WA2-18 Sea Level Rise and Water Supply Adaptation in Coastal Areas

MEMO NUMBER: 77500645-CBI-PL-CBI-000001	TITLE: Bridgeport, CT and Hampton, VA SLOSH Modeling Results
DISCIPLINE: SLOSH Modeling	ORIGINATOR: Zhifei Dong

PURPOSE:

This memorandum contains the details of the SLOSH modeling efforts for WA2-18.

The WA2-18 Sea Level Rise and Water Supply Adaptation in Coastal Areas study ran the SLOSH model at two locations (Bridgeport, CT and Hampton Road, Virginia) to determine the predicted storm surge for different categories of hurricanes and sea level rise scenarios. For Bridgeport CT, two wastewater treatment plants (WWTPs) were the primary interest. For Hampton Road VA, the study focused on three cities: Norfolk, Virginia Beach and Newport News. The same modeling techniques developed during a previous task (WA 04-11) was used for this study. Model inputs were based on previous studies and hurricane conditions. Primary inputs included a matrix of hurricane parameters extracted from NOAA's historical hurricane database.

1. SLOSH verification

SLOSH is best used for defining the potential flooding from storm surge for a location from a threatening hurricane, rather than as a predictor of the specific areas that will be inundated during a particular event. The SLOSH model does not have a calibration option. However, the SLOSH model can be verified using a historical storm. This model verification utilized the 1999 Hurricane Floyd for both locations. Hurricane Floyd was a category 4 hurricane with wind speeds up to 155 mph. Floyd's track passed both Virginia and Connecticut. NOAA tide gauges recorded water level changes during the hurricane. The track file was provided by National Weather Service (NWS). SLOSH model results for Hurricane Floyd were compared with the closest NOAA tide gauges. Two basins were used for each location to compare the grid effects on model results. For Bridgeport CT, SLOSH basins NY3 and PV2 were used for the model runs. For Hampton Road VA, SLOSH basins CP2 and CP5 were used for the model run.

1.1 Bridgeport, CT

The NY3 basin had 189 * 165 grid cells and was designed for SLOSH modeling for areas surrounding New York City. The PV2 basin had 183 * 280 grid cells and was designed for SLOSH modeling of Rhode Island and Massachusetts. Both basins covered Bridgeport with similar grid resolutions (Figure 1 and Figure 2). Bathymetry deeper than 999 feet was set as 999 feet. Topography higher than 99 feet was set as -99 feet.

NOAA tide gauge data were available at Bridgeport, New London and Montauk during the hurricane (Figure 3). Figure 4, Figure 5 and Figure 6 show the time series and surge elevation comparison between the SLOSH model predictions and the respective NOAA tide gauges. The comparison indicated that the SLOSH model successfully forecasted the peak surge magnitude. The forecast time of peak surge was later than the measured data by up to 5 hours. It is important to note that the SLOSH model was designed to forecast the maximum storm surge and not the time series of the storm surge. The NY3 and PV2 basins has similar results.

The NY3 basin was chosen for model production runs for the Bridgeport area because the PV2 basin has limited coverage landward and west of Bridgeport that can result in incorrect boundary effects on the model results.

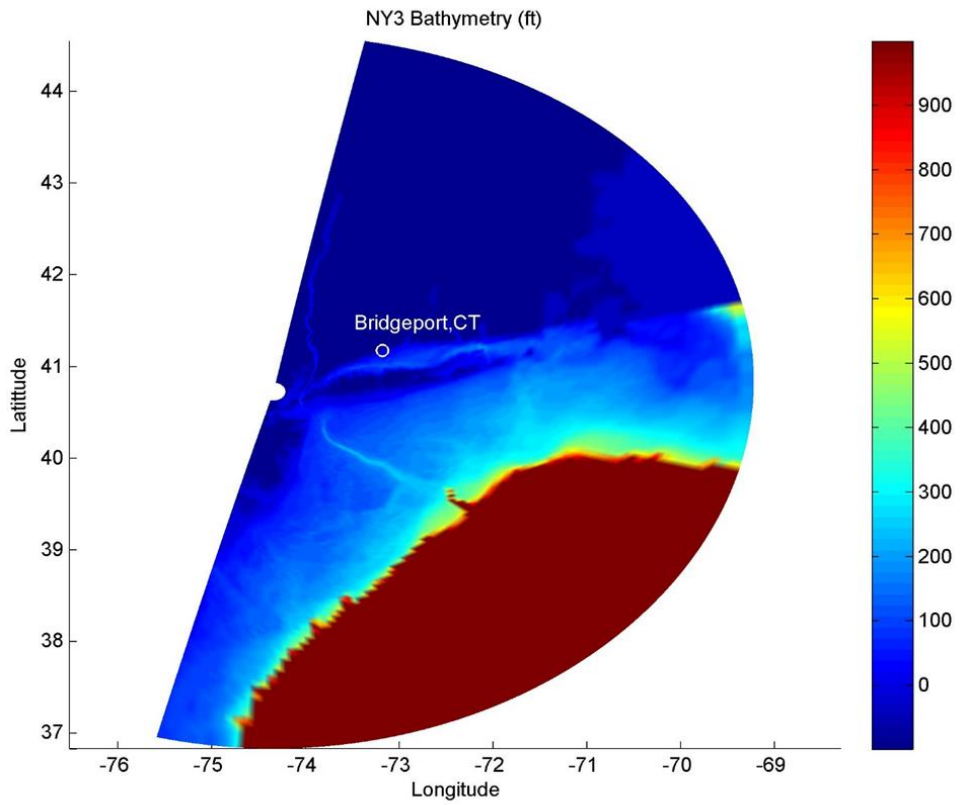


Figure 1. SLOSH basin NY3 bathymetry and topography. Blue is high (negative), red is low (positive).

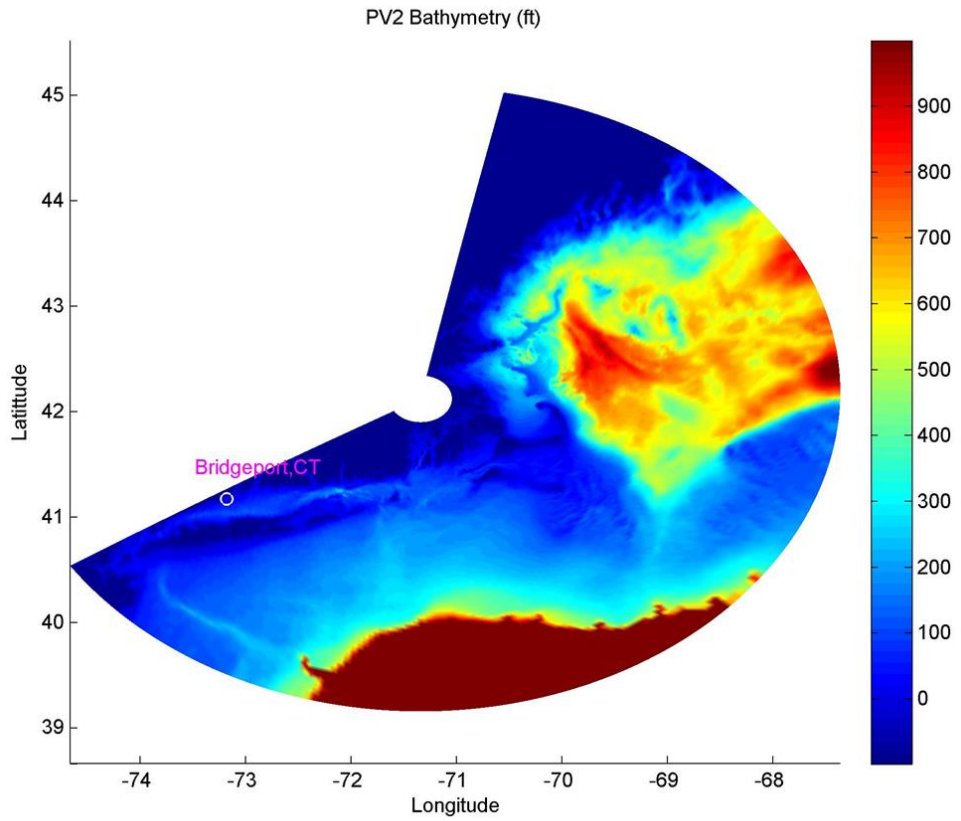


Figure 2. SLOSH basin PV2 bathymetry and topography. Blue is high (negative), red is low (positive).

Figure 3. NOAA tide stations near Bridgeport, CT.

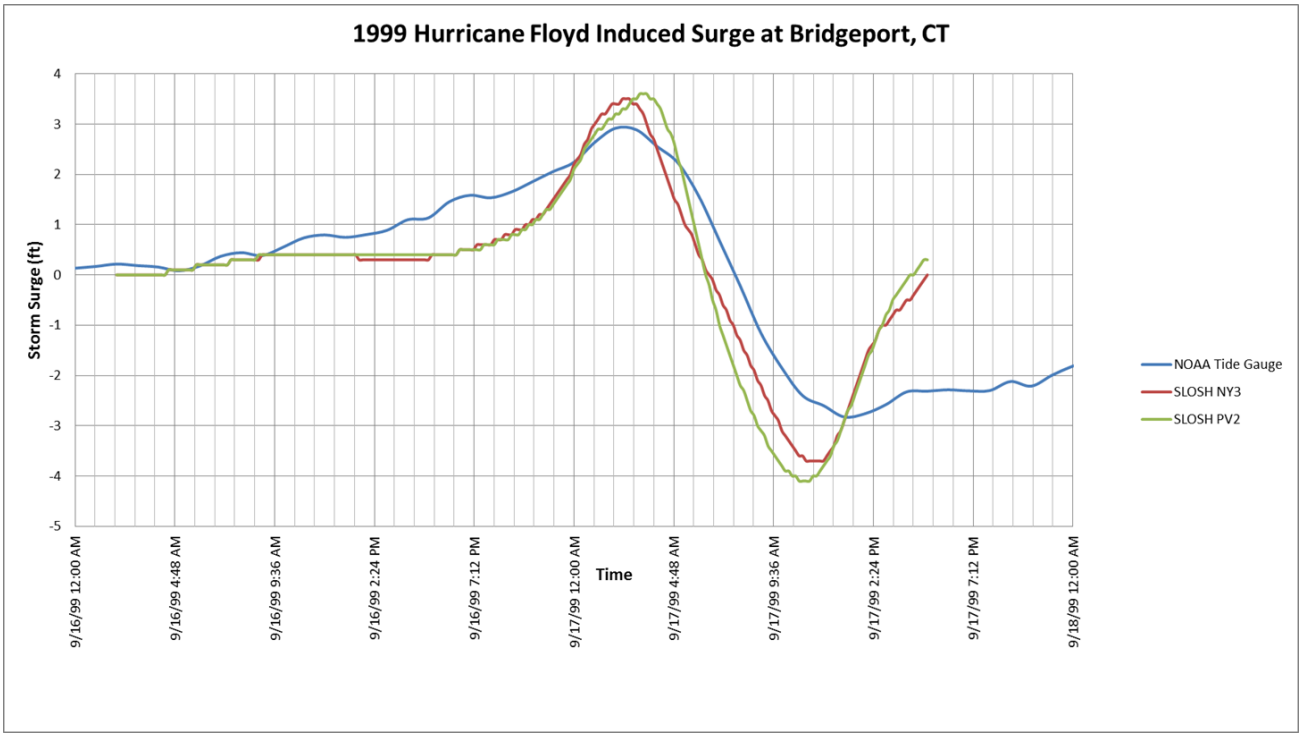


Figure 4. Water level measurements and SLOSH predictions for Hurricane Floyd at Bridgeport, CT.

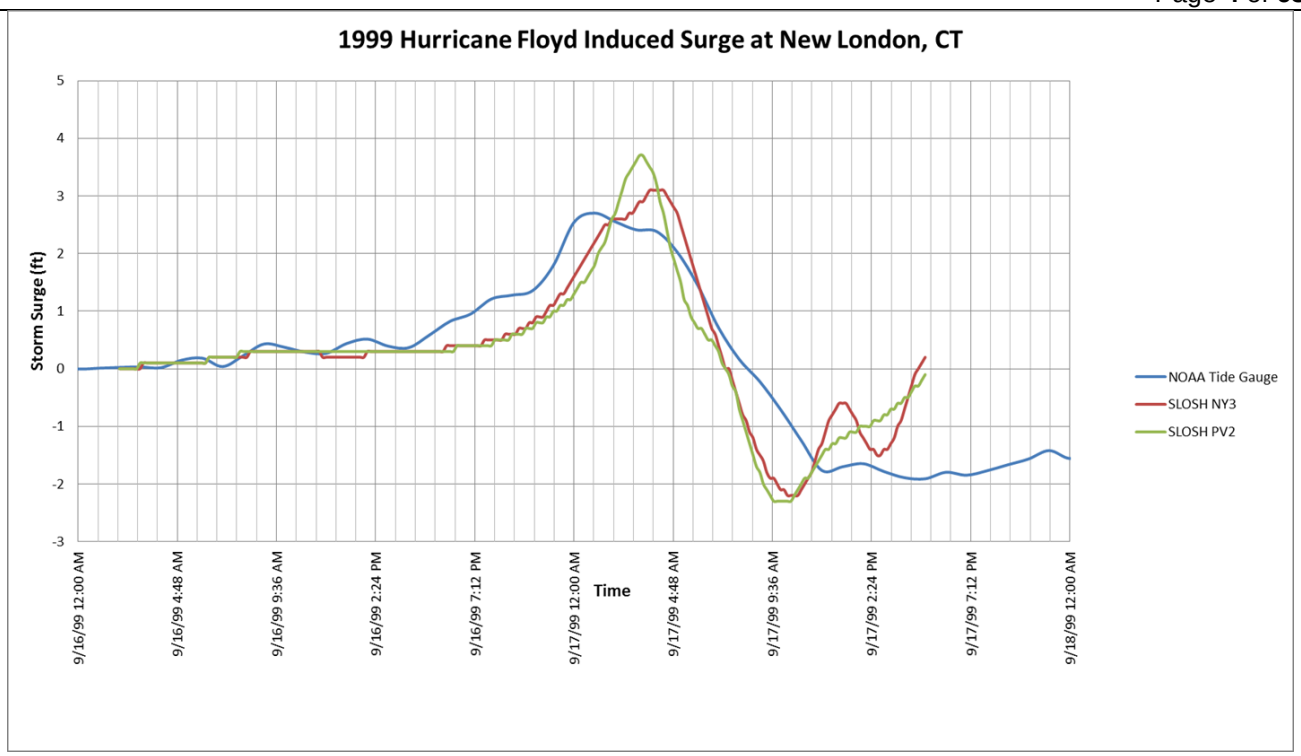


Figure 5. Water level measurements and SLOSH predictions for Hurricane Floyd at New London, CT.

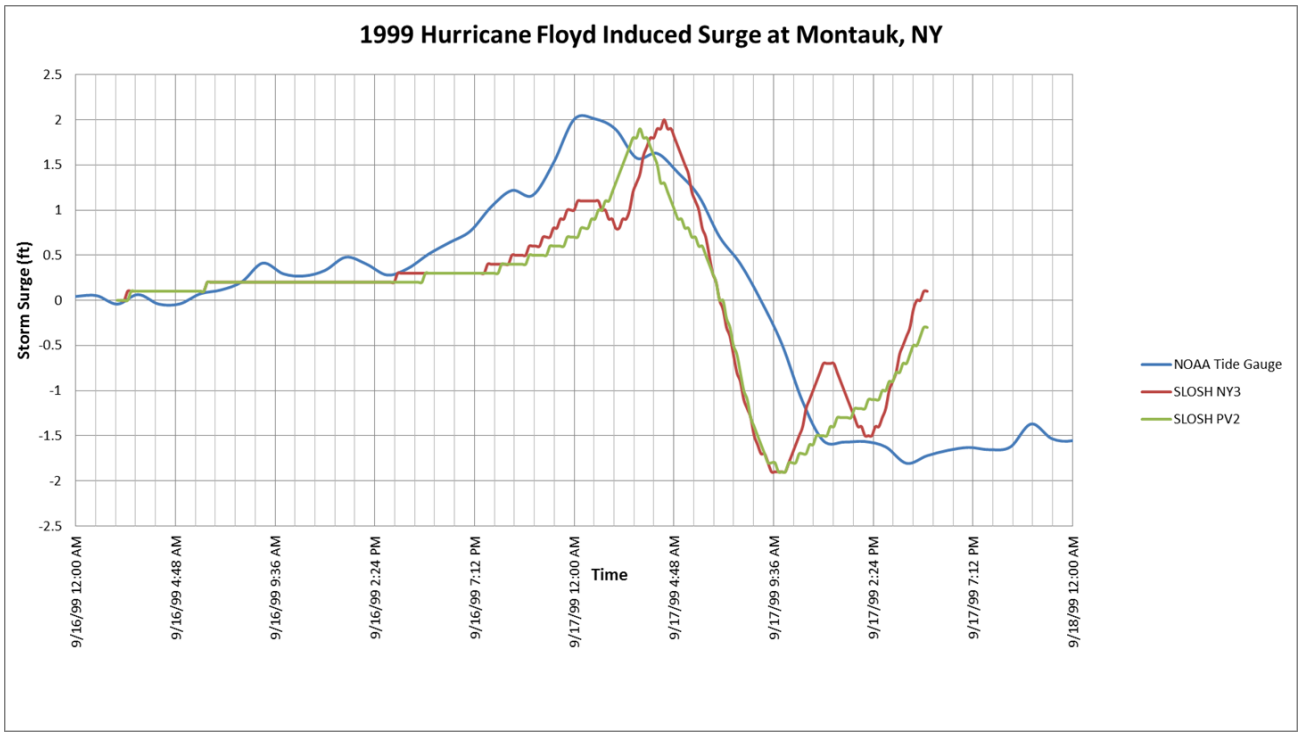


Figure 6. Water level measurements and SLOSH predictions for Hurricane Floyd at Montauk, NY

1.2 Hampton Road, VA

The CP2 basin had 79 * 84 grid cells which was a relatively coarse grid for Chesapeake Bay and allowed for quick runs (Figure 7). The CP5 basin had 481 * 524 grid cells which was a relatively fine grid for Chesapeake Bay and provided detailed runs (Figure 8). NOAA tide gauge data were available at Sewells Point, Chesapeake Bay Bridge Tunnel and Kiptopeke (Figure 9).

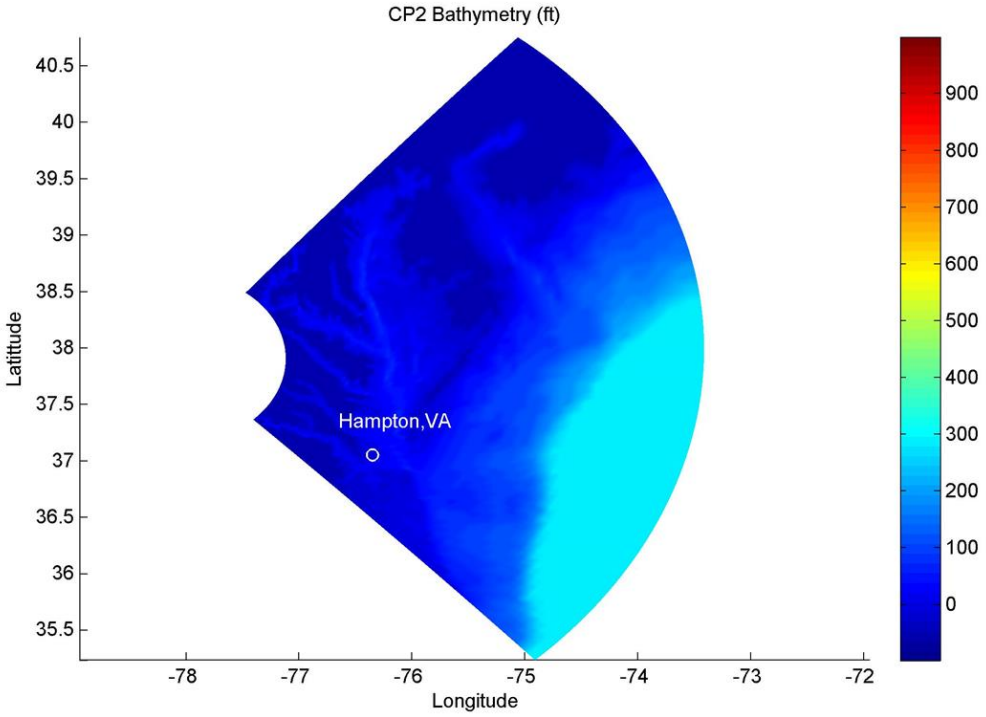


Figure 7. SLOSH basin CP2 bathymetry and topography. Blue is high (negative), red is low (positive).

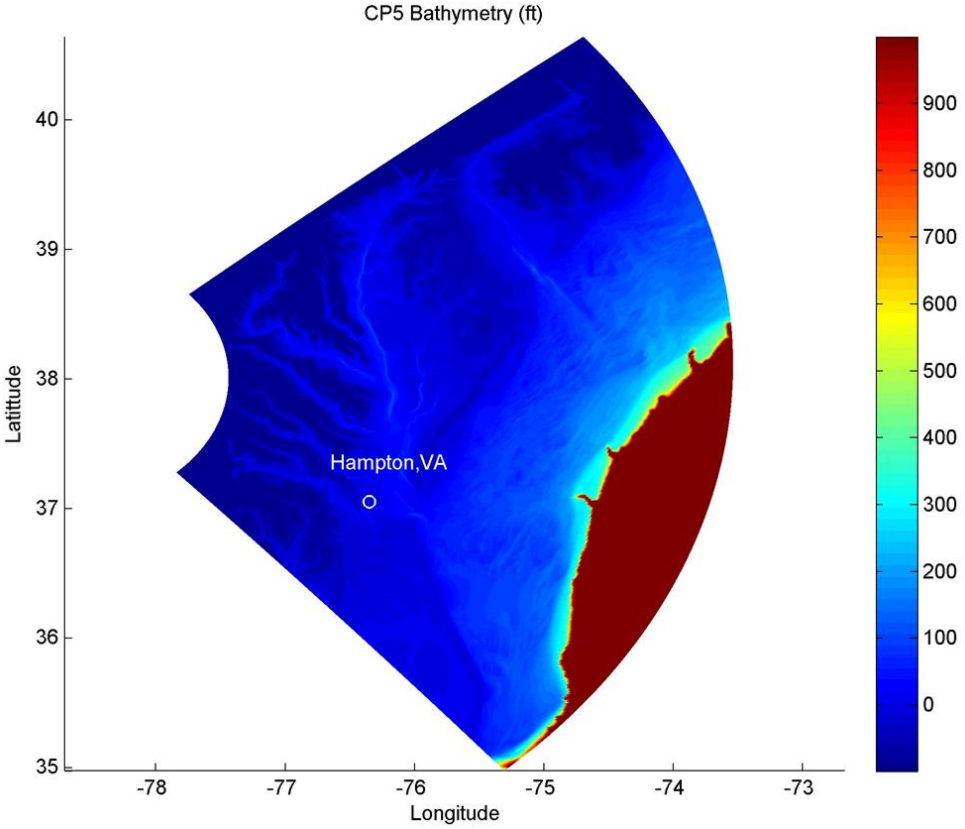


Figure 8. SLOSH basin CP5 bathymetry and topography. Blue is high (negative), red is low (positive).

