needed. The opinions of probable cost include:

- Construction costs for civil, structural, electrical, mechanical, and environmental components of the project,
- Overhead & Profit for construction,
- Engineering/Construction Observation, and
- Contingency

Table 11-1 presents a summary of the probable cost in 2010 dollars for each alternative. Details of the preliminary opinions of probable costs are presented in Appendix C**.** Each alternative includes a price breakdown relative to the storm event analyzed. These elevations include storm events for the 1, 2, 10, 25, 50 and 100 year storm events for both MHHW and coincident events.

Table 11-1. Opinion of Probable Cost

Alternative	Opinion of Probable Costs ($ Millions)				
	2-year Storm	10-year Storm	25-year Storm	50-year Storm	100-year Storm
1	$1.2	$17.3	$18.3	$23.9	$24.9
2	$25.1	$25.1	$25.1	$25.1	$25.1
3	$43.0	$43.0	$43.0	$43.0	$43.0
4	$76.0	$76.0	$76.0	$76.0	$76.0
5	$0.0	$3.1	$6.7	$6.7	$13.5

Based on the Opinion of Probable Cost, Alternative 5 (Property Buyout) is the most cost effective option. However, the overall goal of the study may not be to just select the most cost-effective option, the goal should be to select the option that provides the most flood relief for the dollar. In order to select a preferred alternative entirely based on performance, a benefit-cost ratio analysis was completed for the studied alternatives. The benefit-cost ratio analysis can be found in Section 12.0. Before a benefit-cost analysis can be competed, operational and maintenance costs associated with alternatives 1 through 5 is required and is provided below.

Operational & Maintenance (O&M) Costs with Respect to Design Life

The standard serviceable design life for Alternatives 1 through 4 are estimated to be 50-years. This design life means that if it is properly maintained, the structure will be able to maintain a functional level of serviceability for at least 50 years before requiring replacement due to either deterioration or operational changes. The operational and maintenance costs associated with these alternatives will vary given the different components such as pumps (sizes and quantities) Maintenance costs and operational costs take into account a wide range of variables which include but are not limited to:

- Inspection costs,
- Minor repairs,

- Major repairs,
- Replacement costs,
- Equipment upgrades,
- Machine maintenance,
- Pumps and power costs, and
- Labor costs during "closure" events.

Operational and Maintenance Costs for each alternative are provided in Table 11-2

Table 11-2. Alternative Operational & Maintenance Costs ADD VALUES

Alternatives	Annual Operational Costs ($)	50-yr Operational Costs ($) – Present Worth)
Alternative 1 - Floodwall	$432K	$21.6M
Alternative 2 – Box Culvert, 2 – 60" Dia. Pumps	$139K	$6.9M
Alternative 3 – Box Culvert, 4 – 60" Dia. Pumps	$268K	$13.4M
Alternative 4 – Box Culvert, 4 – 96" Dia. Pumps	$373K	$18.6M

These maintenance and operational costs will be used in conjunction with the Opinion of Probable Cost and damage assessments to determine the Benefit - Cost for all alternatives.

Alternative 5 – Buyout Option does require some maintenance or operational costs due to the fact that the passive use ultimately envisioned (park, etc.) The estimates included demolition, legal processing, site clean-up, reconstruction and a contingency to account for this. Loss of City revenue from property tax was also considered under this evaluation. This loss was calculated by taking the property value purchased and multiplying it by the current property tax rate of $1.10 per $100 dollars of property value. City revenue loss over the life of 50 years for each storm event scenario is provided below in Table 11-3.

Table 11-3. Property Buyout Revenue Loss

Buyout -	Revenue Loss ($ Millions)
5% Damage Buyout – 2 Year Storm Event	$0.0
5% Damage Buyout – 10 Year Storm Event	$0.97
5% Damage Buyout – 25 Year Storm Event	$2.10
5% Damage Buyout – 50 Year Storm Event	$2.10
5% Damage Buyout – 100 Year Storm Event	$4.24

The Revenue Loss will be used in Opinion of Probable Cost and damage assessments to determine the Benefit - Cost for all alternatives.

The five alternatives varied in price from $13.5M (Buyout) to $76M (Culvert, 4 – 96" Pumps) for the 100-Year storm event. In order to select a preferred alternative entirely based on performance, a benefit-cost ratio analysis was completed for the studied alternatives. The benefit-cost ratio analysis can be found in Section 12.0.

12.0 SELECTION OF PREFERRED ALTERNATIVE

BENEFIT – COST (B/C) ANALYSIS RATIO

For this portion of the assessment, the FEMA Benefit-Cost Analysis (BCA) analysis procedure was used because it is an established process and will be required in the event that there becomes an opportunity to solicit FEMA funding. This analysis calculated the benefit-cost for all flood mitigation options described above and took into account several factors including:

- Probability of storm events and their re-occurrence related to damages and benefits on an annual basis,
- Design life of the mitigation option,
- Capital costs with O&M cost at present value
- Estimated flood damages avoided with implementation of mitigation options

FEMA traditionally calculates these flood damage options by taking into several factors; however, as described in the previous Section 8 Flood Damage Estimates only direct damages to the structure and its contents were calculated for this particular assessment. If the City indicates interest in soliciting FEMA funding then the damage values incorporated will need to be refined by incorporating additional factors such as vehicle damage, displacement costs, emergency response, management costs, lost business income, lost rental income, and damage reductions resulting from responses to flood warnings.

Probability of Storm Events and Their Re-Occurrence Related to Damages

This factor was used to estimate the total damages that may occur within the design life of a mitigation option on an annual basis for each storm event. For example, a 2-yr event has a factor of 0.5 given that it has a annual probability of occurrence of 1/R = ½ = 0.5. Likewise, a 100-yr event has a probability of 1/100 = 0.01 of happening in a given year. These probabilities could then be multiplied for the pre- and post-project damages for the individual storms and summed to determine an overall annualized damage for pre- and post-project conditions. The difference between the two would be the project benefit.

Design Life of the Mitigation Option

Based on FEMA B/C requirements, the required design life for structures is estimated to be 50 years.

Present Value of Project

Based on FEMA and OMB direction a 7% interest rate was utilized for the present value analysis. The initial costs as well as the ongoing O&M costs were brought to present value as well as the benefits which are defined as the REDUCTION in damage with the project in place (see Appendix D for calculations).

B/C Ratio

Once the project benefits and costs are brought to present value, the B/C ratio can be computed which is simply the benefits divided by the costs. A B/C ratio over 1.0 would denote that the project benefits outweigh the project costs and the higher the B/C ratio the more cost effective and advantageous the project. Table 12-1 summarizes the B/C ratios for the various alternatives.

Table 12-1. Benefit-Cost Ratio (relative to damage to structure and contents)

Alternative	Estimated Benefit to Cost Ratio				
	2-year Storm	10-year Storm	25-year Storm	50-year Storm	100-year Storm
1	0.00	0.02	0.02	0.02	0.02
2	0.00	0.01	0.02	0.02	0.02
3	0.01	0.01	0.01	0.01	0.01
4	0.00	0.00	0.01	0.01	0.01
5	-	0.06	0.05	0.05	0.03

In addition to the Table 12-1, the various Benefit-Cost ratios were plotted to determine the optimal solution. As shown in Figure 12-1, none of the alternatives have B/C ratios over 1.0 which denotes that the project benefits outweigh the project costs. Since none of these flood mitigation alternatives meet that criteria, other mitigating approaches such as public policy/code changes in conjunction with select property buyouts (with FEMA funding) may be cost effective. Such public policy/codes could include updating current city building code regulations to also require ancillary structures to meet FEMA FFE requirements and the location of structure to shoreline. However, if the City determines that their main goal is to provide flood relief to the residents of Mason Creek and reduce flooding of Granby Street during extreme events, Alternative 2 – Culvert, 2 – 60in Pumps would be the preferred alternative.

13.0 - CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis completed to date and the protocols currently followed by the Navy, the Mason Creek area is provided significant protection from coastal surge events with the closing of a sluice gate at low tide and is traditionally only affected from localized flooding when the sluice gate is closed and a significant rainfall event occurs. When localized flooding does occur, relatively few structures appear to be impacted by the flood events and the ones that are appear to be mainly ancillary structures (garages, sheds, etc.)

From the report findings above, the primary conclusion and recommendations include:

- None of the alternatives identified in the study provide an economically justifiable solution to mitigating flooding within the Mason Creek area. The Benefit-Cost Ratios for all five (5) alternatives were below 1.0 which indicates that the potential costs outweigh the potential benefits.

- Since relatively few primary structures appear to be impacted by flood waters, it may be best to modify existing building regulations (placement to shoreline, finish floor elevation, etc.) to limit impacts to ancillary structures and to further investigate if targeted buyouts are justified (may be justified if FEMA funding can be acquired).

- However, if the City determines that their main goal is to provide flood relief to the residents of Mason Creek, then Alternative 2 – Culvert, 2 – 60in Pumps is the best alternative with an initial investment of $25.1 Million and an annual operation and maintenance cost of $139K/year. This option would reduce the peak flooding elevations within Mason Creek by 1 – 3 feet which could eliminate the flooding on Granby Street during extreme events as well as significantly reduce the peak flood volumes by 40-90%.

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FIGURES

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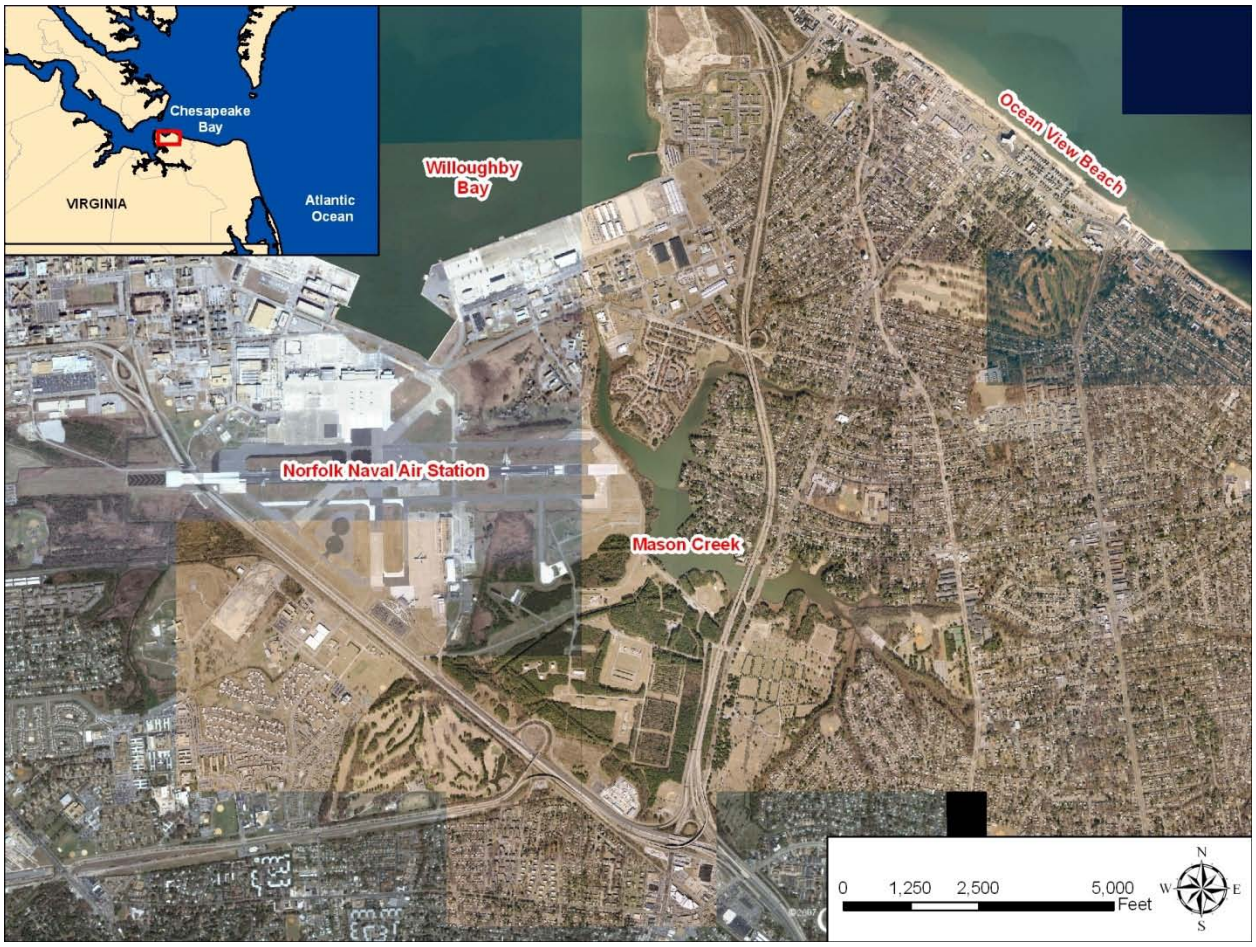


Figure 1-1. Mason Creek Project Location

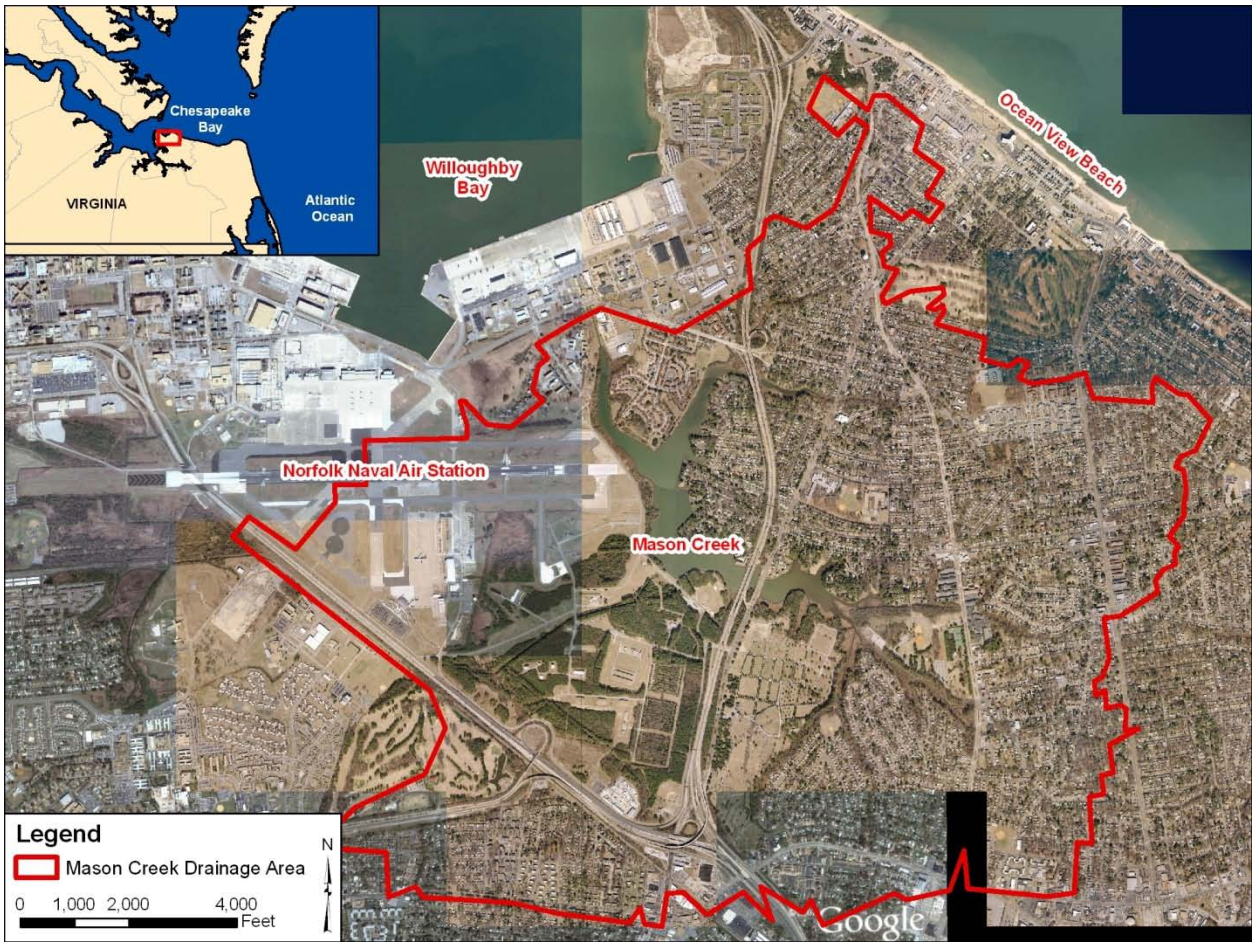


Figure 1-2. Mason Creek Drainage Basin

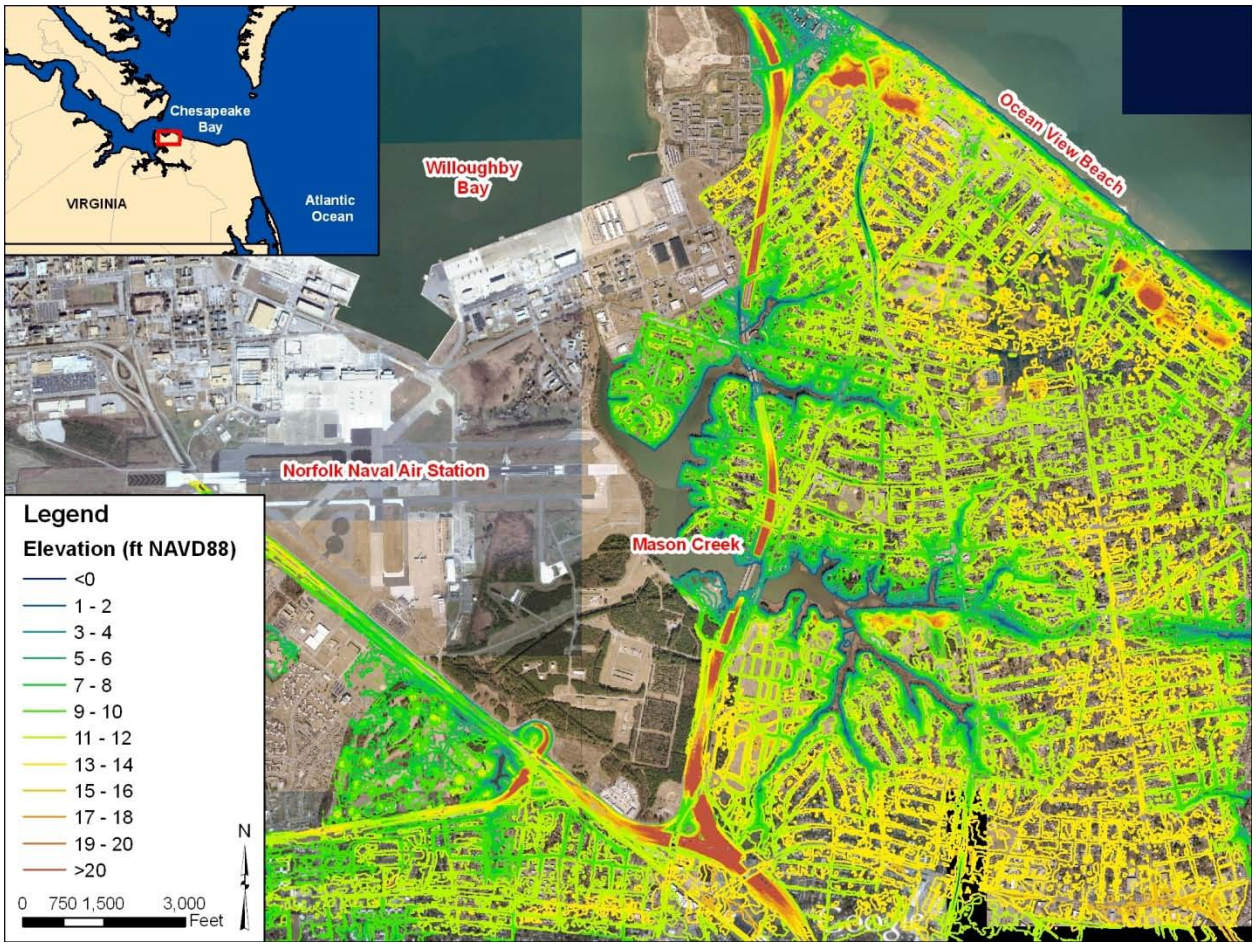


Figure 2-1. Topographic Data For Mason Creek Drainage Basin

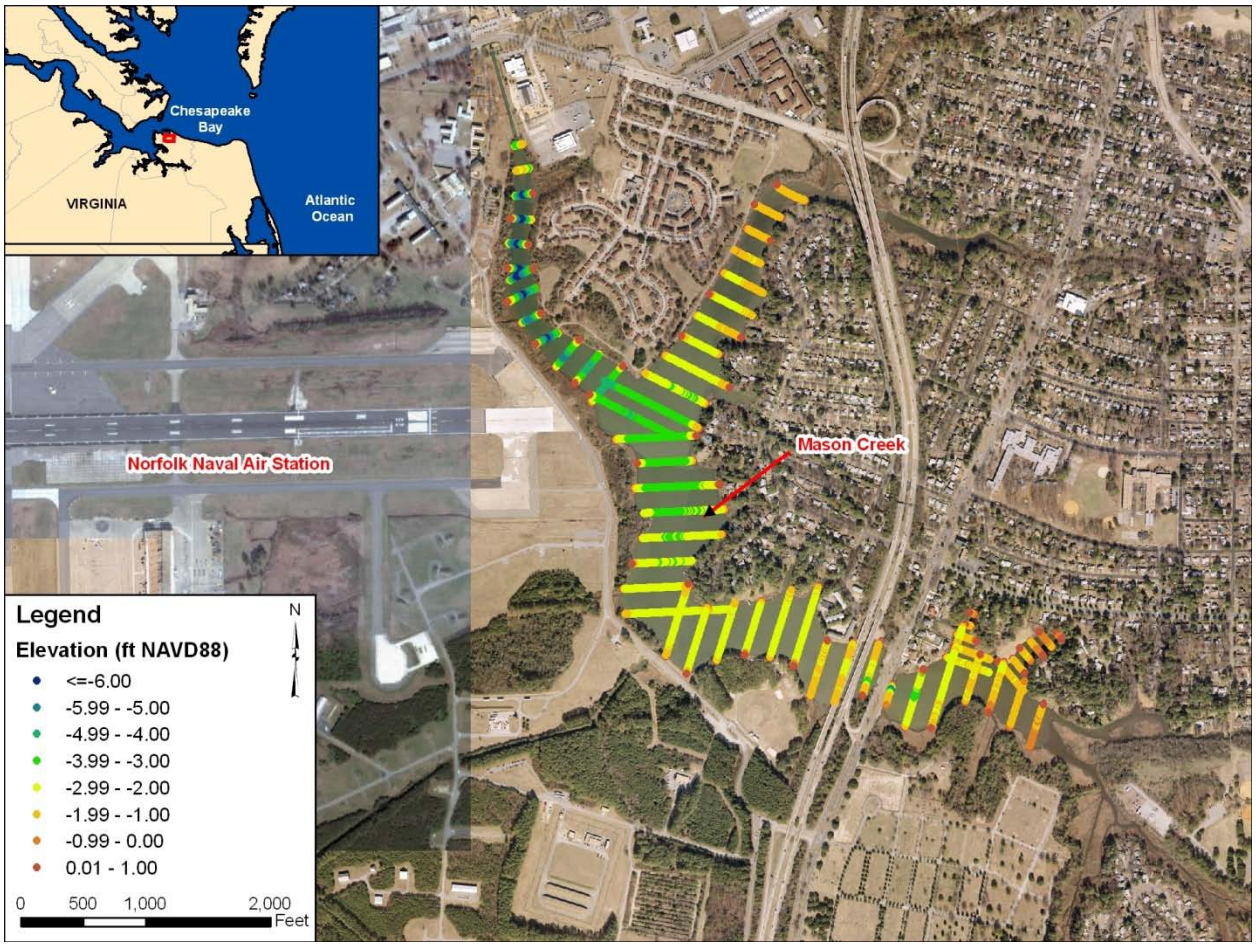


Figure 2-2. Mason Creek Bathymetry Data

Figure 2-3. Mason Creek Macrotide Gage Locations

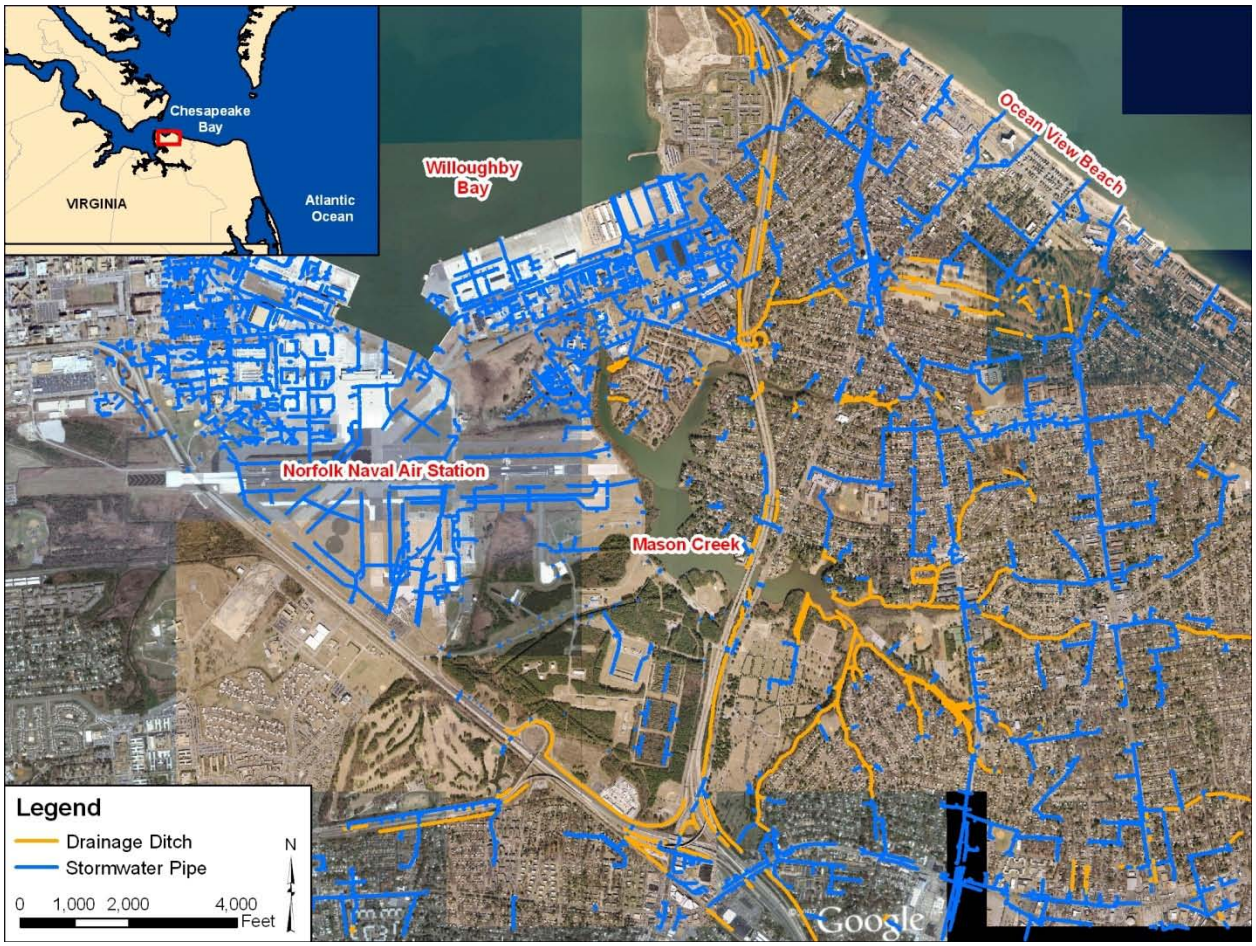


Figure 2-4. Mason Creek Stormwater Infrastructure

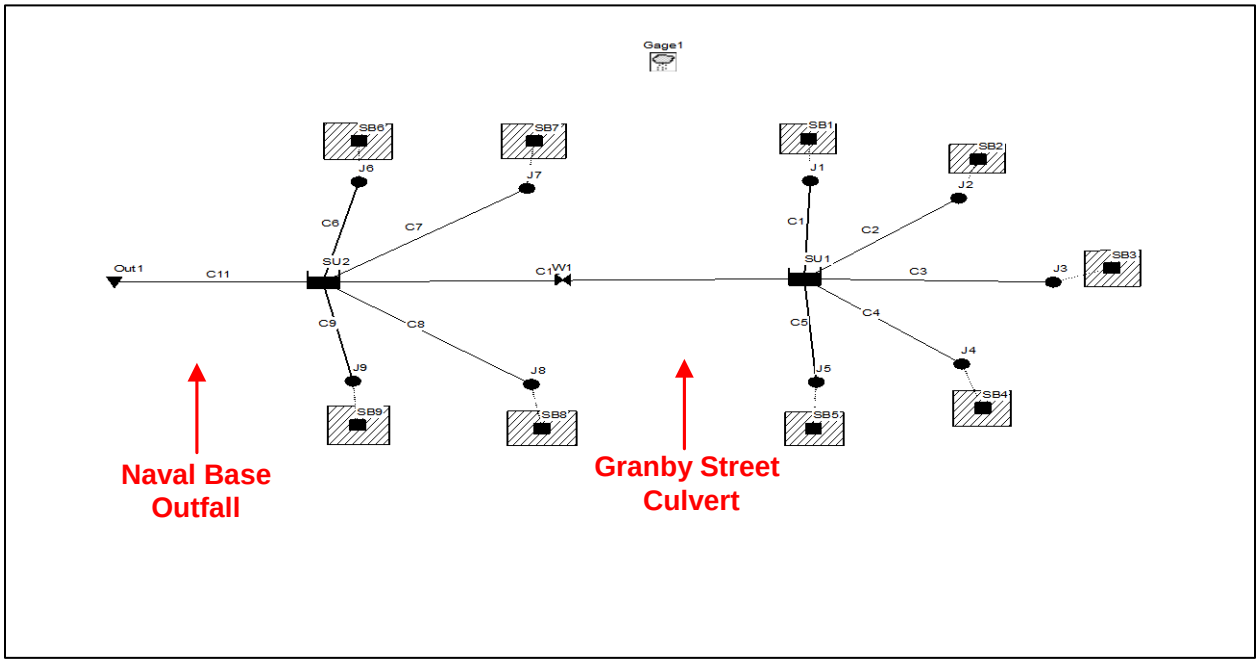


Figure 5-1. SWMM Schematic Mason Creek Stormwater Infrastructure

Figure 5-2. SWMM Subcatchments for Mason Creek Drainage Basin

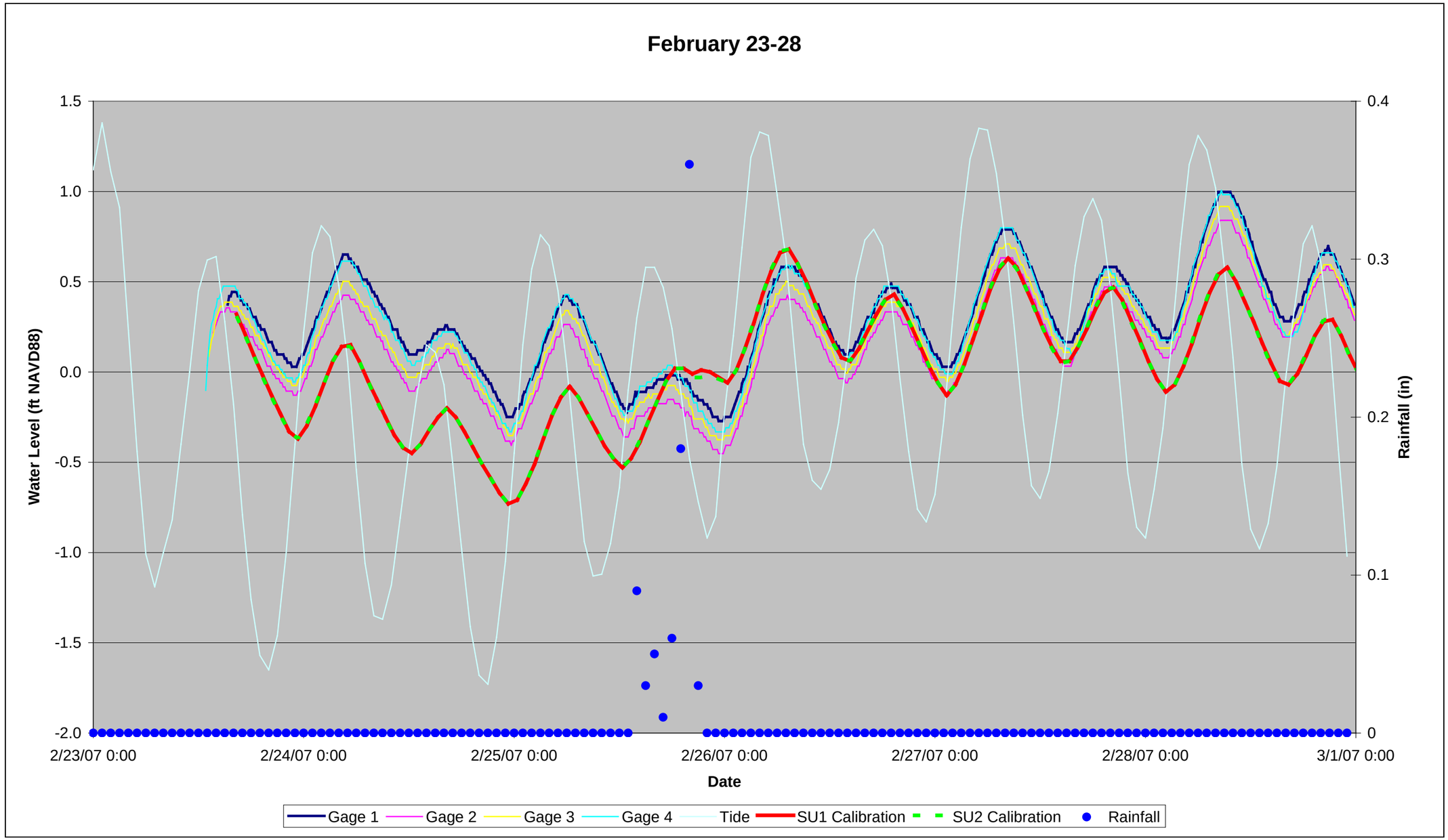


Figure 5-3. SWMM Calibration Results for February 23-February 28 (1 of 5)

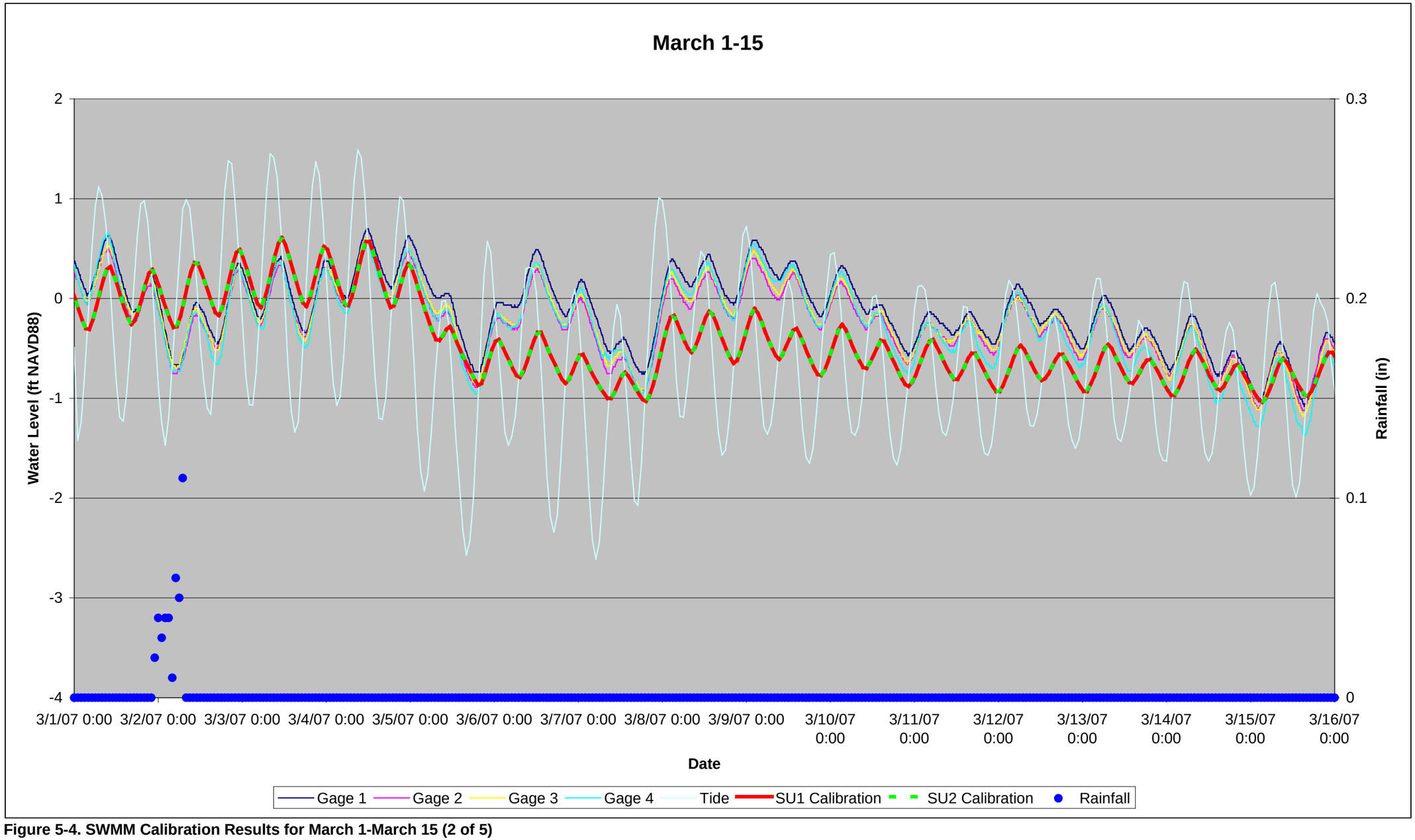


Figure 5-4. SWMM Calibration Results for March 1-March 15 (2 of 5)

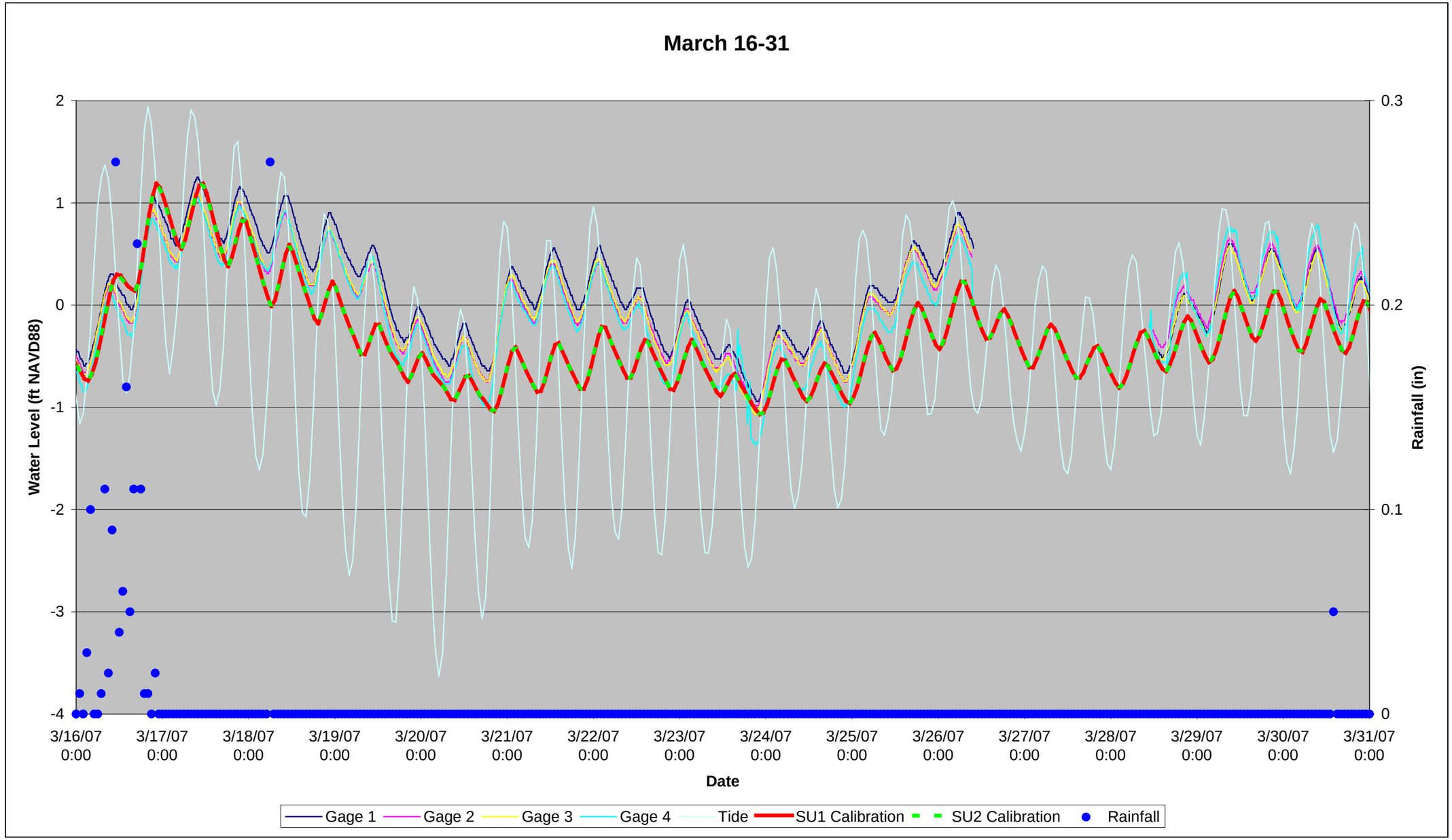


Figure 5-5. SWMM Calibration Results for March 16-31 (3 of 5)

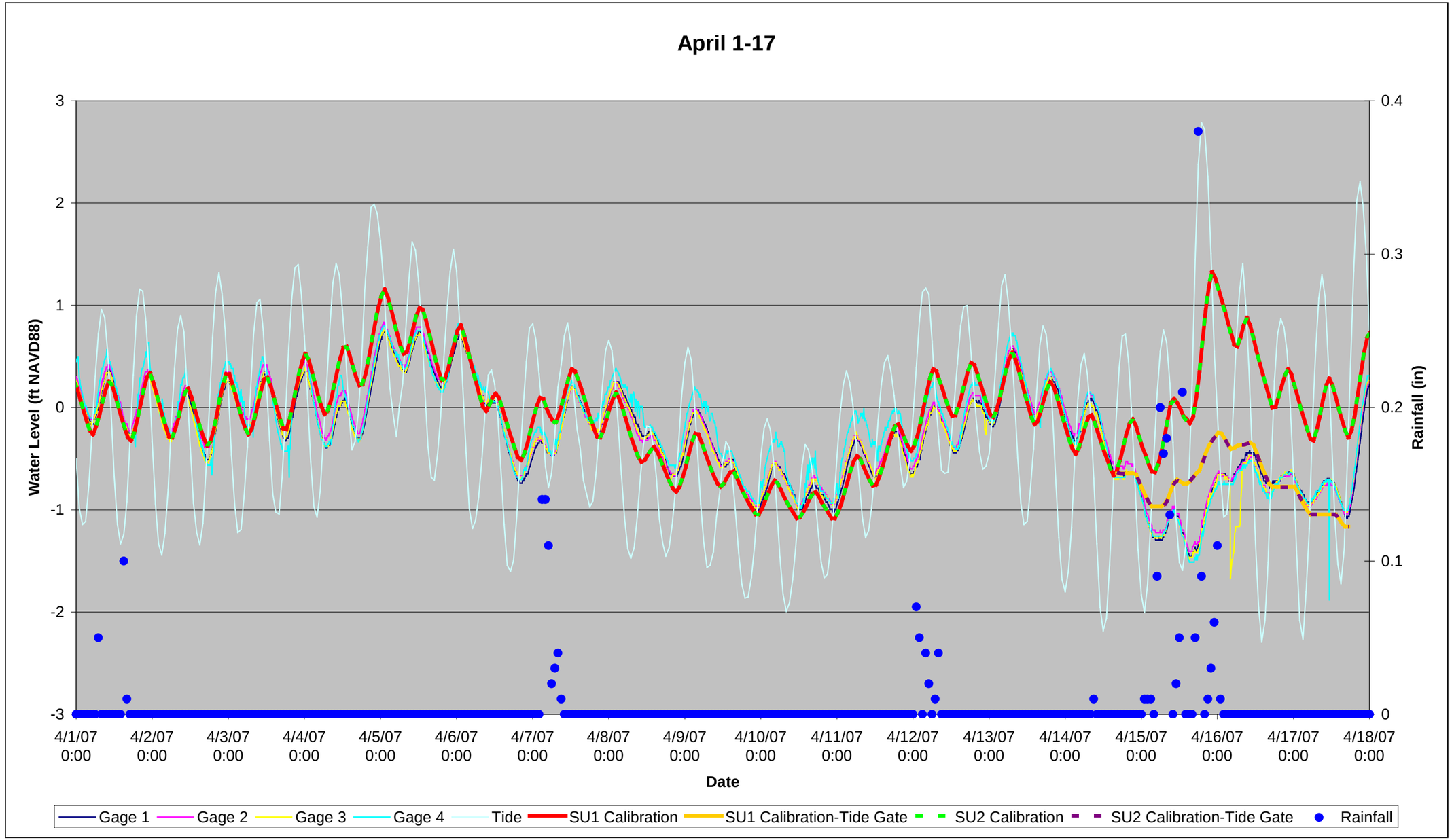


Figure 5-6. SWMM Calibration Results for April 1-April 17 (4 of 5)

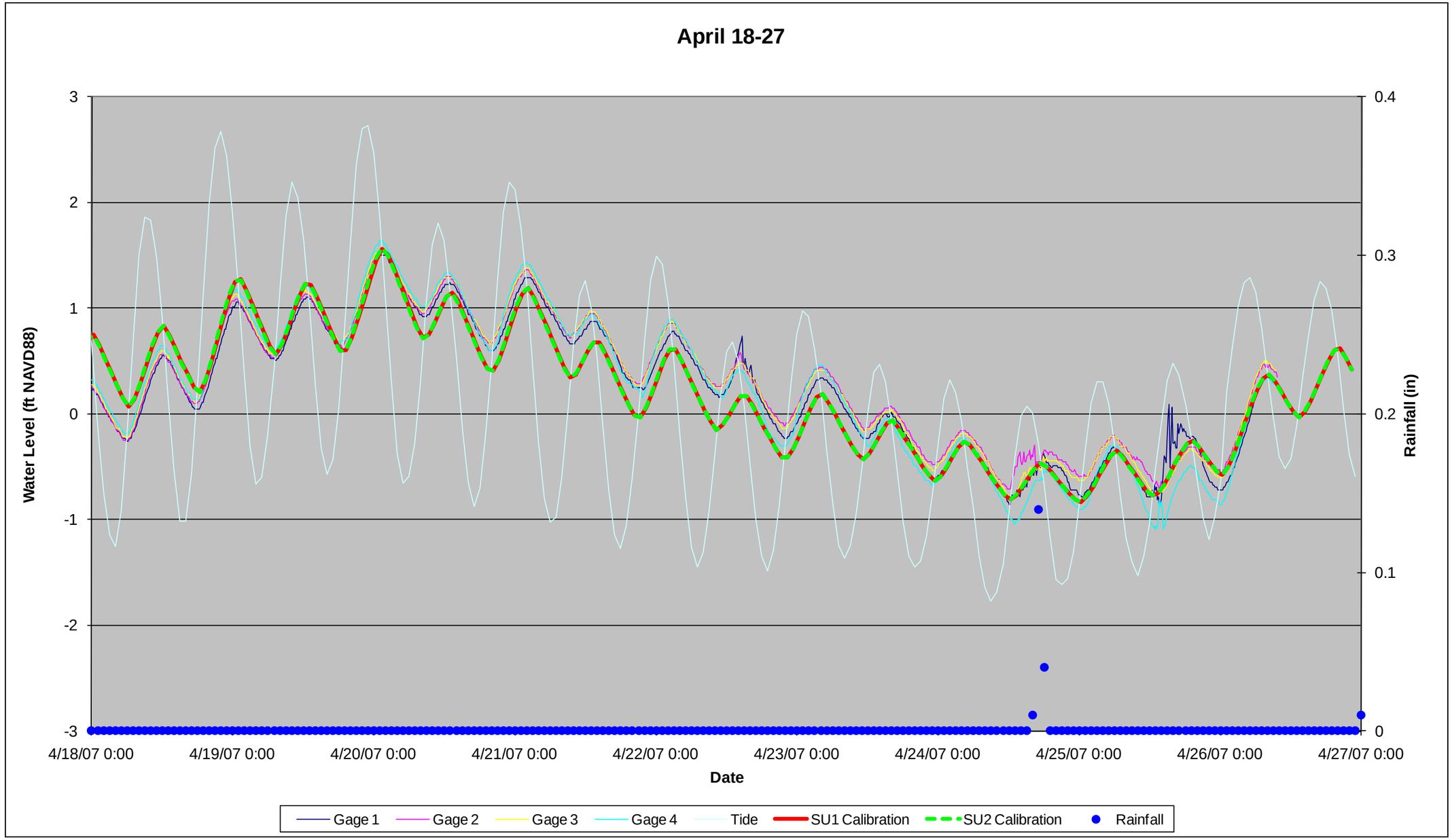


Figure 5-7. SWMM Calibration Results For April 18-April 27 (5 of 5)

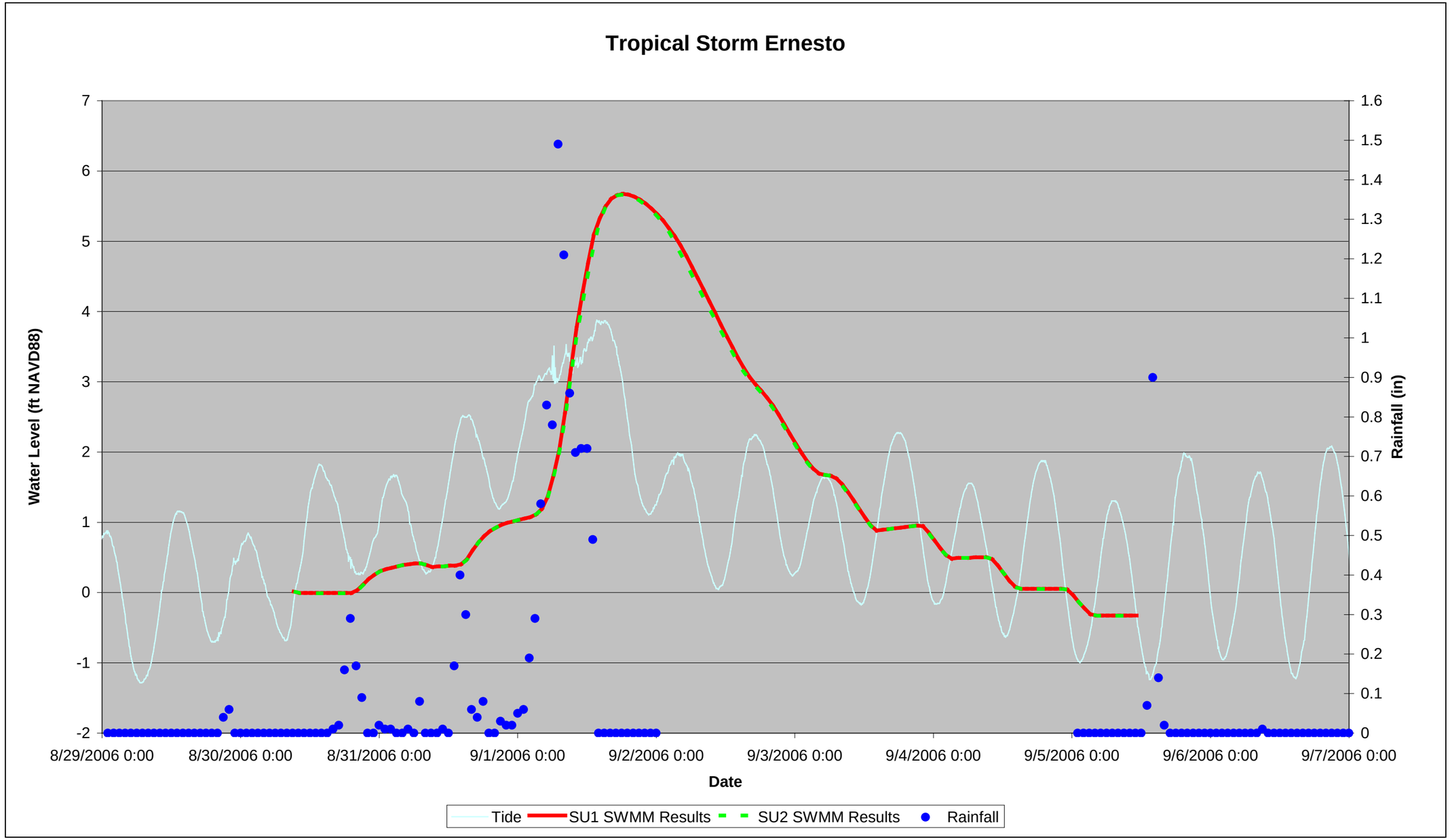


Figure 6-1. SWMM Verification Results for Storm Conditions (Tropical Storm Ernesto)

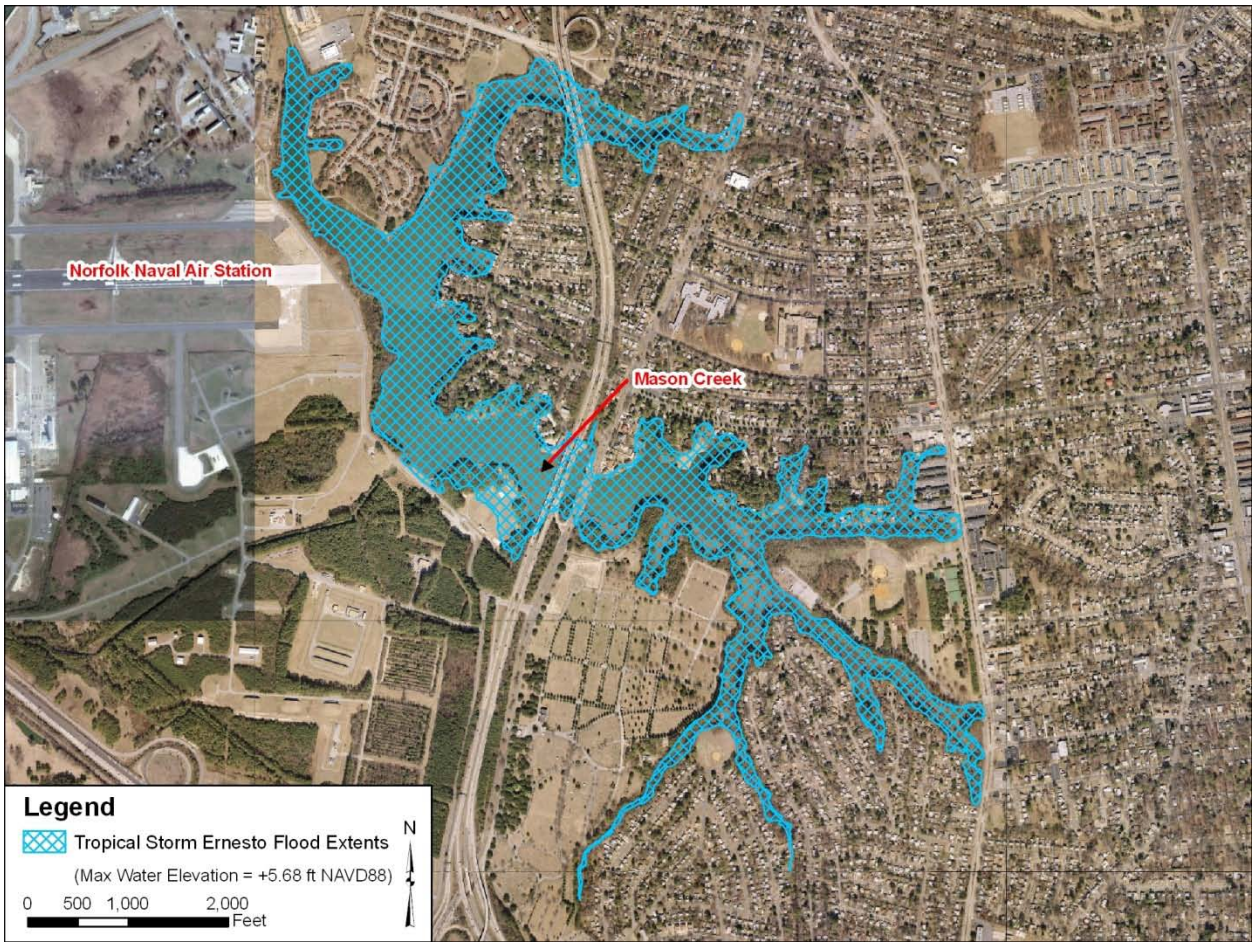


Figure 6-2. Mason Creek Flood Inundation Extents for Tropical Storm Ernesto

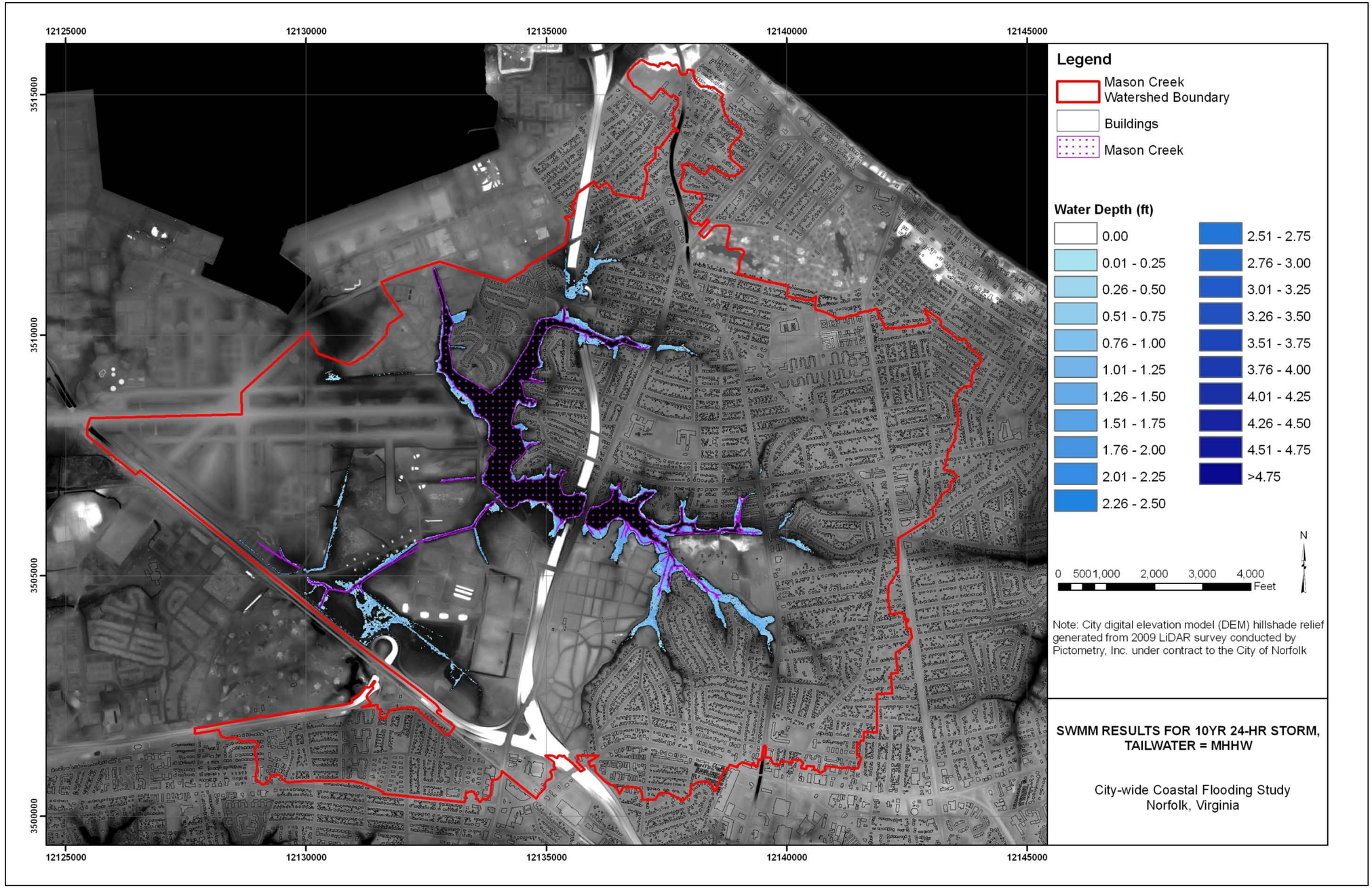


Figure 7-1. SWMM Results For The 10 Year, 24 Hour Storm (Tailwater=MHHW)

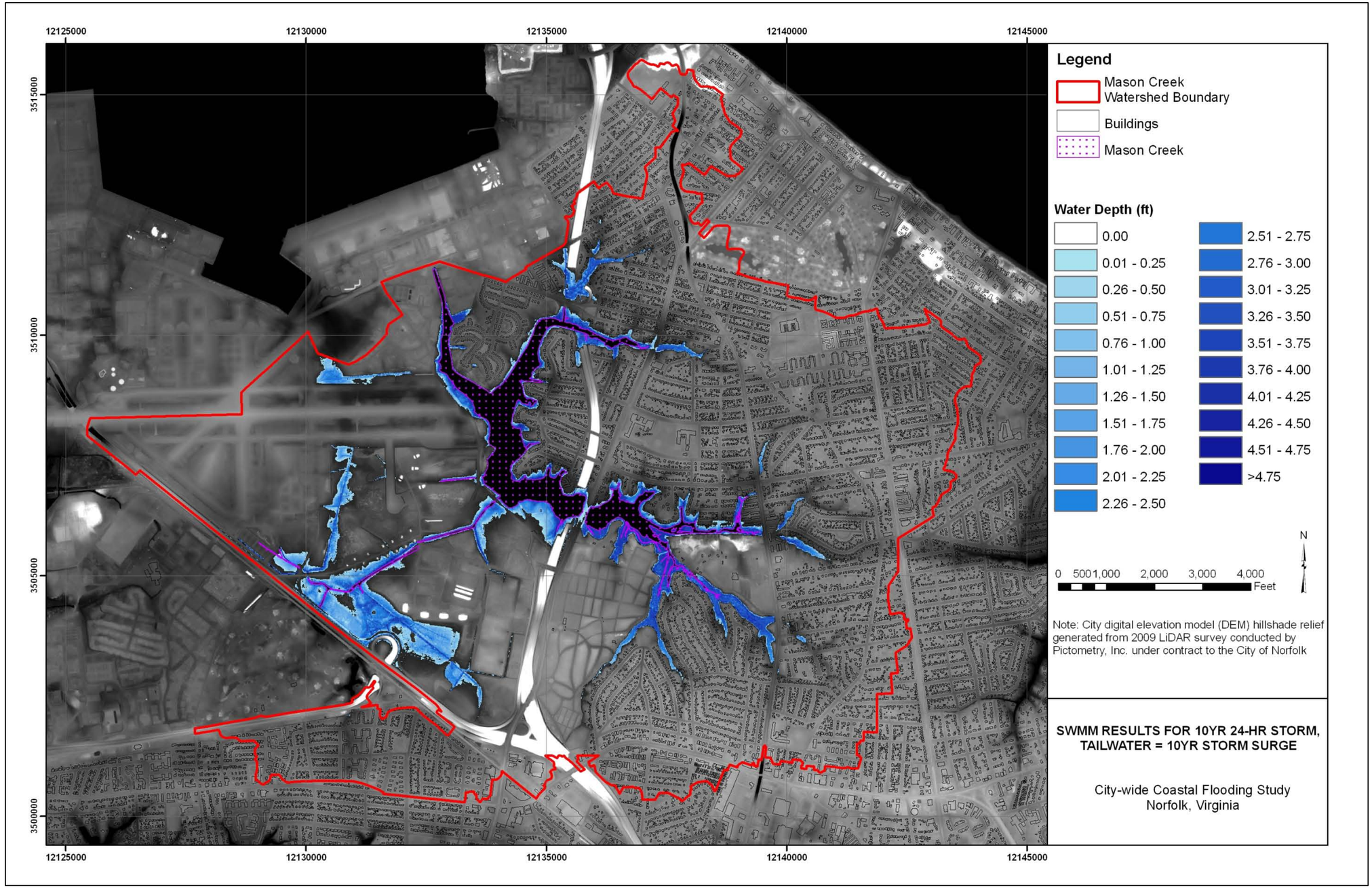


Figure 7-2. SWMM Results For The 10 Year, 24 Hour Storm (Tailwater=10 Year Storm Surge)