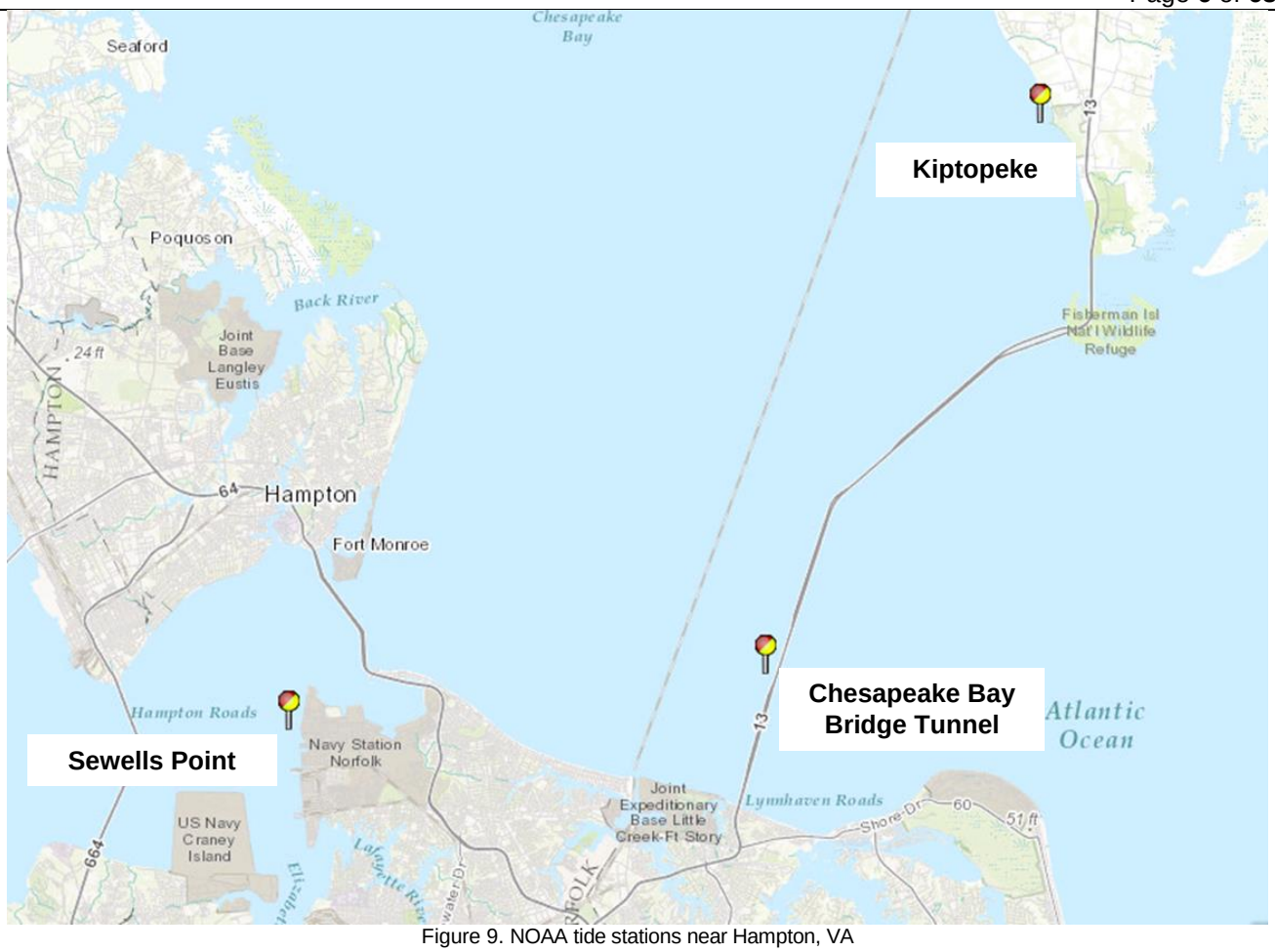


Figure 9. NOAA tide stations near Hampton, VA

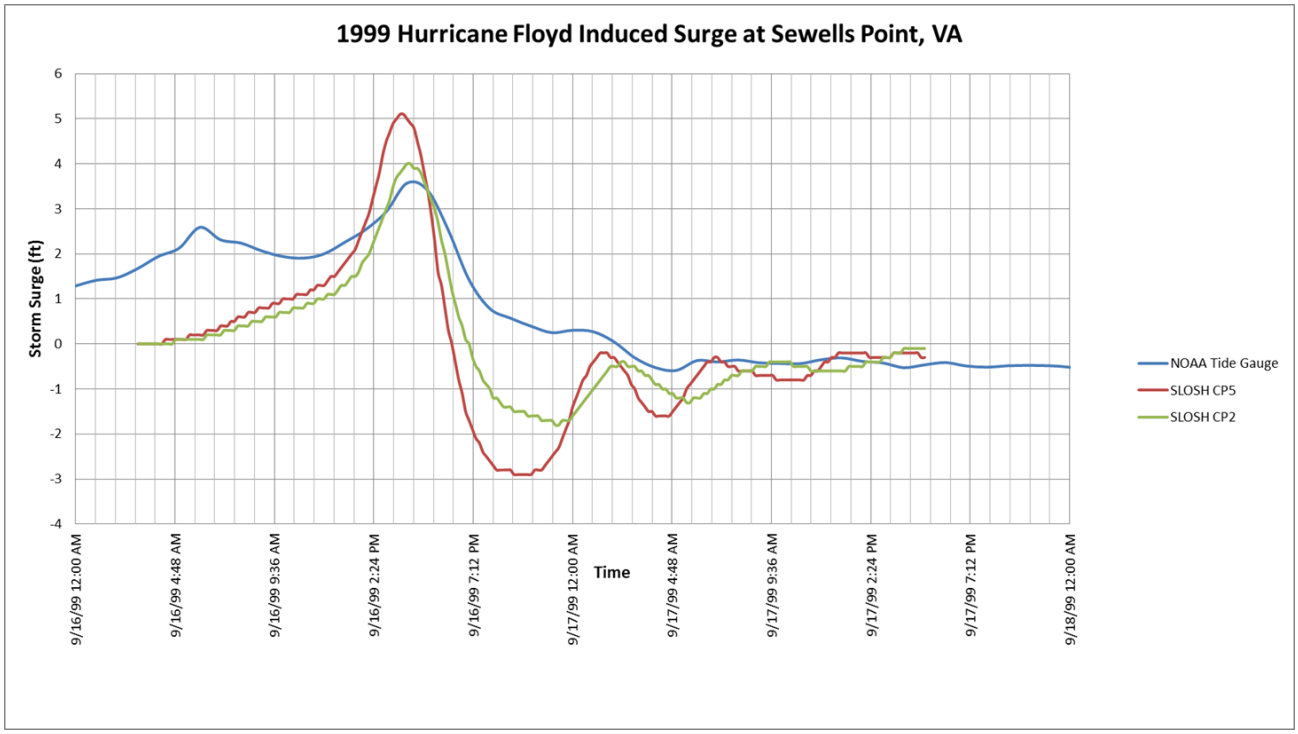


Figure 10. Water level measurements and SLOSH predictions for Hurricane Floyd at Sewells Point, VA

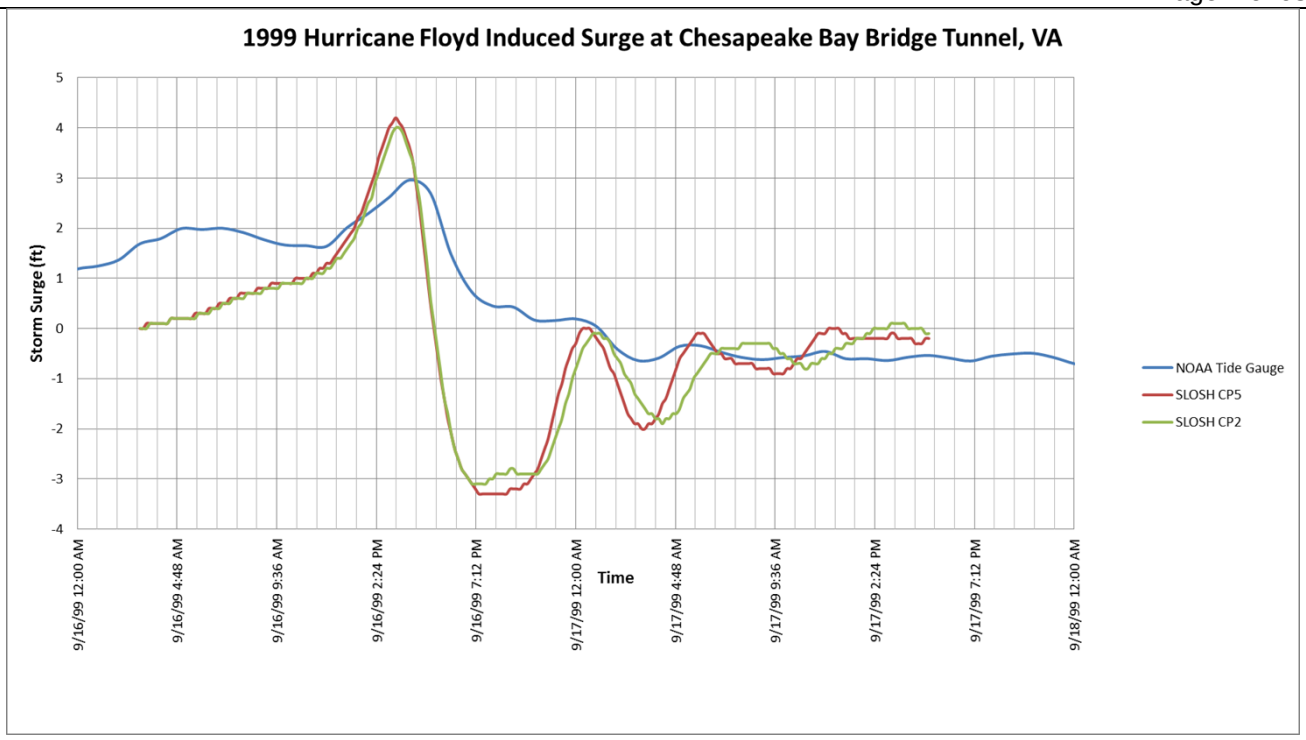


Figure 11. Water level measurements and SLOSH predictions for Hurricane Floyd at Chesapeake Bay Bridge Tunnel, VA

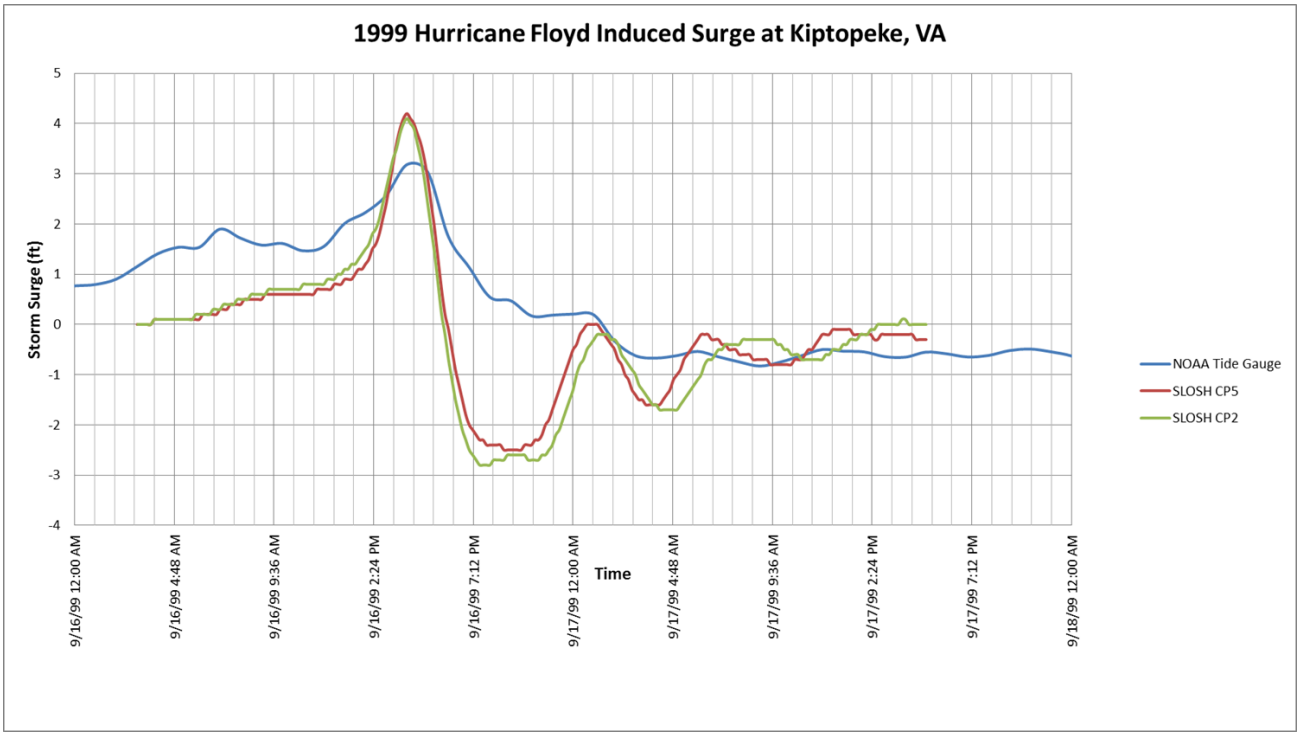


Figure 12. Water level measurements and SLOSH predictions for Hurricane Floyd at Kiptopeke, VA

Comparisons between the measured water levels and SLOSH estimates indicated that the SLOSH model overestimated the peak surge magnitude by up to 1.5 feet, while the forecast peak surge time was similar (Figure 10, Figure 11, Figure 12). Water level oscillations following peak surge in the SLOSH results were not captured in the measured data.

Causes for the differences were likely due to track resolution, basin resolution and complicated local bathymetry. SLOSH track files are limited to 100 points of storm information such as wind direction and speed for each model run. Since variation in storm parameters between each point is not interpolated, localized changes to storm conditions are not recognized. Complicated coastlines like Chesapeake Bay can cause a higher predicted surge due to the track line not dropping the storm's intensity as soon as the

storm interacts with the coastline. The study area's complicated bathymetry and shorelines are too fine to be adequately resolved by the SLOSH grid cells, especially near Sewells Point. SLOSH treats the water boundary as open water. For areas like Sewells Point, the actual area of water is less than the SLOSH basin, thus wind-driven surge will be higher in the model output.

The CP5 basin was selected for production runs at the Hampton Road area due to its finer grid resolution to maximize SLOSH's ability to predict surge given the area's complicated coastline and bathymetry.

2. Model Production Runs

The historical storms were reviewed to ensure that modeling runs included hurricane parameters that have occurred in the past (Table 1). Storms for both Bridgeport and Hampton Road areas were loaded and analyzed using the NOAA historical storm database. Most of the storms hit both Bridgeport and Hampton Road. Change in pressure (ΔP), radius of maximum winds (Rmax), maximum 1 minute velocities (Vmax), hurricane track speed (Speed), and track direction were tabulated.

Table 1. Historical Storms for the Bridgeport and Hampton Road Area

Name	ΔP (mb)	Rmax (mile)	1-min Vmax (knot)	Speed (mph)	Direction
1893 Unnamed	74	35	117	40	NNE - NE
1938 Unnamed	53	30	106	47	N - NNE
1944 Unnamed	73	57	104	48	NNW - N
1954 Carol	77	30	135	62	NNW - N
1960 Donna	46	32	91	33	NNE - NE
1972 Agnes	54	38	98	39	NNE - NE
1976 Belle	58	25	115	45	N - NNE
1985 Gloria	36	24	105	36	NNE - NE
1996 Bertha	56	48	88	31	NNE - NE
1998 Earl	39	39	81	33	NNE - NE
1999 Floyd	77	57	135	62	
2008 Hanna	36	24	81	31	

SLOSH modeling inputs were selected based on historical storms, predicted future winds and potential sea level rise scenarios (Table 2). Three landfall locations were chosen for each study area to simulate as many possibilities as possible and produce more reliable MOMs (Figure 13, Figure 14). One landfall location was chosen in the middle of the study area and the other two landfall locations were placed to the west and east. Pressure (5 combinations), radius of maximum wind (4 combinations), forward speed (3 combinations), and track directions (4 combinations) were based on the historical hurricanes as well as the forecast of GCM model results provided by the EPA research group. According to GCM model, the future wind and gust are estimated to increase 10% ~ 30% over historical observations. Four sea level rise scenarios (existing, 2 feet, 4 feet and 6 feet) were run based on the GCM model. The sea levels were set prior to the model run. Higher sea levels translated to further inland inundation prior to the model run depending on the land elevation. Two thousand one hundred and sixty SLOSH models were for each study area.

Table 2. SLOSH Model Inputs

Parameters	Values	Number of Variations
Landfall Location	3	3
Pressure (mb)	30, 50, 70, 90, 110	5
Radius of Maximum Wind (mi)	30, 45, 60	3
Forward Speed (mph)	20, 40, 60	3
Track Direction (degree)	NNW, N, NNE, NE	4
Sea Level Rise (ft)	0, 2, 4, 6	4
Total Number of Runs		2160

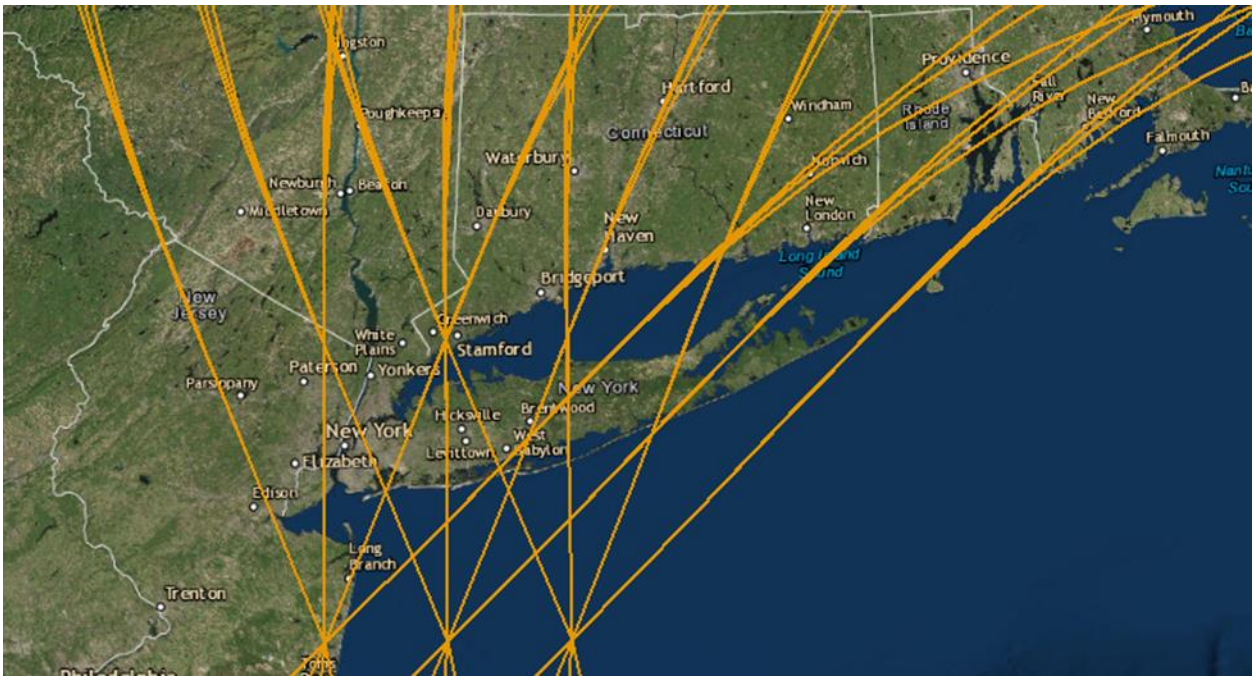


Figure 13. Hurricane tracks for Bridgeport, CT.

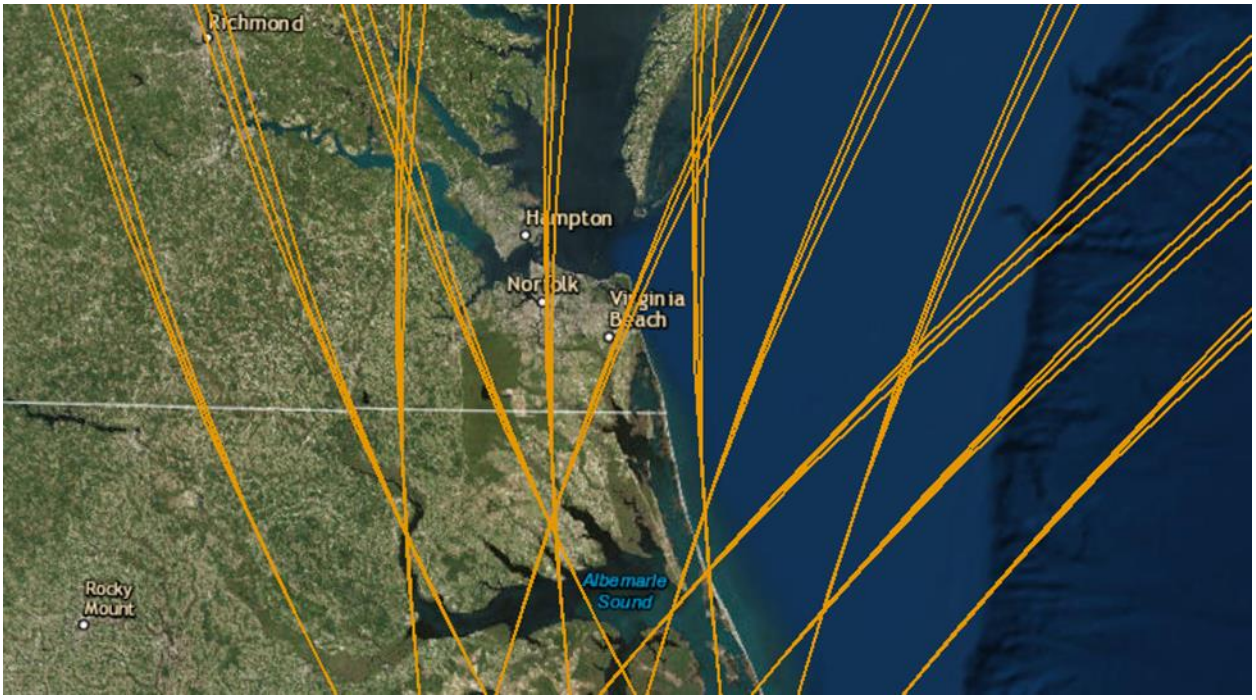


Figure 14. Hurricane tracks for Hampton Road, VA.

The SLOSH modeling runs were grouped based on sea level rise and relative hurricane categories by pressure difference. Hurricane categories 1, 2, 3, 4 and 5 represent pressures 30, 50, 70, 90 and 110, respectively. The maximum of maximum (MOMs) of each category and sea level was calculated based on the highest water elevation for each cell in the SLOSH basin. The five (5) hurricane categories and four (4) sea levels yielded 20 MOMs for each study area. The MOM surge predictions were then subtracted from land elevations derived from LiDAR data to generate flood maps.

Time series data of maximum values at specified locations were also extracted from the SLOSH results. For the Bridgeport area, two locations were selected for time series plots: west side of WWTPs and east Side of WWTPs (Figure 15). For the Hampton Road area, four locations were selected for time series plots: Town Point Park at Norfolk, Fort Monroe at Hampton, Mulberry Island at Newport News and North Bay at Virginia Beach (Figure 16).

Figure 15. Time series for two locations at Bridgeport, CT.

Figure 16. Time series for four locations at Hampton Road, VA.

3. Results

SLOSH modeling outputs were attached to this memorandum as Appendix A and Appendix B. In Appendix A-1, figures show the maximum of maximum (MOM) predicted flooding height for their respective hurricane category and sea level rise at Bridgeport, CT. The MOM flood elevations were differenced from the 2012 post Hurricane Sandy LiDAR data collected by USGS for the State of Connecticut. In Appendix A-2, figures show the flood map for Hampton Road, VA. The MOM flood elevations were differenced from the 2013 LIDAR data collected by USGS for Norfolk, Virginia. Time series of maximum surge at east side WWTPs and west side WWTPs at Bridgeport were attached in Appendix B-1. Time series of maximum surge at Norfolk, Hampton, Newport News and Virginia Beach were attached in Appendix B-2.

4. Discussion

The SLOSH model verification using 1999 Hurricane Floyd indicated that the SLOSH model successfully forecasted the peak surge magnitude during the hurricane. However, differences in peak surge value and time series were likely due to resolution of the hurricane track, complicated localized shorelines and bathymetry, and grid resolution. SLOSH was designed to estimate the worst potential storm surge flooding caused by multiple hurricane scenarios as opposed to predicting flood inundation at specific location for a single event.

The comparison of model results for each hurricane category and sea level rise scenario at Bridgeport indicated that storm surge heights at the west and east side wastewater treatment plants (WWTP) were similar. The 2012 LIDAR data indicated that the elevation of east side WWTP ranged from 7.2 feet NAVD to 8.9 feet NAVD. At current sea levels, the east side WWTP will likely flood during a category 3 hurricane or higher. The elevation of west side WWTP ranges from 9.2 feet NAVD to 14.7 feet NAVD. At current sea levels, the west side WWTP will likely flood by a category 4 hurricane or higher. The probability of flooding at both WWTP sites increase with increase sea levels.