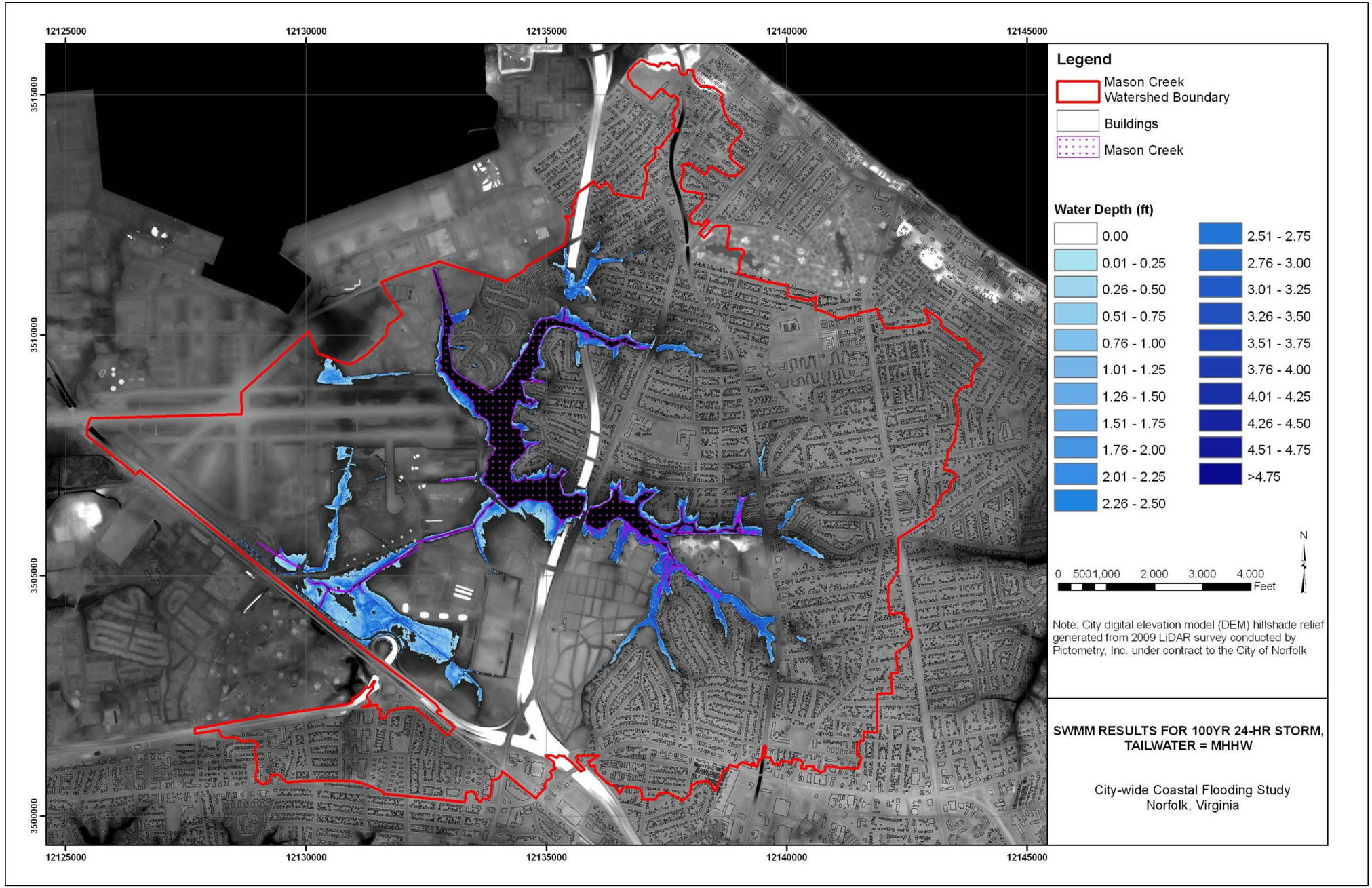


Figure 7-3. SWMM Results For The 100 Year, 24 Hour Storm (Tailwater=MHHW)

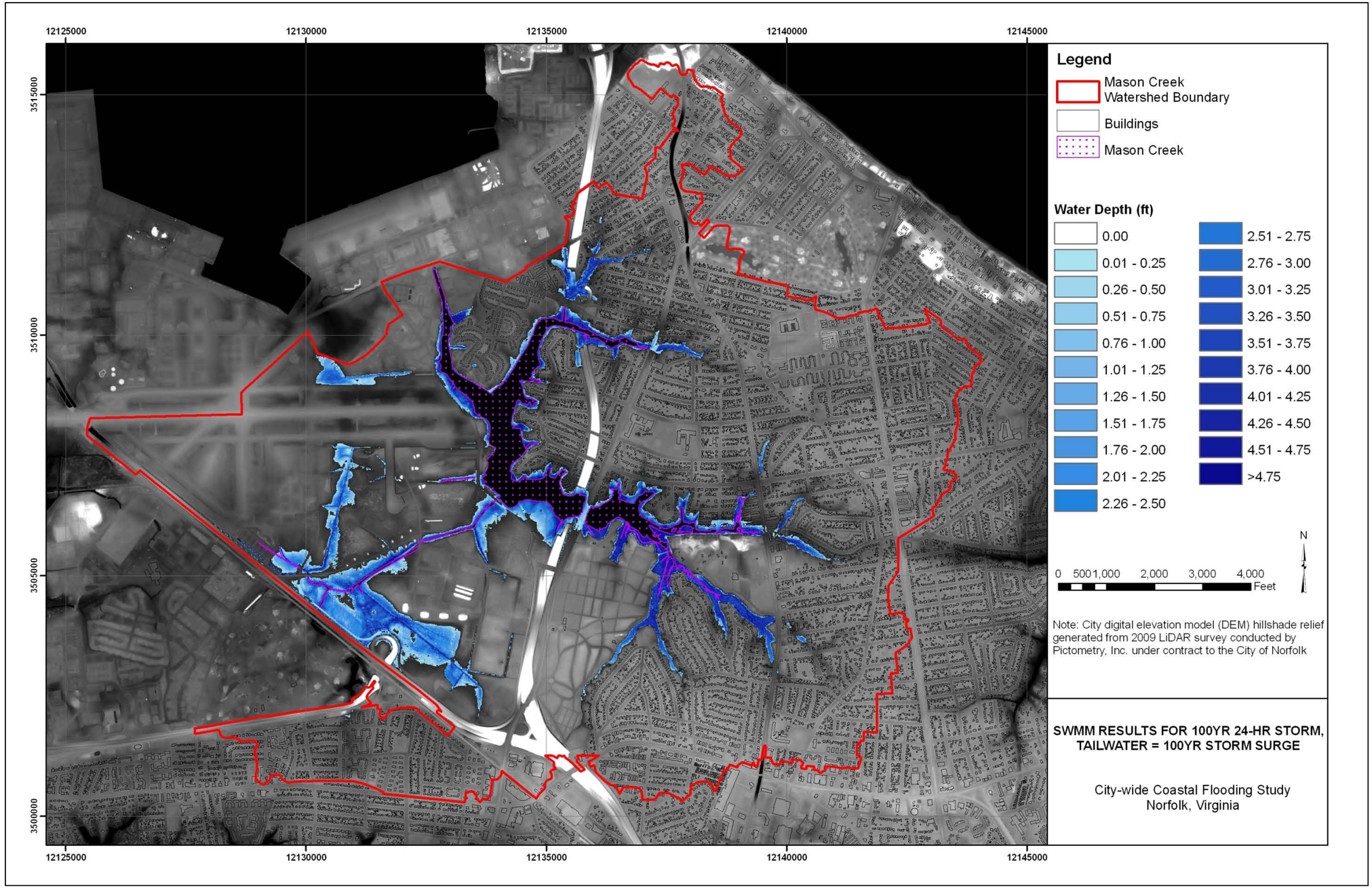


Figure 7-4. SWMM Results For The 100 Year, 24 Hour Storm (Tailwater=100 Year Storm Surge)

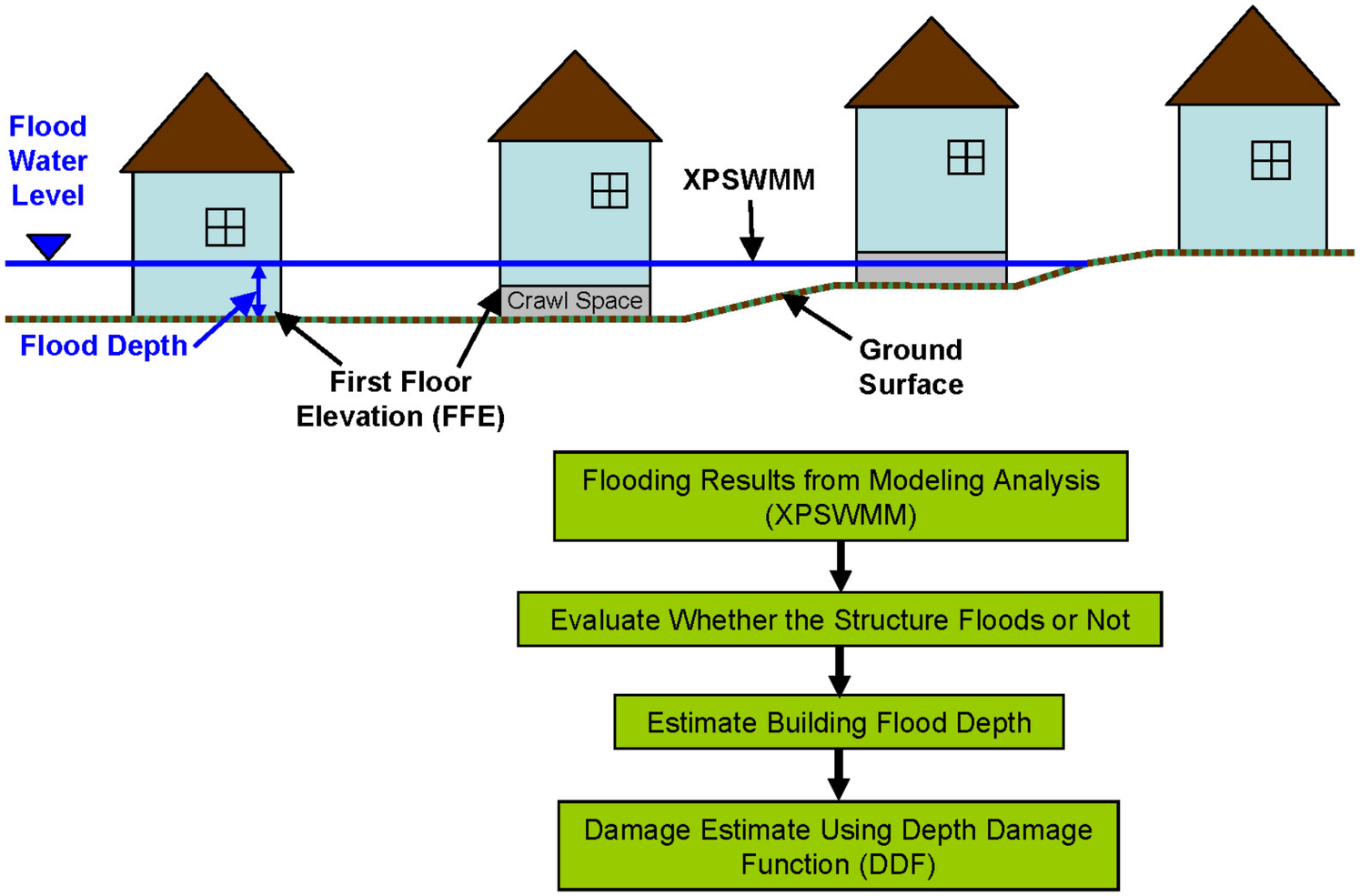


Figure 8-1. Depth Damage Function Concept

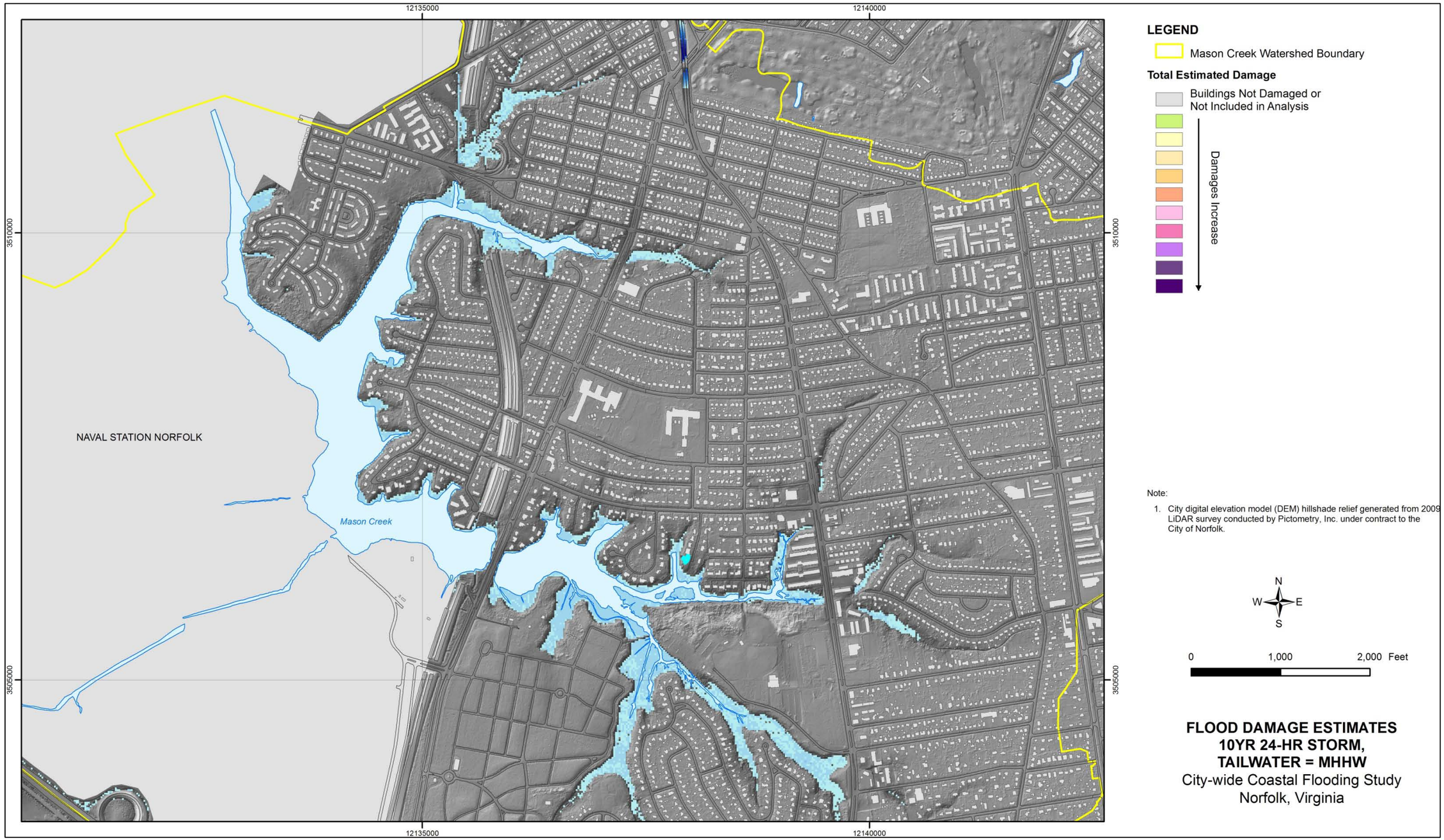


Figure 8-2. Damage Estimate for the 10 Year, 24 Hour Storm (Tailwater=MHHW)

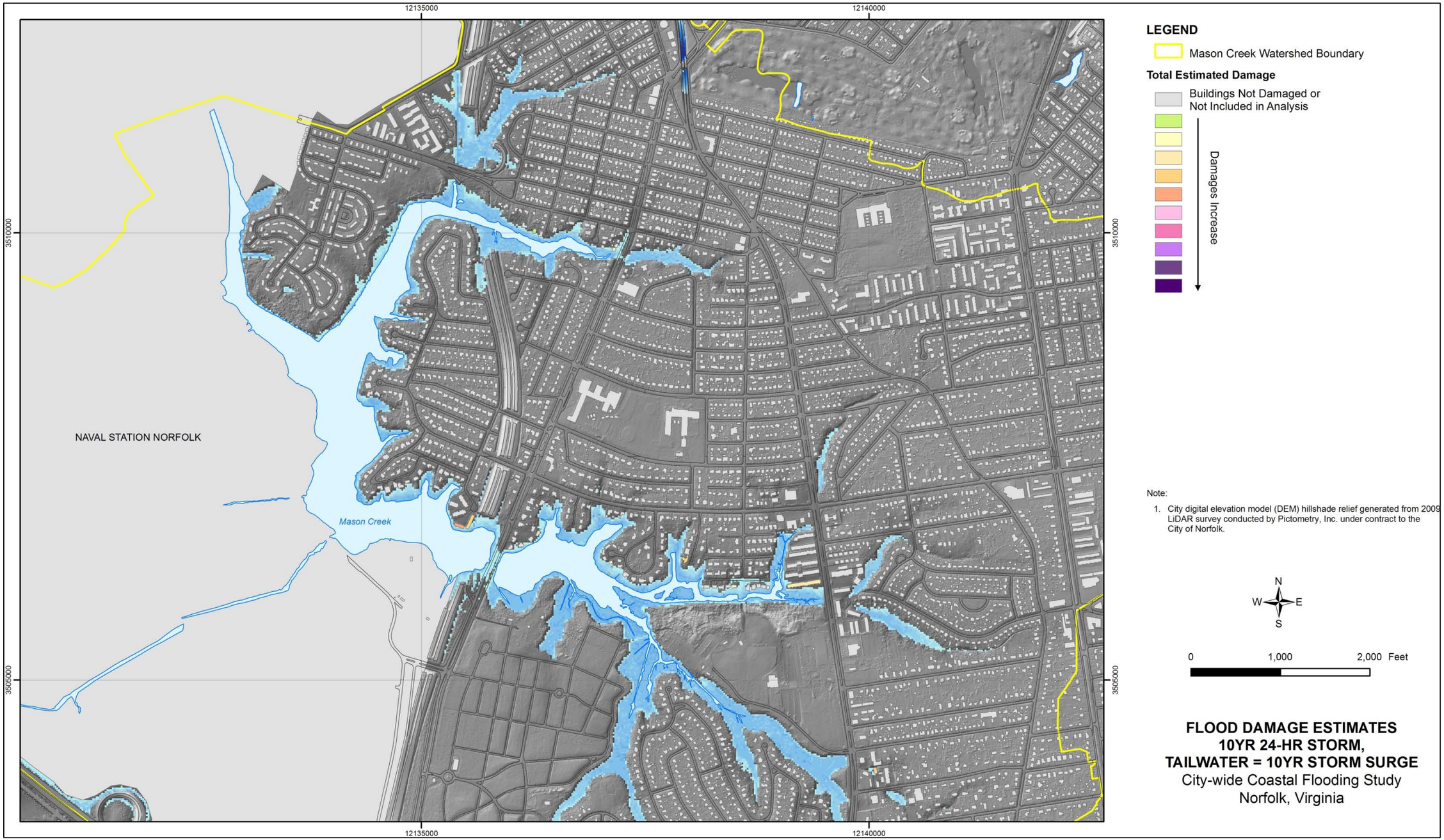


Figure 8-3. Damage Estimate for the 10 Year, 24 Hour Storm (Tailwater=10 Year Storm Surge)

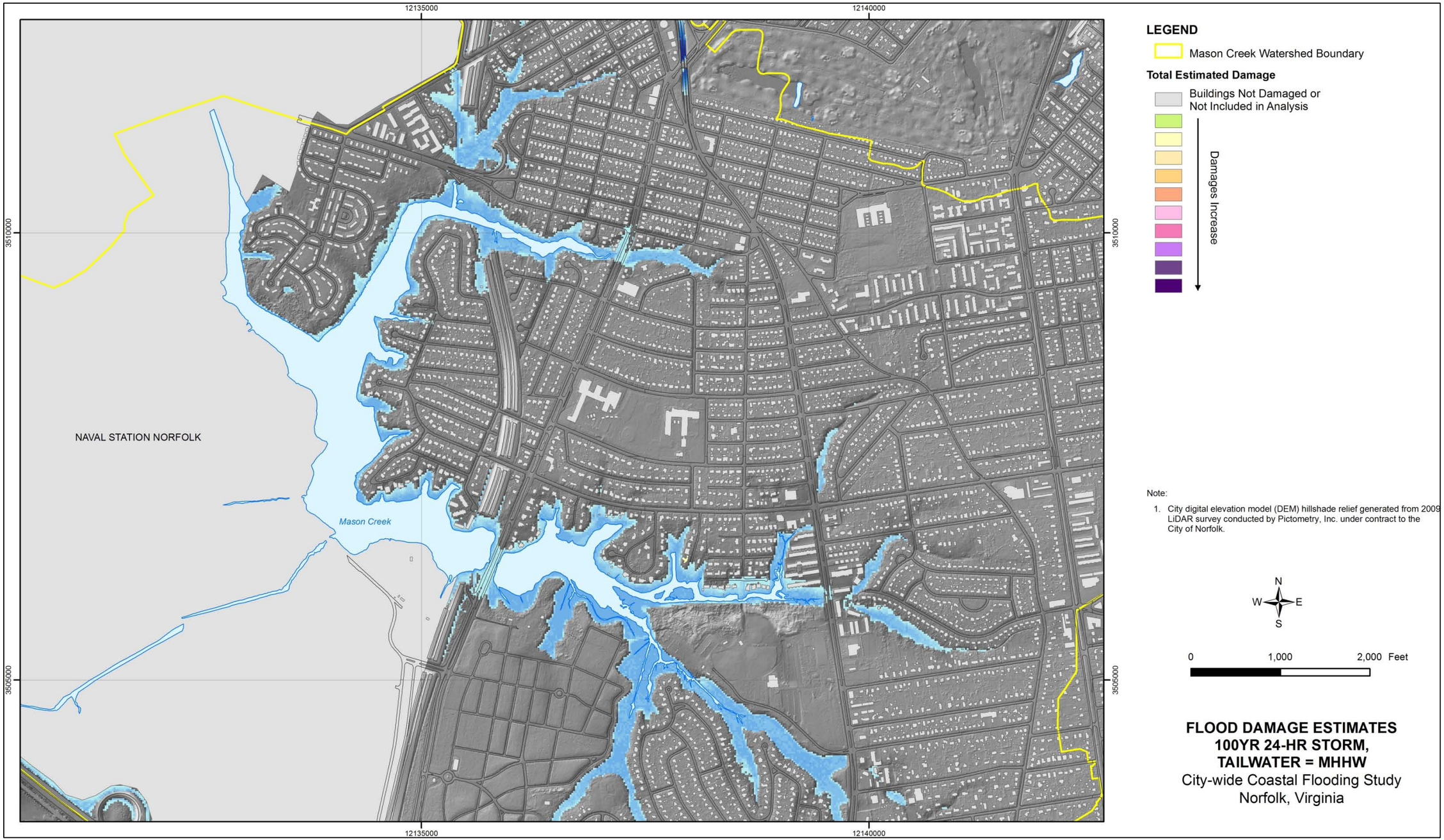


Figure 8-4. Damage Estimate for the 100 Year, 24 Hour Storm (Tailwater=MHHW)

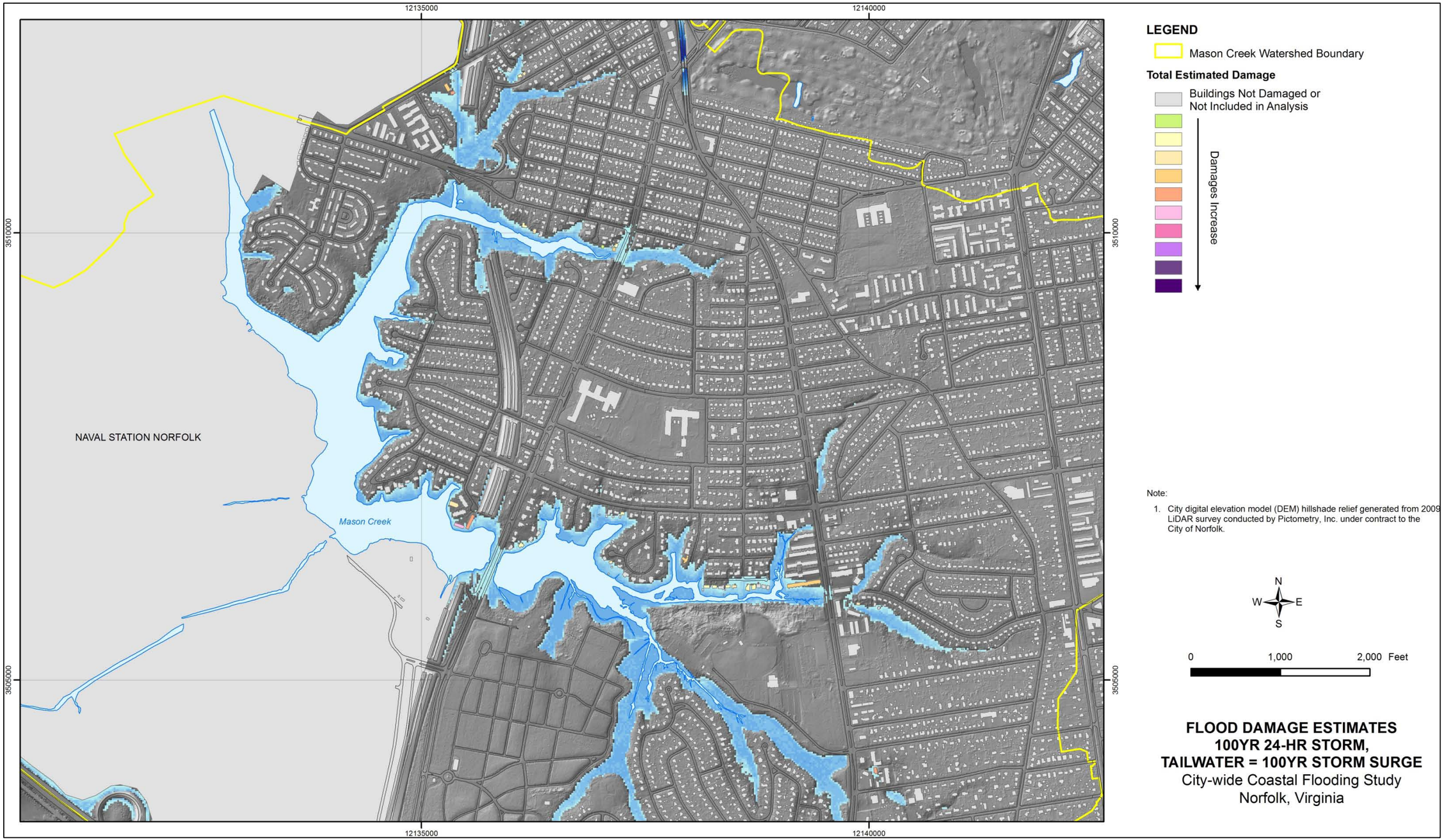


Figure 8-5. Damage Estimate for the 100 Year, 24 Hour Storm (Tailwater=100 Year Storm Surge)

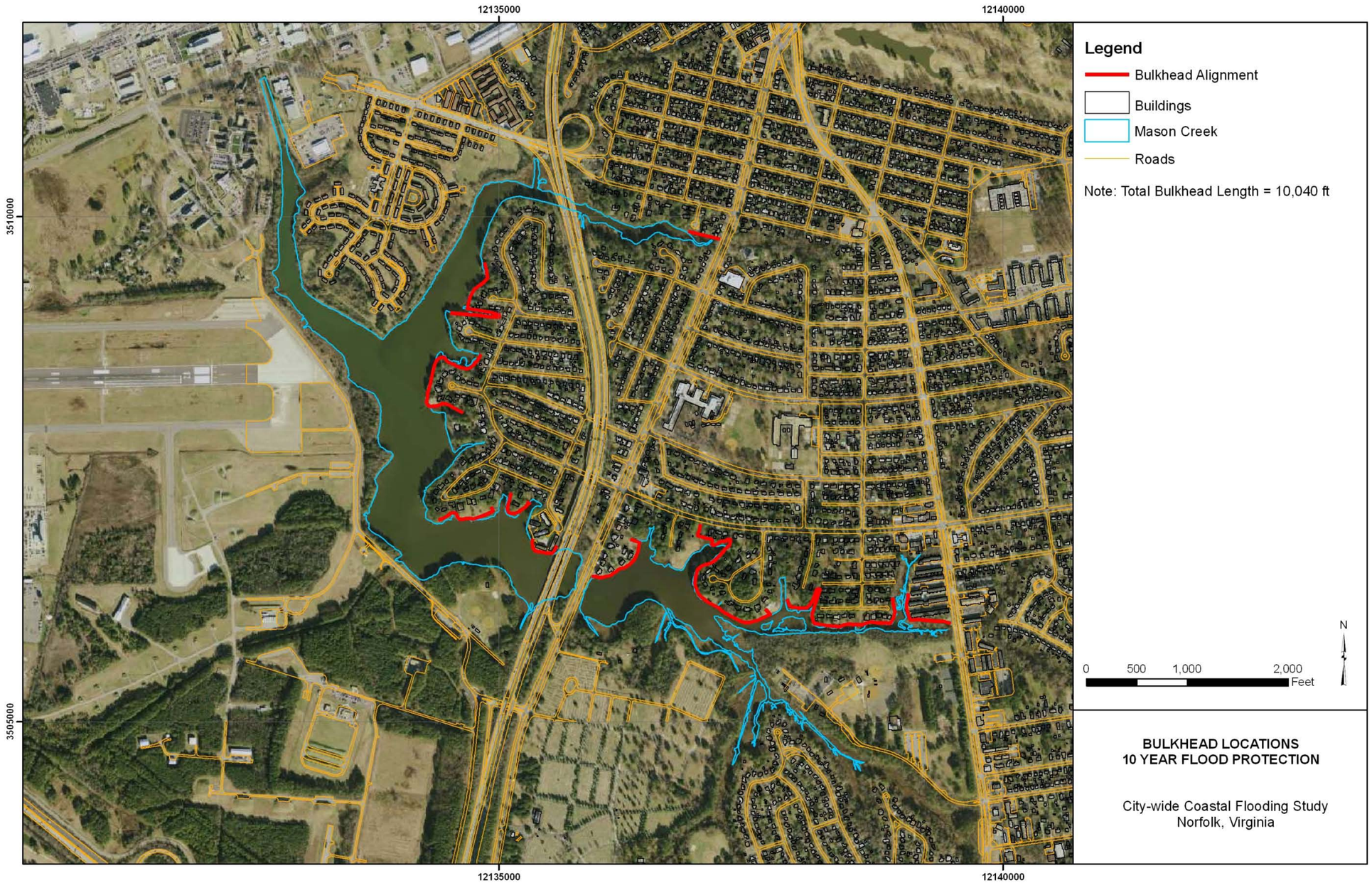


Figure 9-1. Alternative 1 – Floodwall (10YR Surge)

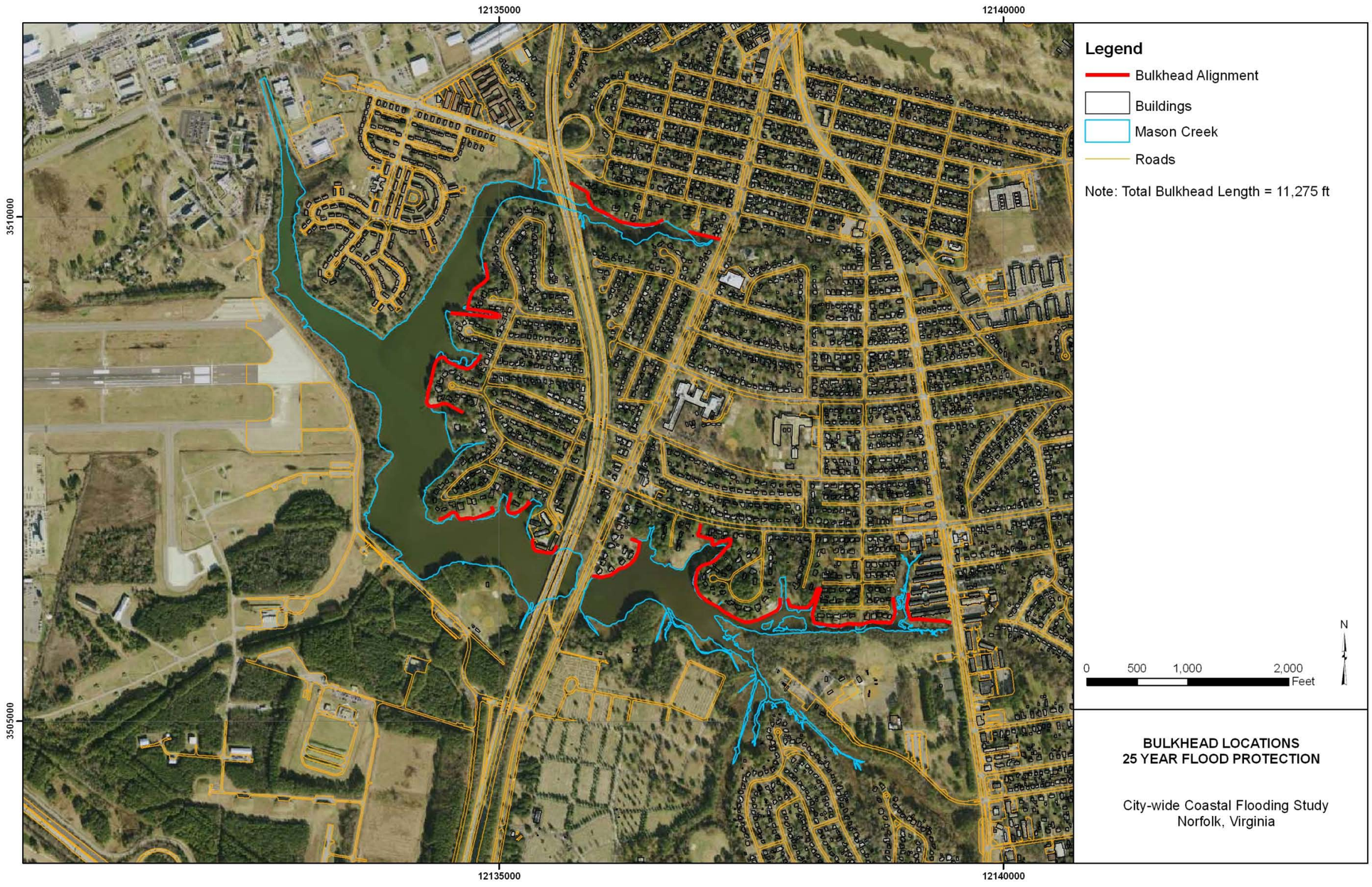


Figure 9-2. Alternative 1 – Floodwall (25YR Surge)

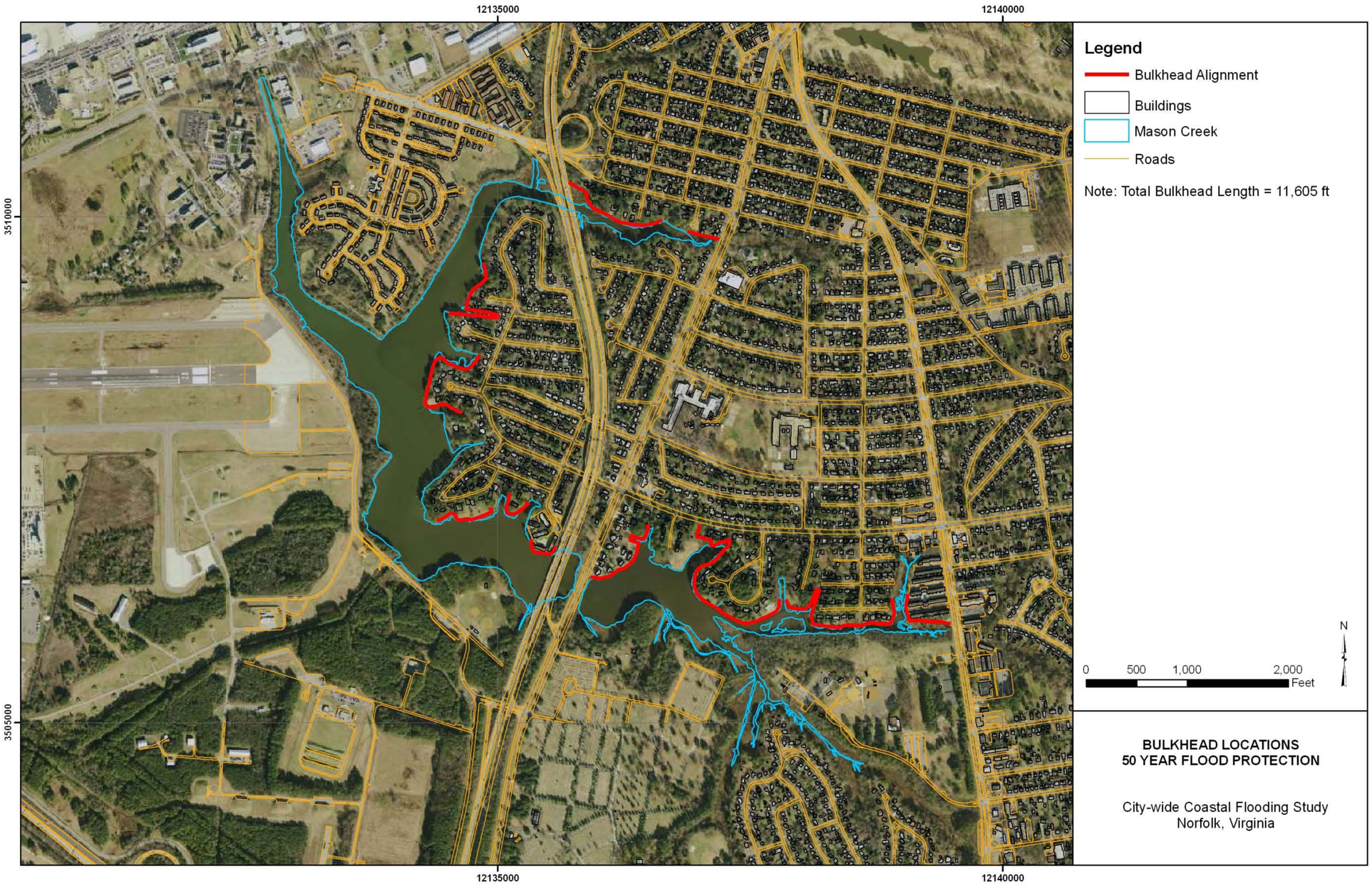


Figure 9-3. Alternative 1 – Floodwall (50YR Surge)

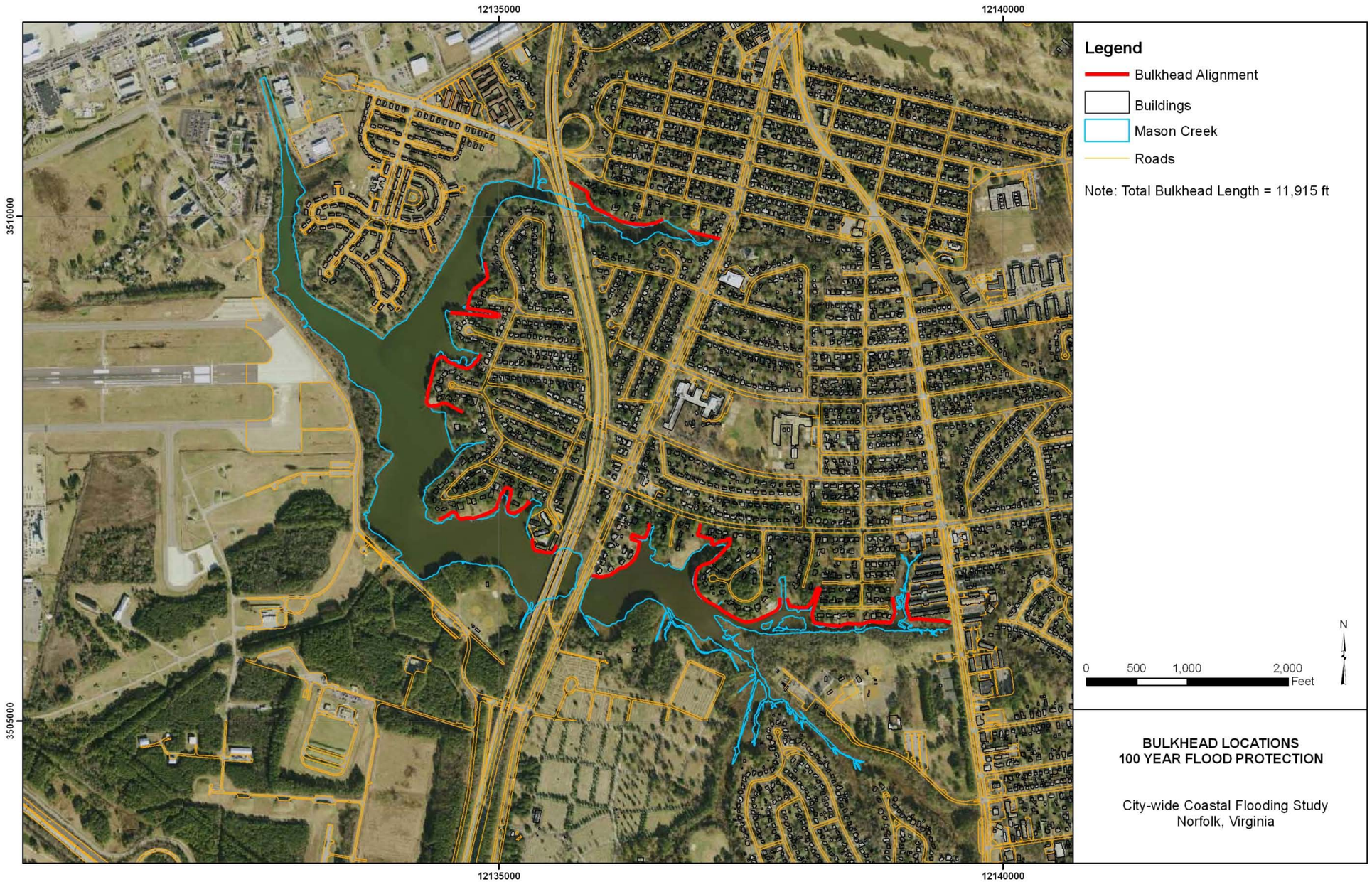


Figure 9-4. Alternative 1 – Floodwall (100YR Surge)

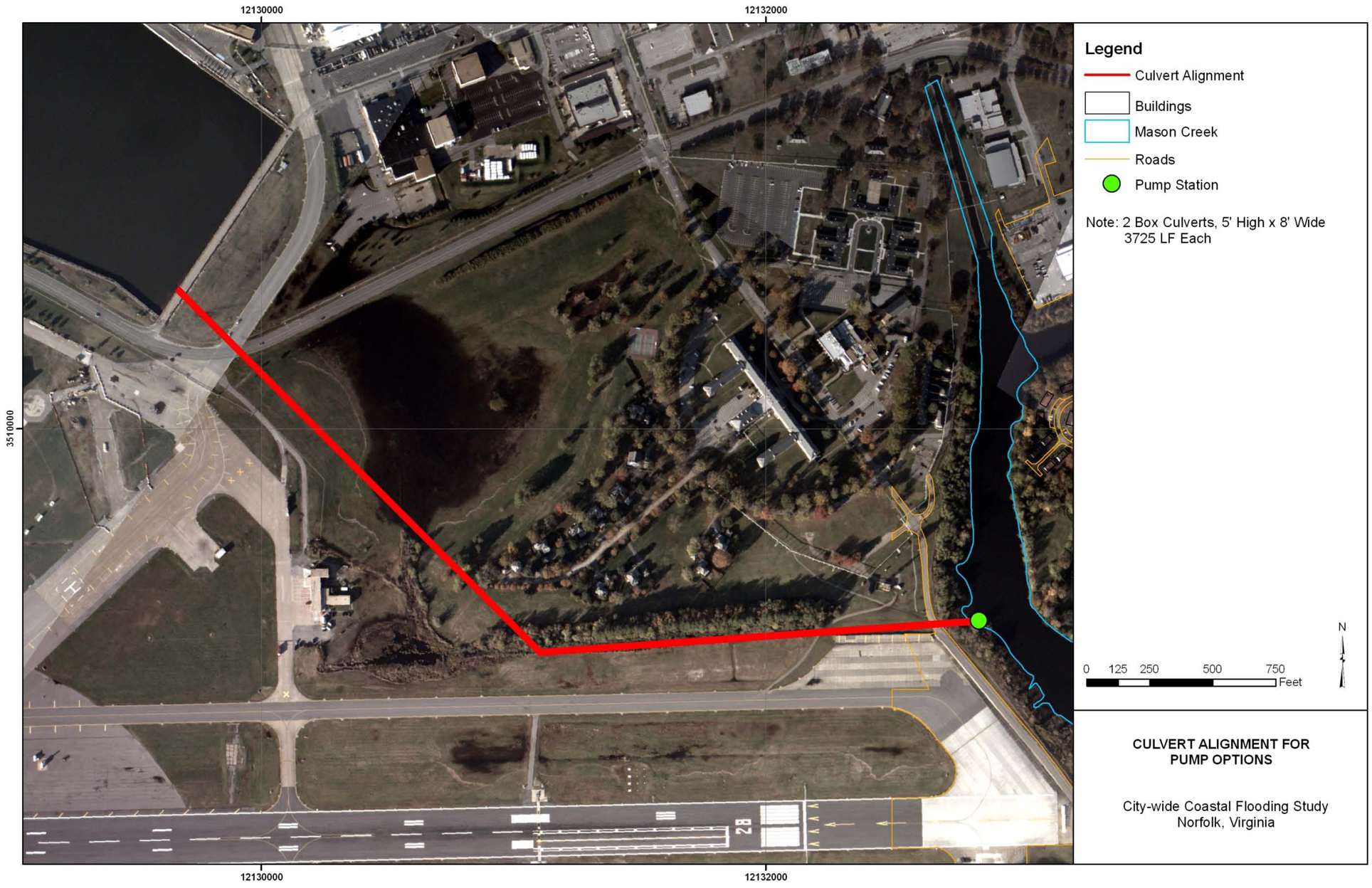


Figure 9-5. Alternative 2 through 4 – Culvert and Pump Options

Figure 9-6. Alternative 6 - Additional Culverts at Granby Street

Figure 9-7. Alternative 7 - Improvement to Existing Norfolk Naval Air Station Culvert

Figure 9-8.Alternative 8 - Additional Culverts Under the Norfolk Naval Air Station

Figure 9-9. Alternative 9 - Open Channel at Norfolk Naval Air Station

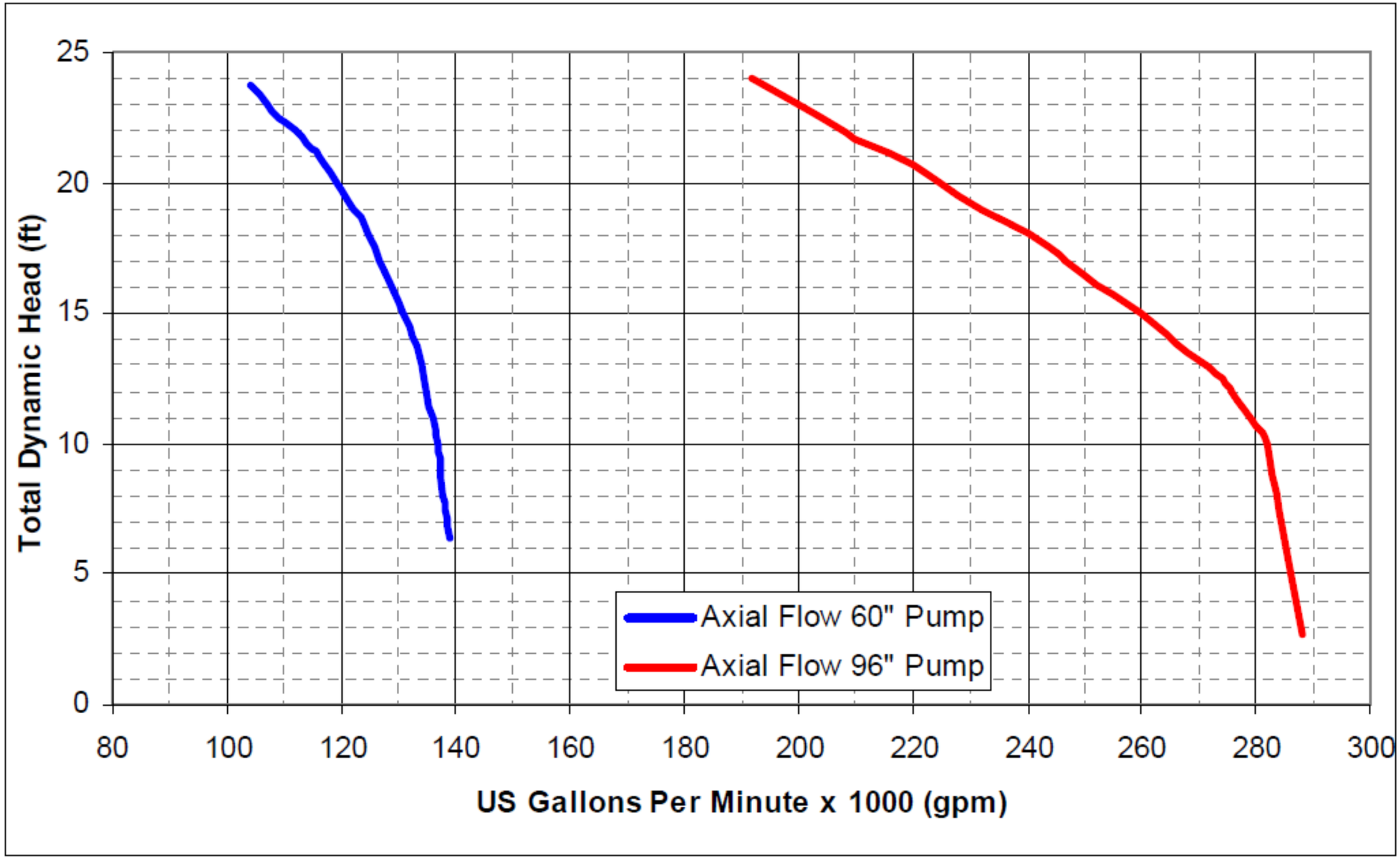


Figure 10-1. Pump Curves for SWMM Models

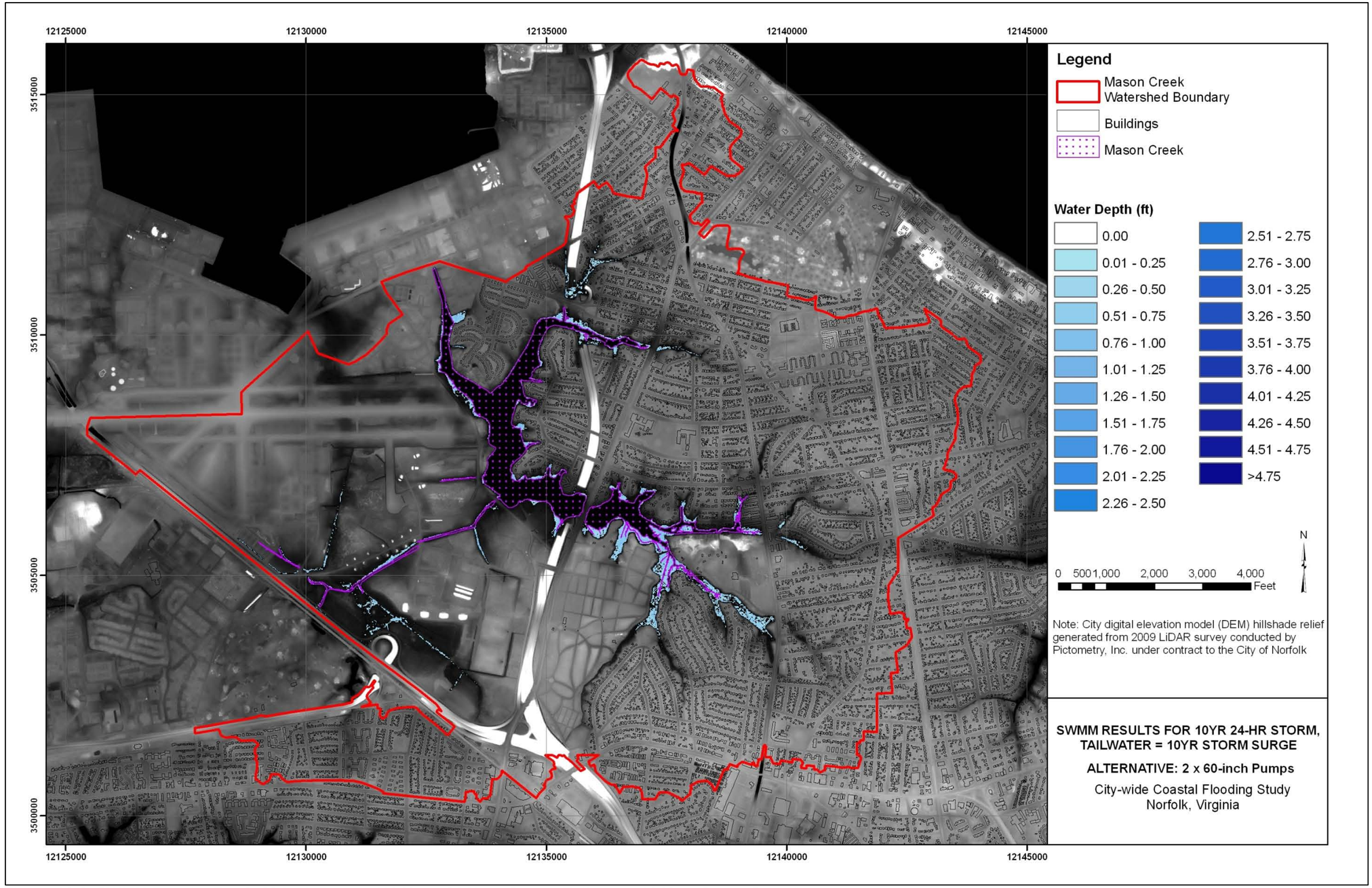


Figure 10-2. SWMM Results For 2x60 Inch Pumps (10 Year, 24 Hour Storm; Tailwater=10 Year Storm Surge)

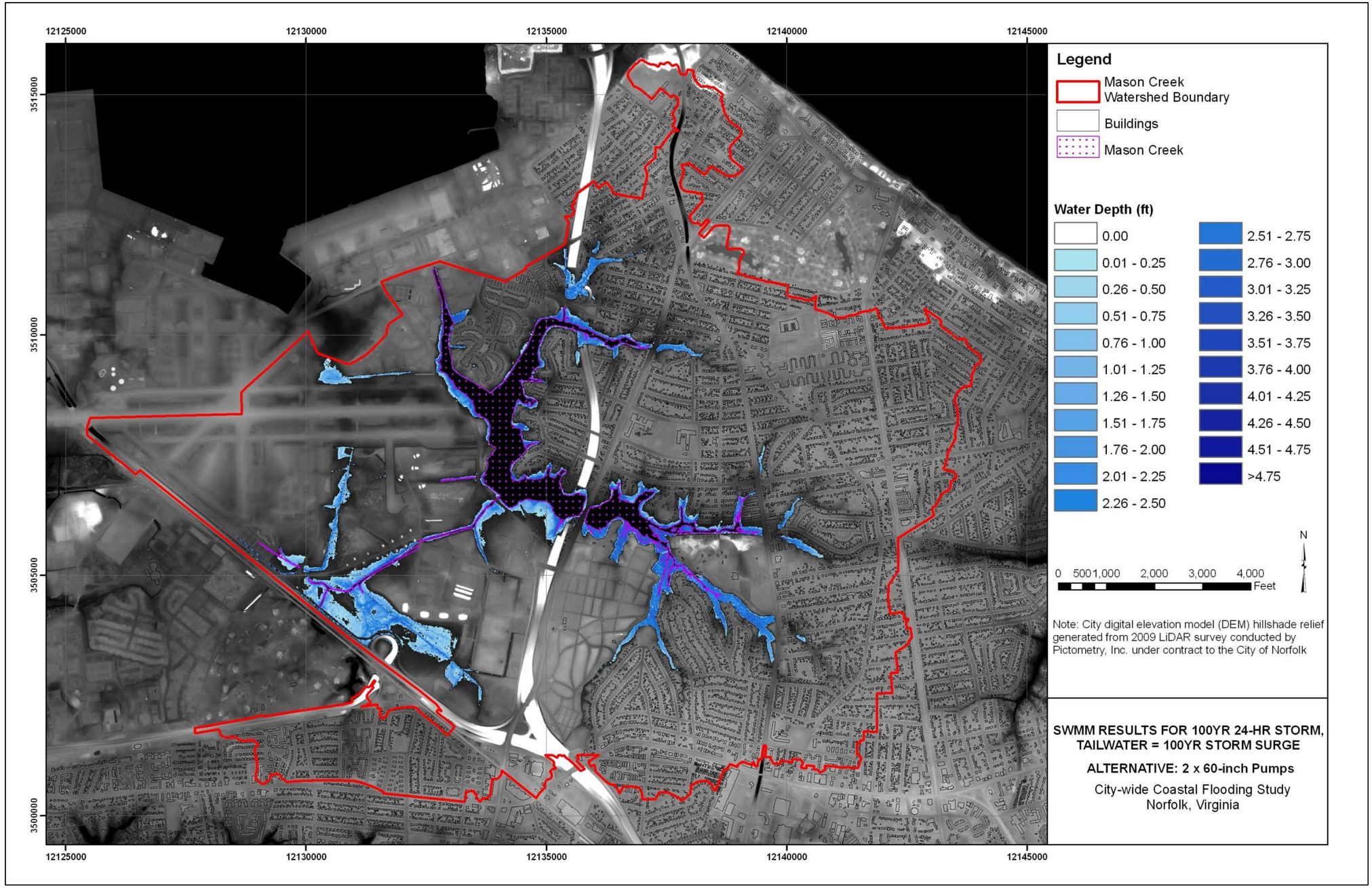


Figure 10-3. SWMM Results For 2x60 Inch Pumps (100 Year, 24 Hour Storm; Tailwater=100 Year Storm Surge)

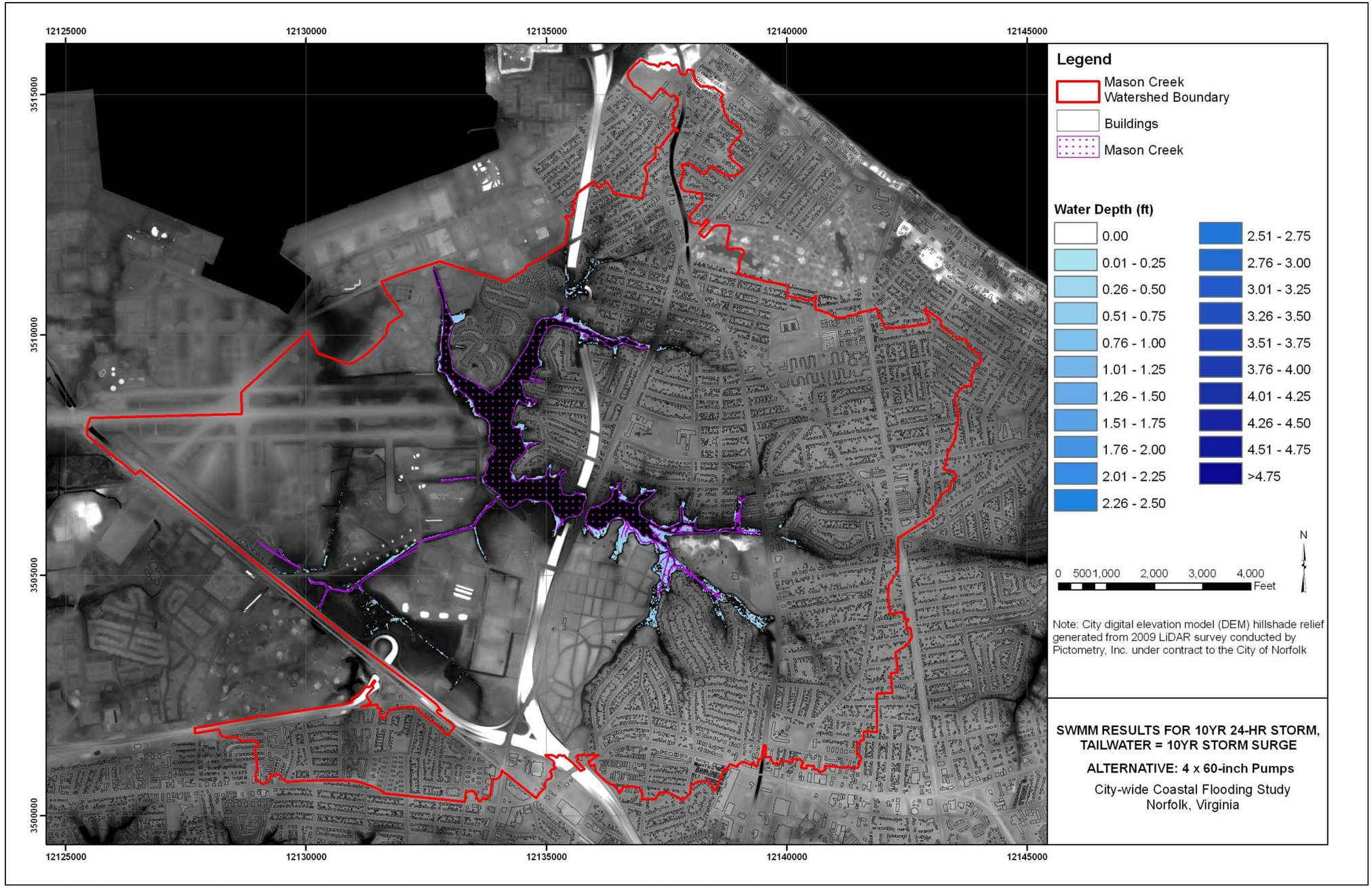


Figure 10-4. SWMM Results For 4x60 Inch Pumps (10 Year, 24 Hour Storm; Tailwater=10 Year Storm Surge)

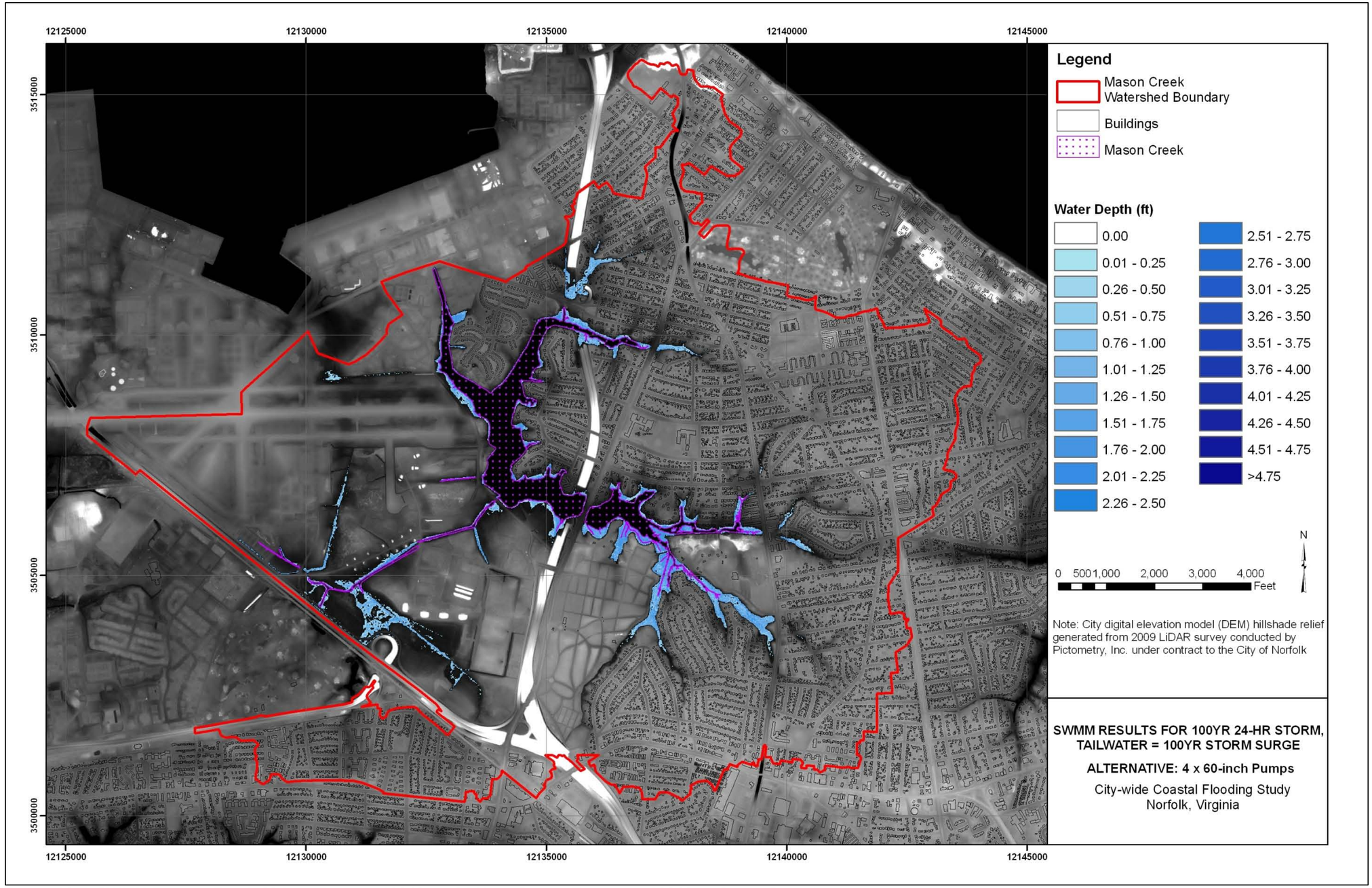


Figure 10-5. SWMM Results For 4x60 Inch Pumps (100 Year, 24 Hour Storm; Tailwater=100 Year Storm Surge)