SLOSH model results at Hampton Road illustrate that Hampton and Virginia Beach were more vulnerable to storm surge due to the relatively low topography and their location adjacent to open ocean. Newport

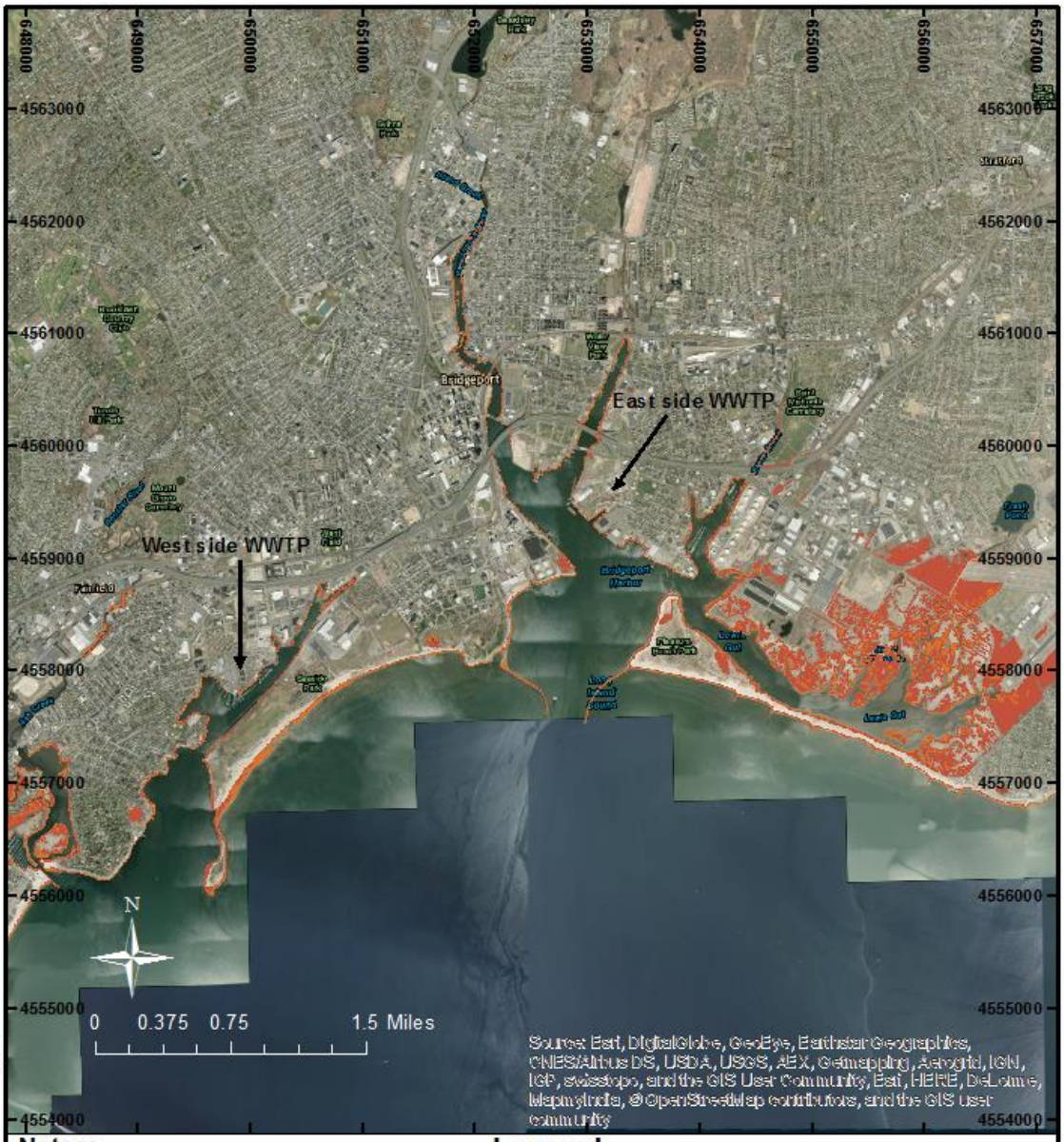
News had the smallest flooding area due to relatively high topography. The increased flooding on Mulberry Island was due to relatively low topography.

5. References

Longley, K. and Lipsky, A., 2014. Climate Change Vulnerability Assessment and Adaptation Planning Study for Water Quality Infrastructure in New Bedford, Fairhaven and Acushnet. SeaPlan, Boston (MA): Doc #220.14.01, 215 p.

Appendix A-1

Flood Map for Bridgeport, CT



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat1
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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TITLE:

SLOSH SLR 0, Category 1
WA2-18 Sea Level Rise and Water Supply Adaptation
Bridgeport, CT

Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A01**

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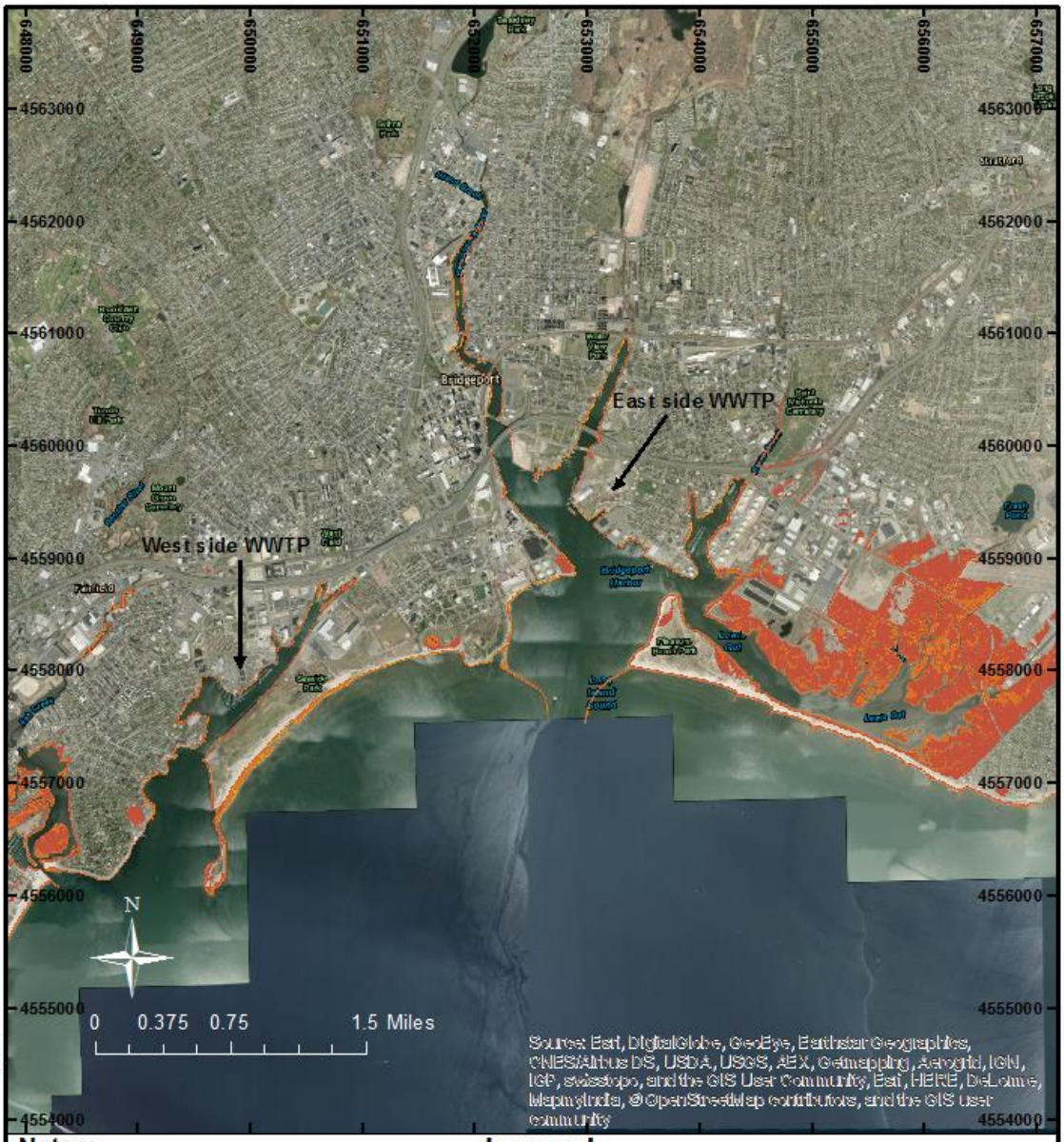

Notes:

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2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat2
Meters

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0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
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	3.0 - 3.6	5.4 - 6.0

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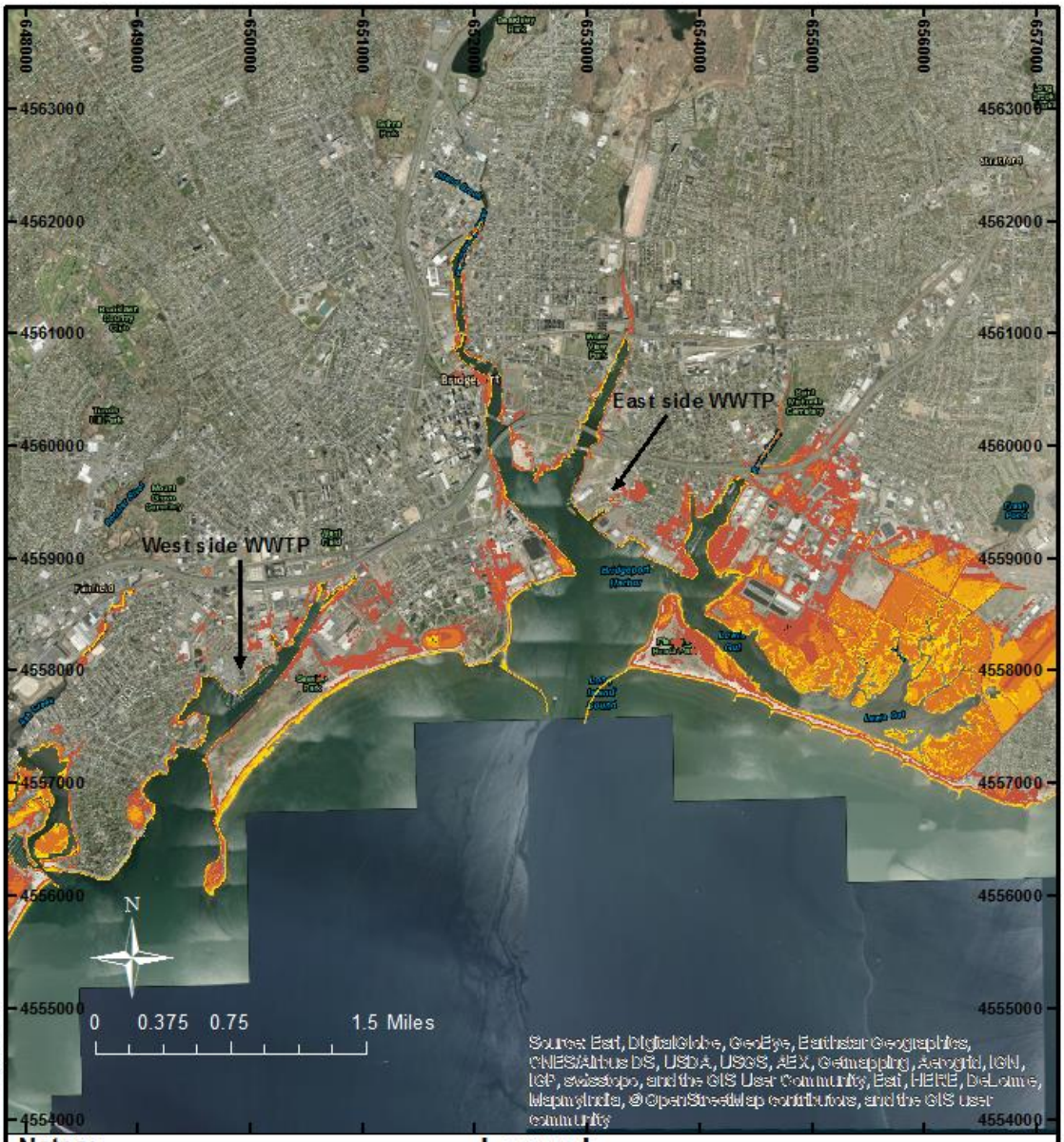

Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat3

Meters

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	3.0 - 3.6	5.4 - 6.0

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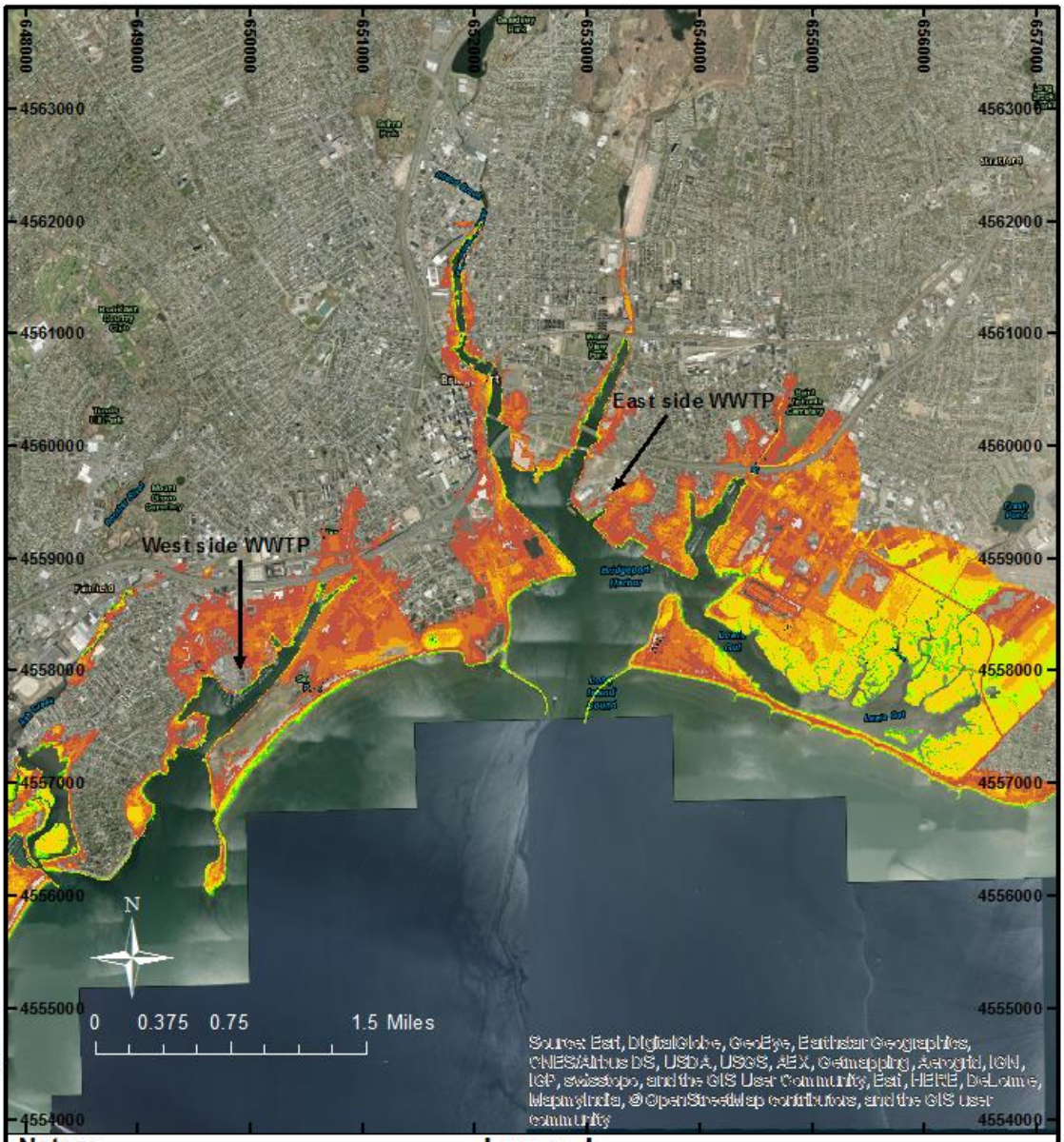

Notes:

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2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat4
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	3.0 - 3.6	5.4 - 6.0

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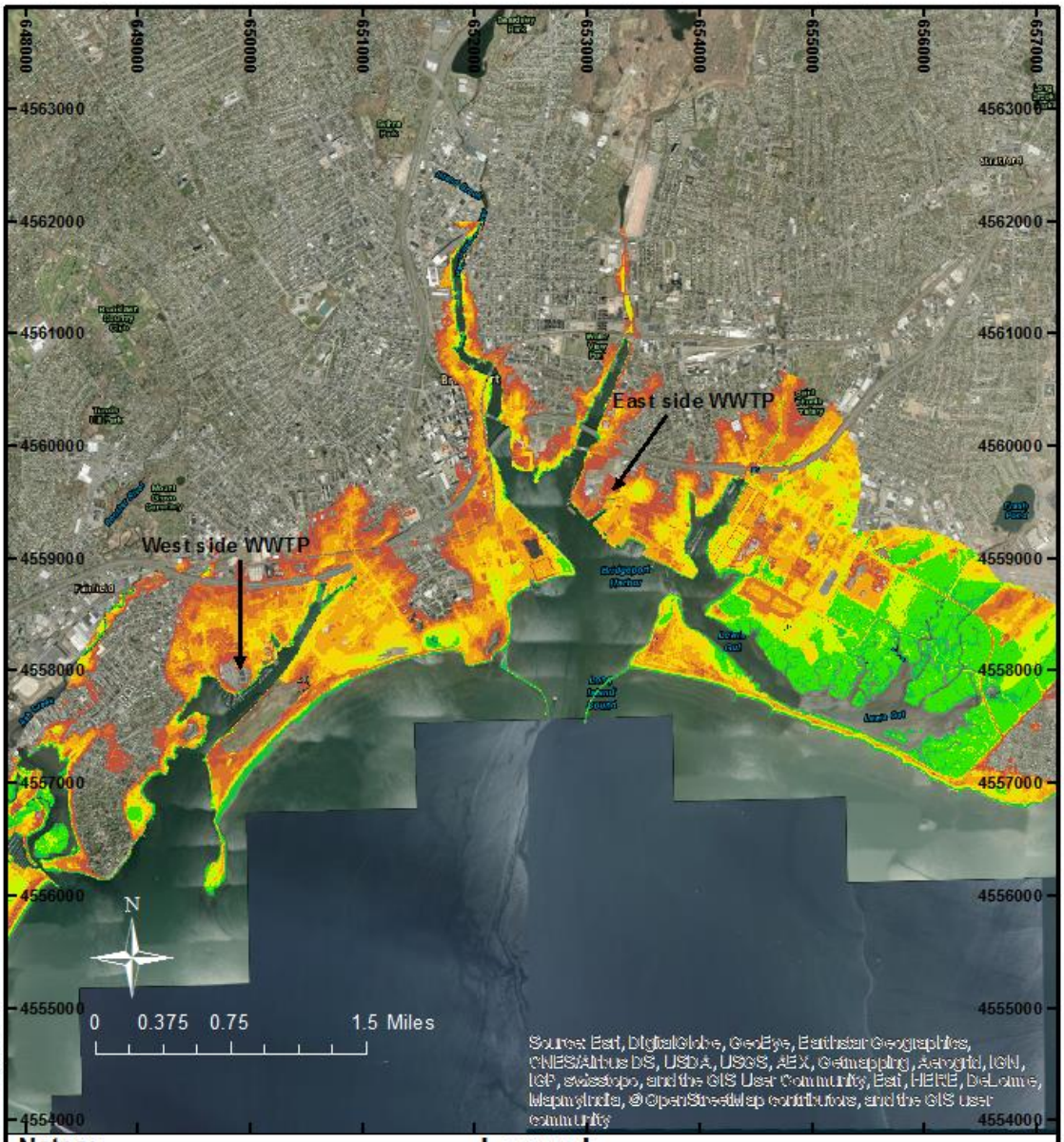

Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat5

Meters

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	3.0 - 3.6	5.4 - 6.0

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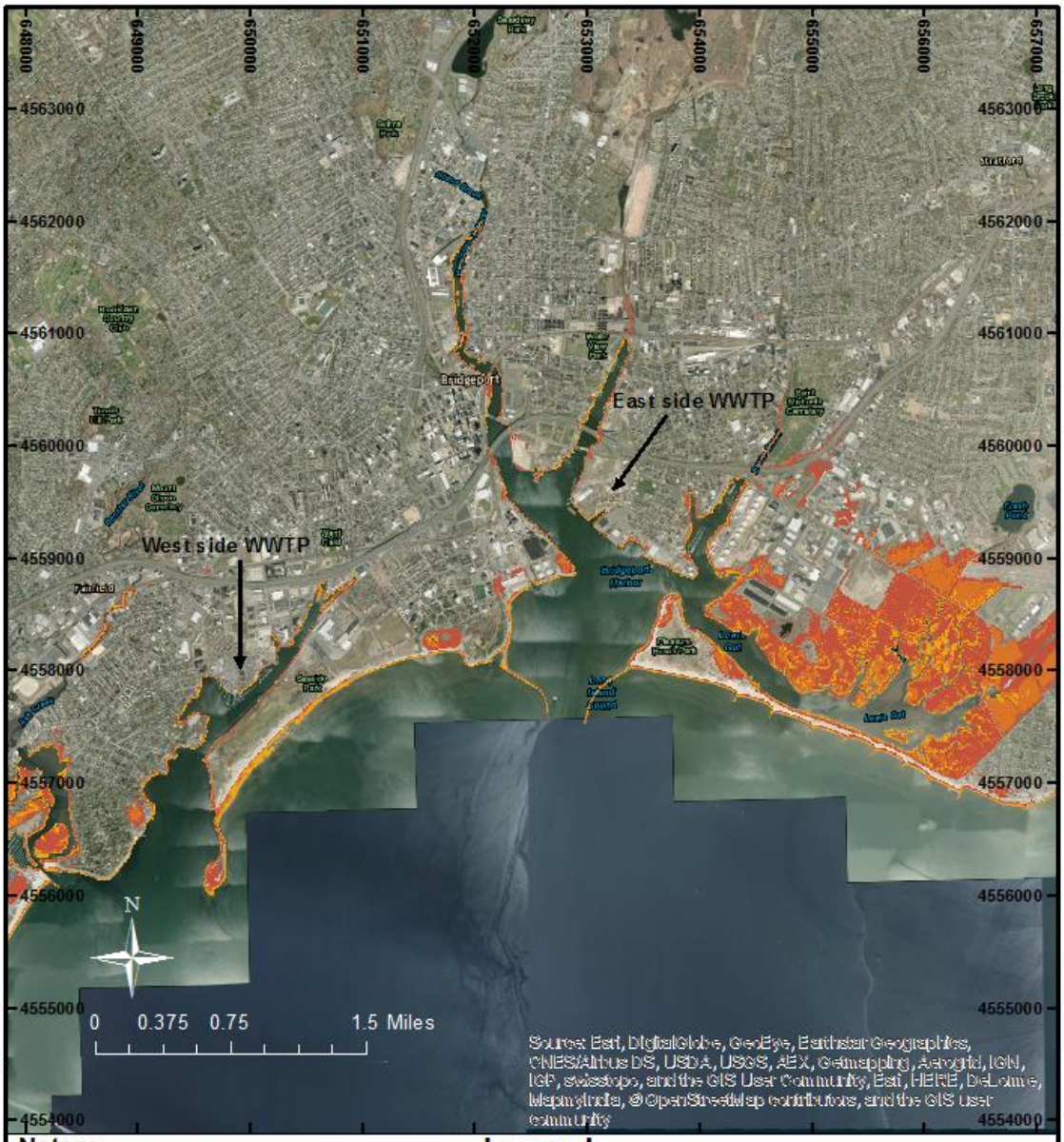

Notes:

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2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat1

Meters

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0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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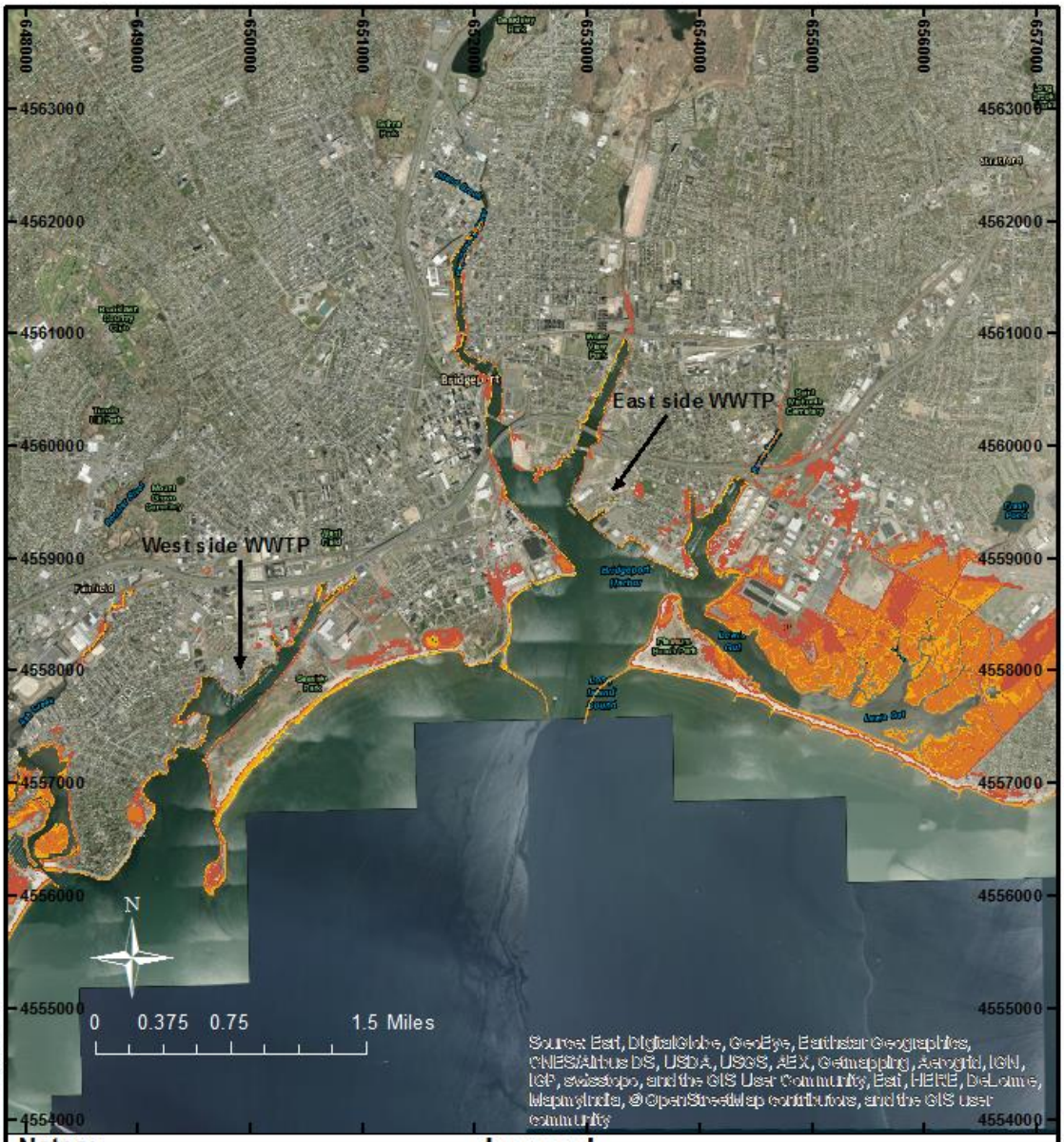

Notes:

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2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat2
Meters

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0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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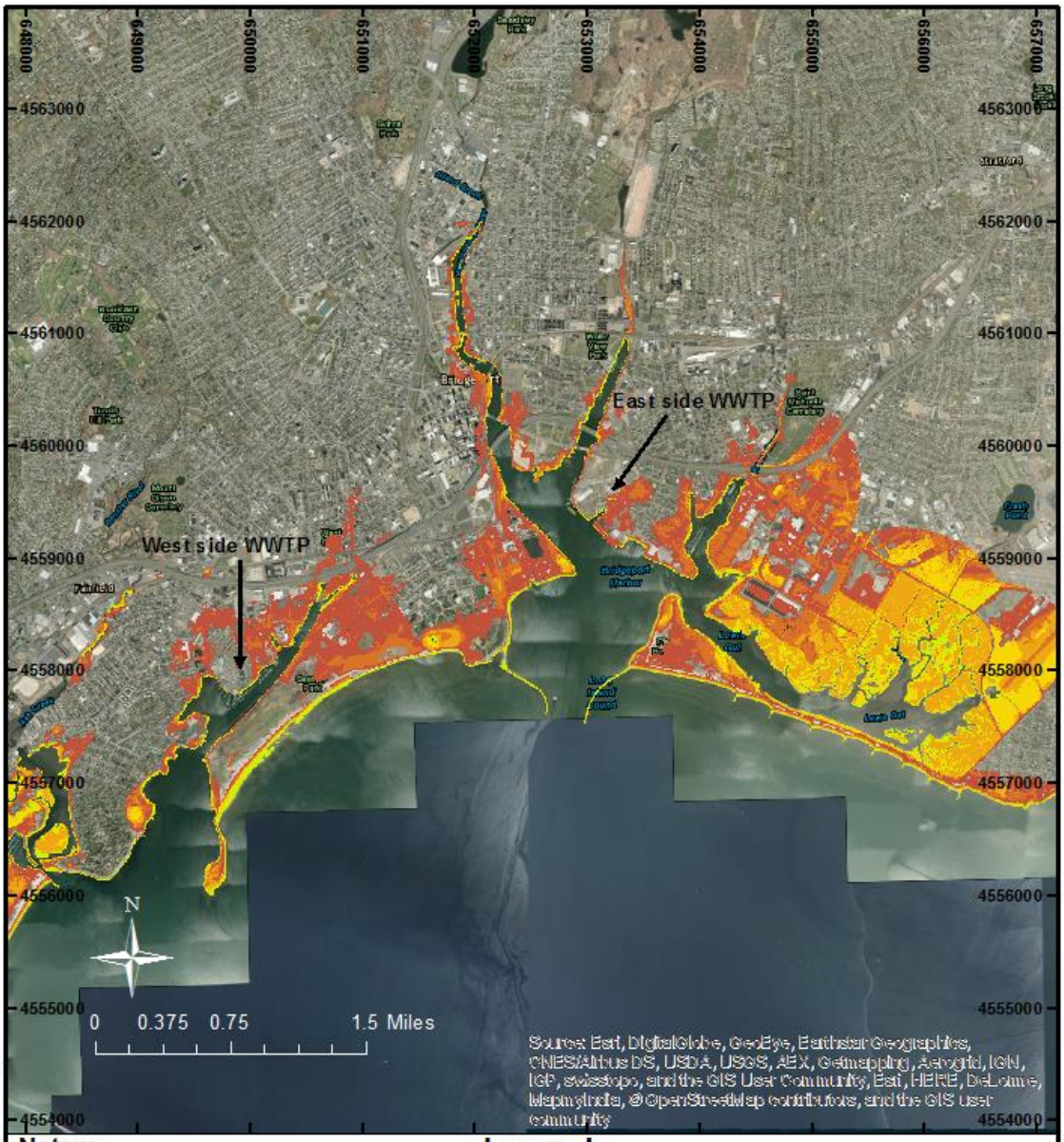