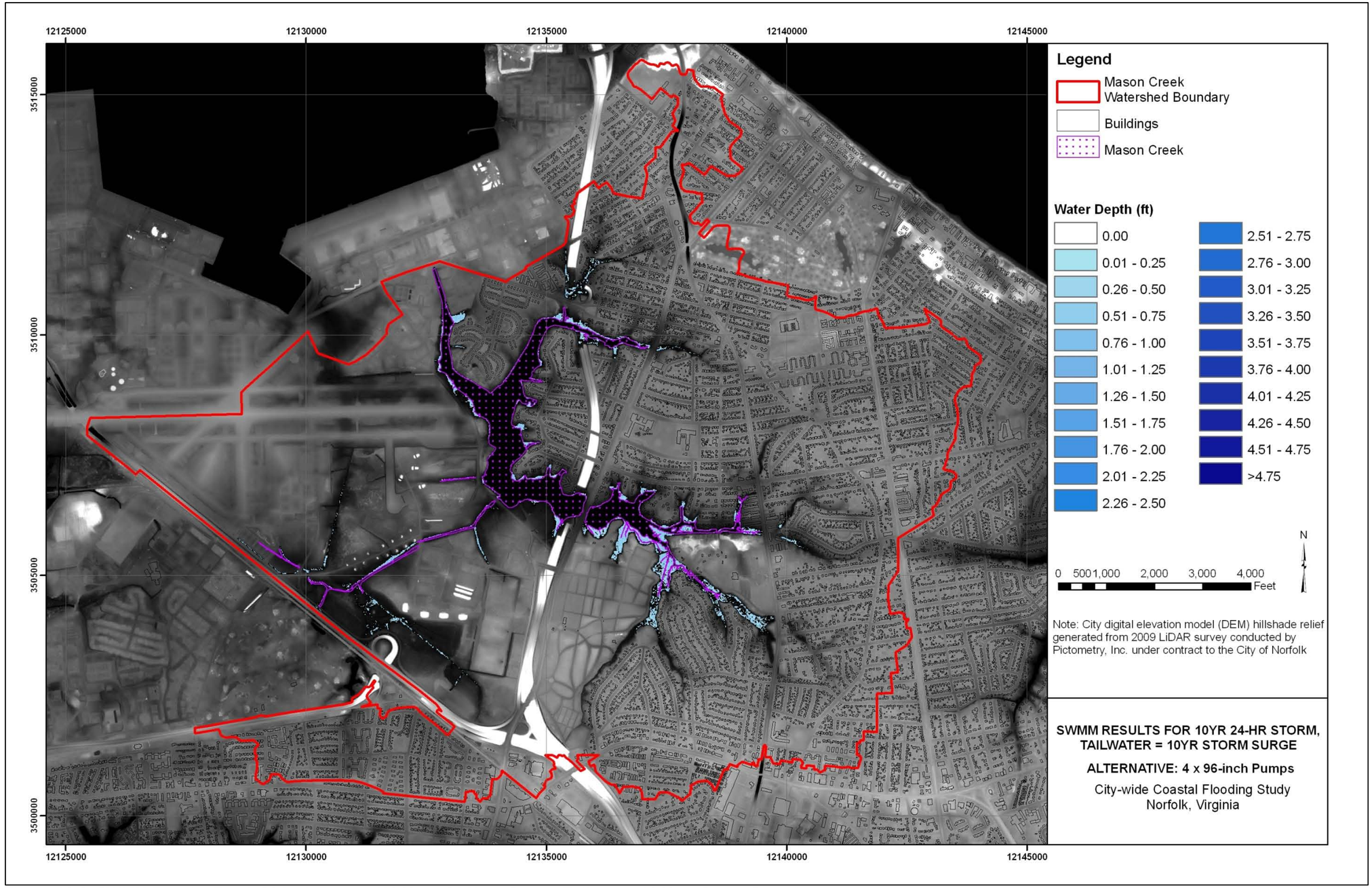


Figure 10-6. SWMM Results For 4x96 Inch Pumps (10 Year, 24 Hour Storm; Tailwater=10 Year Storm Surge)

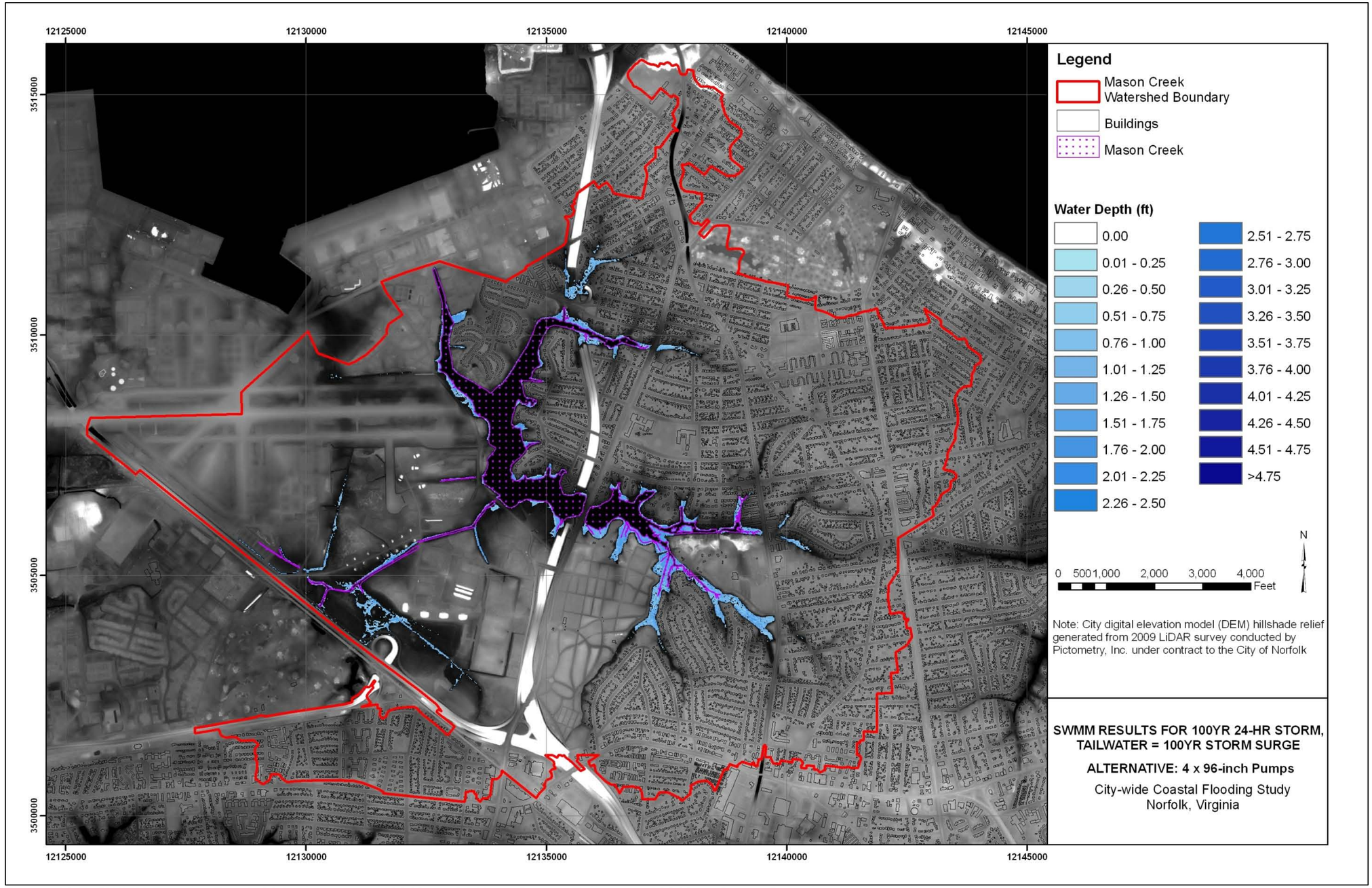


Figure 10-7. SWMM Results For 4x96 Inch Pumps (100 Year, 24 Hour Storm; Tailwater=100 Year Storm Surge)

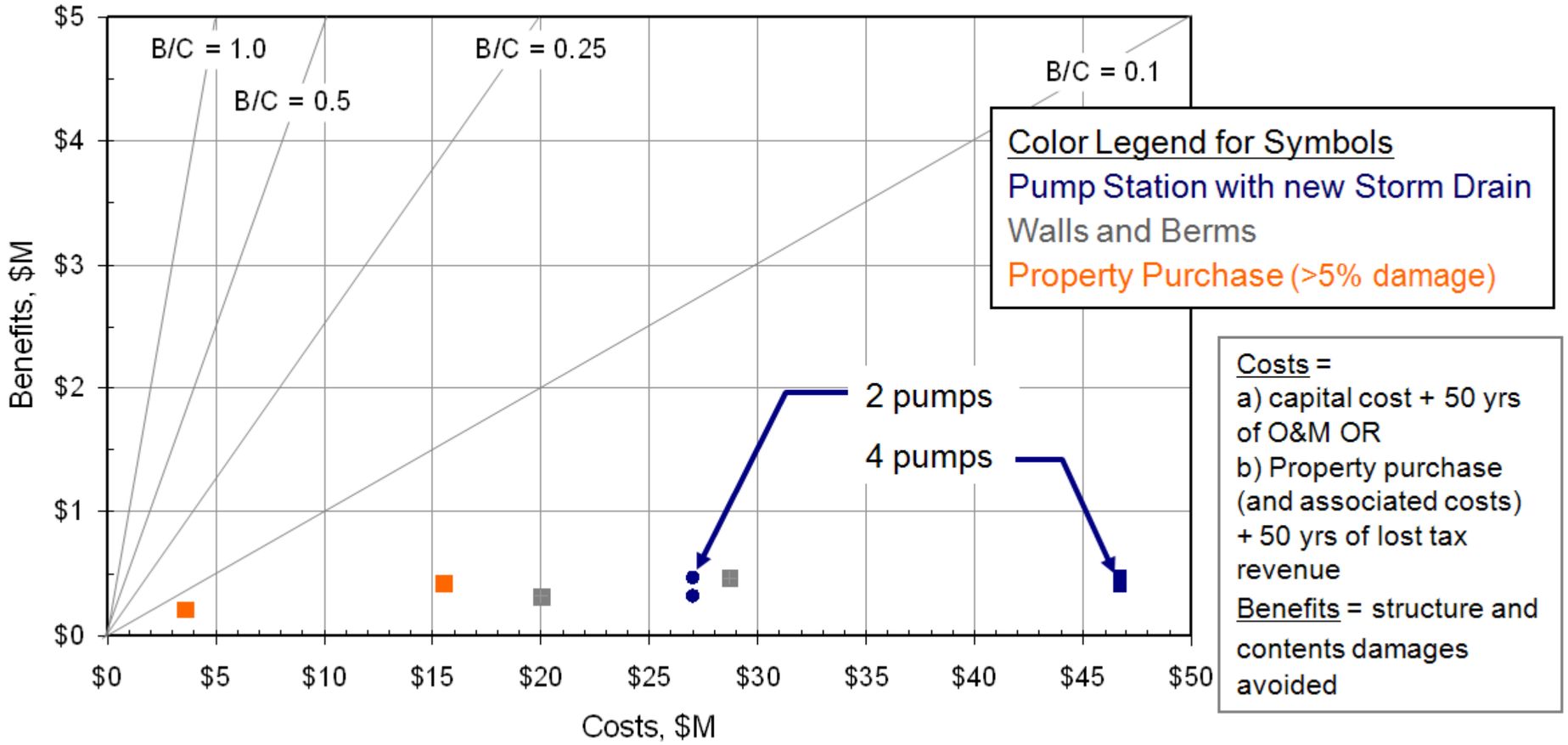


Figure 12-1. Benefit Cost Evaluation

APPENDIX A

DRAFT

Mason Creek
Flood Gate Protocol

Pre-Storm

The Flood Gate will remain in the open position until such time as the National Weather Service or the Fleet Meteorological Center forecast calls for a significant weather event (**Northeaster** or **Hurricane)** to impact the Hampton Roads Area, specifically Naval Station Norfolk. The gate shall be closed approximately 24 to 36 hrs. prior to the storm impacting the area if the tidal predictions indicate a tidal surge or high tide more than two (2) feet above Mean High Tide and wind speeds are predicted to be above 25MPH. The closure will generally occur in the low tide cycle the day before the storm impacts the area.

Post Storm

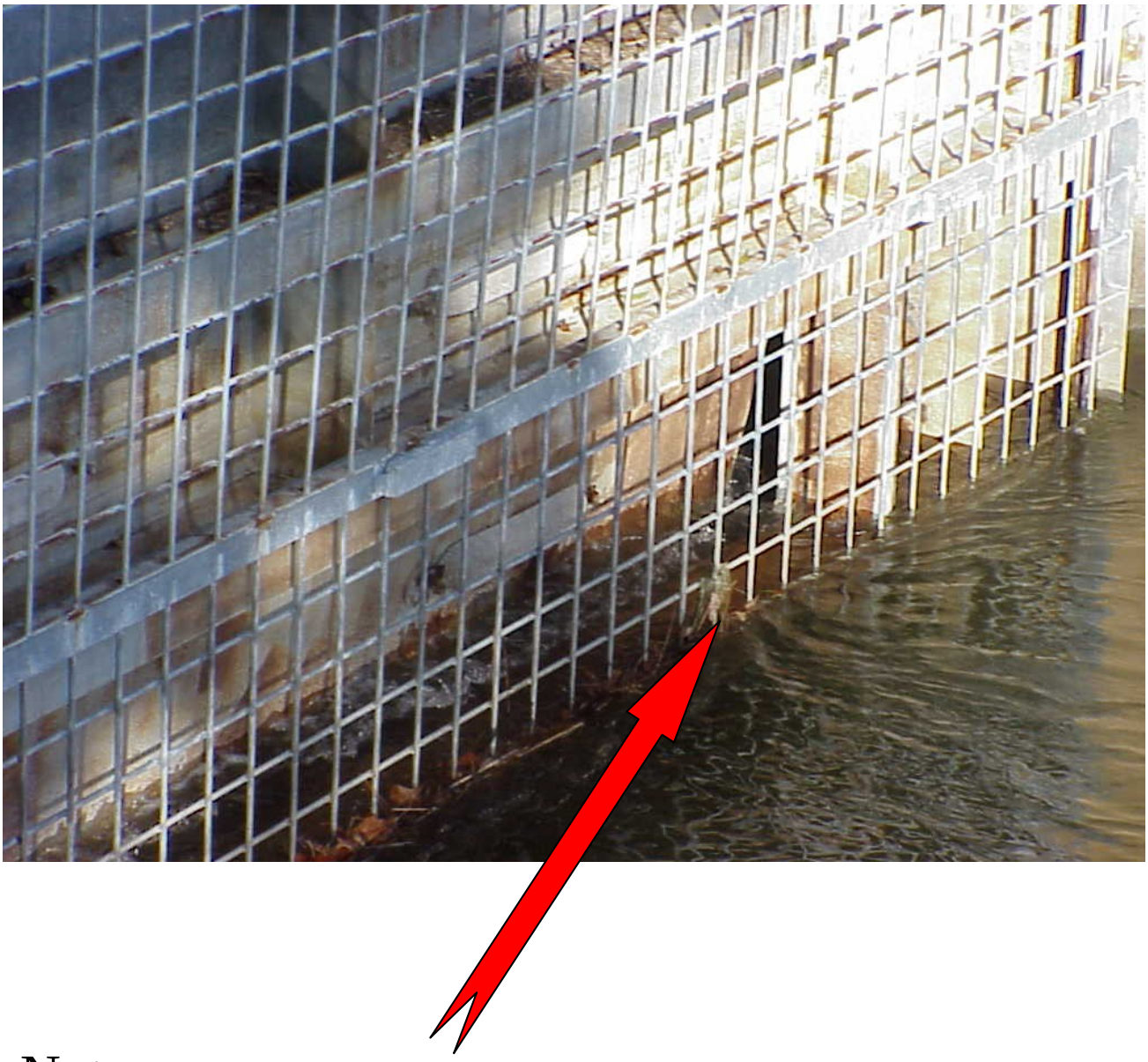
Once the storm passes the gate is returned to the open position after the tide levels fall below the level inside of Mason Creek. The determination to open is based on the weather forecast and direct observation of the conditions at the Flood Gate of tidal flow through a built in relief damper in the gate. Once the water is lower on the outfall side of the gate the relief damper swings open and allows the water to start receding, at this time the gate can be reopened.

Mason Creek Flood Gate Fully Open

Baffle Plate

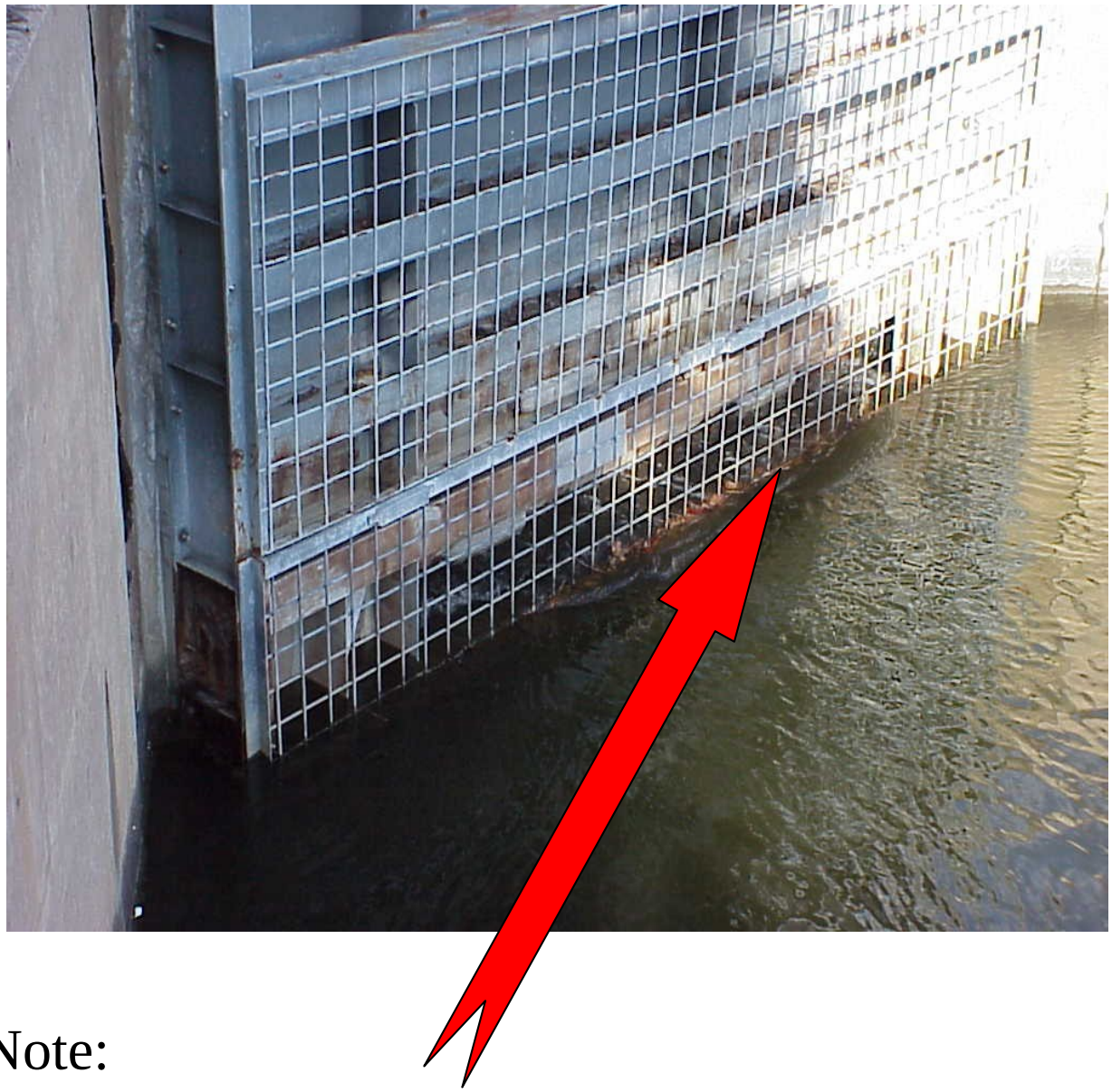
Note:
The following pictures were taken at the crest of high tide.

Mason Creek Flood Gate Partial Closure



Note:
The baffle is open and allowing an outward flow.

Mason Creek Flood Gate Partial Closure



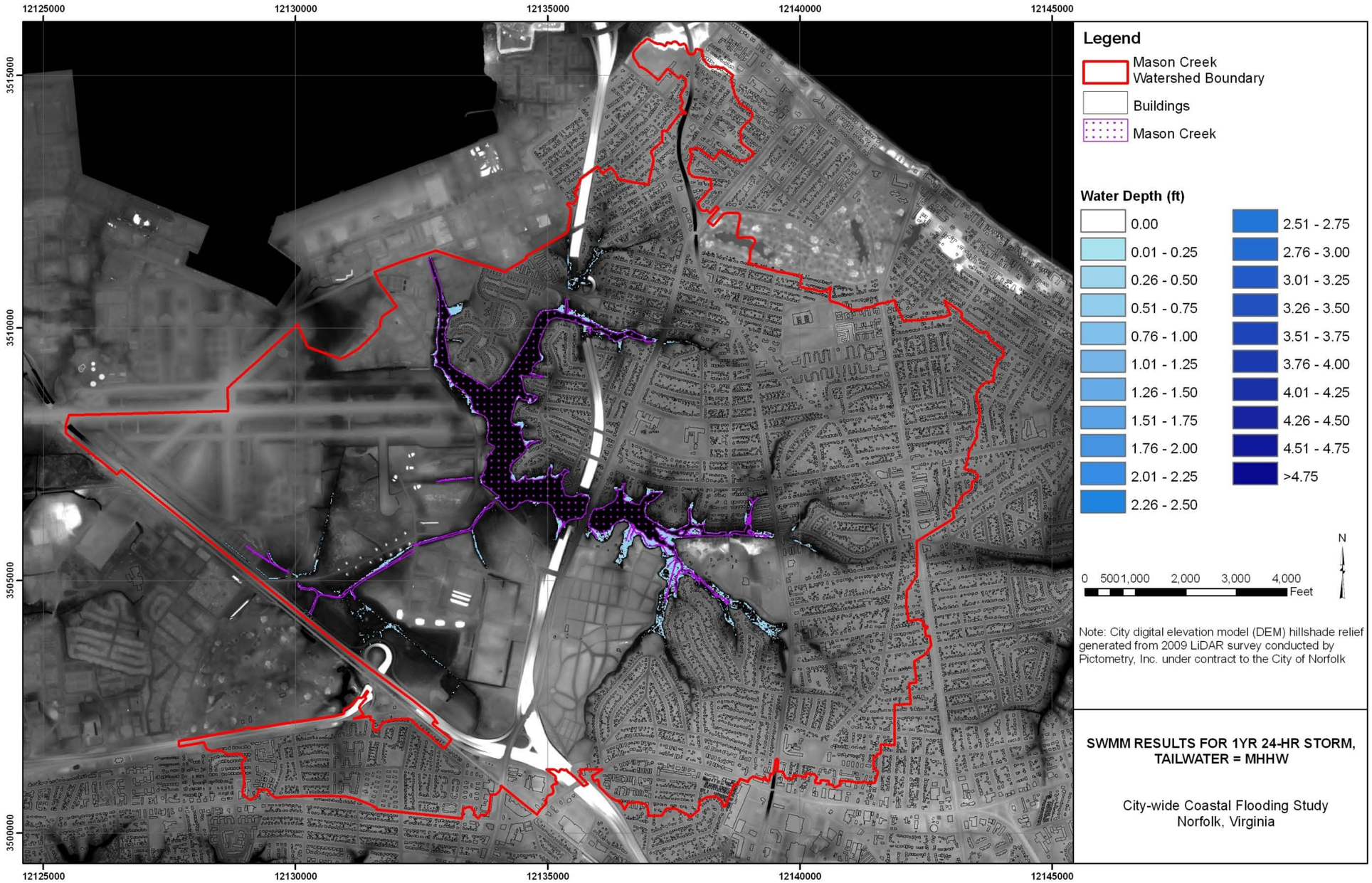
Note:
The baffle is open and allowing an outward flow

Mason Creek Flood Gate Fully Closed

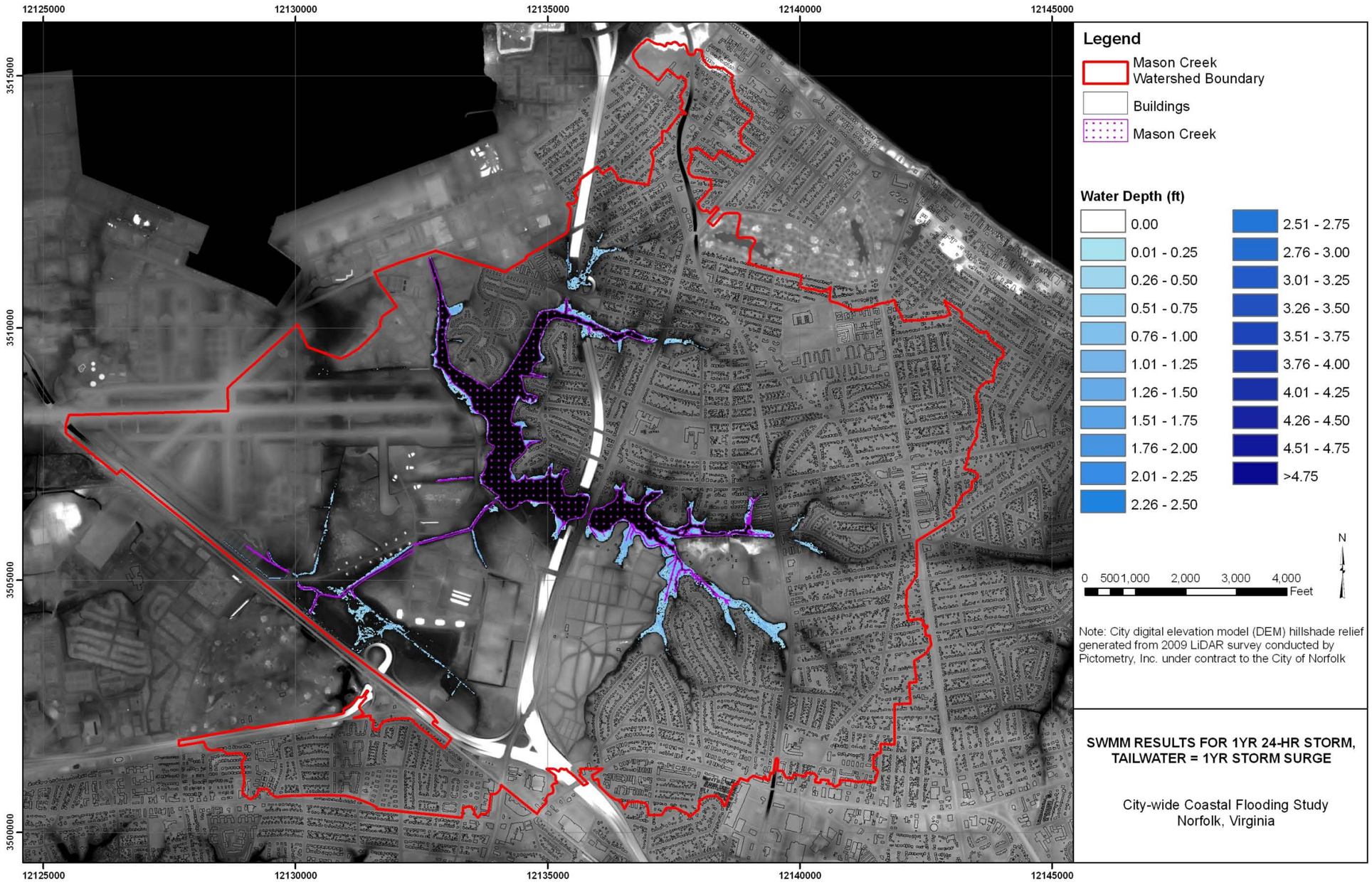
Baffle Plate is submerged

APPENDIX B

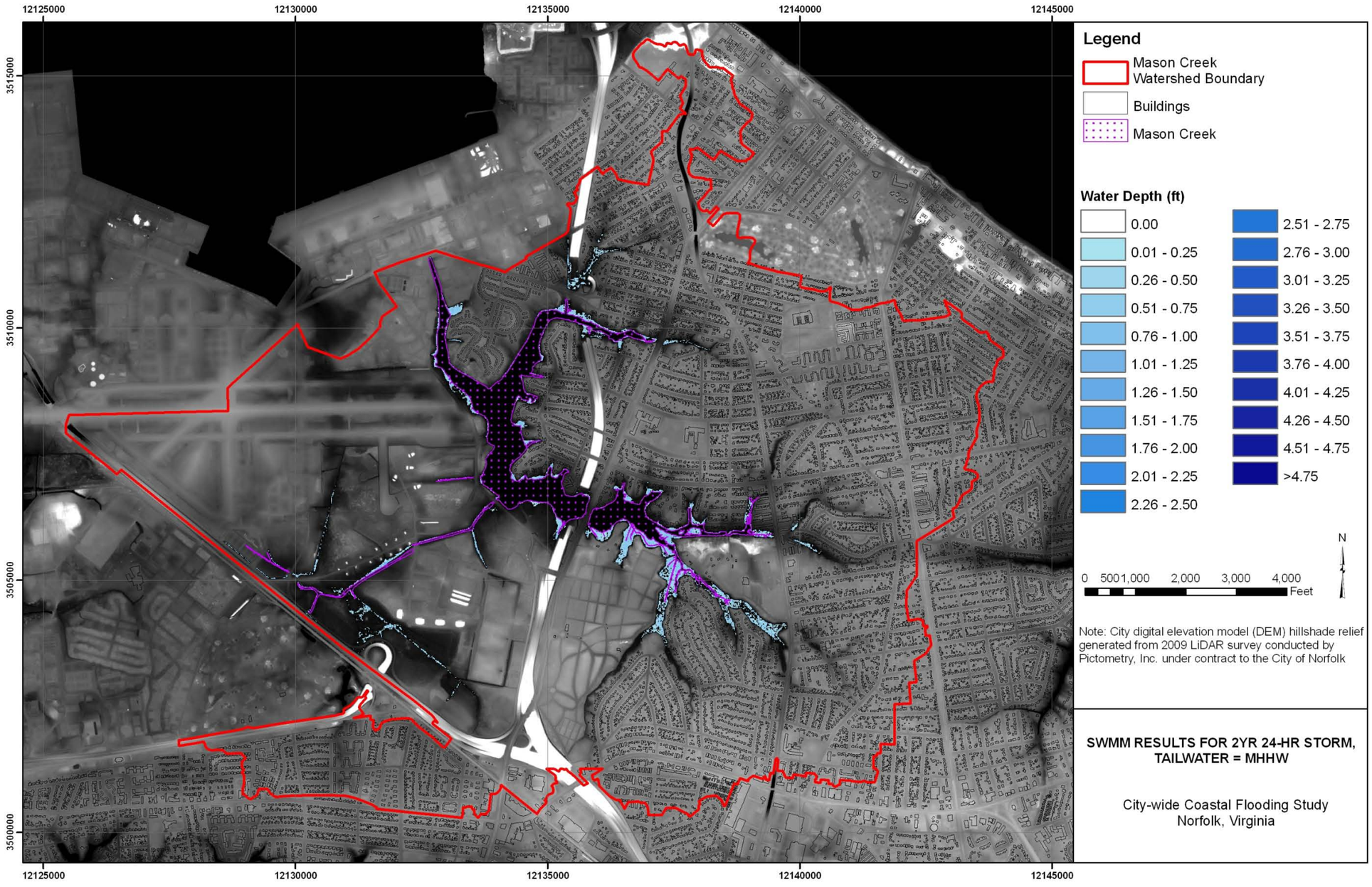
DRAFT



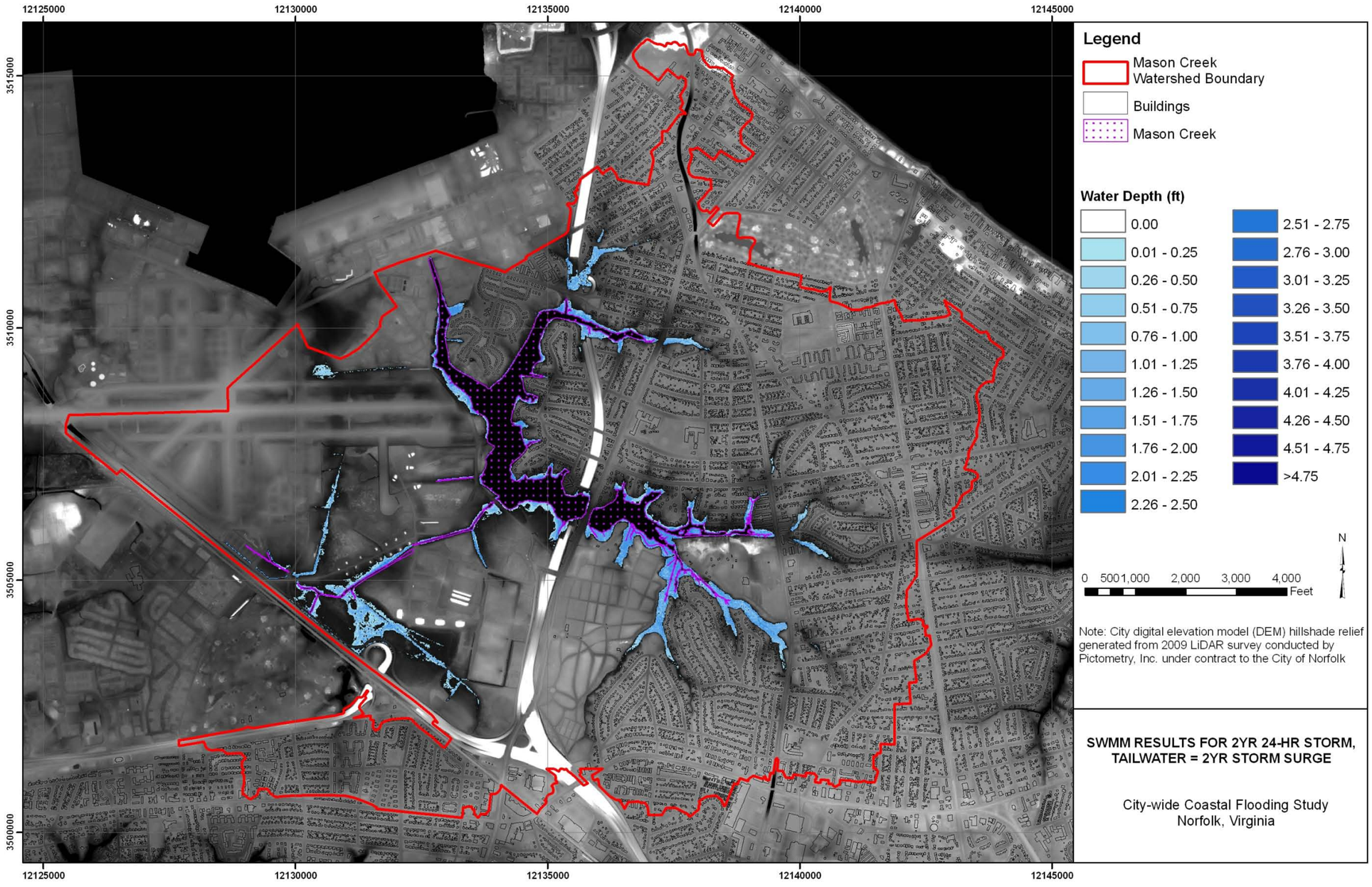
Appendix B - SWMM Results For The 1 Year, 24 Hour Storm (Tailwater=MHHW)