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1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat3
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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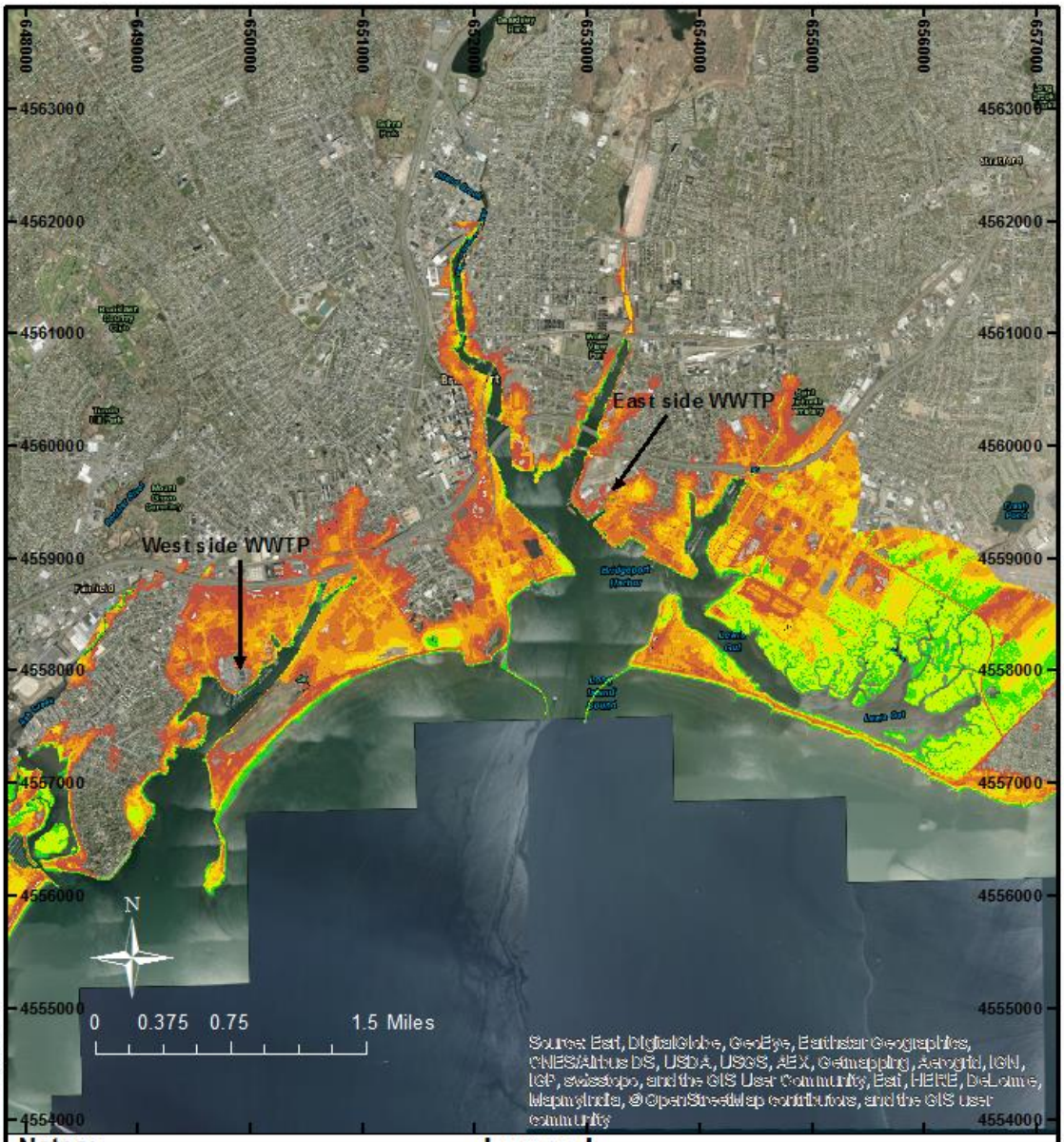
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A08**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_sl2_cat3.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat4
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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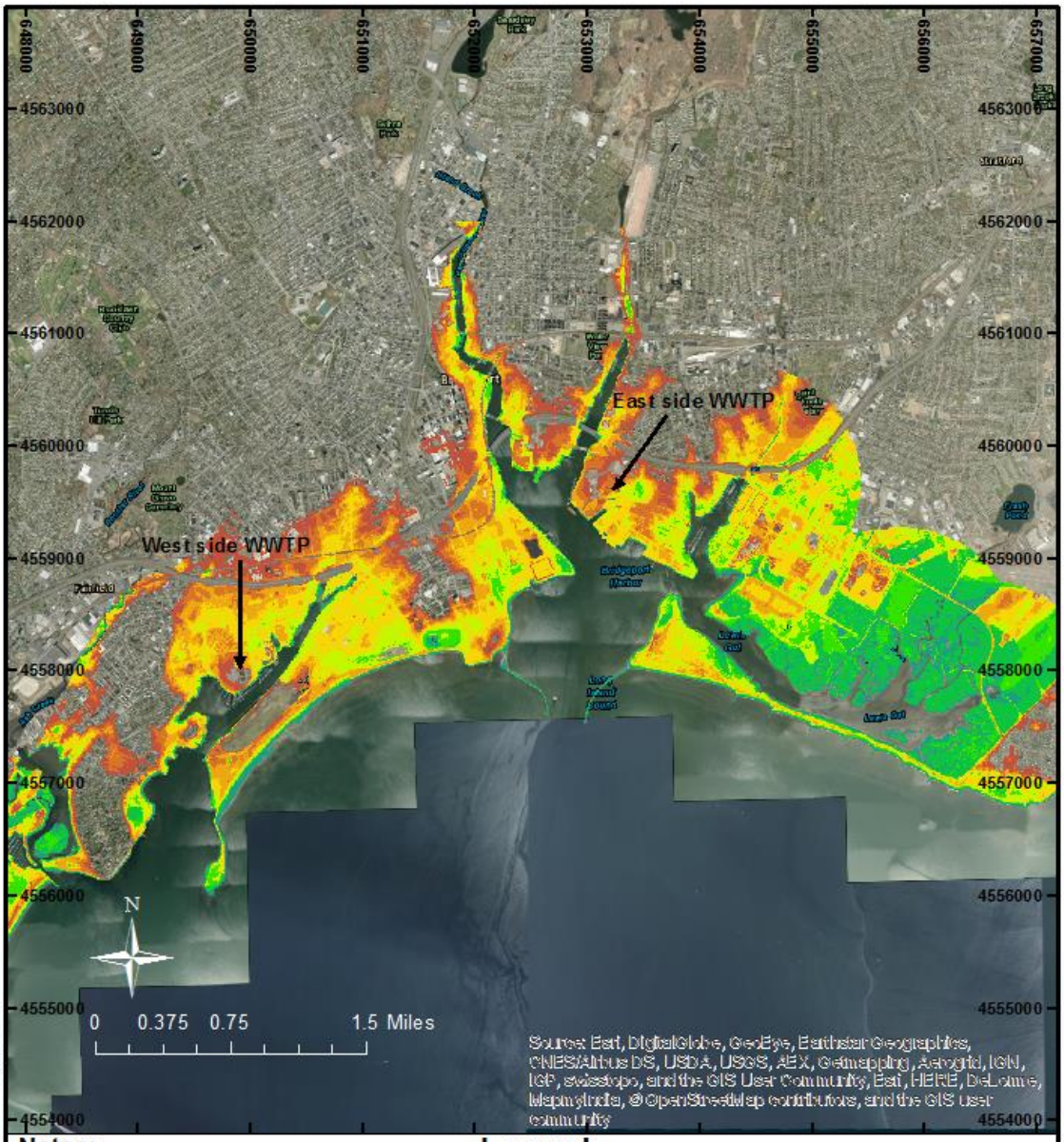
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A09**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_sl2_cat4.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat5
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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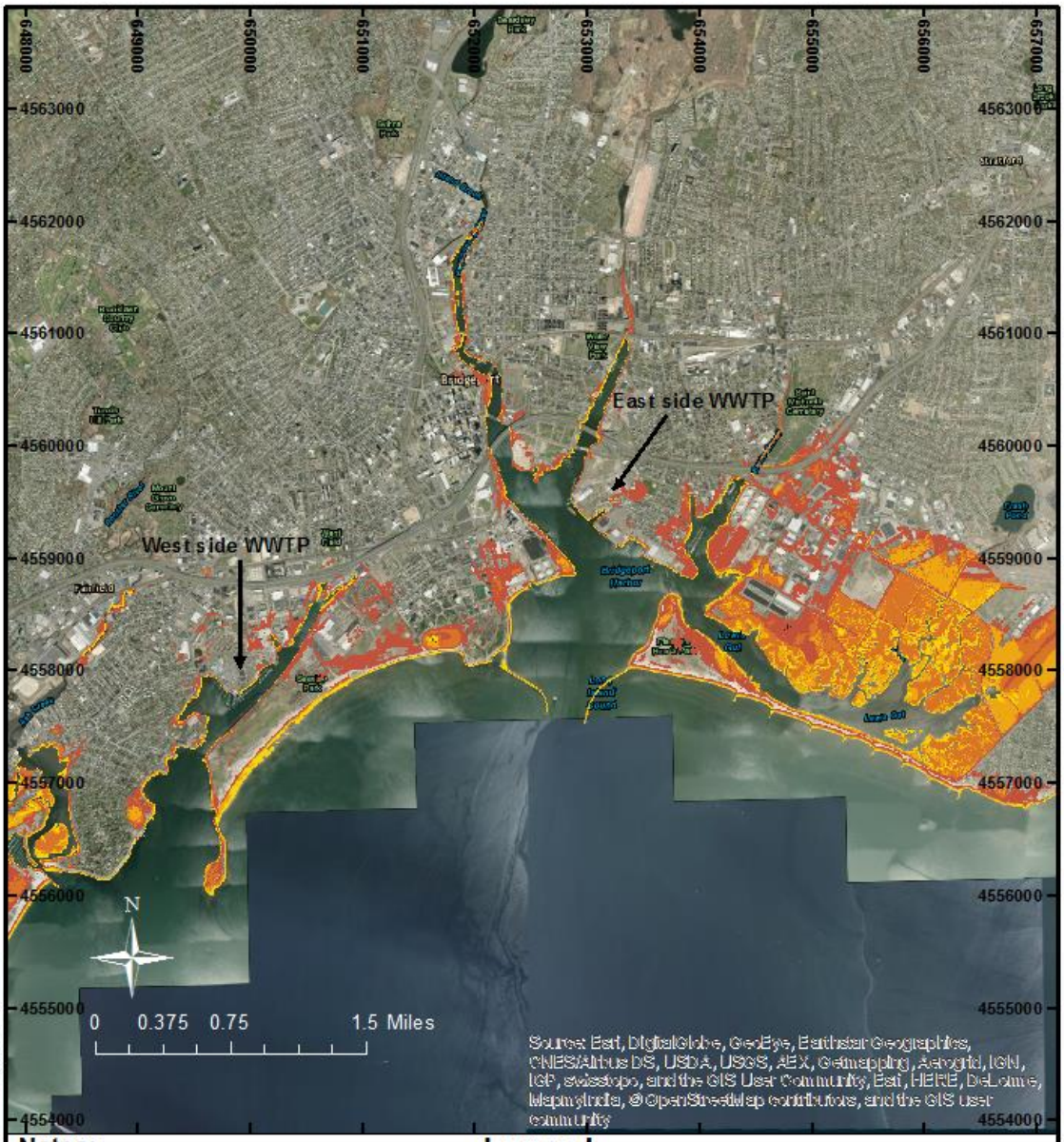
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A10**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_sl2_cat5.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat1
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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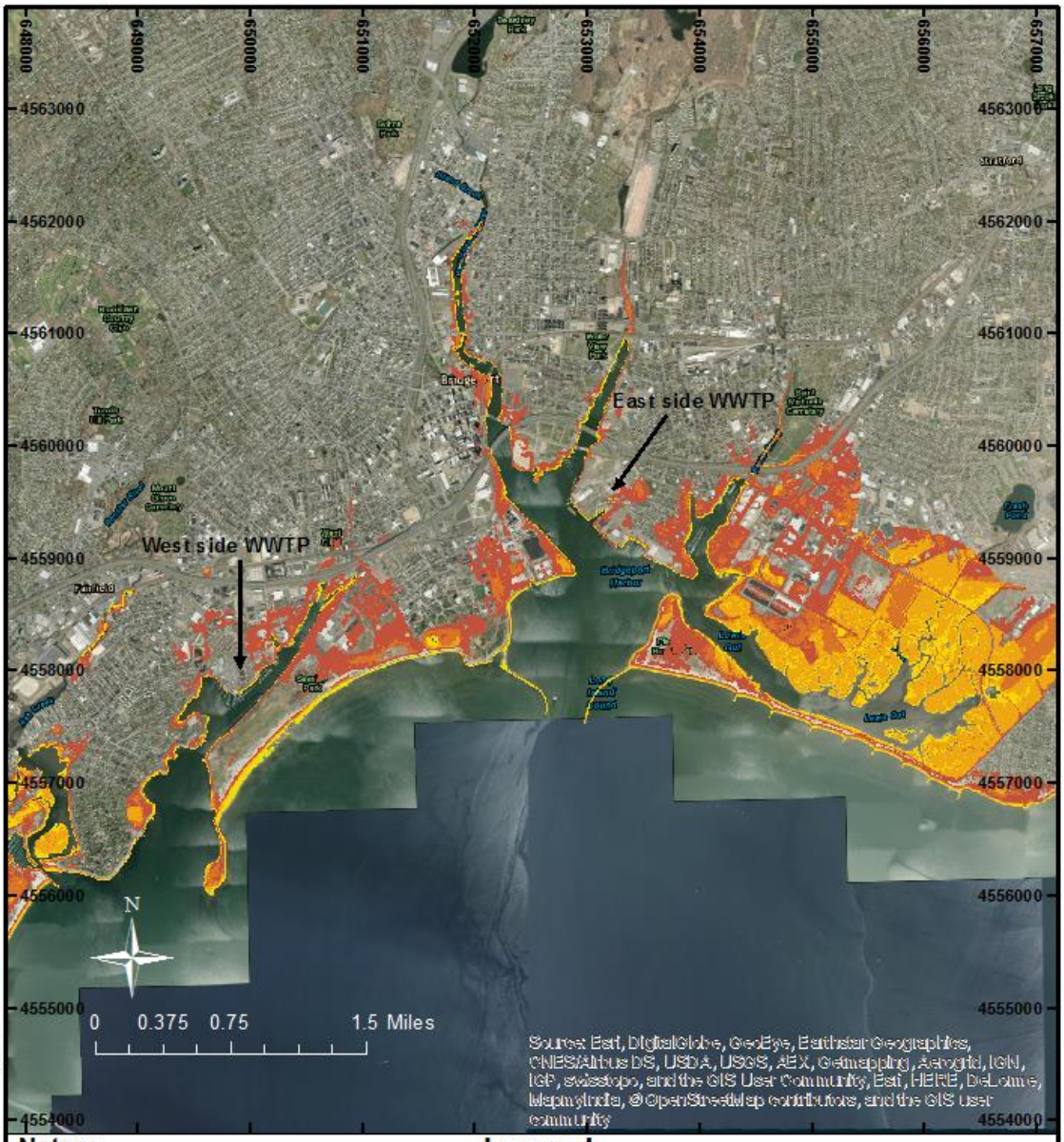
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A11**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr4_cat1.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat2
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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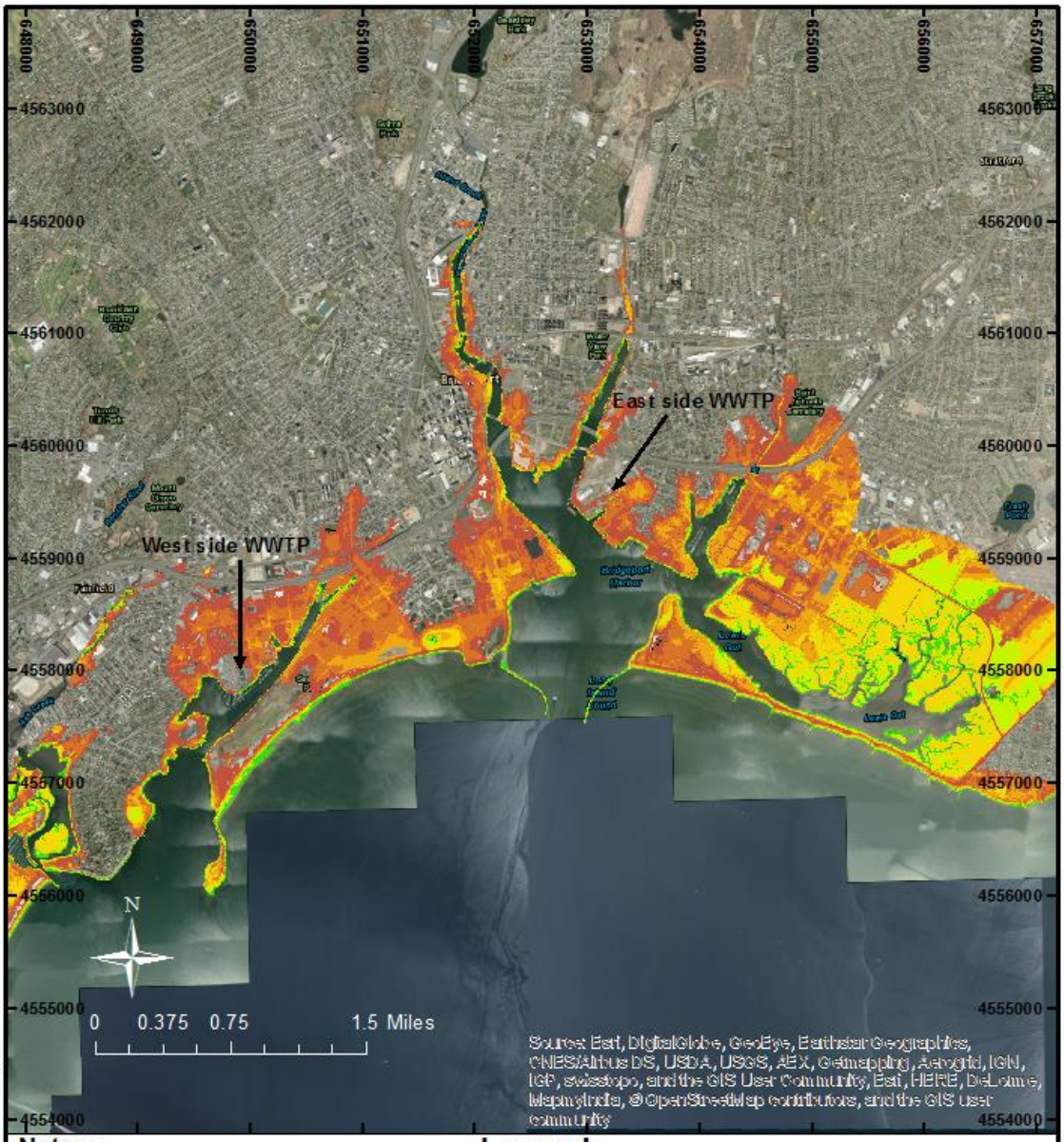
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr4_cat2.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat3
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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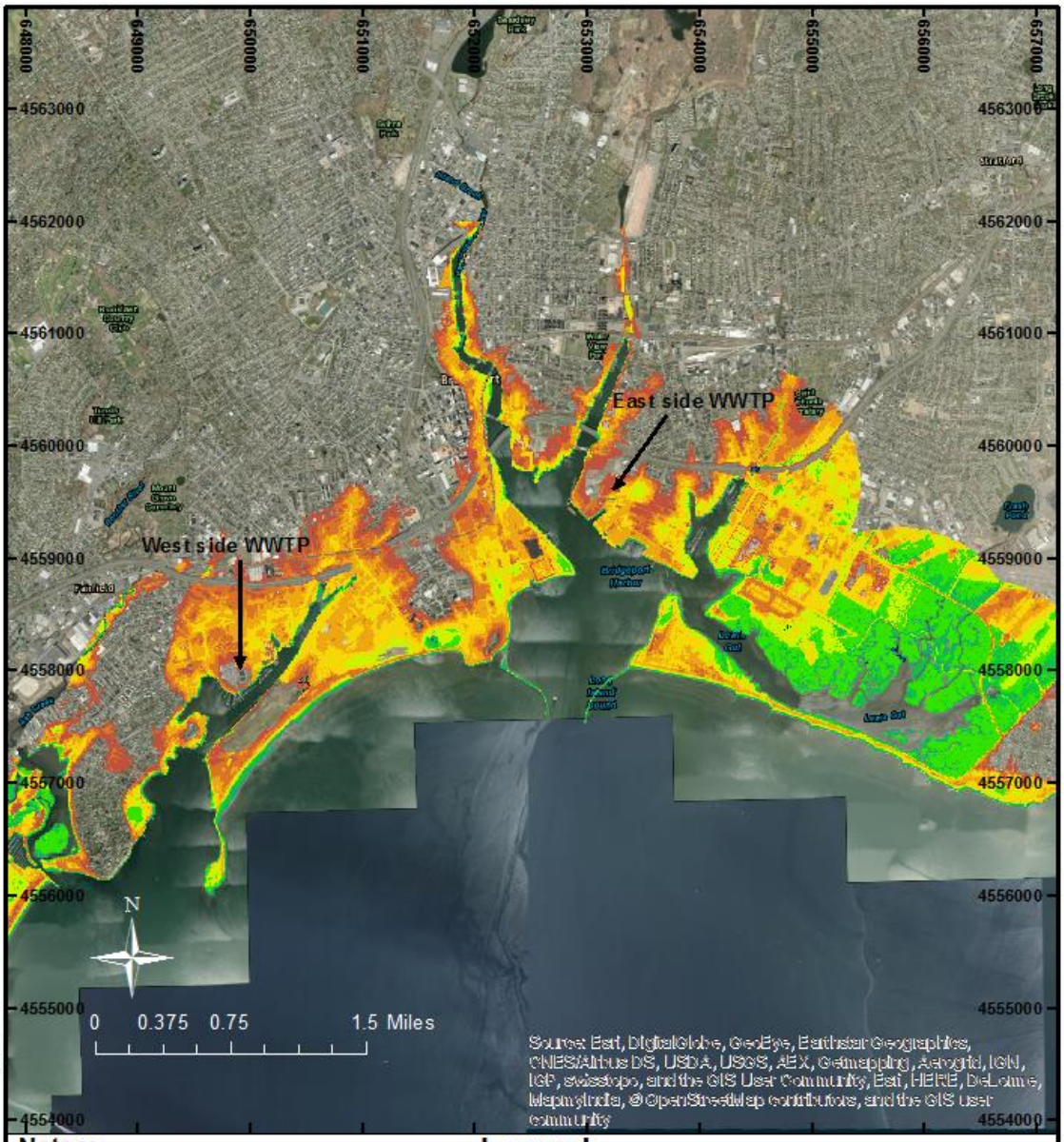
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr4_cat3.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat4
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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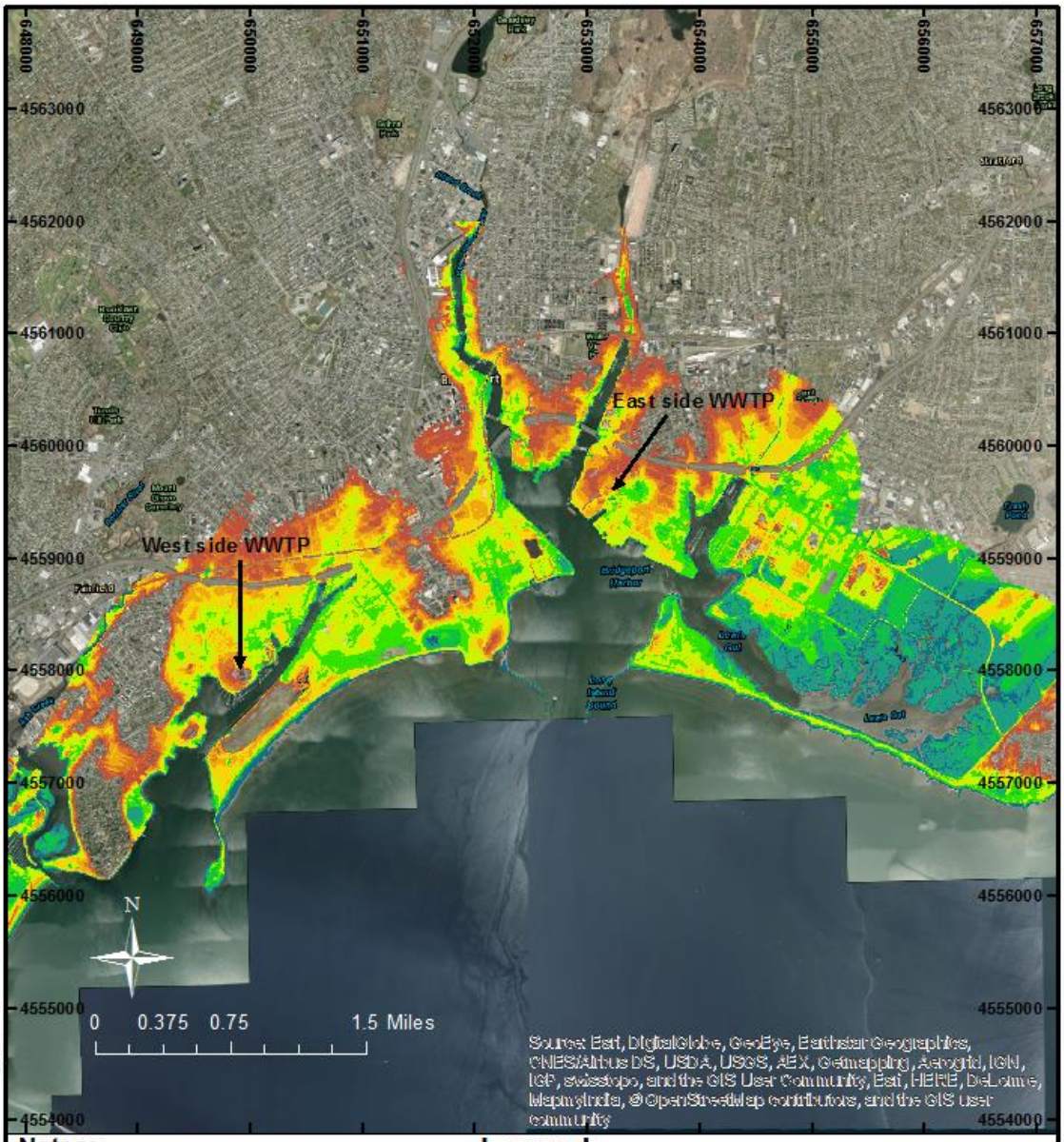
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr4_cat4.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat5
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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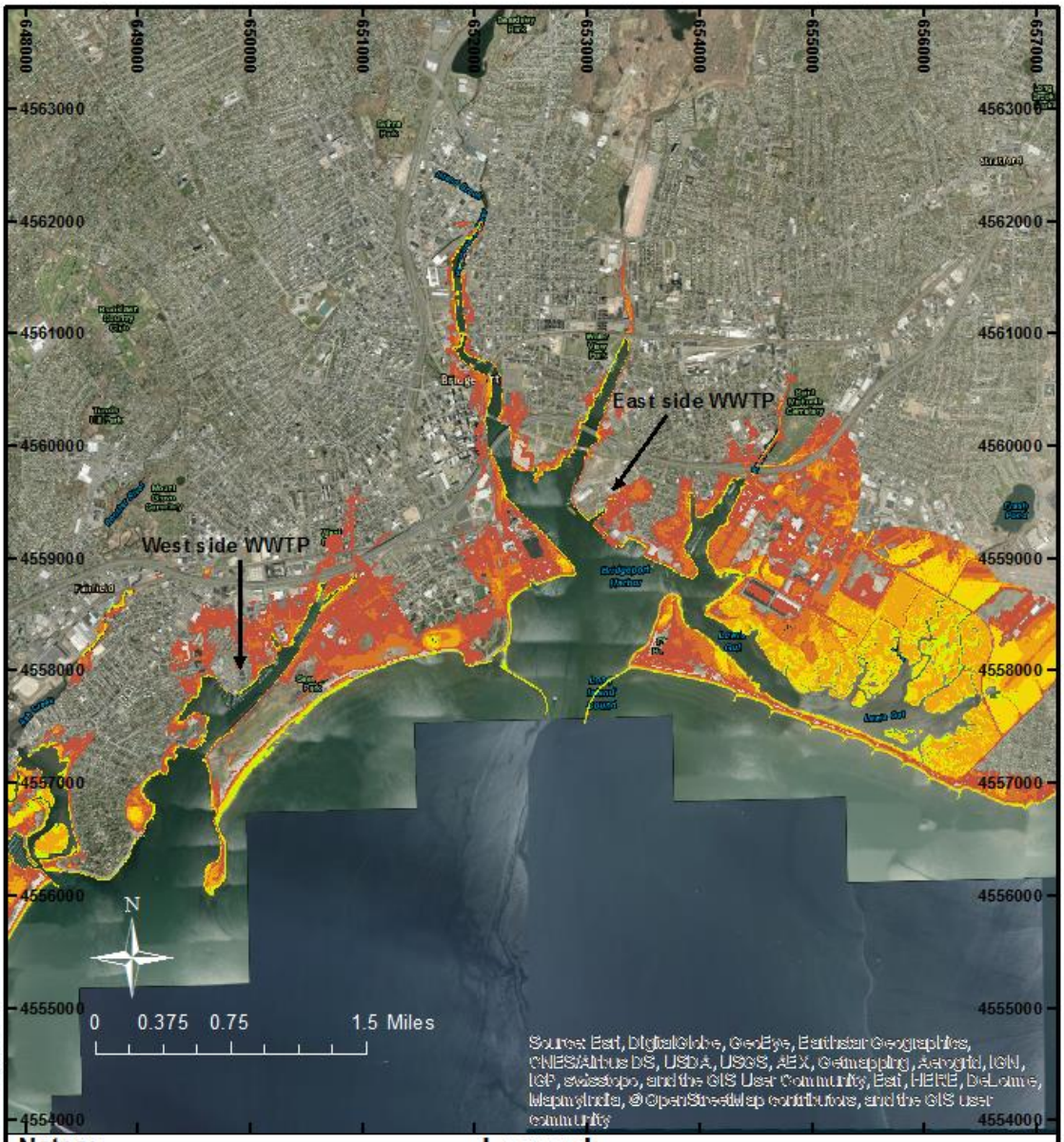
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr4_cat5.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat1
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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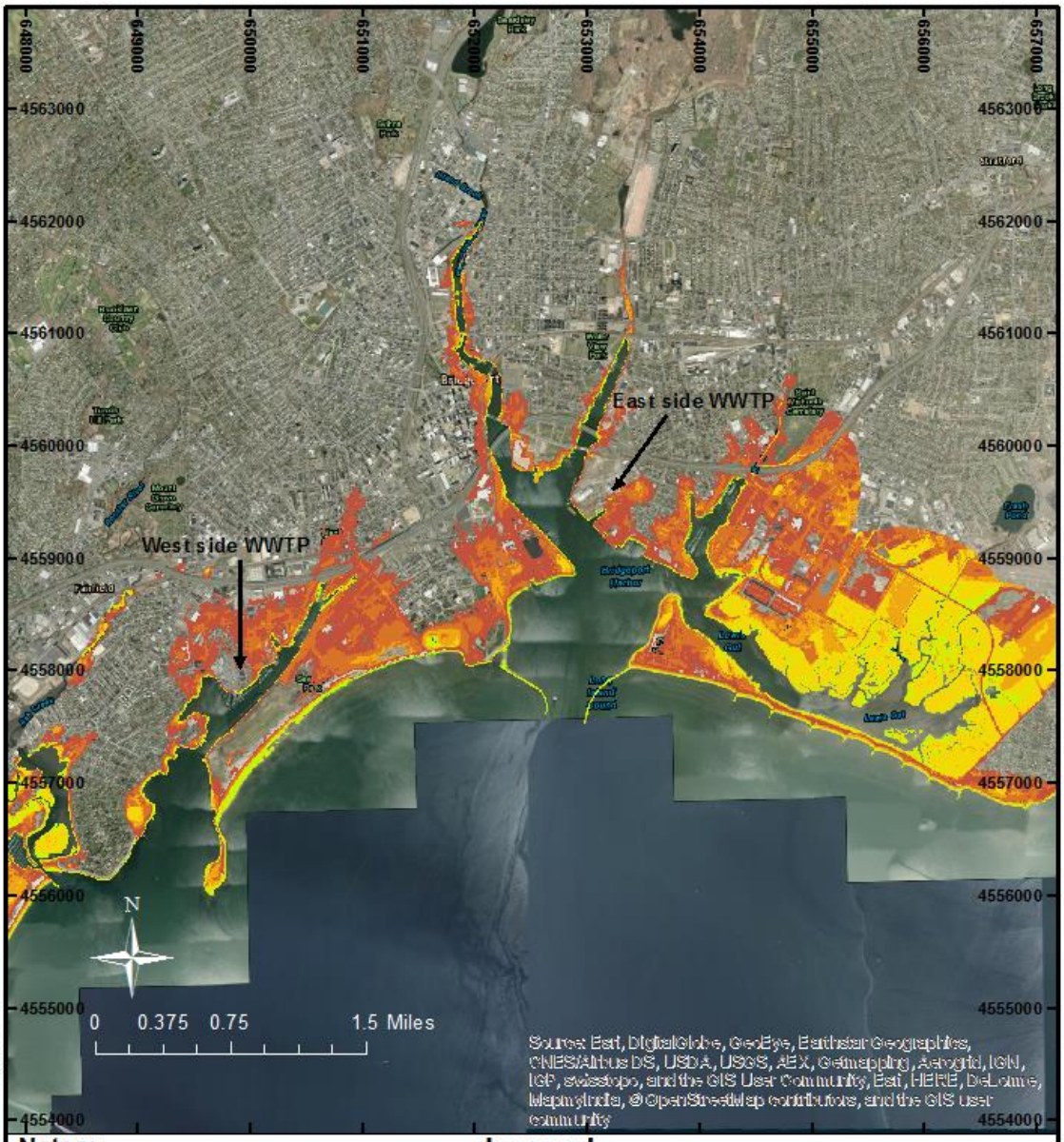
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr6_cat1.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat2
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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WA2-18 Sea Level Rise and Water Supply Adaptation
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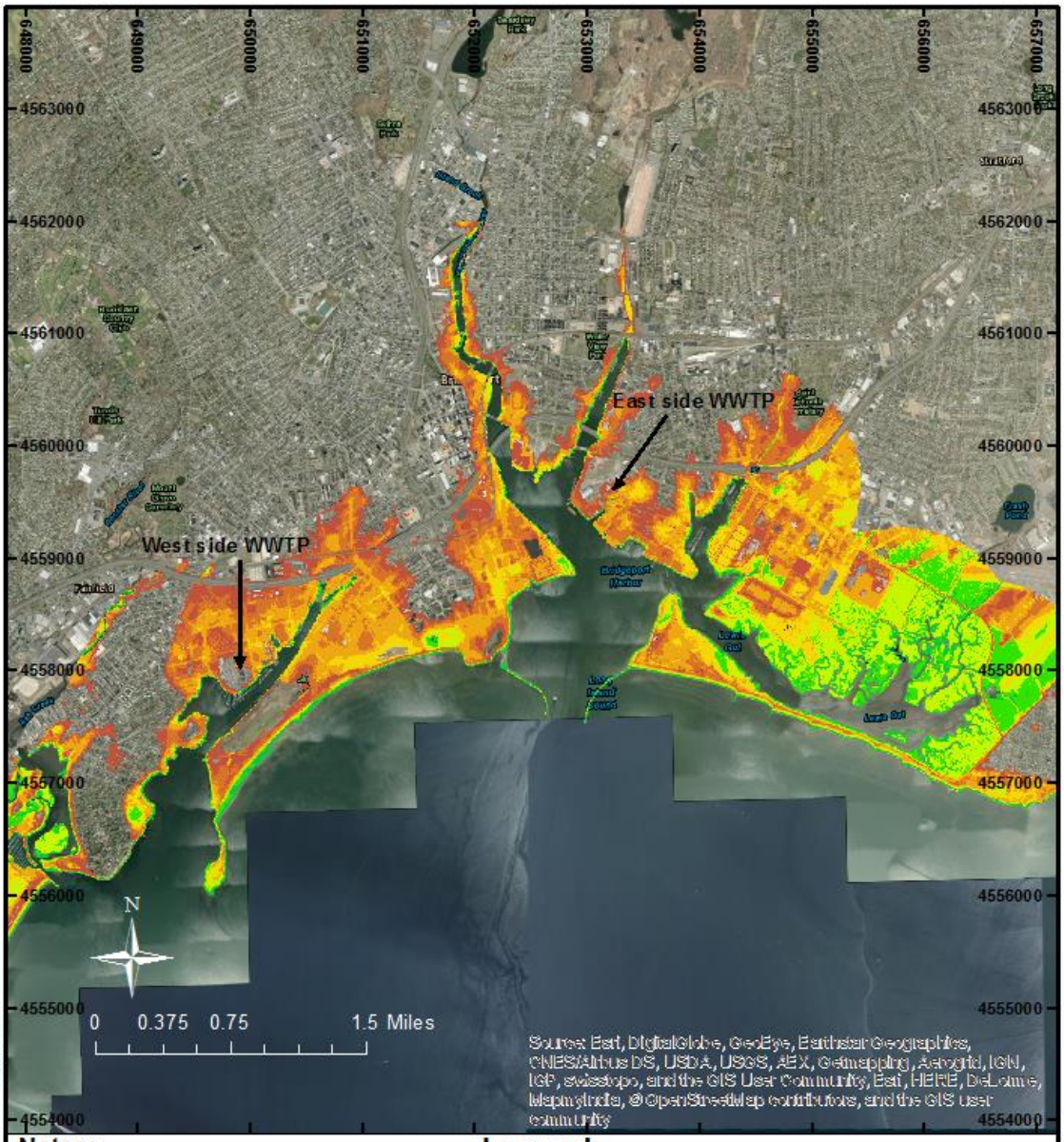
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A17**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr6_cat2.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat3
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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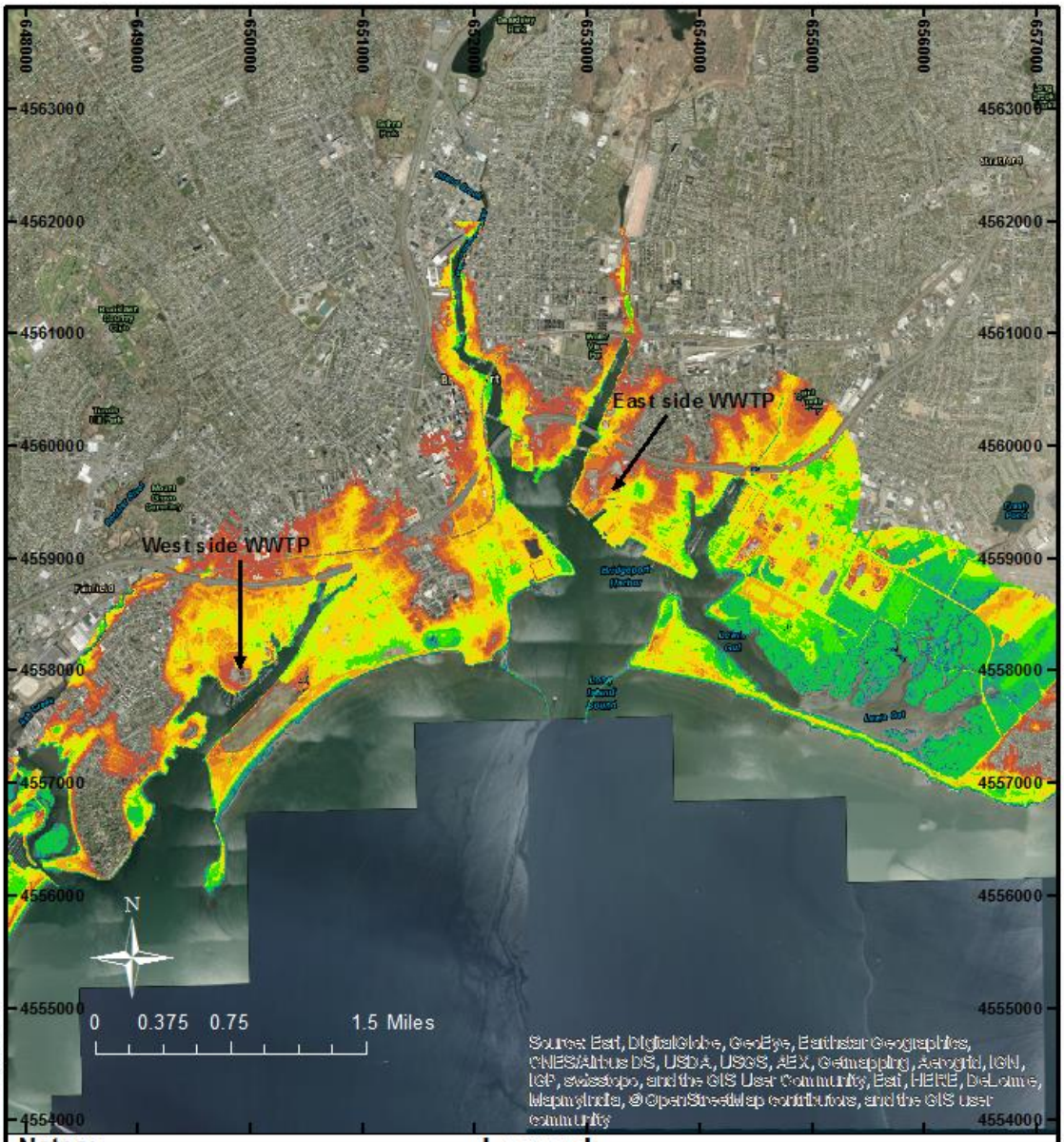
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A18**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr6_cat3.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat4
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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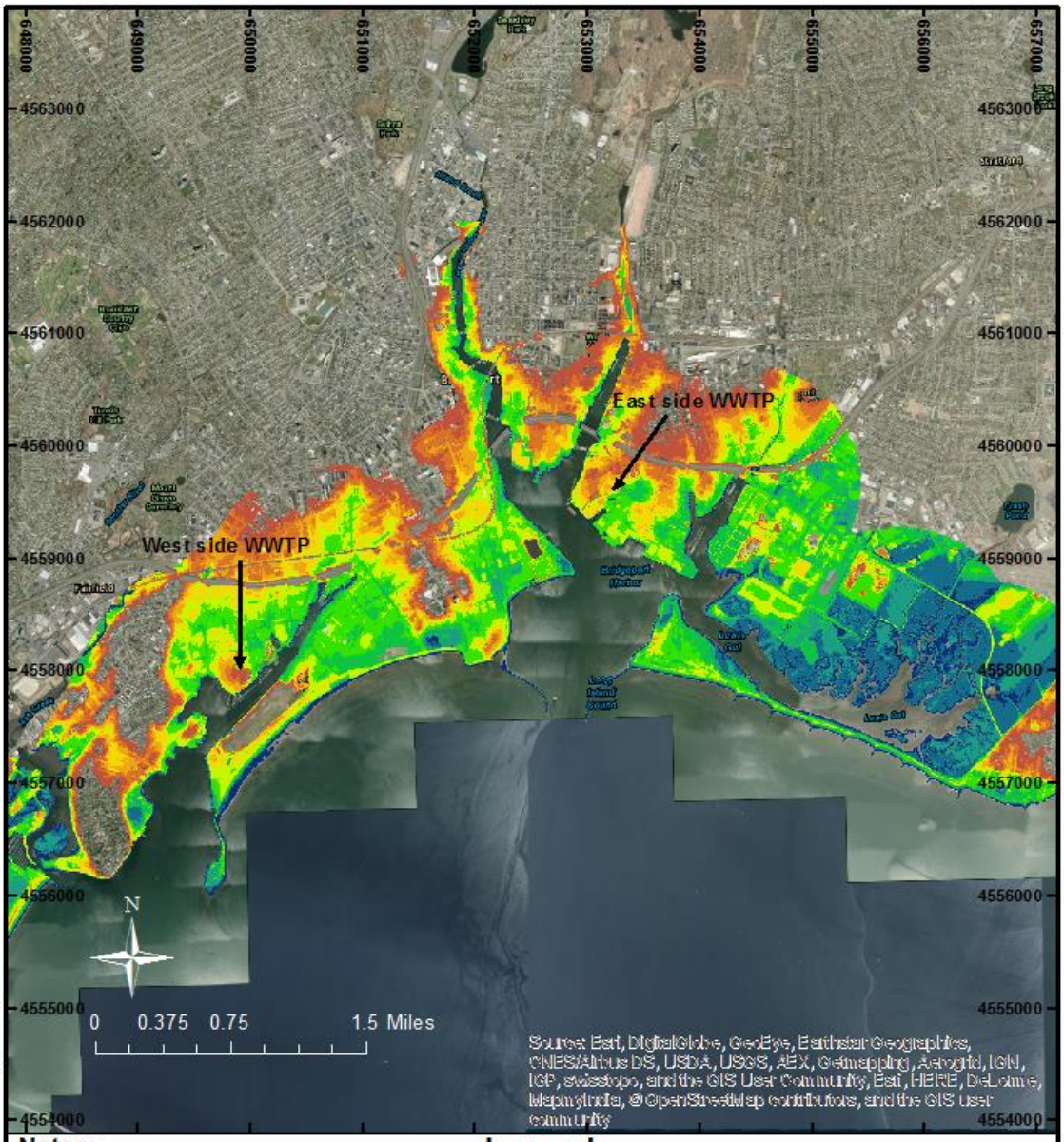
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A19**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr6_cat4.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat5
Meters