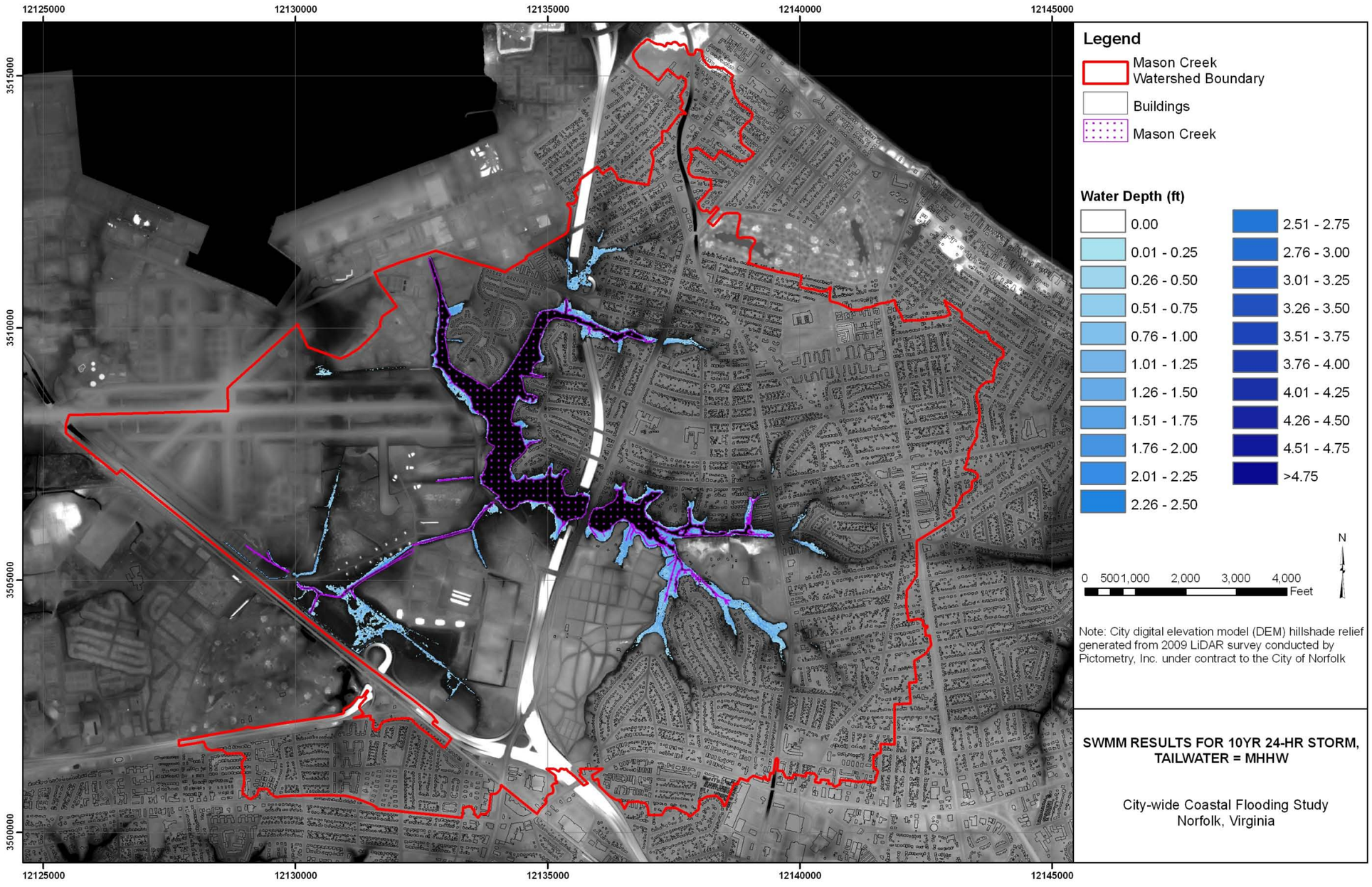
Appendix B. SWMM Results For The 1 Year, 24 Hour Storm (Tailwater=1 Year Surge)



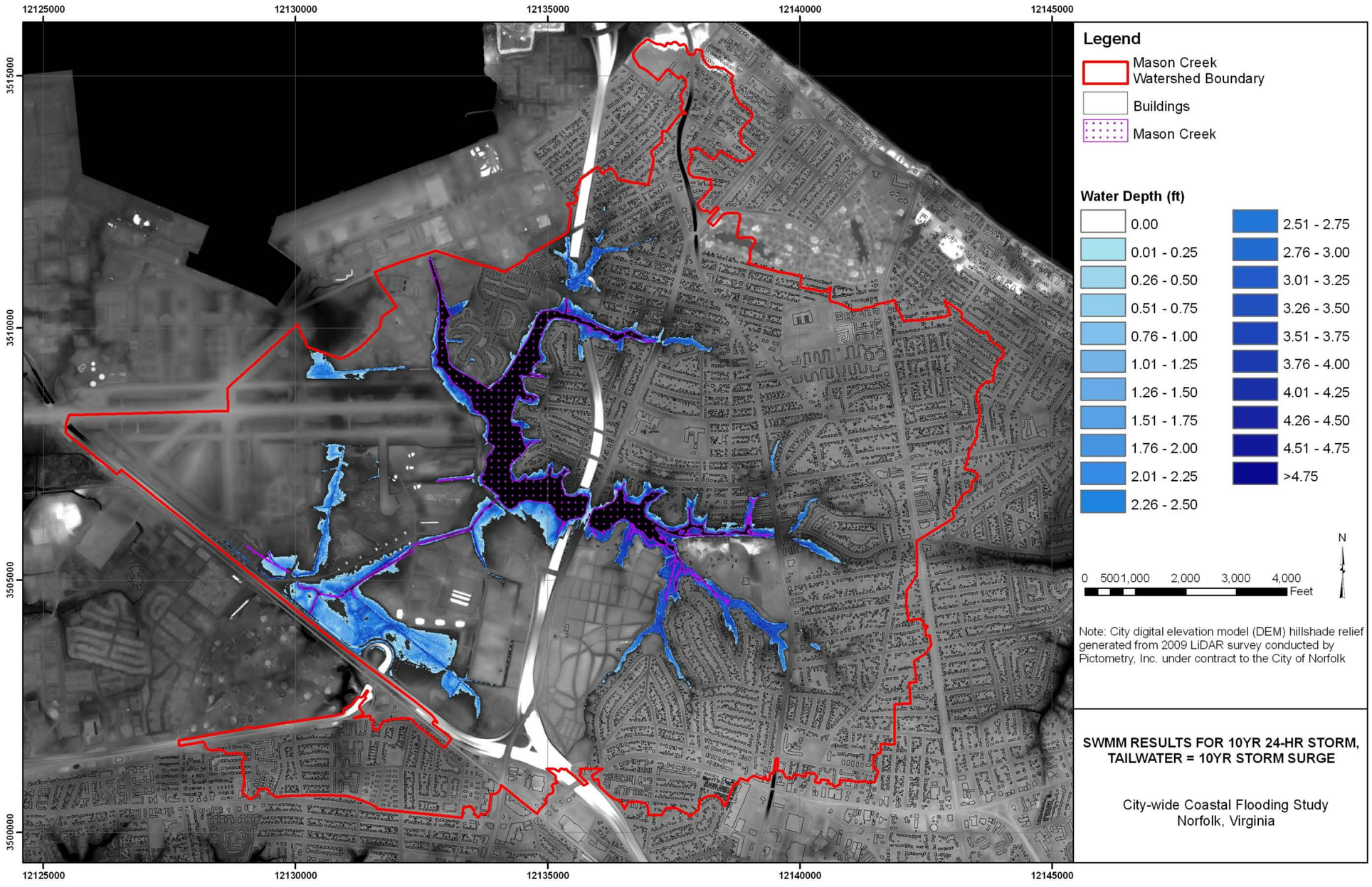
Appendix B. SWMM Results For The 2 Year, 24 Hour Storm (Tailwater=MHHW)



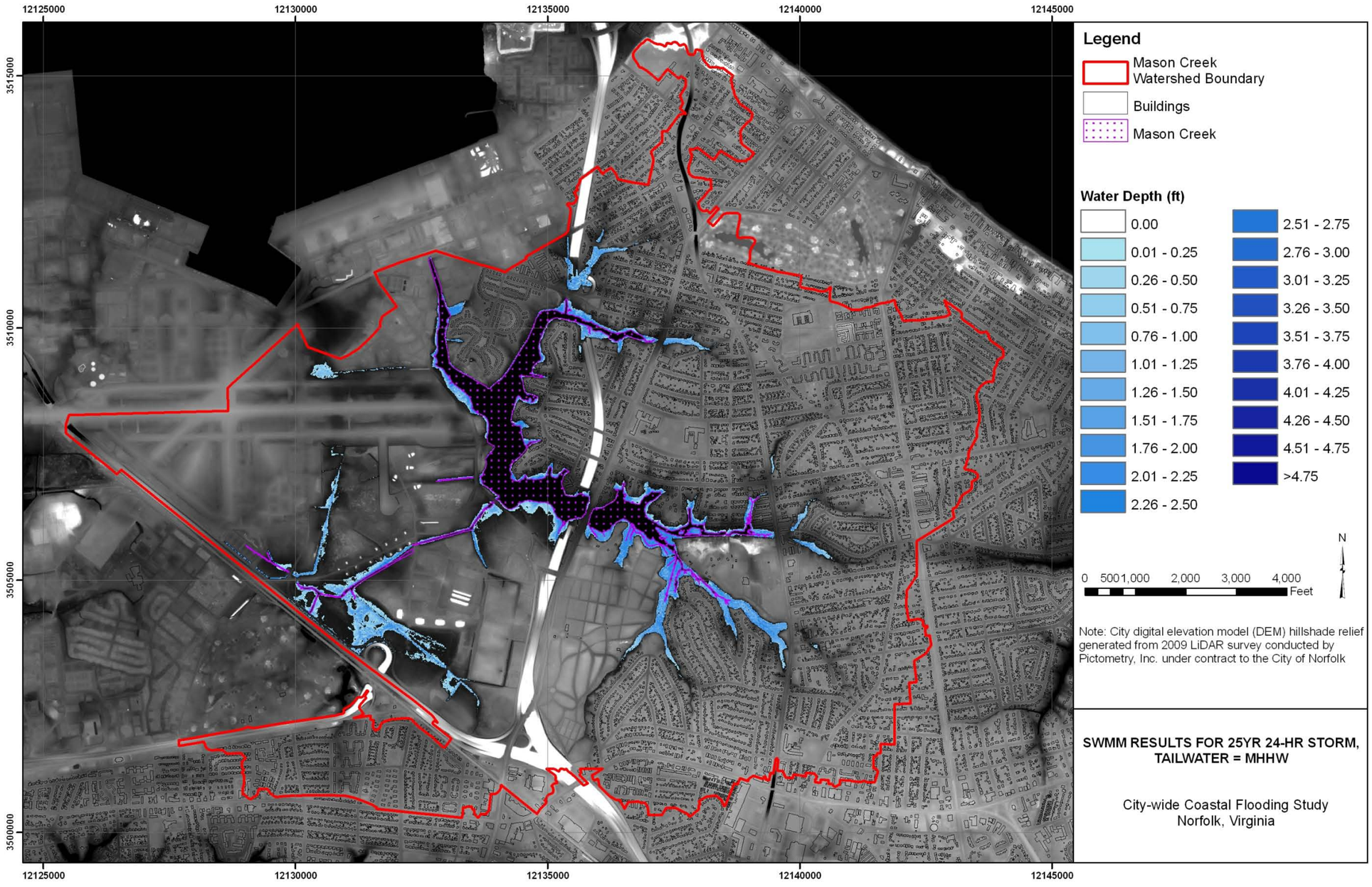
Appendix B. SWMM Results For The 2 Year, 24 Hour Storm (Tailwater=2 Year Storm Surge)



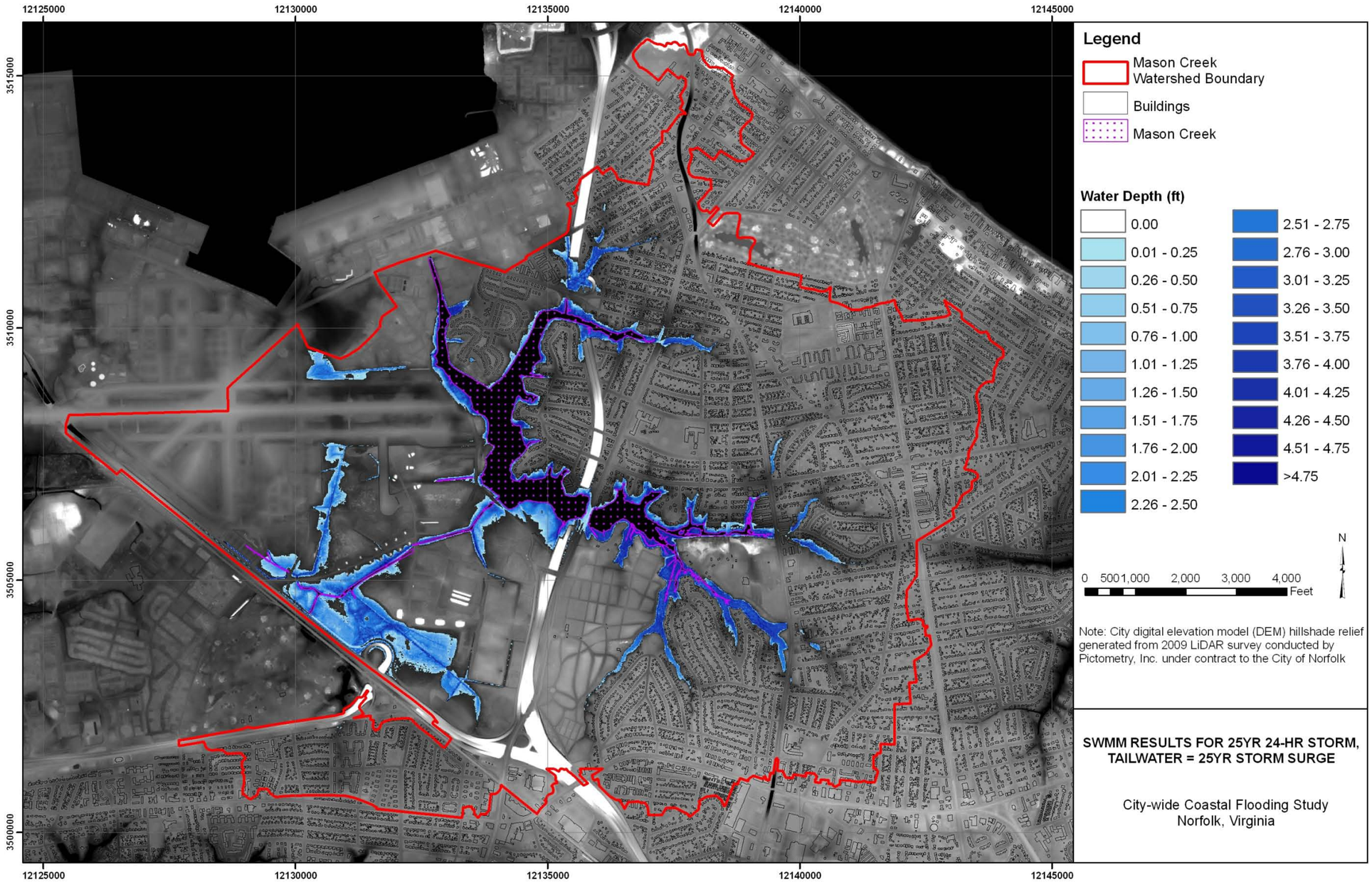
Appendix B. SWMM Results For The 10 Year, 24 Hour Storm (Tailwater=MHHW)



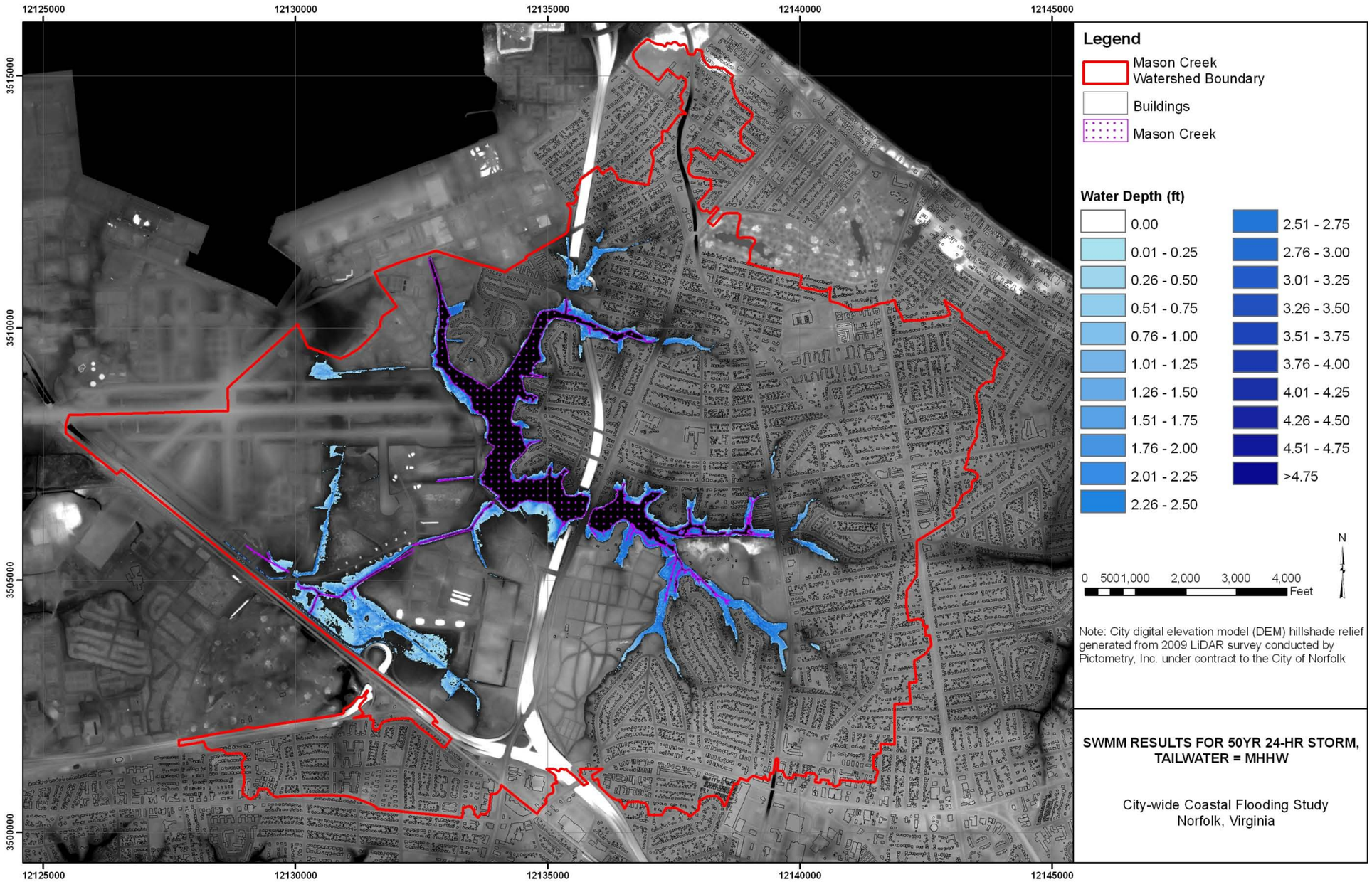
Appendix B. SWMM Results For The 10 Year, 24 Hour Storm (Tailwater=10 Year Storm Surge)



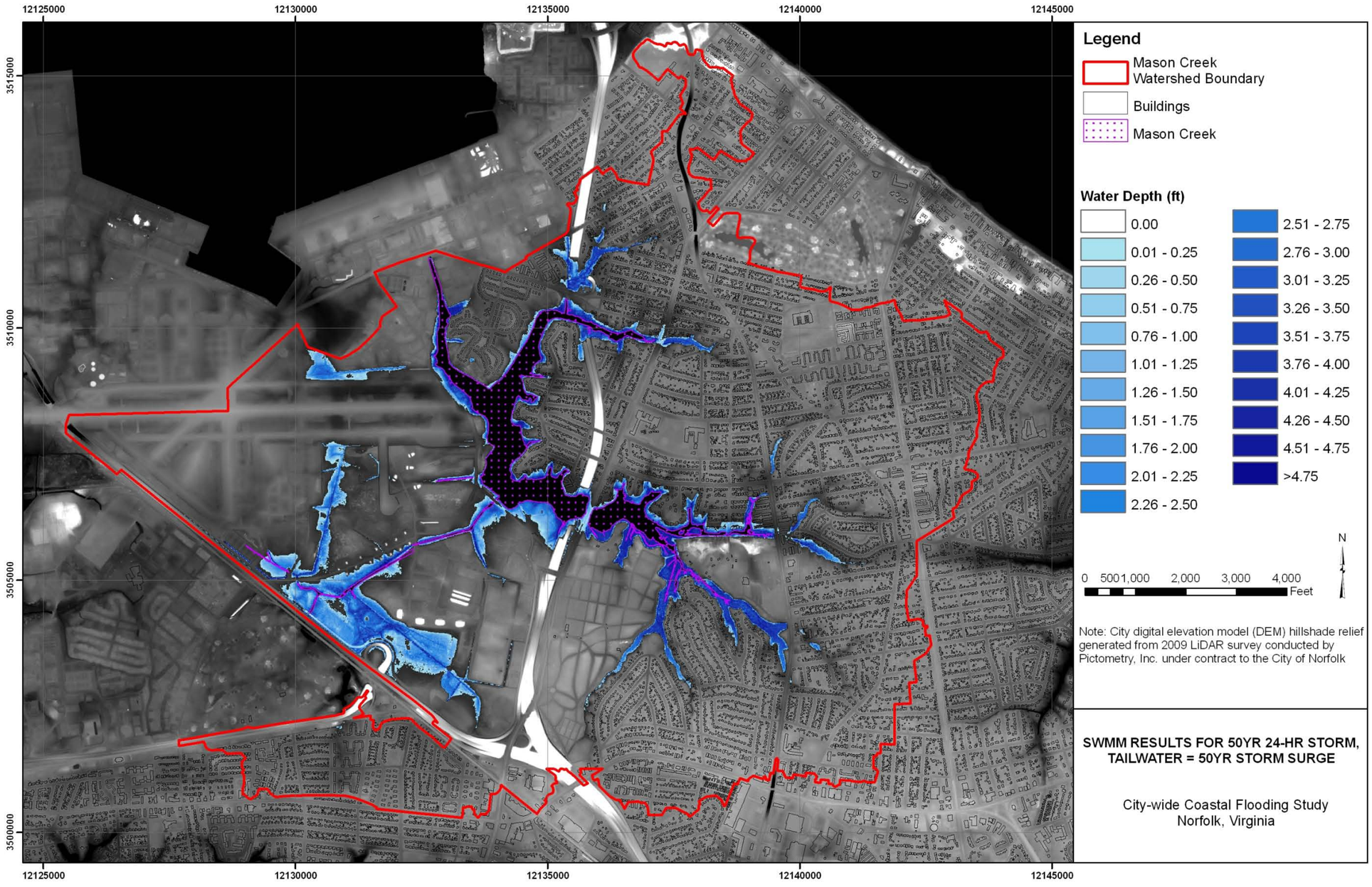
Appendix B. SWMM Results For The 25 Year, 24 Hour Storm (Tailwater=MHHW)



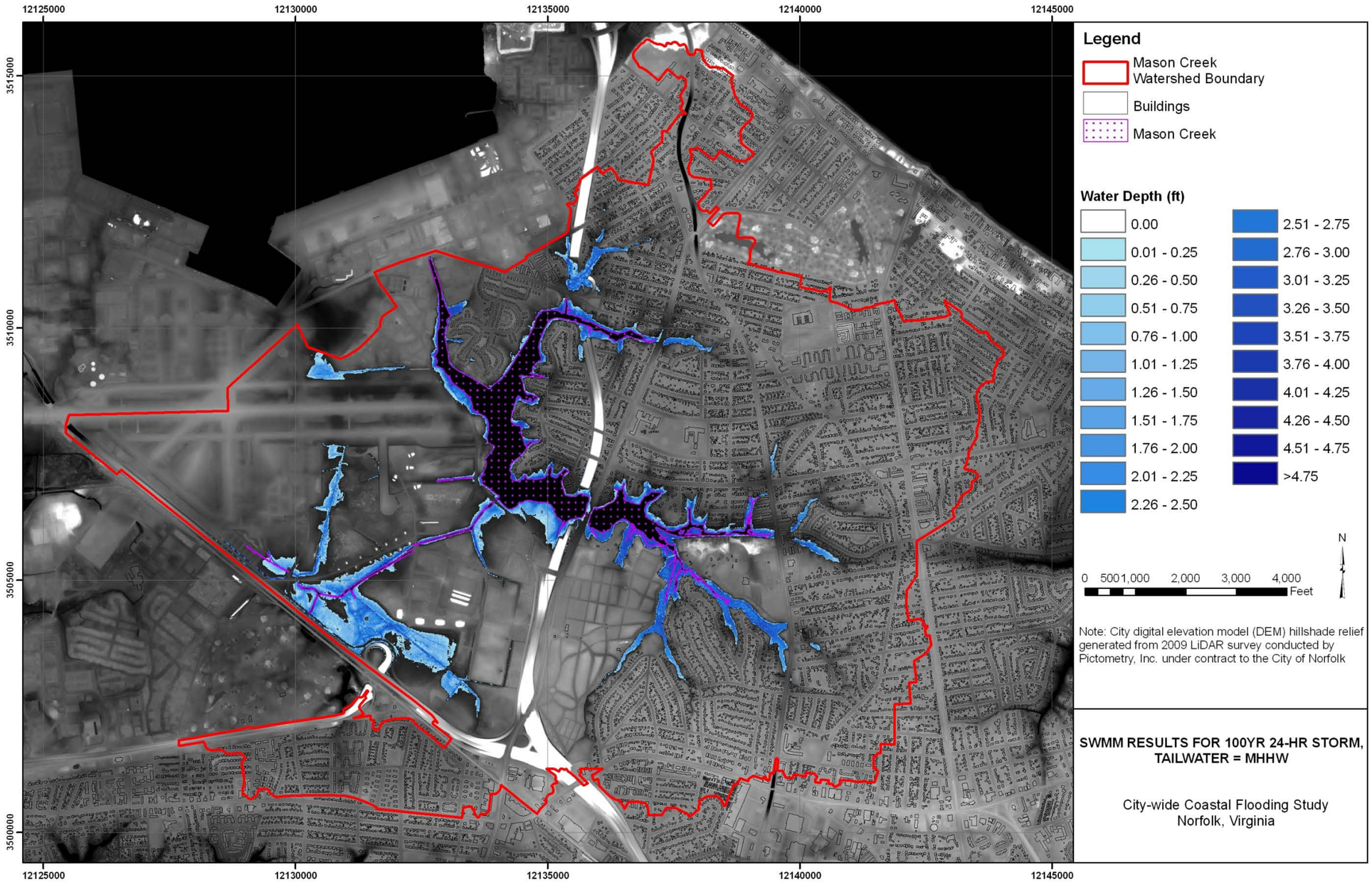
Appendix B. SWMM Results For The 25 Year, 24 Hour Storm (Tailwater=25 Year Storm Surge)



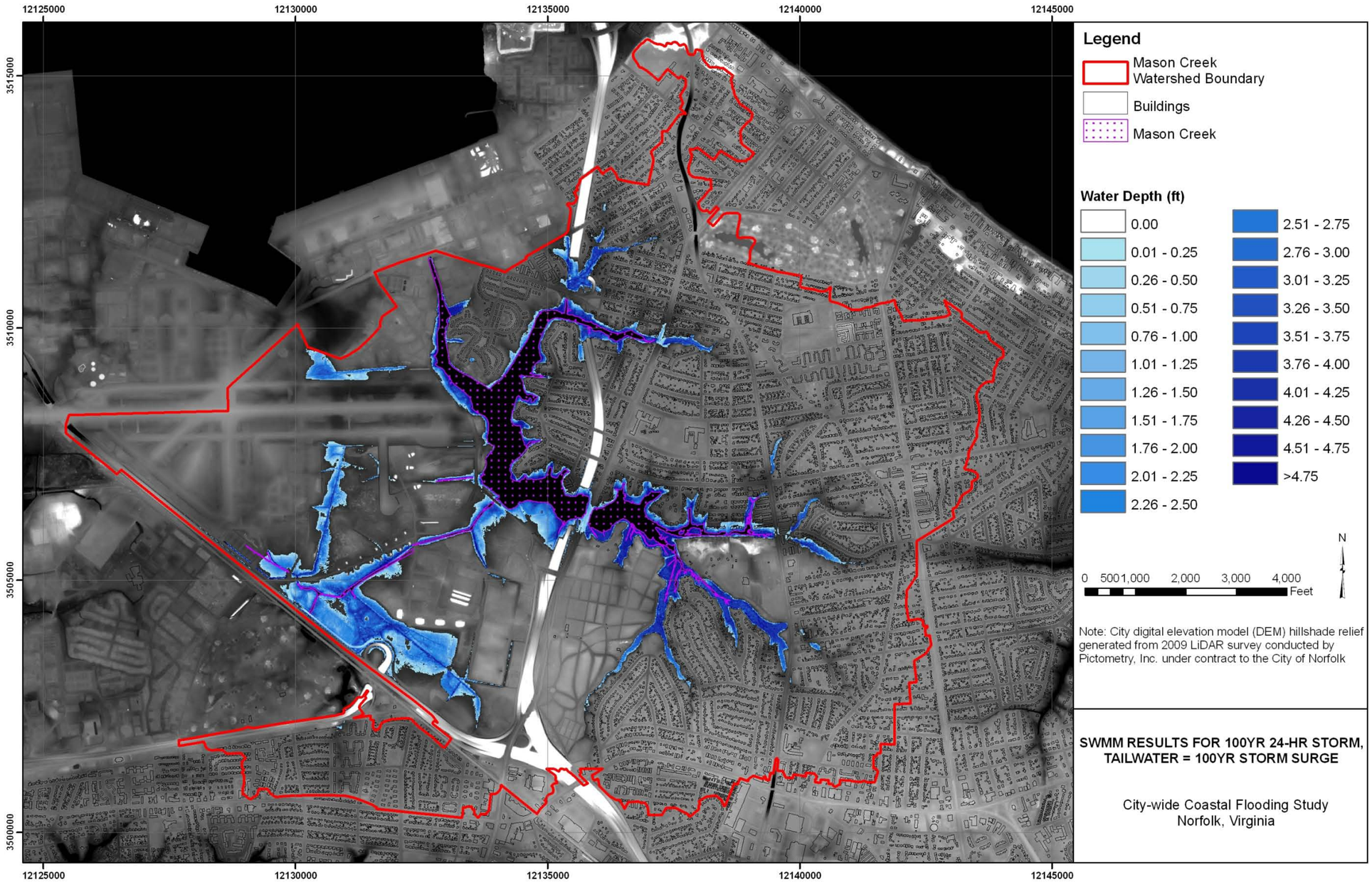
Appendix B. SWMM Results For The 50 Year, 24 Hour Storm (Tailwater=MHHW)



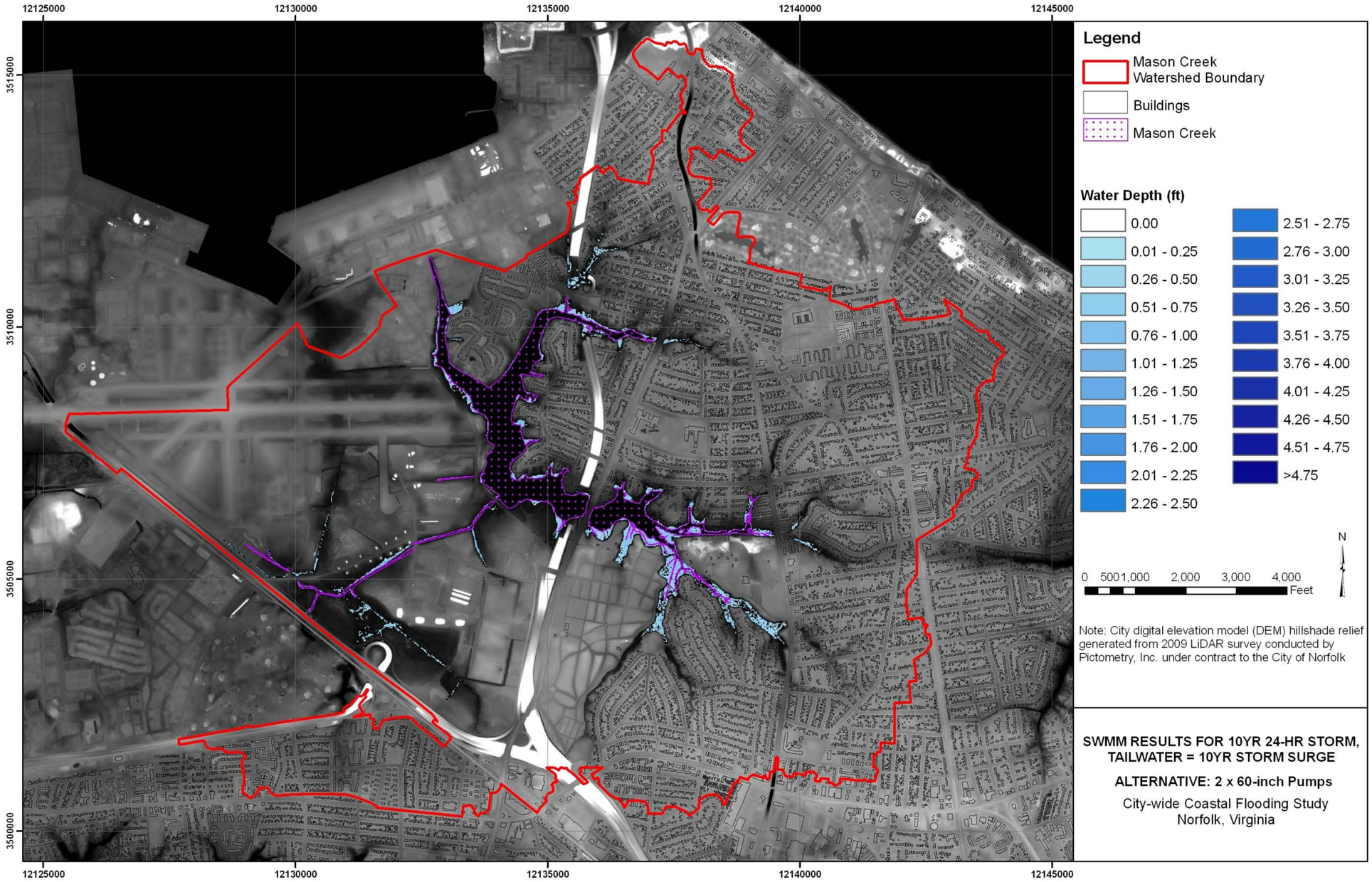
Appendix B. SWMM Results For The 50 Year, 24 Hour Storm (Tailwater=50 Year Storm Surge)



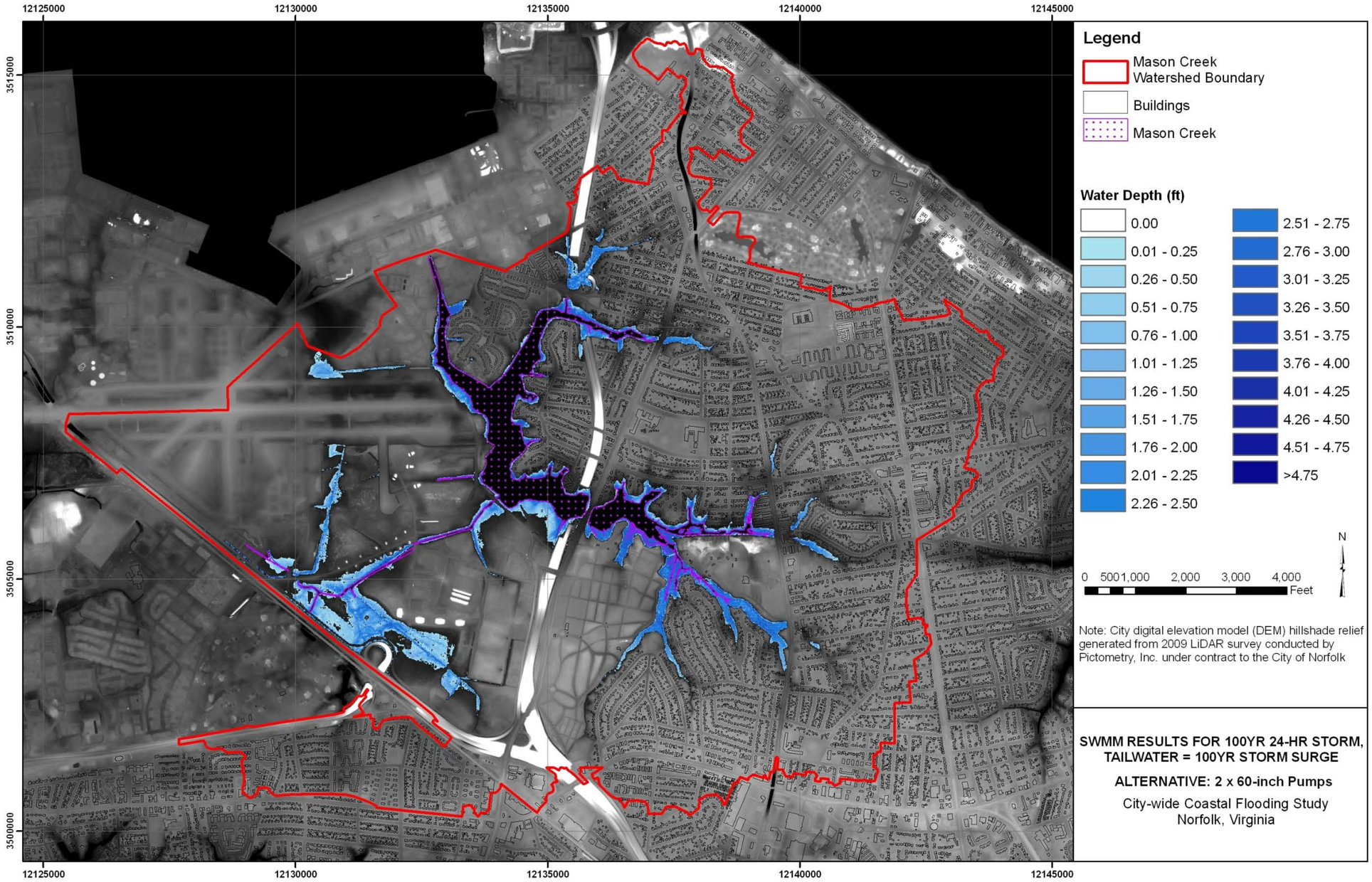
Appendix B. SWMM Results For The 100 Year, 24 Hour Storm (Tailwater=MHHW)



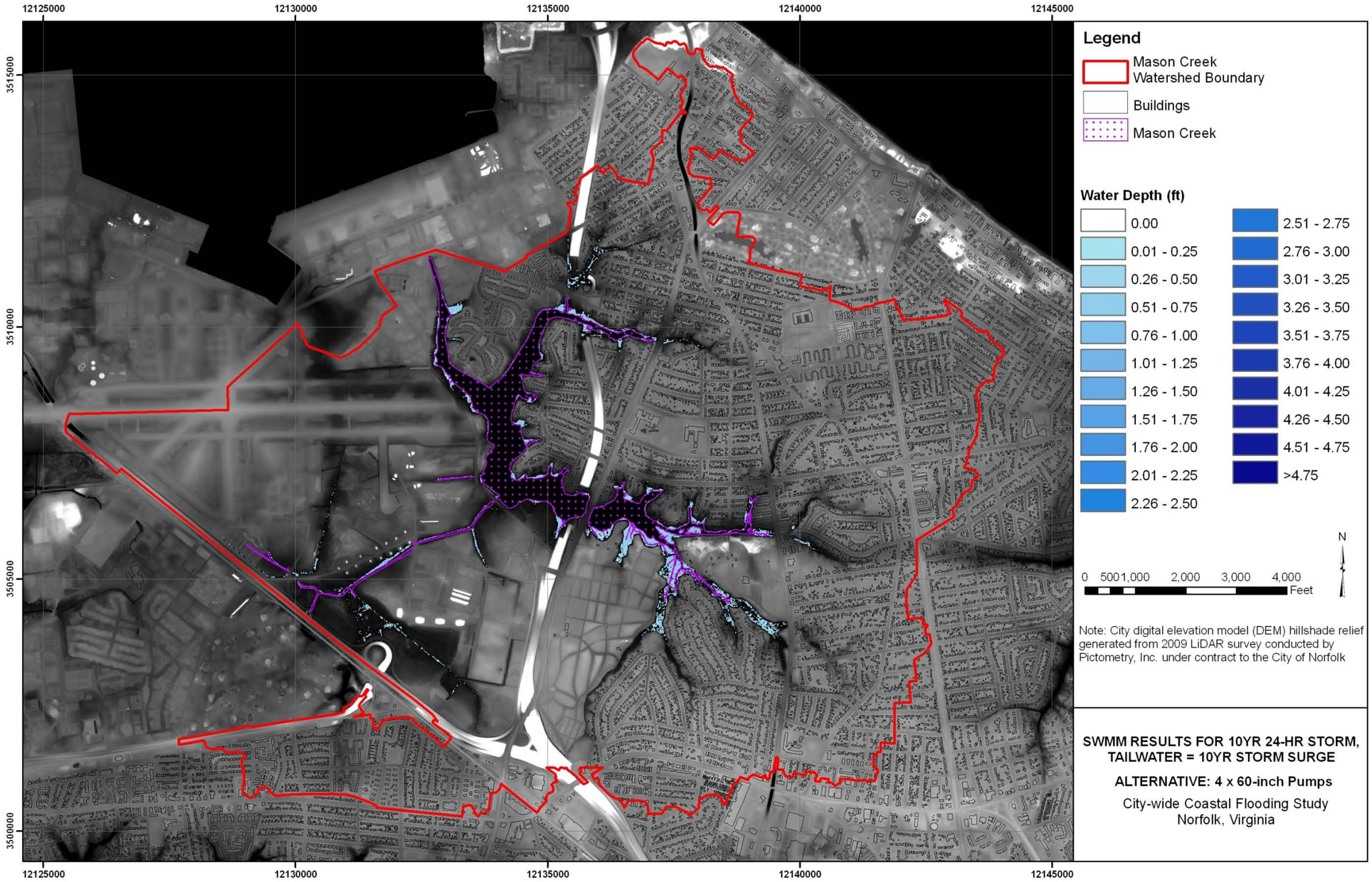
Appendix B. SWMM Results For The 100 Year, 24 Hour Storm (Tailwater=100 Year Storm Surge)



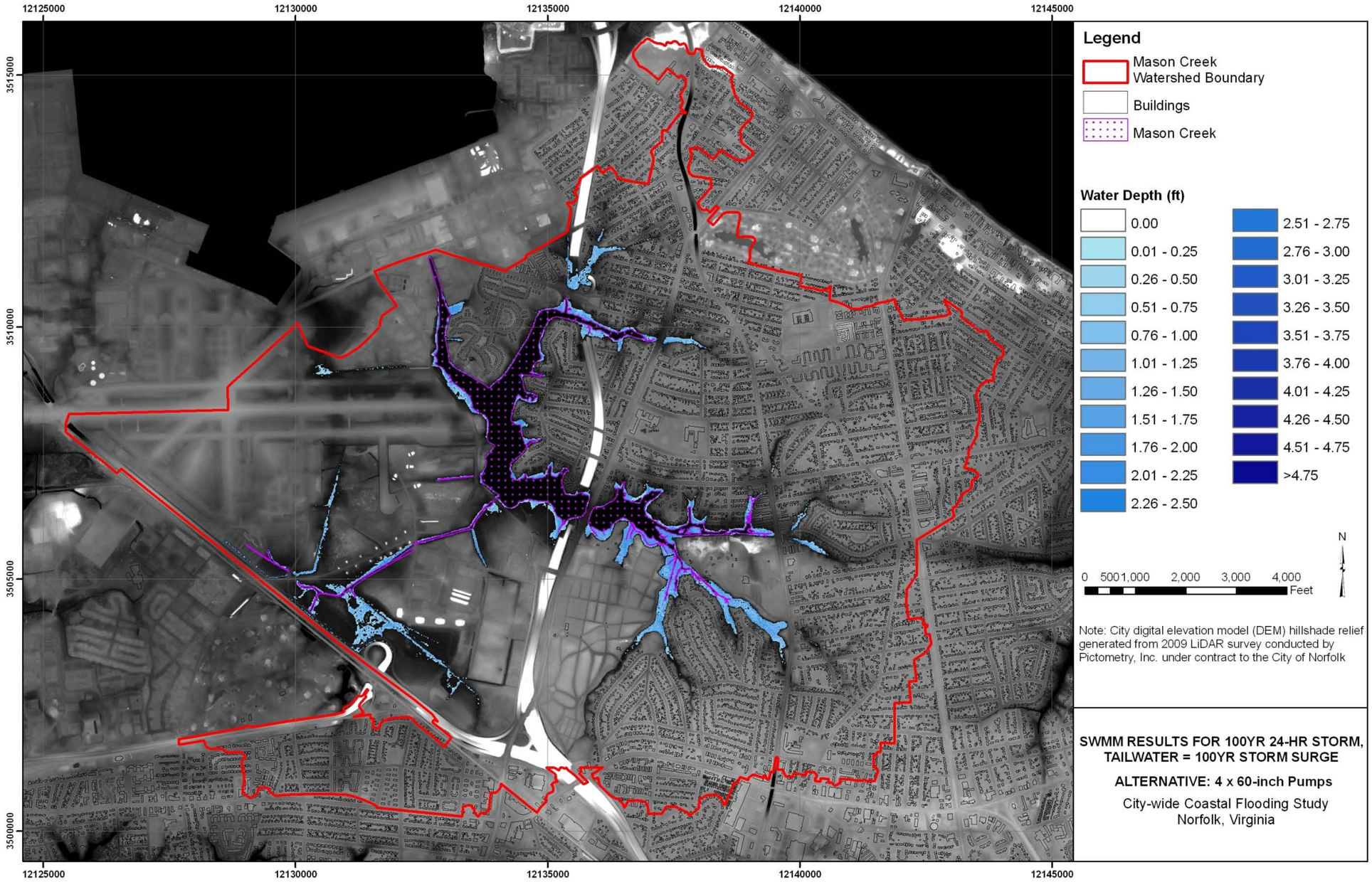
Appendix B. SWMM Results For 2x60 Inch Pumps (10 Year, 24 Hour Storm; Tailwater=10 Year Storm Surge)



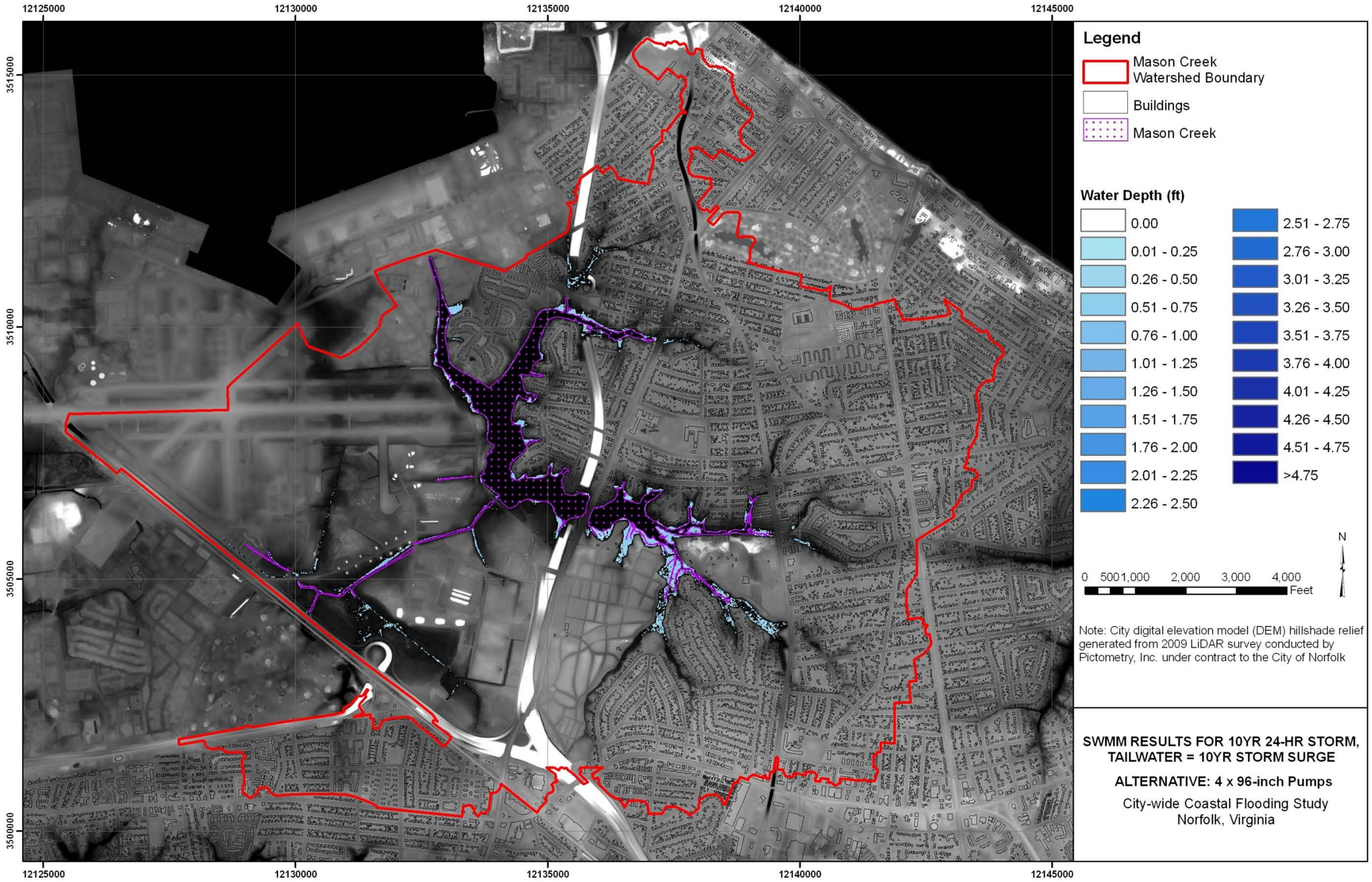
Appendix B. SWMM Results For 2x60 Inch Pumps (100 Year, 24 Hour Storm; Tailwater=100 Year Storm Surge)



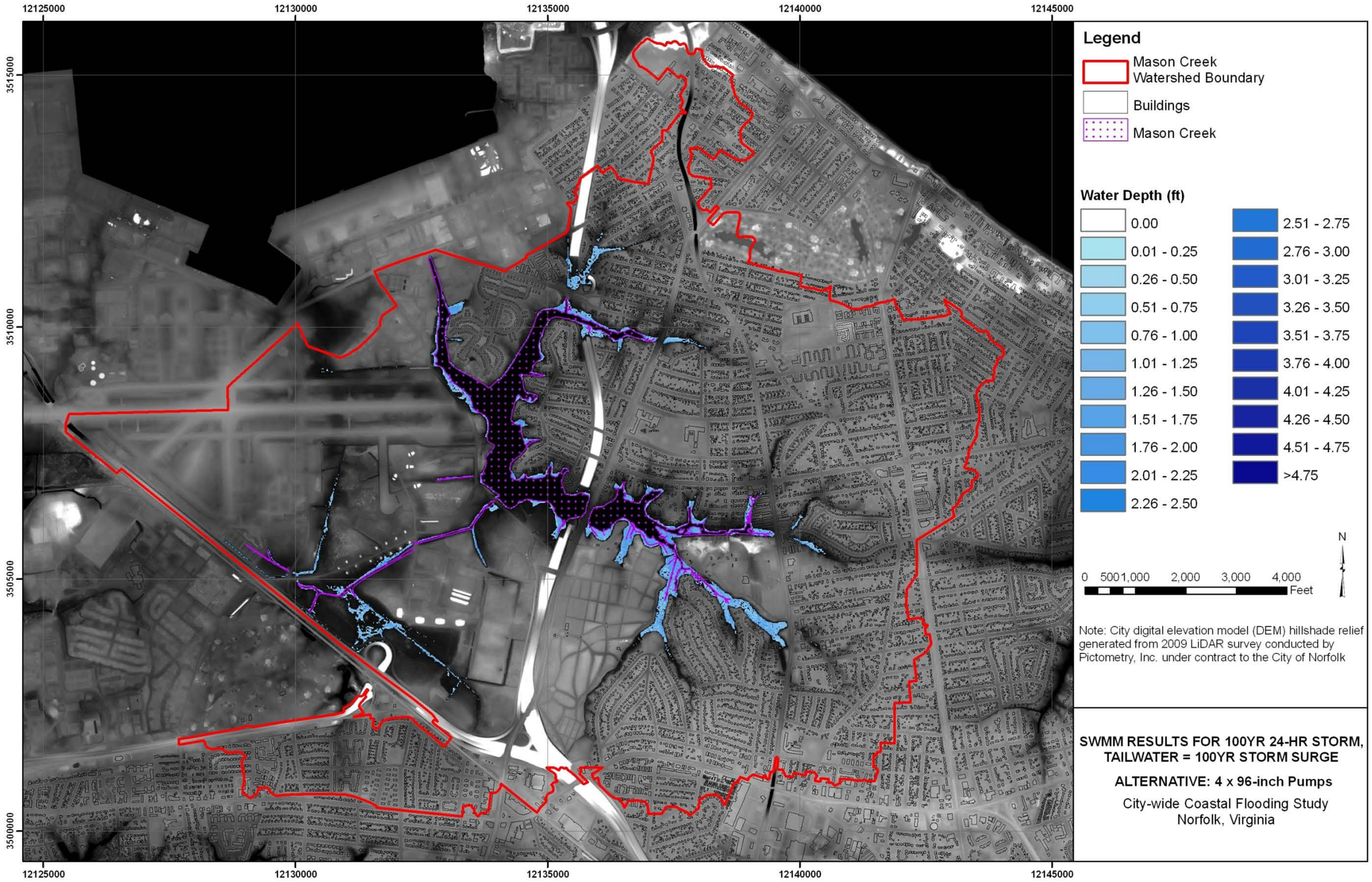
Appendix B. SWMM Results For 4x60 Inch Pumps (10 Year, 24 Hour Storm; Tailwater=10 Year Storm Surge)



Appendix B. SWMM Results For 4x60 Inch Pumps (100 Year, 24 Hour Storm; Tailwater=100 Year Storm Surge)



Appendix B. SWMM Results For 4x96 Inch Pumps (10 Year, 24 Hour Storm; Tailwater=10 Year Storm Surge)



Appendix B. SWMM Results For 4x96 Inch Pumps (100 Year, 24 Hour Storm; Tailwater=100 Year Storm Surge)

APPENDIX C

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION City of Norfolk Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE **Alternative 1 - Mason Creek Floodwall**	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Summary

Scenario	Opinon of Probable Cost
2 Year Surge Condition with Rain	$1,200,000
10 Year Surge Condition with Rain	$17,300,000
25 Year Rain Condition Only	$2,500,000
25 Year Surge Condition with Rain	$18,300,000
50 Year Rain Condition Only	$3,200,000
50 Year Surge Condition with Rain	$23,900,000
100 Year Rain Condition Only	$3,900,000
100 Year Surge Condition with Rain	$24,900,000

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION City of Norfolk Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE **Alternatives 2 - 4 Culvert, Pump Scenarios**	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Summary

Scenario (2yr - 100yr Storm Events)	Opinon of Probable Cost
Alternative 2 - Culvert, 2 - 60" Pumps	$25,000,000
Alternative 3 - Culvert, 4 - 60" Pumps	$43,000,000
Alternative 4 - Culvert, 4 - 96" Pumps	$76,000,000

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION City of Norfolk Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE **Alternative 5 - Buyout - 5% Damage**	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Summary

Scenario	Opinon of Probable Cost
10 - Year Storm Event	$3,093,650
25 - Year Storm Event	$6,682,375
50 - Year Storm Event	$6,682,375
100 - Year Storm Event	$13,487,075

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION City of Norfolk Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE **Alternative 1 - Mason Creek Floodwall @ 2 Year Event**	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Rain & Surge

ITEM DESCRIPTION	QUANTITY NUMBER	QUANTITY UNIT	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
Site Civil				
City of Norfolk Easement	8,850	SF	$6.00	$53,100
Temporary Easement (8% of CoN Easement)	1	LS	$4,248.00	$4,248
Wetland Mitigation	0.07	AC	$500,000.00	$33,861
Bulkhead Elevation w/ 2' Freeboard - Approx. 590 LF				
Bulkhead	5,900	VLF	$55.00	$324,500
Decorative Concrete Cap	3,693	SF	$40.00	$147,736
Pump Stations				
SUBTOTAL				$563,445
Overhead & Profit	15%			$84,517
Mobilization/Demobilization	10%			$56,345
Clearing & Grubbing	5%			$28,172
Erosion/Sediment Control	2%			$11,269
Traffic Control	2%			$11,269
Surveying/Engineering/Construction Observation	15%			$84,517
Permitting	5%			$28,172
Maintenance Costs	5%			$28,172
Subtotal with Mark-ups				**$895,878**
Contingency	25%			$223,970
Subtotal				**$1,119,848**
TOTAL				**$1,119,848**
			SAY	**$1,200,000**

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION City of Norfolk Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE **Alternative 1 - Mason Creek Floodwall @ 10 Year Event**	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Rain & Surge

ITEM DESCRIPTION	QUANTITY NUMBER	QUANTITY UNIT	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
Site Civil				
City of Norfolk Easement	90,000	SF	$6.00	$540,000
Temporary Easement (8% of CoN Easement)	1	LS	$43,200.00	$43,200
Wetland Mitigation	0.69	AC	$500,000.00	$344,353
Bulkhead Elevation w/ 2' Freeboard - Approx. 6000 LF				
Bulkhead	96,000	VLF	$55.00	$5,280,000
Decorative Concrete Cap	62,040	SF	$40.00	$2,481,600
Pump Stations				
SUBTOTAL				$8,689,153
Overhead & Profit	15%			$1,303,373
Mobilization/Demobilization	10%			$868,915
Clearing & Grubbing	5%			$434,458
Erosion/Sediment Control	2%			$173,783
Traffic Control	2%			$173,783
Surveying/Engineering/Construction Observation	15%			$1,303,373
Permitting	5%			$434,458
Maintenance Costs	5%			$434,458
Subtotal with Mark-ups				**$13,815,753**
Contingency	25%			$3,453,938
Subtotal				**$17,269,691**
TOTAL				**$17,269,691**
			SAY	**$17,300,000**

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 1 - Mason Creek Floodwall @ 25 Year Event	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Rain

ITEM DESCRIPTION	QUANTITY NUMBER	QUANTITY UNIT	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
Site Civil				
City of Norfolk Easement	33,600	SF	$6.00	$201,600
Temporary Easement (8% of CoN Easement)	1	LS	$16,128.00	$16,128
Wetland Mitigation	0.26	AC	$500,000.00	$128,558
Bulkhead Elevation w/ 2' Freeboard - Approx. 2240 LF				
Bulkhead	11,200	VLF	$55.00	$616,000
Decorative Concrete Cap	6,272	SF	$40.00	$250,880
Pump Stations				
SUBTOTAL				$1,213,166
Overhead & Profit	15%			$181,975
Mobilization/Demobilization	10%			$121,317
Clearing & Grubbing	5%			$60,658
Erosion/Sediment Control	2%			$24,263
Traffic Control	2%			$24,263
Surveying/Engineering/Construction Observation	15%			$181,975
Permitting	5%			$60,658
Maintenance Costs	5%			$60,658
Subtotal with Mark-ups				**$1,928,934**
Contingency	25%			$482,234
Subtotal				**$2,411,168**
TOTAL				**$2,411,168**
			SAY	**$2,500,000**

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 1 - Mason Creek Floodwall @ 25 Year Event	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Rain & Surge	QUANTITY		ENGINEERING ESTIMATE	
ITEM DESCRIPTION	NUMBER	UNIT	UNIT COST	TOTAL
Site Civil				
City of Norfolk Easement	90,000	SF	$6.00	$540,000
Temporary Easement (8% of CoN Easement)	1	LS	$43,200.00	$43,200
Wetland Mitigation	0.69	AC	$500,000.00	$344,353
Bulkhead Elevation w/ 2' Freeboard - Approx. 6000 LF				
Bulkhead	102,000	VLF	$55.00	$5,610,000
Decorative Concrete Cap	65,640	SF	$40.00	$2,625,600
Pump Stations				
SUBTOTAL				$9,163,153
Overhead & Profit	15%			$1,374,473
Mobilization/Demobilization	10%			$916,315
Clearing & Grubbing	5%			$458,158
Erosion/Sediment Control	2%			$183,263
Traffic Control	2%			$183,263
Surveying/Engineering/Construction Observation	15%			$1,374,473
Permitting	5%			$458,158
Maintenance Costs	5%			$458,158
Subtotal with Mark-ups				**$14,569,413**
Contingency	25%			$3,642,353
Subtotal				**$18,211,766**
TOTAL				**$18,211,766**
			SAY	**$18,300,000**

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 1 - Mason Creek Floodwall @ 50 Year Event	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Rain

ITEM DESCRIPTION	QUANTITY NUMBER	QUANTITY UNIT	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
Site Civil				
City of Norfolk Easement	33,600	SF	$6.00	$201,600
Temporary Easement (8% of CoN Easement)	1	LS	$16,128.00	$16,128
Wetland Mitigation	0.26	AC	$500,000.00	$128,558
Bulkhead Elevation w/ 2' Freeboard - Approx. 2240 LF				
Bulkhead	15,680	VLF	$55.00	$862,400
Decorative Concrete Cap	9,005	SF	$40.00	$360,192
Pump Stations				
SUBTOTAL				$1,568,878
Overhead & Profit	15%			$235,332
Mobilization/Demobilization	10%			$156,888
Clearing & Grubbing	5%			$78,444
Erosion/Sediment Control	2%			$31,378
Traffic Control	2%			$31,378
Surveying/Engineering/Construction Observation	15%			$235,332
Permitting	5%			$78,444
Maintenance Costs	5%			$78,444
Subtotal with Mark-ups				**$2,494,517**
Contingency	25%			$623,629
Subtotal				**$3,118,146**
TOTAL				**$3,118,146**
			SAY	**$3,200,000**

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Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 1 - Mason Creek Floodwall @ 50 Year Event	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Rain & Surge	QUANTITY		ENGINEERING ESTIMATE	
ITEM DESCRIPTION	NUMBER	UNIT	UNIT COST	TOTAL
Site Civil				
City of Norfolk Easement	116,550	SF	$6.00	$699,300
Temporary Easement (8% of CoN Easement)	1	LS	$55,944.00	$55,944
Wetland Mitigation	0.89	AC	$500,000.00	$445,937
Bulkhead Elevation w/ 2' Freeboard - Approx. 7770 LF				
Bulkhead	132,090	VLF	$55.00	$7,264,950
Decorative Concrete Cap	87,801	SF	$40.00	$3,512,040
Pump Stations				
SUBTOTAL				$11,978,171
Overhead & Profit	15%			$1,796,726
Mobilization/Demobilization	10%			$1,197,817
Clearing & Grubbing	5%			$598,909
Erosion/Sediment Control	2%			$239,563
Traffic Control	2%			$239,563
Surveying/Engineering/Construction Observation	15%			$1,796,726
Permitting	5%			$598,909
Maintenance Costs	5%			$598,909
Subtotal with Mark-ups				**$19,045,291**
Contingency	25%			$4,761,323
Subtotal				**$23,806,614**
TOTAL				**$23,806,614**
			SAY	**$23,900,000**

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 1 - Mason Creek Floodwall @ 100 Year Event	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Rain	QUANTITY		ENGINEERING ESTIMATE	
ITEM DESCRIPTION	NUMBER	UNIT	UNIT COST	TOTAL
Site Civil				
City of Norfolk Easement	33,600	SF	$6.00	$201,600
Temporary Easement (8% of CoN Easement)	1	LS	$16,128.00	$16,128
Wetland Mitigation	0.26	AC	$500,000.00	$128,558
Bulkhead Elevation w/ 2' Freeboard - Approx. 2240 LF				
Bulkhead	20,160	VLF	$55.00	$1,108,800
Decorative Concrete Cap	12,006	SF	$40.00	$480,256
Pump Stations				
SUBTOTAL				$1,935,342
Overhead & Profit	15%			$290,301
Mobilization/Demobilization	10%			$193,534
Clearing & Grubbing	5%			$96,767
Erosion/Sediment Control	2%			$38,707
Traffic Control	2%			$38,707
Surveying/Engineering/Construction Observation	15%			$290,301
Permitting	5%			$96,767
Maintenance Costs	5%			$96,767
Subtotal with Mark-ups				**$3,077,194**
Contingency	25%			$769,299
Subtotal				**$3,846,493**
TOTAL				**$3,846,493**
			SAY	**$3,900,000**

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 1 - Mason Creek Floodwall @ 100 Year Event	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

Rain & Surge	QUANTITY		ENGINEERING ESTIMATE	
ITEM DESCRIPTION	NUMBER	UNIT	UNIT COST	TOTAL
Site Civil				
City of Norfolk Easement	116,550	SF	$6.00	$699,300
Temporary Easement (8% of CoN Easement)	1	LS	$55,944.00	$55,944
Wetland Mitigation	0.89	AC	$500,000.00	$445,937
Bulkhead Elevation w/ 2' Freeboard - Approx. 7770 LF				
Bulkhead	139,860	VLF	$55.00	$7,692,300
Decorative Concrete Cap	90,132	SF	$40.00	$3,605,280
Pump Stations				
SUBTOTAL				$12,498,761
Overhead & Profit	15%			$1,874,814
Mobilization/Demobilization	10%			$1,249,876
Clearing & Grubbing	5%			$624,938
Erosion/Sediment Control	2%			$249,975
Traffic Control	2%			$249,975
Surveying/Engineering/Construction Observation	15%			$1,874,814
Permitting	5%			$624,938
Maintenance Costs	5%			$624,938
Subtotal with Mark-ups				**$19,873,029**
Contingency	25%			$4,968,257
Subtotal				**$24,841,287**
TOTAL				**$24,841,287**
			SAY	**$24,900,000**

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY	CATEGORY CODE NUMBER
Alternative 2 - Mason Creek Box Culvert, 2 - 60" Dia. Pumps	Moffatt & Nichol	
	STATUS OF DESIGN	JOB ORDER NUMBER
	Conceptual	7175-07

ITEM DESCRIPTION	QUANTITY		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL
Site Civil				
Excavation	26,844	CY	$16.00	$429,511
Stone Base	3,624	Ton	$33.00	$119,592
5' x 8' RCBC	3,775	LF	$900.00	$3,397,500
Fill	18,211	CY	$20.00	$364,218
Grass Seeding	13,422	SY	$1.25	$16,778
Utility Relocation	1	EA	$250,000	$250,000
Navy Traffic Reroute	1	LS	$250,000	$250,000
Road Raise	600	LF	$450	$270,000
Pump Station				
Precast Concrete Enclosure for Generator	1	EA	$450,000.00	$450,000
60 Inch Pump	3	EA	$1,380,000	$4,140,000
Concrete Headwall	2	EA	$80,000.00	$160,000
Support Structure - piles, header, rods, etc.	1	EA	$28,000.00	$28,000
Flap Gates	3	EA	$24,000.00	$72,000
Miscellaneous Pipe Section	3	EA	$8,000.00	$24,000
Special Concrete Transitition	1	EA	$30,000.00	$30,000
Electrical				
Dominion Power Installation Costs	1	LS	$100,000.00	$100,000
Common Costs				
Line Truck	20	DY	$283.25	$5,665
Backhoe	10	DY	$395.52	$3,955
Scissors Lift	40	DY	$265.20	$10,608
Site Work				
Trench & Backfill	400	LF	$1.96	$784
Pole, Foundation & Flood It	6	EA	$1,223.02	$7,338
Quasite Handhole	3	EA	$607.04	$1,821
Power				
Switchboard	1	LS	$74,231.00	$74,231
400A 208V service panel W/MCB	1	EA	$4,475.00	$4,475
100A 30ckt 208v 3 phase panel	6	EA	$2,090.00	$12,540
225A 42 ckt 208v 3 phase panel	2	EA	$3,400.00	$6,800
100-225A 3P 208v CB	4	EA	$998.00	$3,992
20A 1P 120v Circuit Breaker	42	EA	$53.30	$2,239
Surge Arrestor (SPD) 208V 10-Mode NEMA 4x box	2	EA	$9,849.00	$19,698
4" GRS Conduit	1500	LF	$49.80	$74,700
3/4" GRS Conduit	2500	LF	$7.93	$19,825

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION City of Norfolk Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
PROJECT TITLE **Alternative 2 - Mason Creek Box Culvert, 2 - 60" Dia. Pumps**	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

ITEM DESCRIPTION	QUANTITY		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL
1/2" GRS Conduit	5000	LF	$7.14	$35,700
4" GRS Fittings	100	EA	$455.00	$45,500
3/4" GRS Fittings	200	EA	$42.95	$8,590
1/2" GRS Fittings	200	EA	$35.45	$7,090
# 500 kcmil XHHW	7500	LF	$14.10	$105,750
#4/0 AWG THWN	1500	LF	$6.86	$10,290
#8 THWN Copper	1500	LF	$0.91	$1,365
#12 THWN Copper	25000	LF	$0.50	$12,500
# 500 kcmil cable connector	18	EA	$160.00	$2,880
GFI Receptacle W/ Box & Cover	25	EA	$107.09	$2,677
Duplex recptacle W/box & cover	80	EA	$60.82	$4,866
Motor Connection	3	EA	$9,203.13	$27,609
VFD Drive	3	EA	$150,000.00	$450,000
2500 KW Standby Generator - natural gas	2	EA	$1,245,875.00	$2,491,750
Paralleling Switchgear	1	LS	$429,800.00	$429,800
150 KVA Dry Transformer	1	EA	$15,452.00	$15,452
30kVA UPS owner purchase (including commission	1	EA	$40,000.00	$40,000
Annunciator	1	LS	$14,200.00	$14,200
Insurance & Taxes for Electrical	1	LS	$159,404.00	$159,404
Sales Tax for Electrical	1	LS	$173,859.00	$173,859
Subtotal				**$14,389,552**
Overhead & Profit	15%			$2,158,433
Mobilization/Demobilization	10%			$1,438,955
Erosion/Sediment Control	1%			$143,896
Traffic Control	1%			$143,896
Surveying/Engineering/Construction Observation	12%			$1,726,746
Subtotal with Mark-ups				**$20,001,477**
Contingency	25%			$5,000,369
TOTAL				**$25,001,846**

SAY $25,100,000

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY	CATEGORY CODE NUMBER
Alternative 3 - Mason Creek Box Culvert, 4 - 60" Dia. Pumps	Moffatt & Nichol	
	STATUS OF DESIGN	JOB ORDER NUMBER
	Conceptual	7175-07

ITEM DESCRIPTION	QUANTITY		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL
Site Civil				
Excavation	35,793	CY	$16.00	$572,681
Stone Base	5,436	Ton	$33.00	$179,388
5' x 8' RCBC	7,550	LF	$900.00	$6,795,000
Fill	18,525	CY	$20.00	$370,509
Grass Seeding	16,778	SY	$1.25	$20,972
Utility Relocation	1	EA	$250,000	$250,000
Navy Traffic Reroute	1	LS	$250,000	$250,000
Road Raise	600	LF	$450	$270,000
Pump Station				
Precast Concrete Enclosure for Generator	1	EA	$450,000.00	$450,000
60 Inch Pump	5	EA	$1,380,000	$6,900,000
Concrete Headwall	2	EA	$80,000.00	$160,000
Support Structure - piles, header, rods, etc.	2	EA	$28,000.00	$56,000
Flap Gates	2	EA	$28,000.00	$56,000
Miscellaneous Pipe Section	2	EA	$8,000.00	$16,000
Special Concrete Transitition	2	EA	$30,000.00	$60,000
Operating Cost Per Service Life				
Electrical				
Dominion Power Installation Costs	1	LS	$150,000.00	$150,000
Common Costs				
Line Truck	40	DY	$283.25	$11,330
Backhoe	25	DY	$395.52	$9,888
Scissors Lift	80	DY	$265.20	$21,216
Site Work				
Trench & Backfill	400	LF	$1.96	$784
Pole, Foundation & Flood It	12	EA	$1,223.02	$14,676
Quasite Handhole	3	EA	$607.04	$1,821
Power				
Switchboard	3	LS	$74,231.00	$222,693
400A 208V service panel W/MCB	2	EA	$4,475.00	$8,950
100A 30ckt 208v 3 phase panel	6	EA	$2,090.00	$12,540
225A 42 ckt 208v 3 phase panel	2	EA	$3,400.00	$6,800
100-225A 3P 208v CB	4	EA	$998.00	$3,992
20A 1P 120v Circuit Breaker	42	EA	$53.30	$2,239
Surge Arrestor (SPD) 208V 10-Mode NEMA 4x	2	EA	$9,849.00	$19,698

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 3 - Mason Creek Box Culvert, 4 - 60" Dia. Pumps	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

ITEM DESCRIPTION	QUANTITY		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL
4" GRS Conduit	1500	LF	$49.80	$74,700
3/4" GRS Conduit	2500	LF	$7.93	$19,825
1/2" GRS Conduit	5000	LF	$7.14	$35,700
4" GRS Fittings	100	EA	$455.00	$45,500
3/4" GRS Fittings	200	EA	$42.95	$8,590
1/2" GRS Fittings	200	EA	$35.45	$7,090
# 500 kcmil XHHW	7500	LF	$14.10	$105,750
#4/0 AWG THWN	1500	LF	$6.86	$10,290
#8 THWN Copper	1500	LF	$0.91	$1,365
#12 THWN Copper	25000	LF	$0.50	$12,500
# 500 kcmil cable connector	18	EA	$160.00	$2,880
GFI Receptacle W/ Box & Cover	25	EA	$107.09	$2,677
Duplex recptacle W/box & cover	80	EA	$60.82	$4,866
Motor Connection	5	EA	$9,203.13	$46,016
VFD Drive	5	EA	$150,000.00	$750,000
2500 KW Standby Generator - natural gas	4	EA	$1,245,875.00	$4,983,500
Paralleling Switchgear	2	LS	$429,800.00	$859,600
150 KVA Dry Transformer	1	EA	$15,452.00	$15,452
30kVA UPS owner purchase (including commi	2	EA	$40,000.00	$80,000
Annunciator	1	LS	$14,200.00	$14,200
Insurance & Taxes for Electrical	1	LS	$253,759.00	$253,759
Sales Tax for Electrical	1	LS	$331,342.00	$331,342
Subtotal				**$24,558,779**
Overhead & Profit	15%			$3,683,817
Mobilization/Demobilization	10%			$2,455,878
Erosion/Sediment Control	2%			$491,176
Traffic Control	1%			$245,588
Surveying/Engineering/Construction Observati	12%			$2,947,054
Subtotal with Mark-ups				**$34,382,291**
Contingency	25%			$8,595,573
TOTAL				**$42,977,864**

SAY $43,000,000

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 4 - Mason Creek Box Culvert, 4 - 96" Dia. Pumps	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

ITEM DESCRIPTION	QUANTITY		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL
Site Civil				
Excavation	35,793	CY	$16.00	$572,681
Stone Base	5,436	Ton	$33.00	$179,388
5' x 8' RCBC	7,550	LF	$900.00	$6,795,000
Fill	18,525	CY	$20.00	$370,509
Grass Seeding	16,778	SY	$1.25	$20,972
Utility Relocation	1	EA	$250,000	$250,000
Navy Traffic Reroute	1	LS	$250,000	$250,000
Road Raise	600	LF	$450	$270,000
Pump Station				
Precast Concrete Enclosure for Generator	1	EA	$450,000.00	$450,000
96 inch Pump	5	EA	$3,950,000.00	$19,750,000
Concrete Headwall	2	EA	$80,000.00	$160,000
Support Structure - piles, header, rods, etc.	2	EA	$28,000.00	$56,000
Flap Gates	2	EA	$28,000.00	$56,000
Miscellaneous Pipe Section	2	EA	$8,000.00	$16,000
Special Concrete Transitition	2	EA	$40,000.00	$80,000
Electrical				
Dominion Power Installation Costs	1	LS	$500,000.00	$500,000
Common Costs				
Line Truck	40	DY	$283.25	$11,330
Backhoe	25	DY	$395.52	$9,888
Scissors Lift	80	DY	$265.20	$21,216
Site Work				
Trench & Backfill	400	LF	$1.96	$784
Pole, Foundation & Flood It	12	EA	$1,223.02	$14,676
Quasite Handhole	3	EA	$607.04	$1,821
Power				
Switchboard	5	LS	$74,231.00	$371,155
400A 208V service panel W/MCB	2	EA	$4,475.00	$8,950
100A 30ckt 208v 3 phase panel	6	EA	$2,090.00	$12,540
225A 42 ckt 208v 3 phase panel	2	EA	$3,400.00	$6,800
100-225A 3P 208v CB	4	EA	$998.00	$3,992
20A 1P 120v Circuit Breaker	42	EA	$53.30	$2,239
Surge Arrestor (SPD) 208V 10-Mode NEMA 4x box	2	EA	$9,849.00	$19,698
4" GRS Conduit	1500	LF	$49.80	$74,700

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
17-Jan-11

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
City of Norfolk Norfolk, Virginia		
PROJECT TITLE	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
Alternative 4 - Mason Creek Box Culvert, 4 - 96" Dia. Pumps	STATUS OF DESIGN Conceptual	JOB ORDER NUMBER 7175-07

ITEM DESCRIPTION	QUANTITY		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL
3/4" GRS Conduit	2500	LF	$7.93	$19,825
1/2" GRS Conduit	5000	LF	$7.14	$35,700
4" GRS Fittings	100	EA	$455.00	$45,500
3/4" GRS Fittings	200	EA	$42.95	$8,590
1/2" GRS Fittings	200	EA	$35.45	$7,090
# 500 kcmil XHHW	7500	LF	$14.10	$105,750
#4/0 AWG THWN	1500	LF	$6.86	$10,290
#8 THWN Copper	1500	LF	$0.91	$1,365
#12 THWN Copper	25000	LF	$0.50	$12,500
# 500 kcmil cable connector	18	EA	$160.00	$2,880
GFI Receptacle W/ Box & Cover	25	EA	$107.09	$2,677
Duplex recptacle W/box & cover	80	EA	$60.82	$4,866
Motor Connection	5	EA	$9,203.13	$46,016
VFD Drive	5	EA	$275,000.00	$1,375,000
2500 KW Standby Generator - natural gas	4	EA	$1,951,750.00	$7,807,000
Paralleling Switchgear	4	LS	$631,800.00	$2,527,200
150 KVA Dry Transformer	1	EA	$15,452.00	$15,452
30kVA UPS owner purchase (including commissionin	2	EA	$40,000.00	$80,000
Annunciator	1	LS	$14,200.00	$14,200
Insurance & Taxes for Electrical	1	LS	$413,744.00	$413,744
Sales Tax for Electrical	1	LS	$595,303.00	$595,303
Subtotal				**$43,467,287**
Overhead & Profit	15%			$6,520,093
Mobilization/Demobilization	10%			$4,346,729
Erosion/Sediment Control	1%			$434,673
Traffic Control	1%			$434,673
Surveying/Engineering/Construction Observation	12%			$5,216,074
Subtotal with Mark-ups				**$60,419,530**
Contingency	25%			$15,104,882
TOTAL				**$75,524,412**

SAY $76,000,000

MASON CREEK: Preliminary Buy Out Option

Scenario: Existing Conditions Properties that Reach th Existing Conditions (Damages Reported in Dollars)

Event	Number of Properties with Damages Worth 10% of Building Value	Total Value of Properties	Number of Buildings with Damages Remaining After Buyout	Avoided Damage of Buildings	Damage of Buildings Remaining
1-yr / 1-yr		0	0	0	0
2-yr / 2-yr		0	0	0	0
10-yr / 10-yr	2	1,767,800	35	46,588	53,303
25-yr / 25-yr		26,873,800	52	66,786	96,758
50-yr / 50-yr		27,539,300	55	78,870	135,251
100-yr / 100-yr		29,713,000	62	88,585	196,045

Propery Costs	$	1,767,800.00
Demolition (25%)	$	441,950.00
Legal/Process (10%)	$	176,780.00
Reconstruction/Cleanup (20%)	$	353,560.00
Contingency (20%)	$	353,560.00
Total Buy-Out Costs	$	3,093,650.00

moffatt & nichol

Opinion of Probable Cost

DATE PREPARED
7-Dec-10

ACTIVITY AND LOCATION

CONSTRUCTION CONTRAC IDENTIFICATION NUMBE

ESTIMATED BY
Moffatt & Nichol

CATEGORY CODE NUMB

PROJECT TITLE
Mason Creek - Culvert & Pumpstation with 2 - 60" Pumps
Operational & Maintenance Costs (Anticipated Service Life of 50 Years)

STATUS OF DESIGN

JOB ORDER NUMBER

	Quantities	Price	Unit	Total Price
Culvert				
Inspections (Completed Every 5 Years)	10	$125,000	EACH	$1,250,000.00
Minor Repairs (Years 15, 35, 45)	3	$250,000	EACH	$750,000.00
Major Repairs (Years 25 & 40)	2	$750,000	EACH	$1,500,000.00
Operational Cost per Event (8 Events per Year)	400	$500	EACH	$200,000.00
Pump Station				
Maintenance Cost Per Generator Per Year (2 Gen Sets)	100	$2,000	EACH	$200,000.00
Operational Cost for Generator Per Event (Once Every 5 Yr)	20	$40,000	EACH	$800,000.00
Maintenance Cost Per Pump (Per Year Per Pump)	100	$40,000	EACH	$4,000,000.00
Replacement of Pumps (Year 30)	2	$690,000	EACH	$1,380,000.00
Operational Cost per Pump Per Event Per Pump Per Year	100	$785	EACH	$78,500.00
Operation Cost (City Employees - 2 Employees per Event)	19200	$25	HOUR	$480,000.00
Total				$10,638,500.00

APPENDIX D

DRAFT

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 2-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 2-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 2-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$0	$0	$0		
0.100	10		$0					
		0.06		$0	$0	$0		
0.040	25		$0					
		0.02		$0	$0	$0	7.00%	INTEREST RATE
0.020	50		$0				50	YEARS
		0.01		$0	$0	$0	$0	PRESENT WORTH
0.010	100		$0					

$1,100,000 PRESENT WORTH PROJECT COST

$22,000 ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

$303,616 PRESENT WORTH O&M COSTS

$1,403,616 PRESENT WORTH TOTAL PROJECT COST

0.000 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 10-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 10-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$0	$0	$0		
0.100	10		$0					
		0.06		$81,772	$4,906	$4,906		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$8,683	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$11,177	$154,247	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 10-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$49,946	$2,997	$22,975		
0.040	25		$0					
		0.02		$0	$0	$22,975	7.00%	INTEREST RATE
0.020	50		$0				50	YEARS
		0.01		$0	$0	$22,975	$317,071	PRESENT WORTH
0.010	100		$0					

$15,700,000	PRESENT WORTH PROJECT COST	$314,000	ANNUAL OPERATION & MAINTENANCE (O&M) COSTS
$4,333,434	PRESENT WORTH O&M COSTS	$20,033,434	PRESENT WORTH TOTAL PROJECT COST

0.016 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 25-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 25-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$0	$0	$0		
0.100	10		$0					
		0.06		$0	$0	$0		
0.040	25		$0					
		0.02		$107,060	$2,141	$2,141	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$4,635	$63,966	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 25-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$81,772	$1,635	$29,517	7.00%	INTEREST RATE
0.020	50		$0				50	YEARS
		0.01		$0	$0	$29,517	$407,352	PRESENT WORTH
0.010	100		$0					

$16,500,000 PRESENT WORTH PROJECT COST

$330,000 ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

$4,554,246 PRESENT WORTH O&M COSTS

$21,054,246 PRESENT WORTH TOTAL PROJECT COST

0.019 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 50-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 50-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$0	$0	$0		
0.100	10		$0					
		0.06		$0	$0	$0		
0.040	25		$0					
		0.02		$0	$0	$0	7.00%	INTEREST RATE
0.020	50		$0				50	YEARS
		0.01		$142,315	$1,423	$1,423	$19,641	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 50-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	EXPECTED ANNUAL BENEFITS SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$107,060	$1,071	$32,728	$451,678	PRESENT WORTH
0.010	100		$0					

$21,600,000	PRESENT WORTH PROJECT COST	$432,000	ANNUAL OPERATION & MAINTENANCE (O&M) COSTS
$5,961,922	PRESENT WORTH O&M COSTS	$27,561,922	PRESENT WORTH TOTAL PROJECT COST

0.016 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 100-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 100-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$0	$0	$0		
0.100	10		$0					
		0.06		$0	$0	$0		
0.040	25		$0					
		0.02		$0	$0	$0	7.00%	INTEREST RATE
0.020	50		$0				50	YEARS
		0.01		$0	$0	$0	$0	PRESENT WORTH
0.010	100		$0					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 100-yr Bulkhead - SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	EXPECTED ANNUAL BENEFITS SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					

$22,500,000 PRESENT WORTH PROJECT COST

$450,000 ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

$6,210,336 PRESENT WORTH O&M COSTS

$28,710,336 PRESENT WORTH TOTAL PROJECT COST

0.016 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 2-60" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 2-60" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$0	$0	$0		
0.100	10		$0					
		0.06		$0	$0	$0		
0.040	25		$0					
		0.02		$0	$0	$0	7.00%	INTEREST RATE
0.020	50		$0				50	YEARS
		0.01		$5,644	$56	$56	$779	PRESENT WORTH
0.010	100		$11,287					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 2-60" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	EXPECTED ANNUAL BENEFITS SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$243,732	$2,437	$34,095	$470,539	PRESENT WORTH
0.010	100		$273,343					

$25,100,000 PRESENT WORTH PROJECT COST

$138,770 ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

$1,915,130 PRESENT WORTH O&M COSTS

$27,015,130 PRESENT WORTH TOTAL PROJECT COST

0.017 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 4-60" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 4-60" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$0	$0	$0		
0.100	10		$0					
		0.06		$0	$0	$0		
0.040	25		$0					
		0.02		$0	$0	$0	7.00%	INTEREST RATE
0.020	50		$0				50	YEARS
		0.01		$0	$0	$0	$0	PRESENT WORTH
0.010	100		$0					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 4-60" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	EXPECTED ANNUAL BENEFITS SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					

$43,000,000 PRESENT WORTH PROJECT COST

$267,940 ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

$3,697,772 PRESENT WORTH O&M COSTS

$46,697,772 PRESENT WORTH TOTAL PROJECT COST

0.010 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 4-96" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 4-96" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$0	$0	$0		
0.100	10		$0					
		0.06		$0	$0	$0		
0.040	25		$0					
		0.02		$0	$0	$0	7.00%	INTEREST RATE
0.020	50		$0				50	YEARS
		0.01		$0	$0	$0	$0	PRESENT WORTH
0.010	100		$0					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 4-96" PUMPS - SURGE_100yr
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	EXPECTED ANNUAL BENEFITS SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					

$76,000,000 PRESENT WORTH PROJECT COST

$372,580 ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

$5,141,882 PRESENT WORTH O&M COSTS

$81,141,882 PRESENT WORTH TOTAL PROJECT COST

0.006 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 10yr Surge
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 10yr Surge
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$26,651	$10,661	$10,661		
0.100	10		$53,303					
		0.06		$75,030	$4,502	$15,162		
0.040	25		$96,758					
		0.02		$116,004	$2,320	$17,482	7.00%	INTEREST RATE
0.020	50		$135,251				50	YEARS
		0.01		$165,648	$1,656	$19,139	$264,132	PRESENT WORTH
0.010	100		$196,045					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 10yr Surge
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$23,294	$9,318	$9,318		
0.100	10		$46,588					
		0.06		$56,687	$3,401	$12,719		
0.040	25		$66,786					
		0.02		$72,828	$1,457	$14,175	7.00%	INTEREST RATE
0.020	50		$78,869				50	YEARS
		0.01		$83,727	$837	$15,013	$207,186	PRESENT WORTH
0.010	100		$88,585					

$3,093,650 PRESENT WORTH PROJECT COST

$34,030 ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

$469,641 PRESENT WORTH O&M COSTS

$3,563,291 PRESENT WORTH TOTAL PROJECT COST

0.058 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 25yr Surge
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 25yr Surge
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$6,072	$2,429	$2,429		
0.100	10		$12,145					
		0.06		$23,122	$1,387	$3,816		
0.040	25		$34,099					
		0.02		$42,332	$847	$4,663	7.00%	INTEREST RATE
0.020	50		$50,566				50	YEARS
		0.01		$71,579	$716	$5,379	$74,230	PRESENT WORTH
0.010	100		$92,593					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 25yr Surge
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$43,873	$17,549	$17,549		
0.100	10		$87,746					
		0.06		$108,596	$6,516	$24,065		
0.040	25		$129,445					
		0.02		$146,500	$2,930	$26,995	7.00%	INTEREST RATE
0.020	50		$163,554				50	YEARS
		0.01		$177,796	$1,778	$28,773	$397,088	PRESENT WORTH
0.010	100		$192,037					

$6,682,375	PRESENT WORTH PROJECT COST	$73,506	ANNUAL OPERATION & MAINTENANCE (O&M) COSTS
$1,014,439	PRESENT WORTH O&M COSTS	$7,696,814	PRESENT WORTH TOTAL PROJECT COST

0.052 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout 50-yr SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout 50-yr SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$6,072	$2,429	$2,429		
0.100	10		$12,145					
		0.06		$23,122	$1,387	$3,816		
0.040	25		$34,099					
		0.02		$42,332	$847	$4,663	7.00%	INTEREST RATE
0.020	50		$50,566				50	YEARS
		0.01		$71,579	$716	$5,379	$74,230	PRESENT WORTH
0.010	100		$92,593					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout 50-yr SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$43,873	$17,549	$17,549		
0.100	10		$87,746					
		0.06		$108,596	$6,516	$24,065		
0.040	25		$129,445					
		0.02		$146,500	$2,930	$26,995	7.00%	INTEREST RATE
0.020	50		$163,554				50	YEARS
		0.01		$177,796	$1,778	$28,773	$397,088	PRESENT WORTH
0.010	100		$192,037					

$6,682,375	PRESENT WORTH PROJECT COST	$73,506	ANNUAL OPERATION & MAINTENANCE (O&M) COSTS
$1,014,439	PRESENT WORTH O&M COSTS	$7,696,814	PRESENT WORTH TOTAL PROJECT COST

0.052 B/C RATIO

EXPECTED ANNUAL DAMAGES
EXISTING CONDITIONS

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 100 yr SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.40		$49,946	$19,978	$19,978		
0.100	10		$99,891					
		0.06		$131,718	$7,903	$27,881		
0.040	25		$163,544					
		0.02		$188,832	$3,777	$31,658	7.00%	INTEREST RATE
0.020	50		$214,120				50	YEARS
		0.01		$249,375	$2,494	$34,152	$471,318	PRESENT WORTH
0.010	100		$284,630					
		0.99						

EXPECTED ANNUAL DAMAGES
RESIDUAL DAMAGES WITH PROJECT

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 100 yr SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	DAMAGES	AVERAGE DAMAGES	EXPECTED ANNUAL DAMAGES INTERVAL	EXPECTED ANNUAL DAMAGES SUMMATION		
1.000	1		$0					
		0.50		$0	$0	$0		
0.500	2		$0					
		0.4		$2,632	$1,053	$1,053		
0.100	10		$5,265					
		0.06		$14,416	$865	$1,918		
0.040	25		$23,567					
		0.02		$30,272	$605	$2,523	7.00%	INTEREST RATE
0.020	50		$36,977				50	YEARS
		0.01		$55,639	$556	$3,080	$42,502	PRESENT WORTH
0.010	100		$74,301					
		0.99						

EXPECTED ANNUAL DAMAGES
NET BENEFITS

PROJECT: CITY OF NORFOLK - MASON CREEK - 5% Buyout - 100 yr SURGE
PROJ NO: DESIGNER: JDM DATE: 28-Apr-11

FREQUENCY %	RETURN PERIOD	INTERVAL	BENEFITS	AVERAGE BENEFITS	EXPECTED ANNUAL BENEFITS INTERVAL	EXPECTED ANNUAL BENEFITS SUMMATION		
0.990	1		$0					
		0.49		$0	$0	$0		
0.500	2		$0					
		0.4		$47,313	$18,925	$18,925		
0.100	10		$94,626					
		0.06		$117,302	$7,038	$25,963		
0.040	25		$139,977					
		0.02		$158,560	$3,171	$29,135	7.00%	INTEREST RATE
0.020	50		$177,143				50	YEARS
		0.01		$193,736	$1,937	$31,072	$428,816	PRESENT WORTH
0.010	100		$210,329					

$13,487,075 PRESENT WORTH PROJECT COST

$148,358 ANNUAL OPERATION & MAINTENANCE (O&M) COSTS

$2,047,449 PRESENT WORTH O&M COSTS

$15,534,524 PRESENT WORTH TOTAL PROJECT COST

0.028 B/C RATIO