0.0 - 0.6	1.2 - 1.8	3.6 - 4.2
0.6 - 1.2	1.8 - 2.4	4.2 - 4.8
	2.4 - 3.0	4.8 - 5.4
	3.0 - 3.6	5.4 - 6.0

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G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\bridgeport_slr6_cat5.mxd

Appendix A-2

Flood Map for Hampton Road, VA

Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat1
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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SLOSH SLR 0, Category 1
WA2-18 Sea Level Rise and Water Supply Adaptation
Hampton Road, VA

Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A01**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr0_cat1.mxd

Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat2
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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Hampton Road, VA

Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A02**

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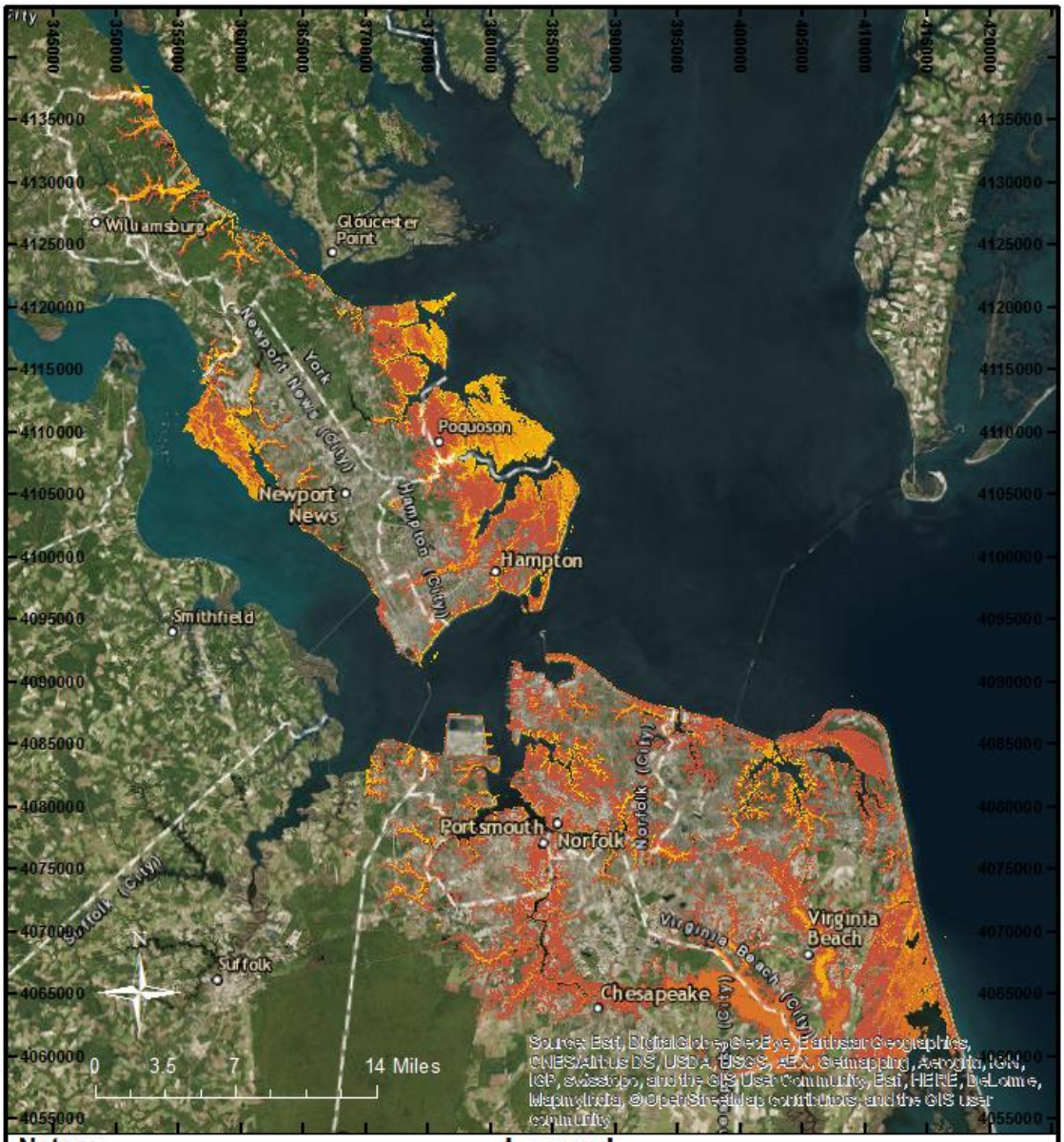

Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat3
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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SLOSH SLR 0, Category 3
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Hampton Road, VA

Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A03**

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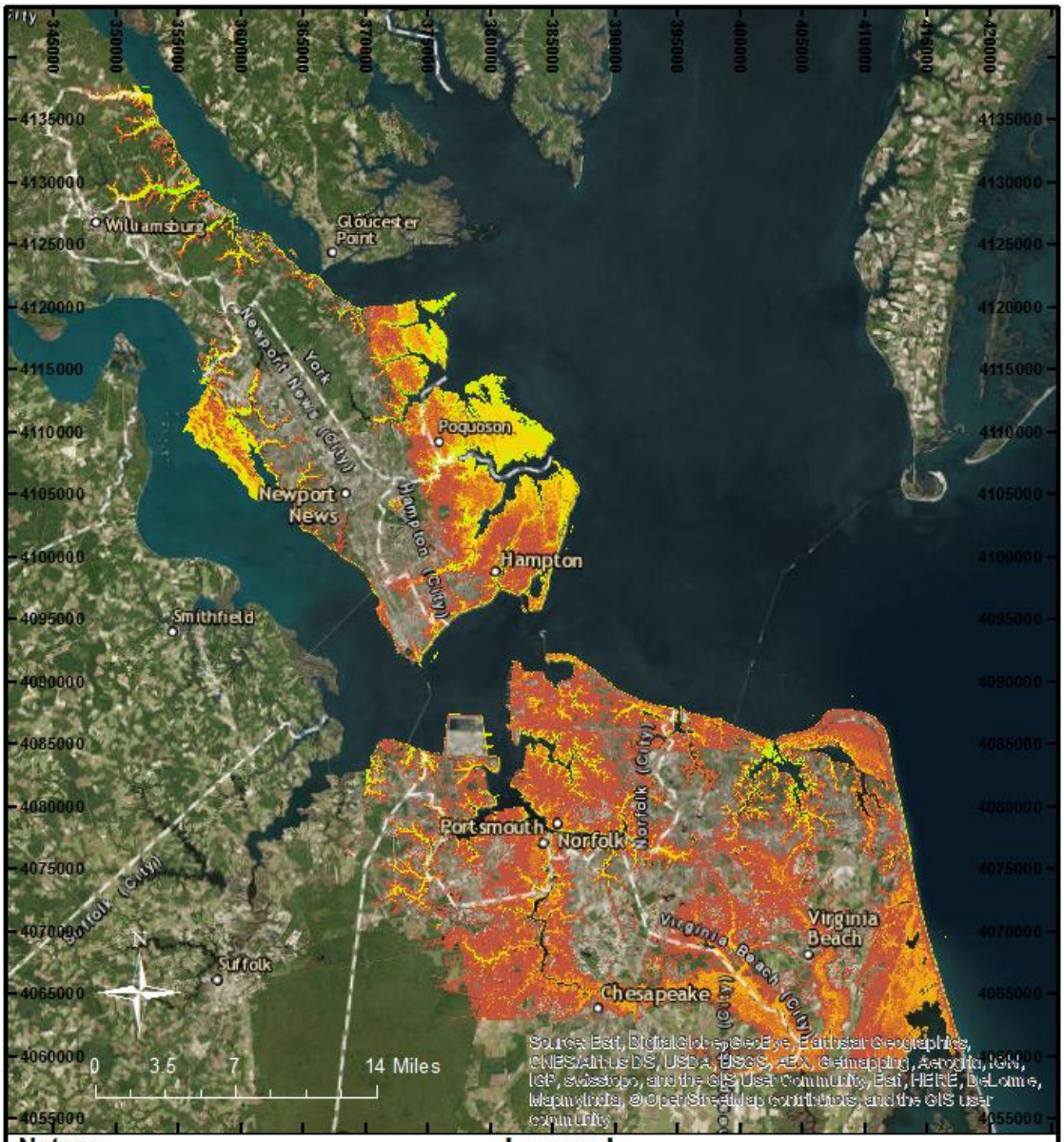

Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat4
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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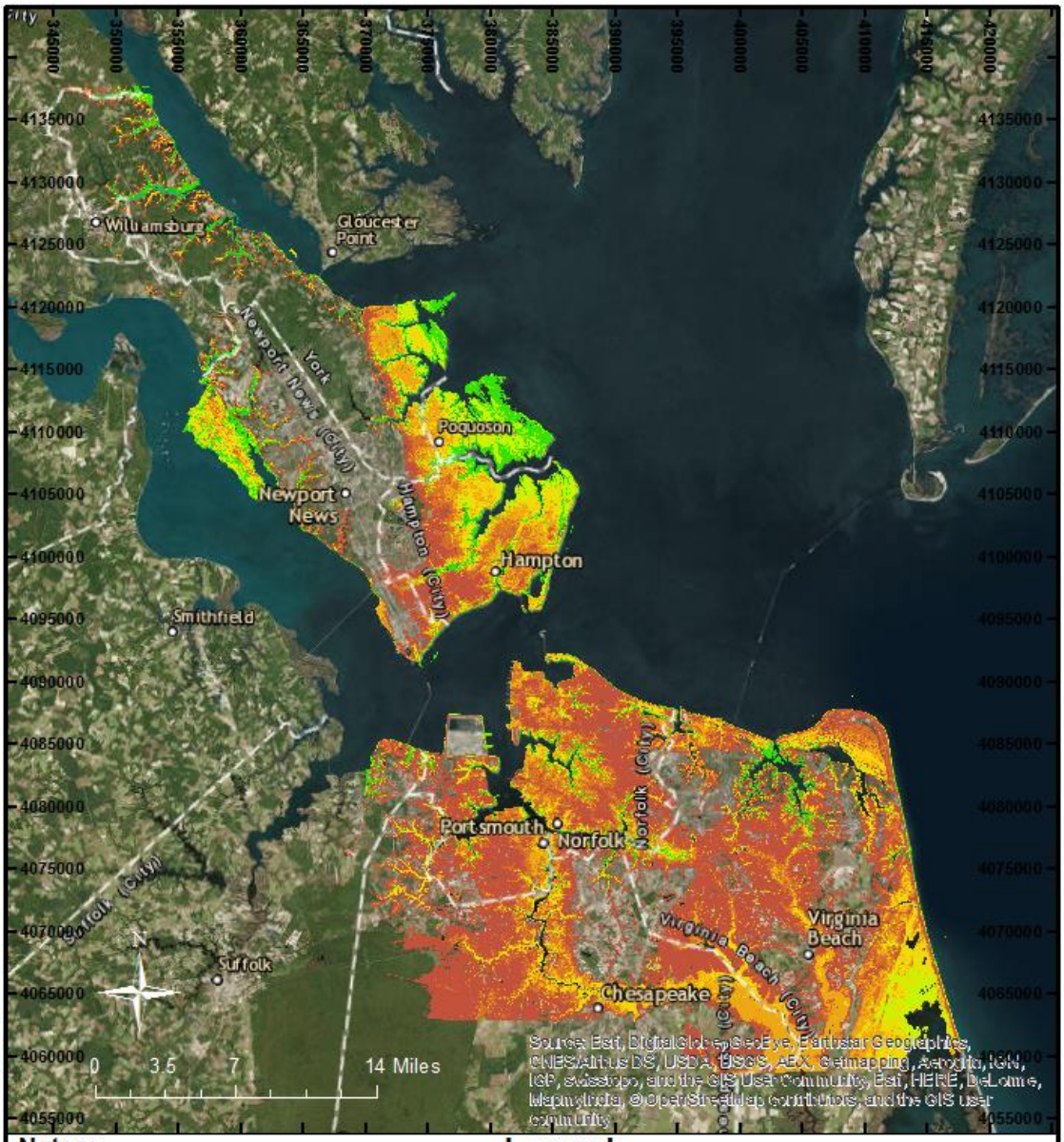
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A04**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_sl0_cat4.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR0_Cat5
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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Hampton Road, VA

Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A05**

Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat1
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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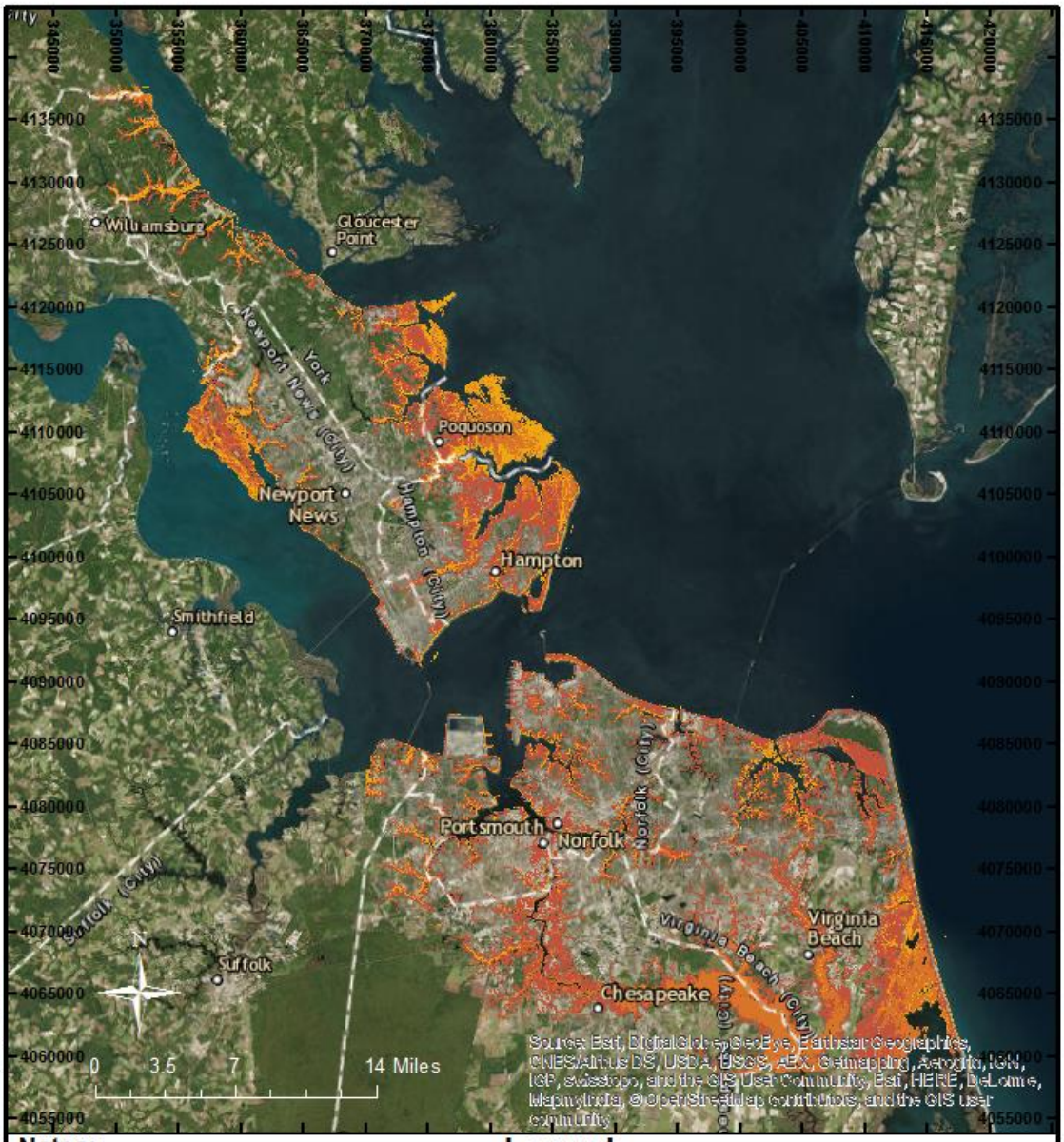
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A06**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\hampton_slr2_cat1.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat2
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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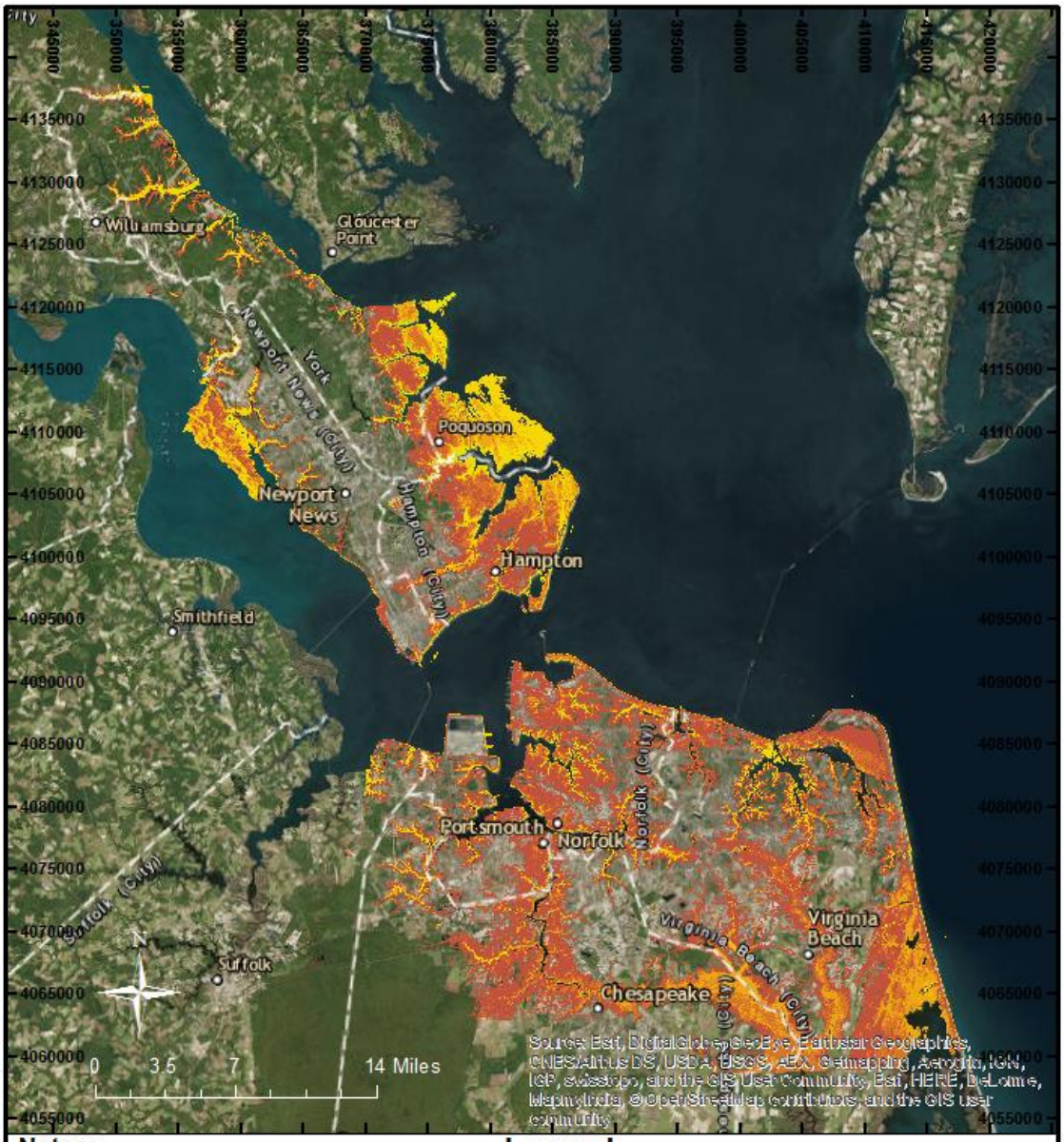
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A07**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\hampton_slr2_cat2.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat3
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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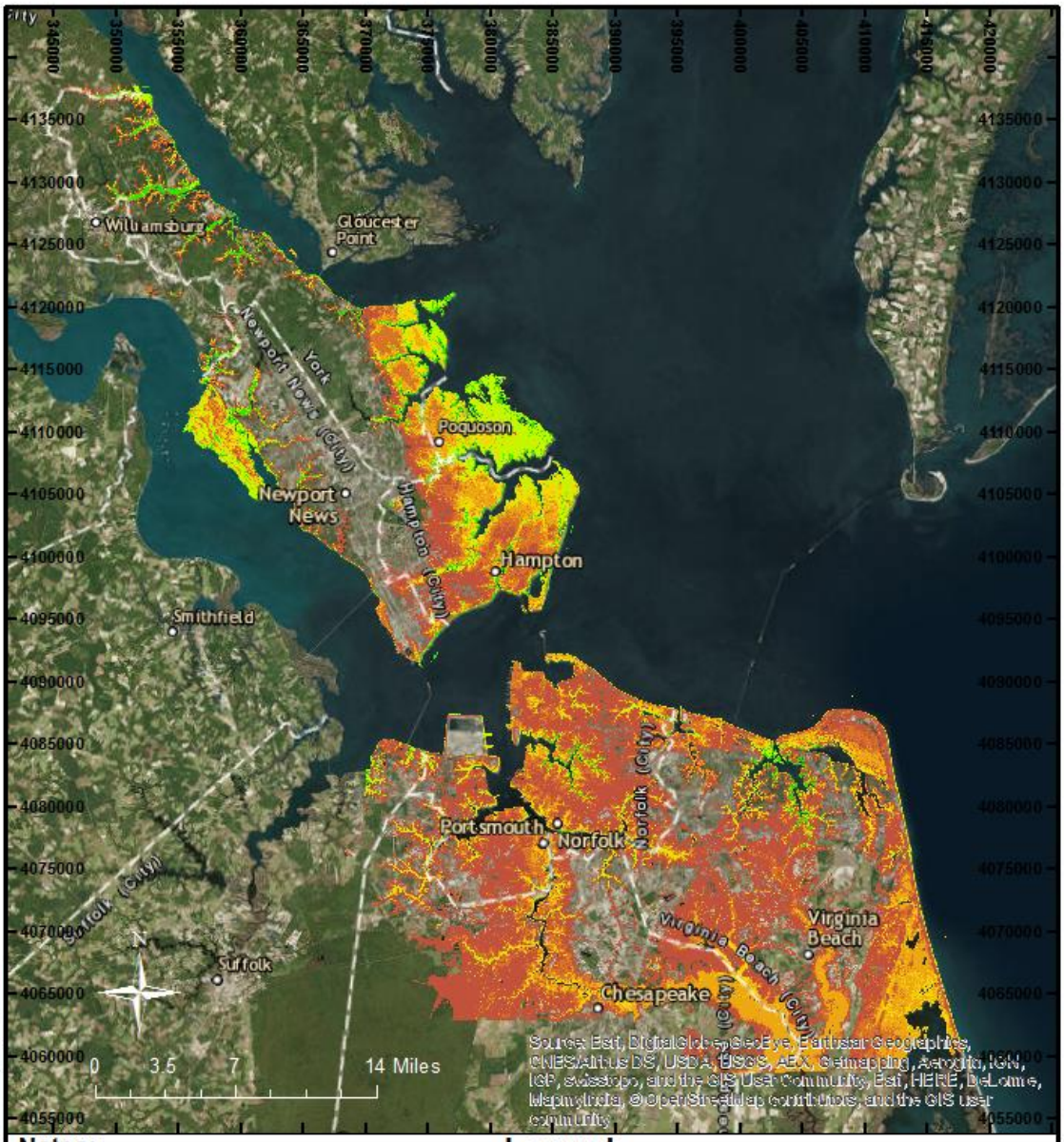
Hampton Road, VA

Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A08**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr2_cat3.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat4
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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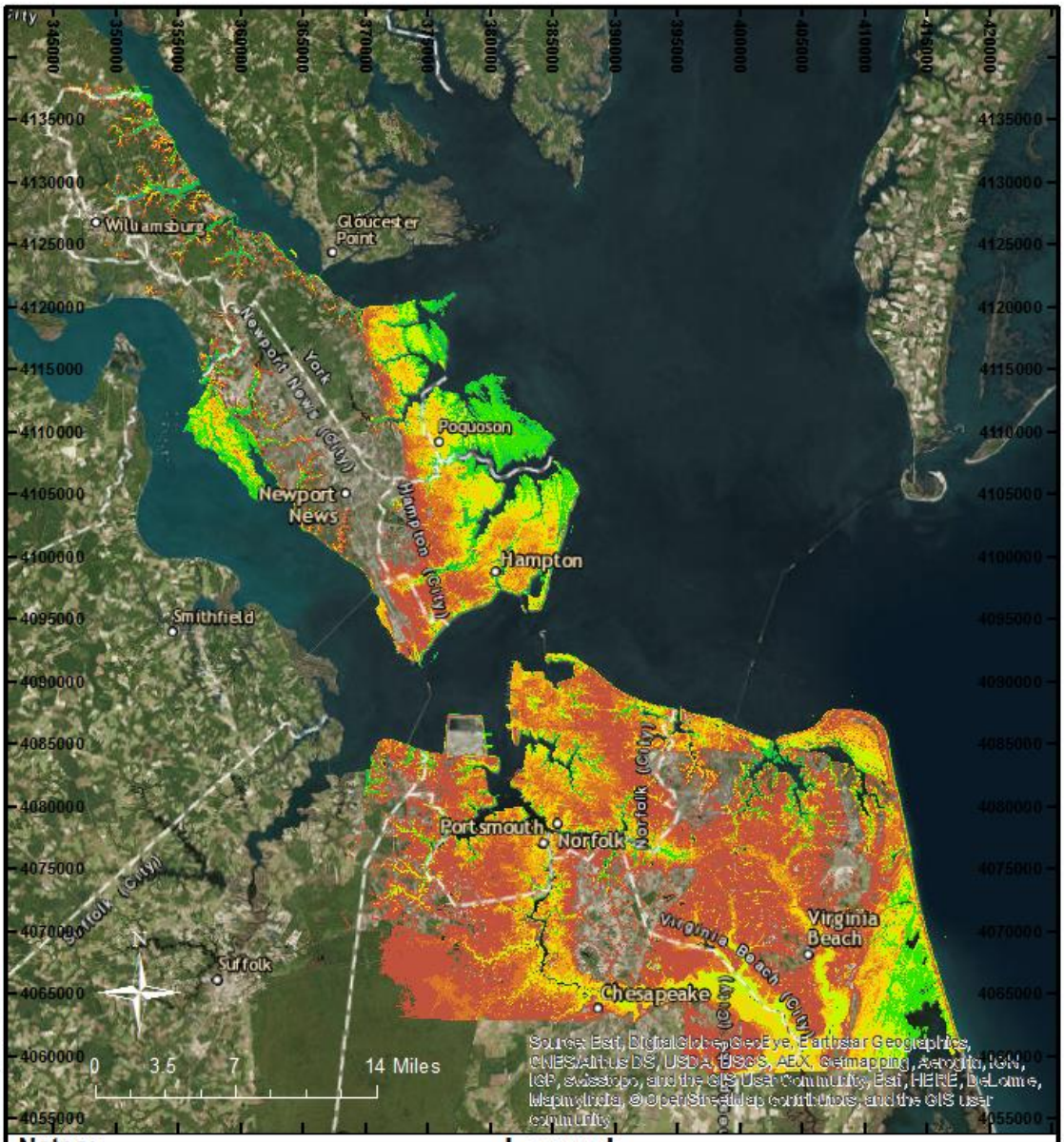
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A09**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr2_cat4.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR2_Cat5
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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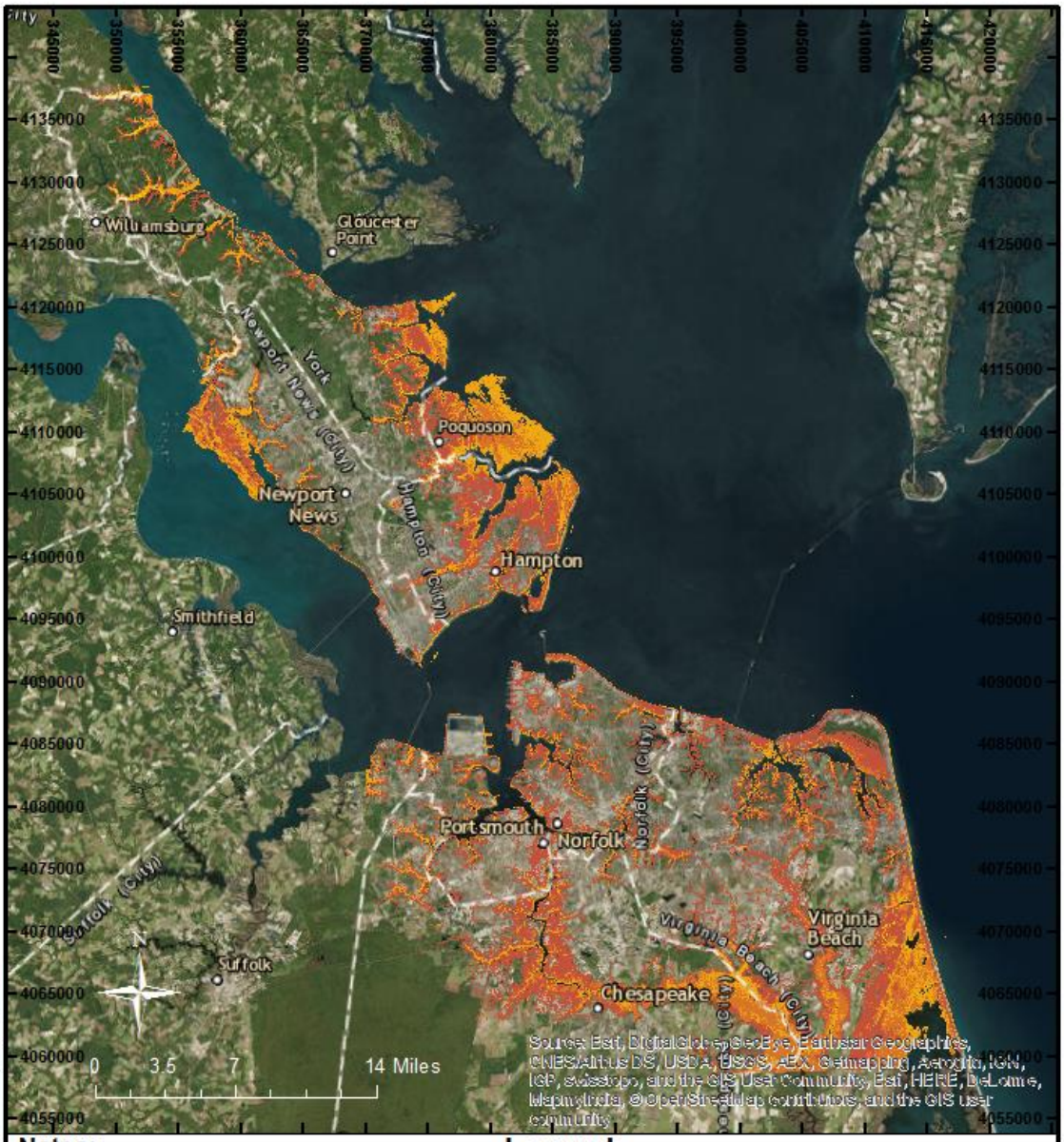
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A10**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\hampton_slr2_cat5.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat1
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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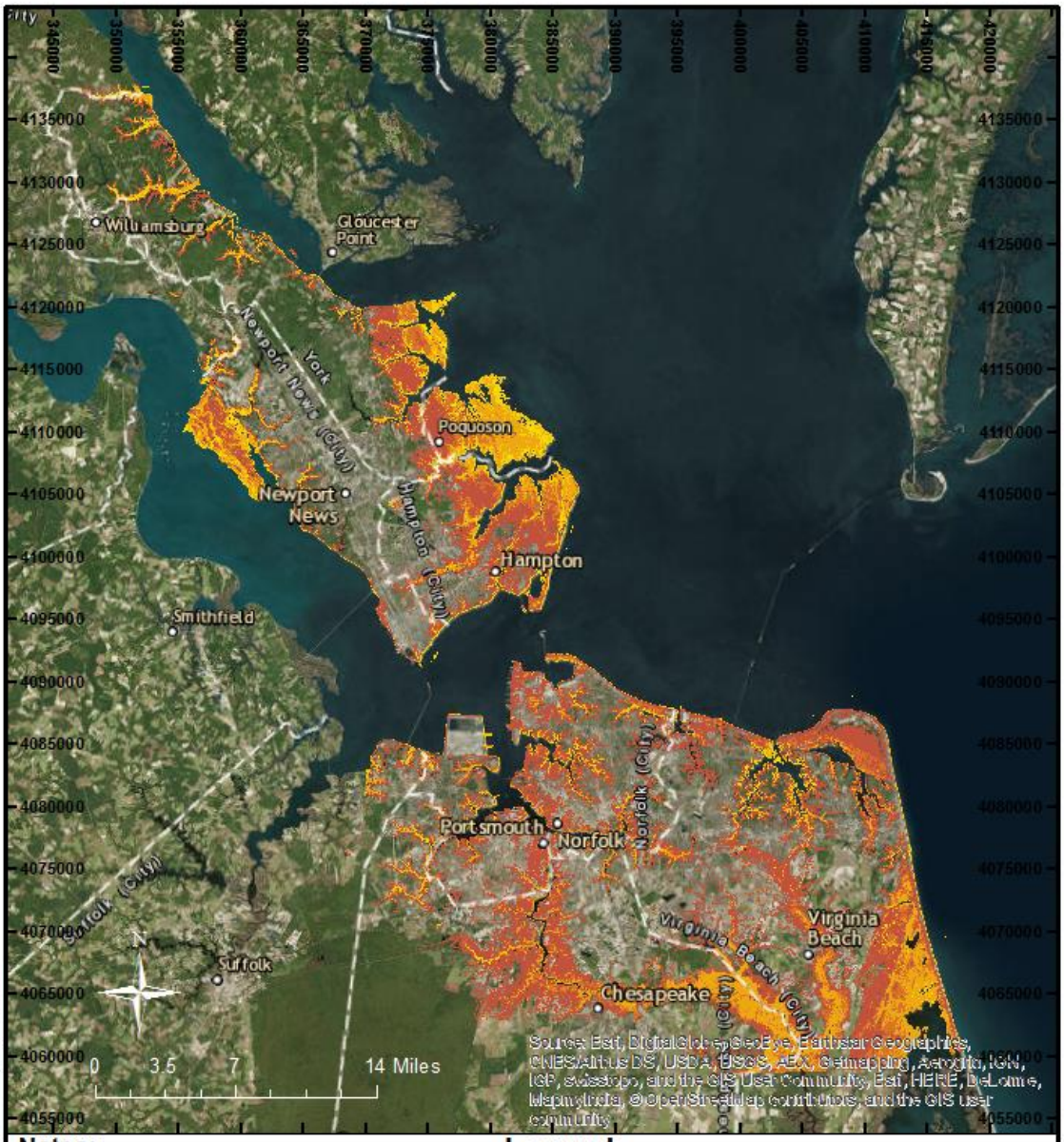
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A11**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr4_cat1.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat2
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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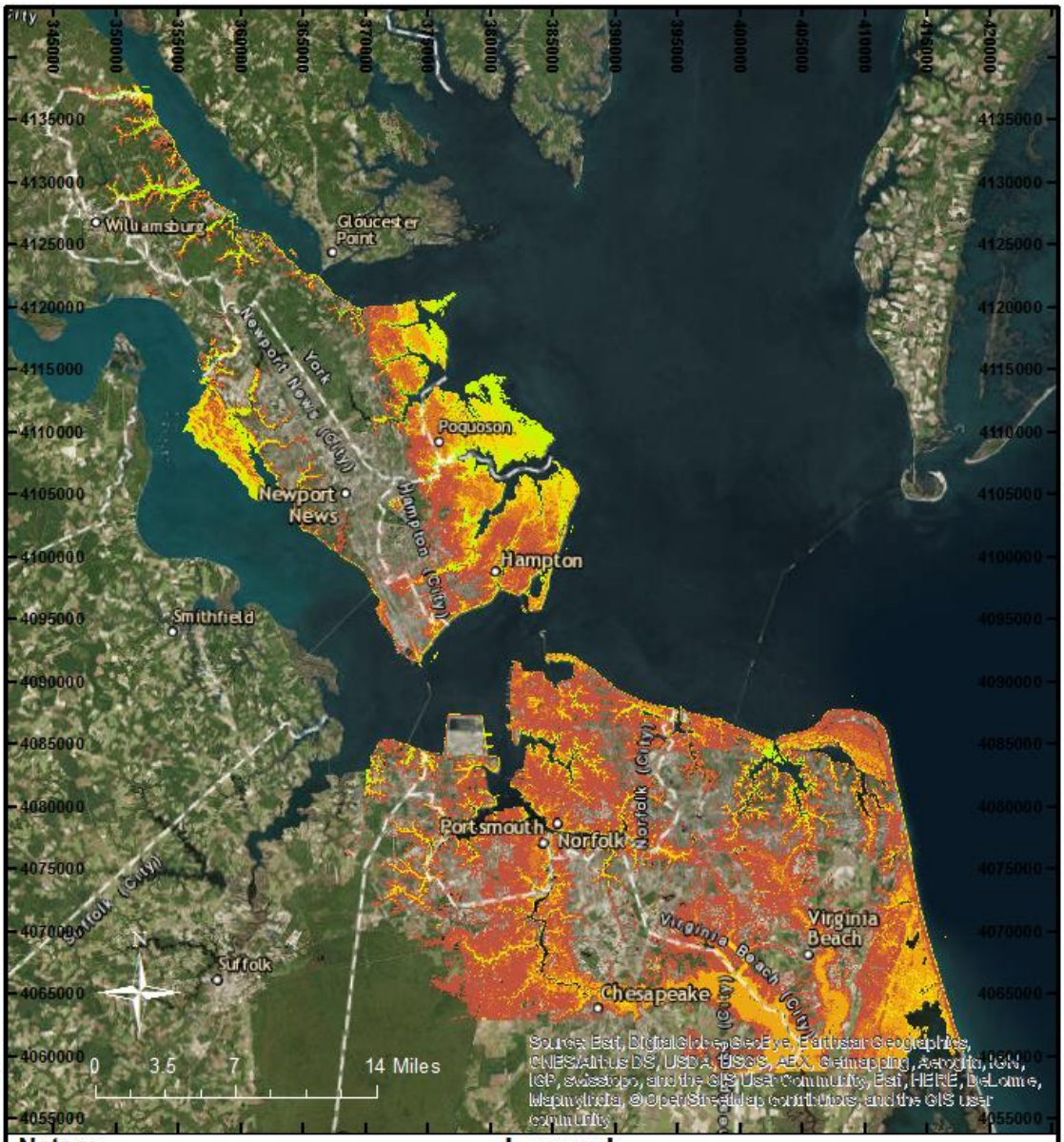
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A12**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\hampton_slr4_cat2.mxd



Notes:

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2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat3
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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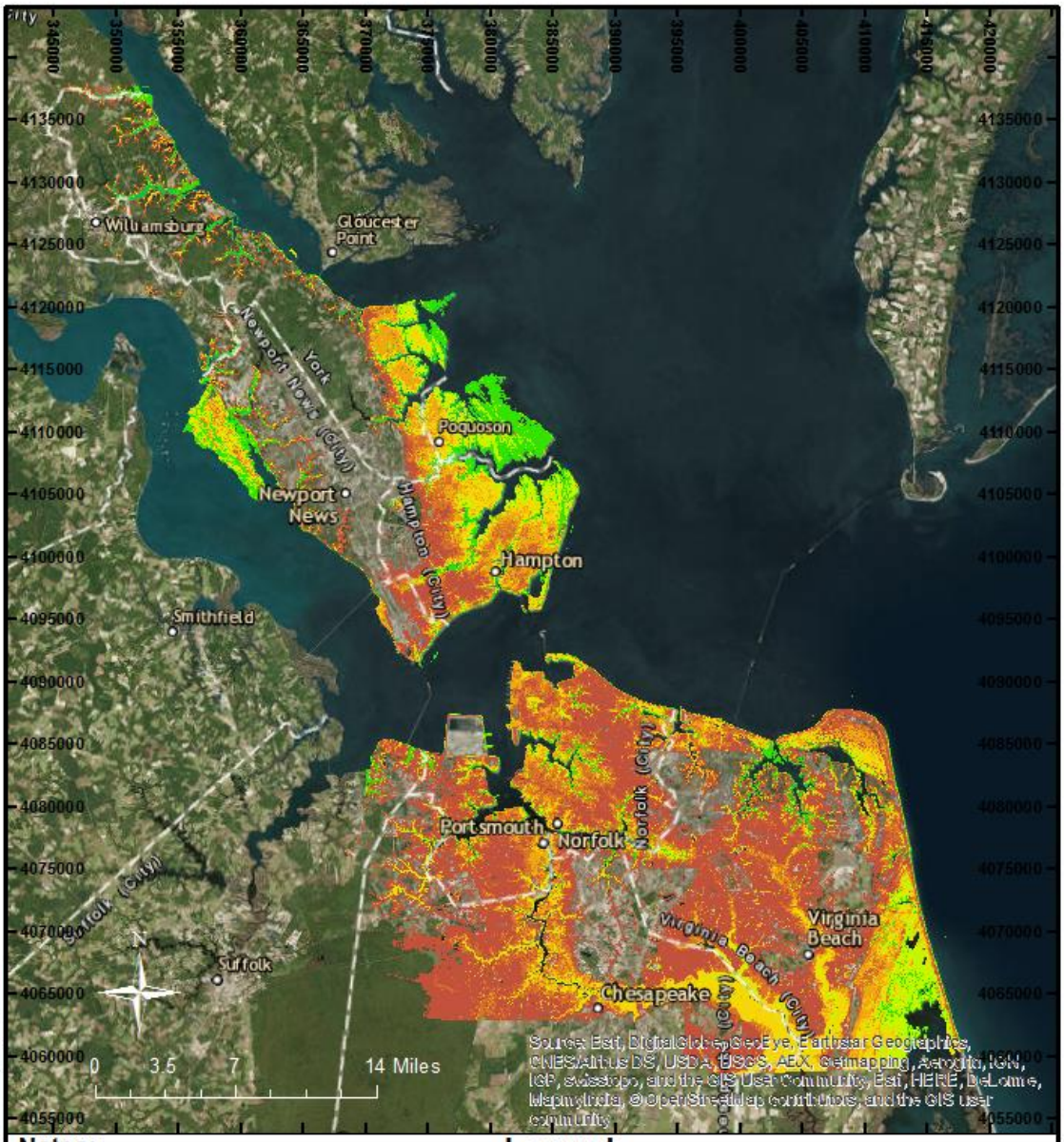
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A13**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\hampton_slr4_cat3.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat4
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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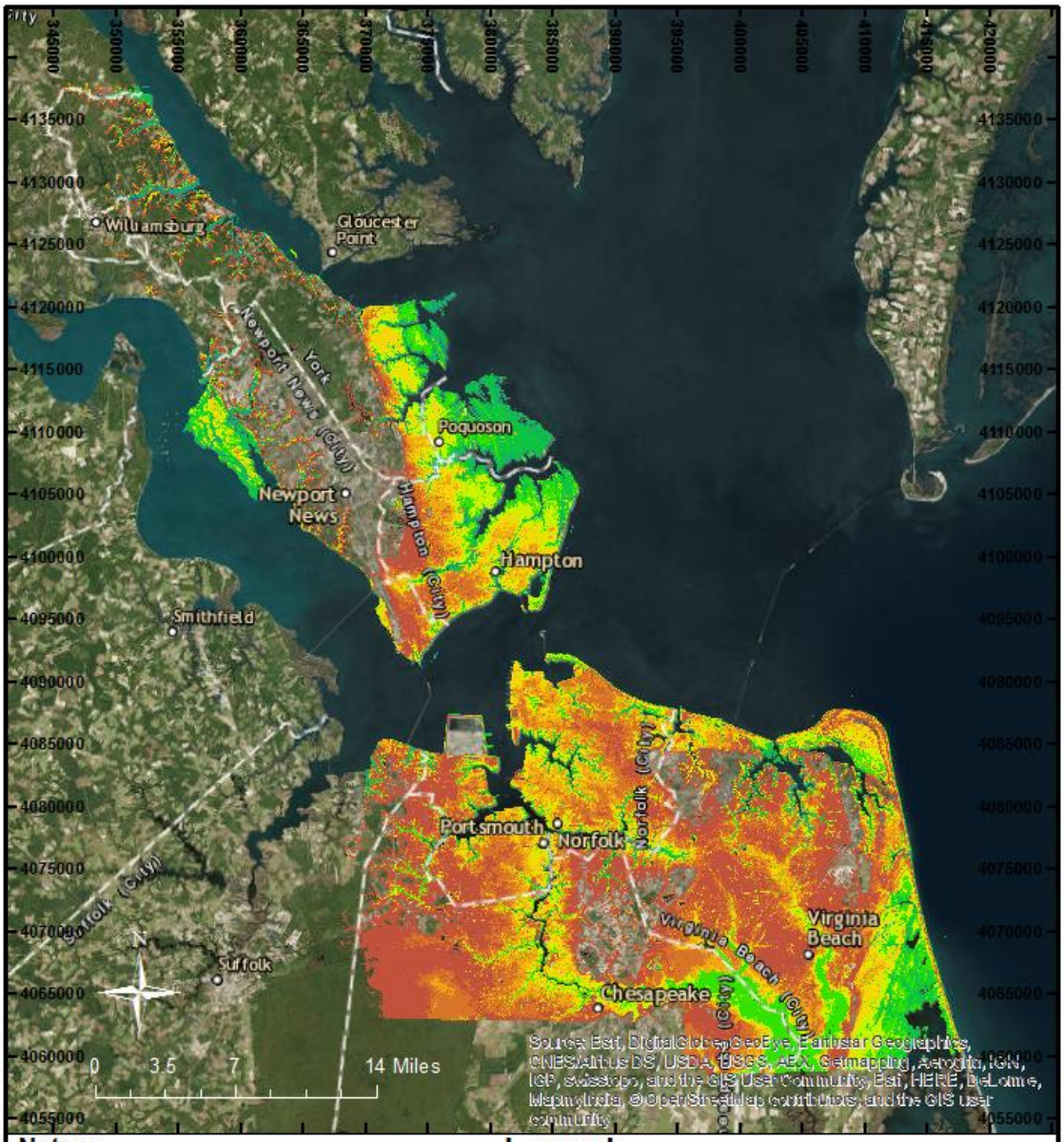
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr4_cat4.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR4_Cat5
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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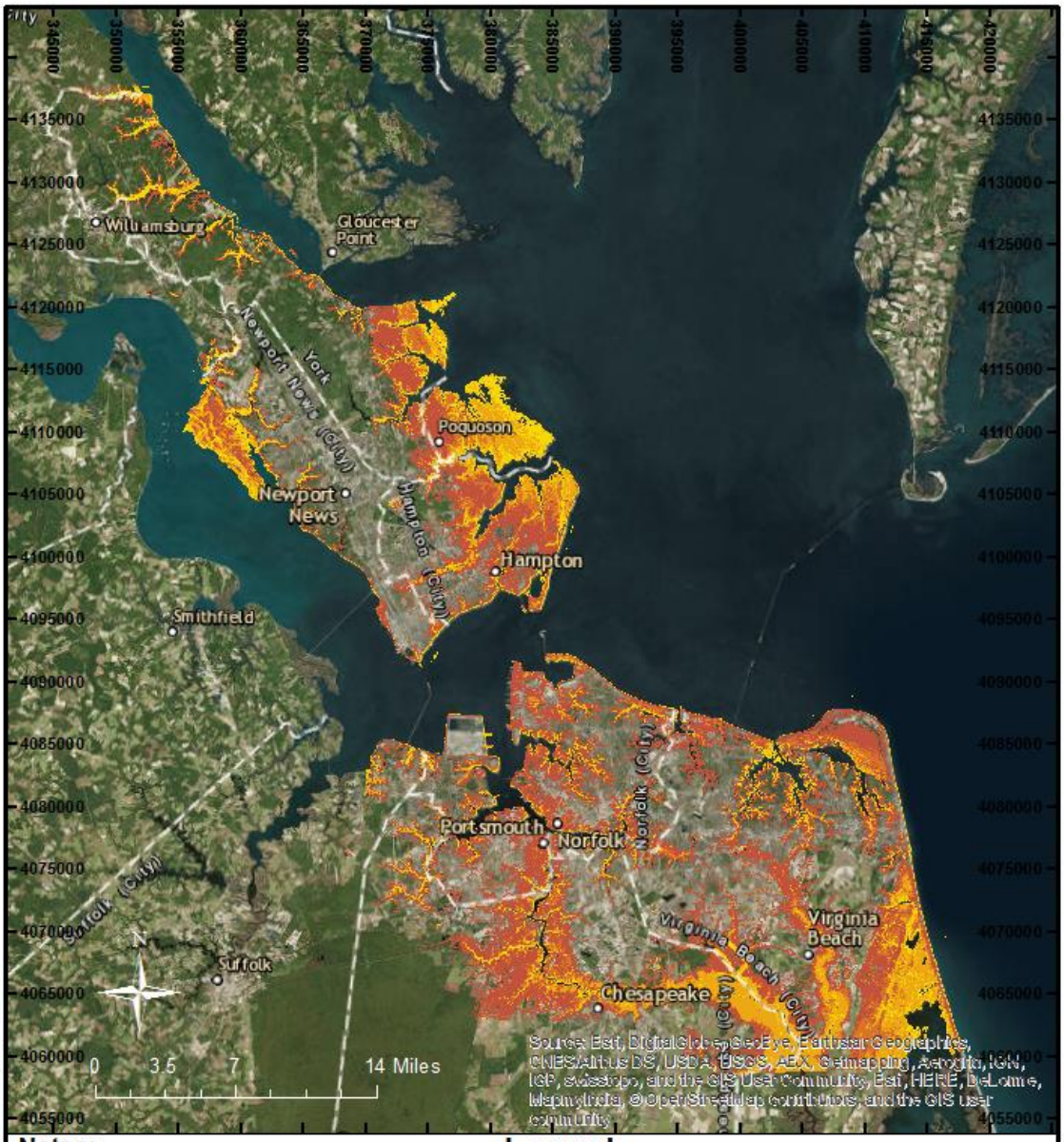
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A15**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr4_cat5.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat1
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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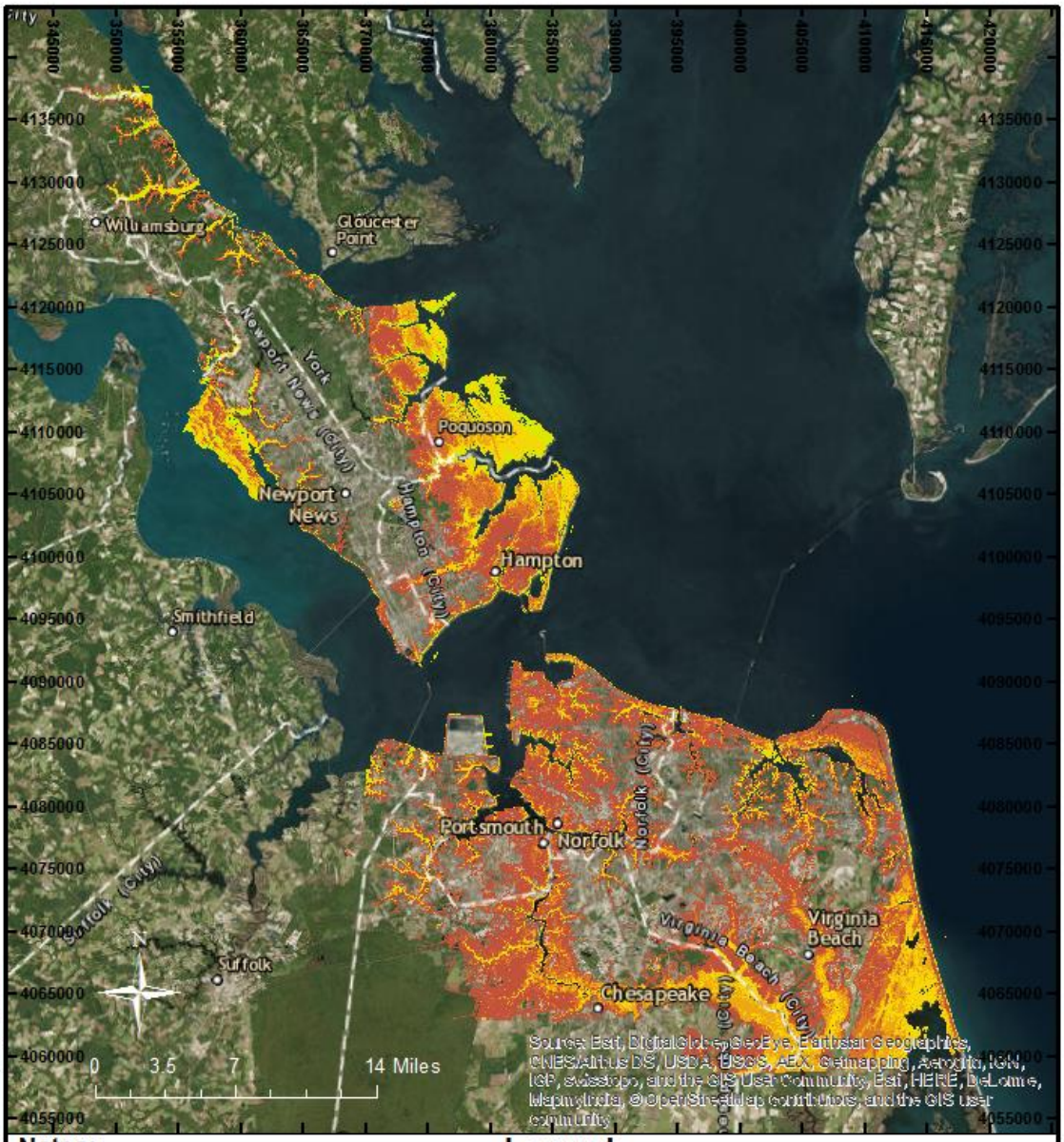
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr6_cat1.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat2
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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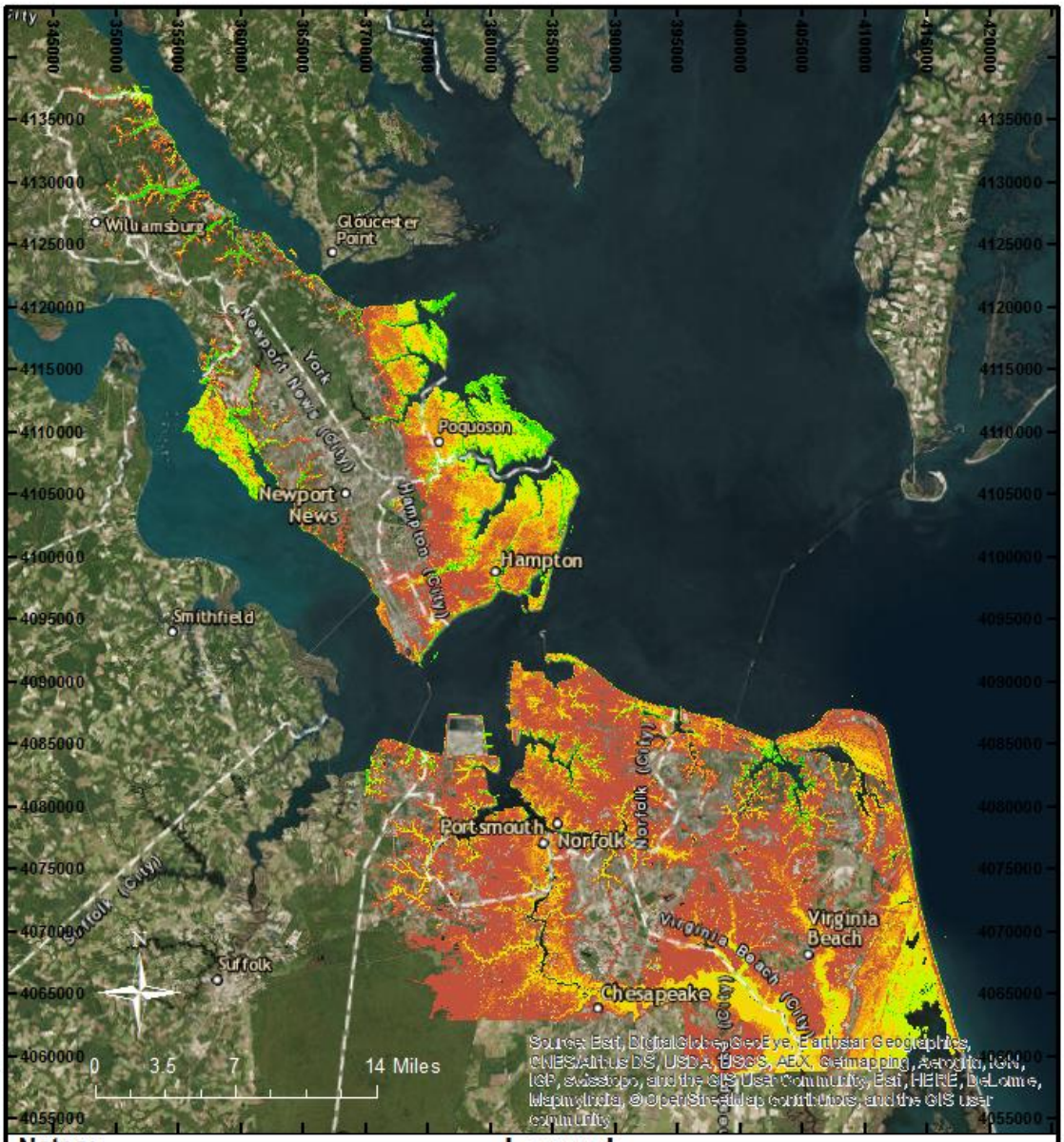
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\hampton_slr6_cat2.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat3

Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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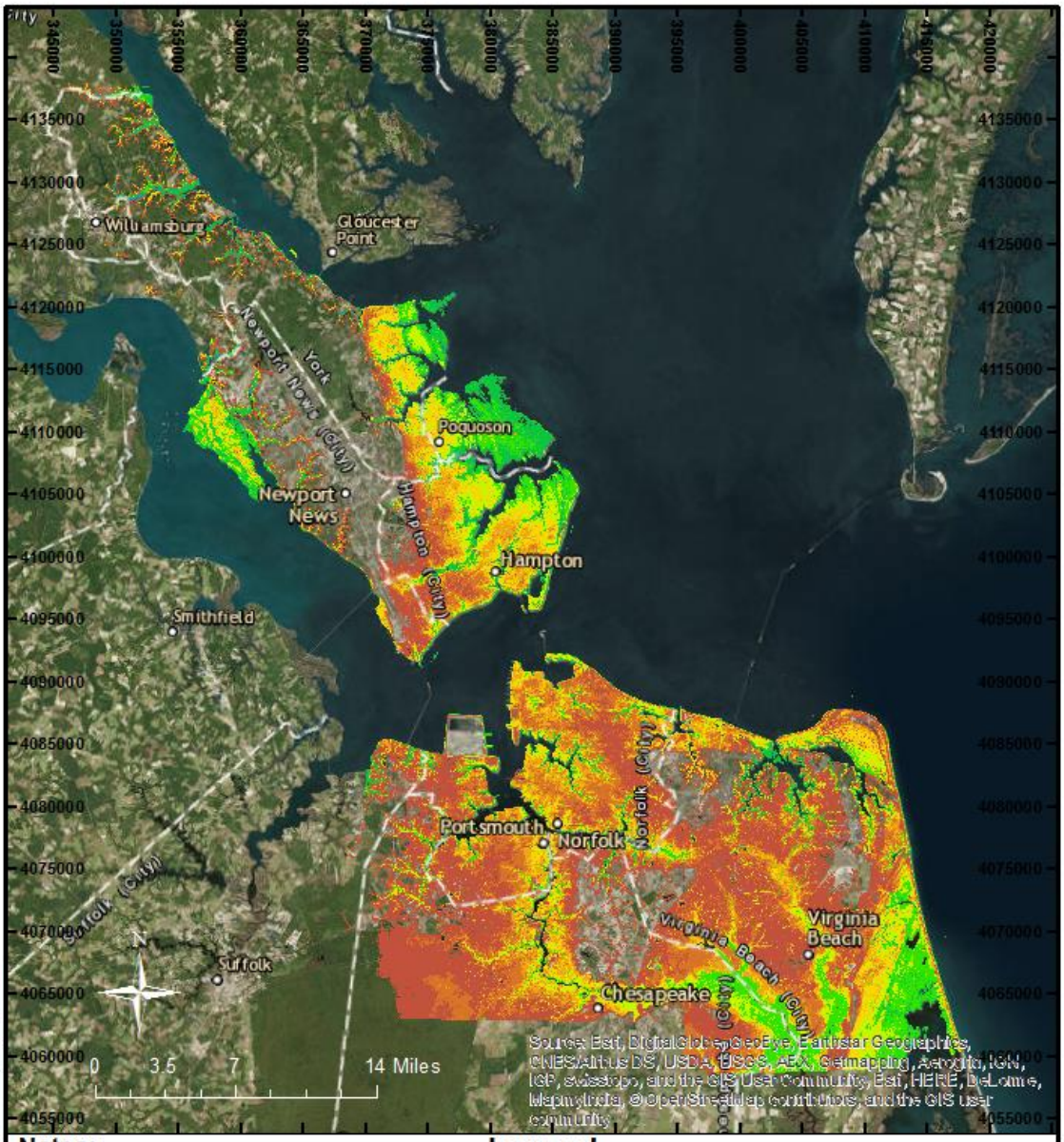
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A18**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr6_cat3.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat4
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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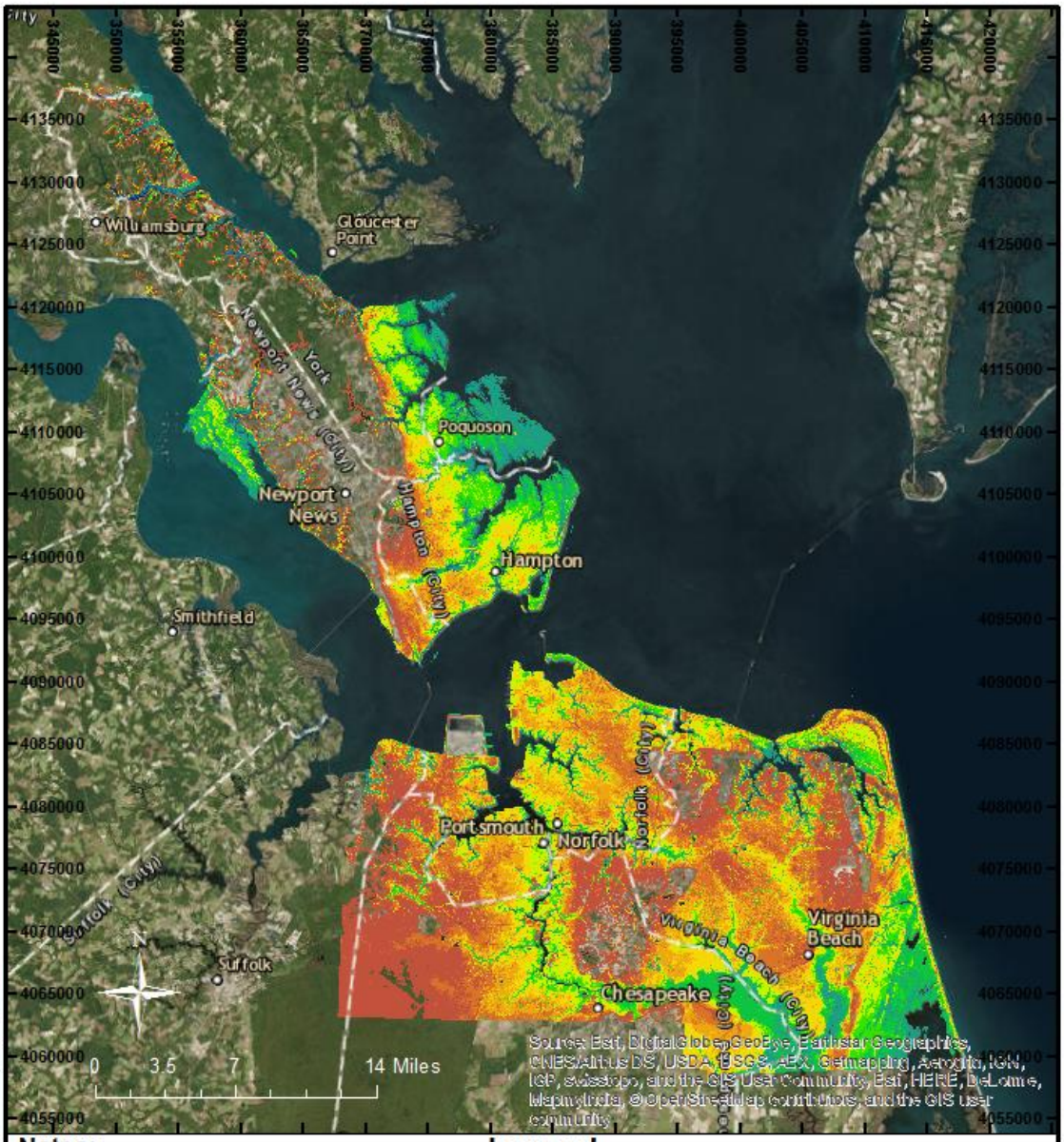
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A19**

G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr6_cat4.mxd



Notes:

1. Coordinates are in meters based on the UTM Coordinate System, Zone 18, North American Datum of 1983 (NAD 83).
2. Aerial photography provided by ESRI Base Maps, collected in 2013.
3. Elevations are water level above ground in meters.

Legend

SLR6_Cat5
Meters

0.0 - 0.7	1.4 - 2.1	4.2 - 4.9
0.7 - 1.4	2.1 - 2.8	4.9 - 5.6
	2.8 - 3.5	5.6 - 6.3
	3.5 - 4.2	6.3 - 7.0

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SLOSH SLR 6, Category 5
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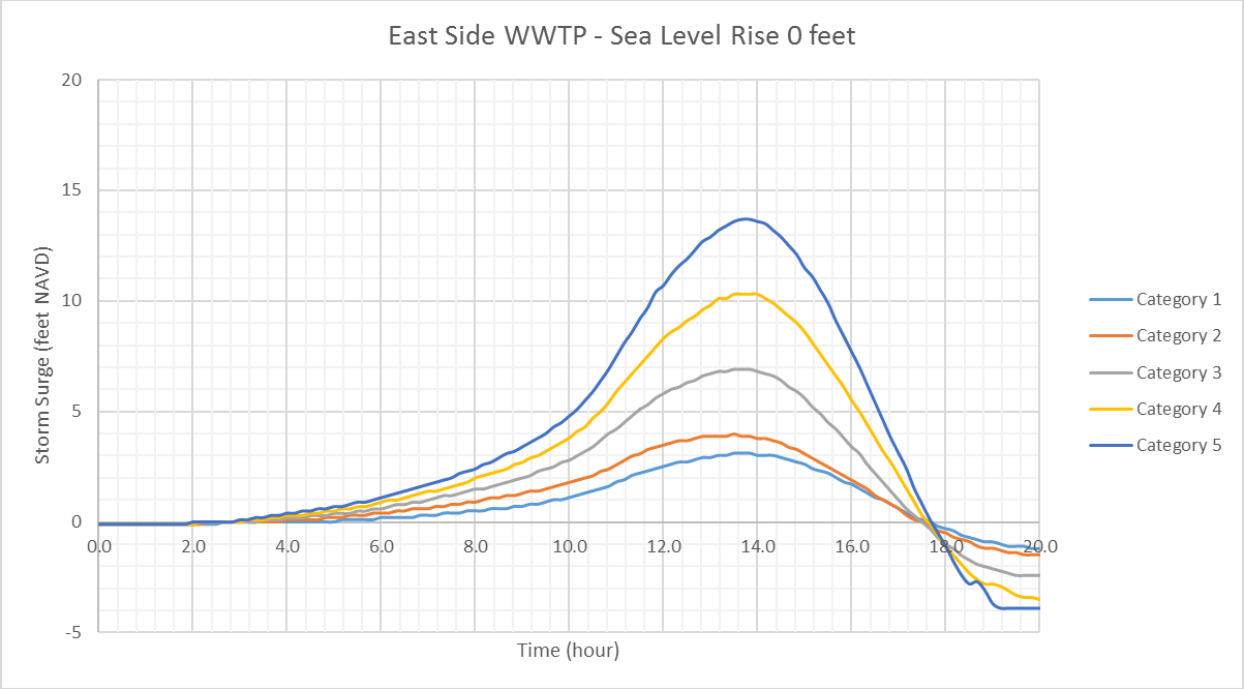
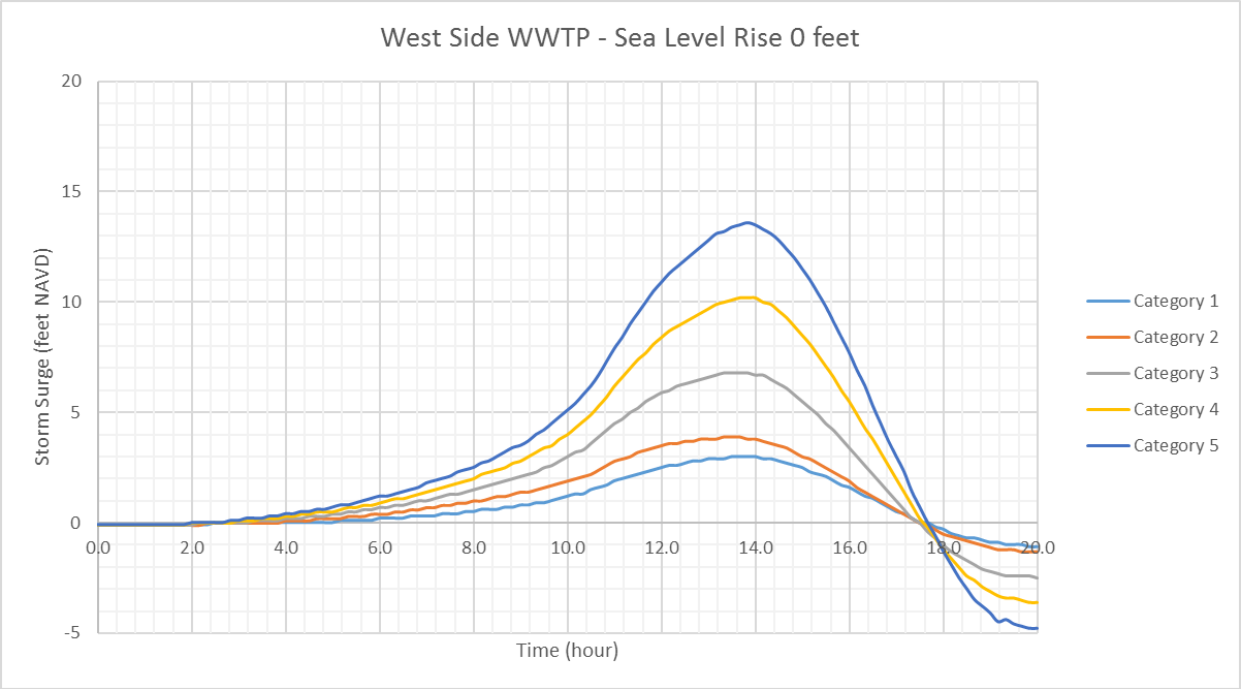
Date: 11/01/2016 | By: ZD | Comm. No.: 77500645 | **Figure No. A20**

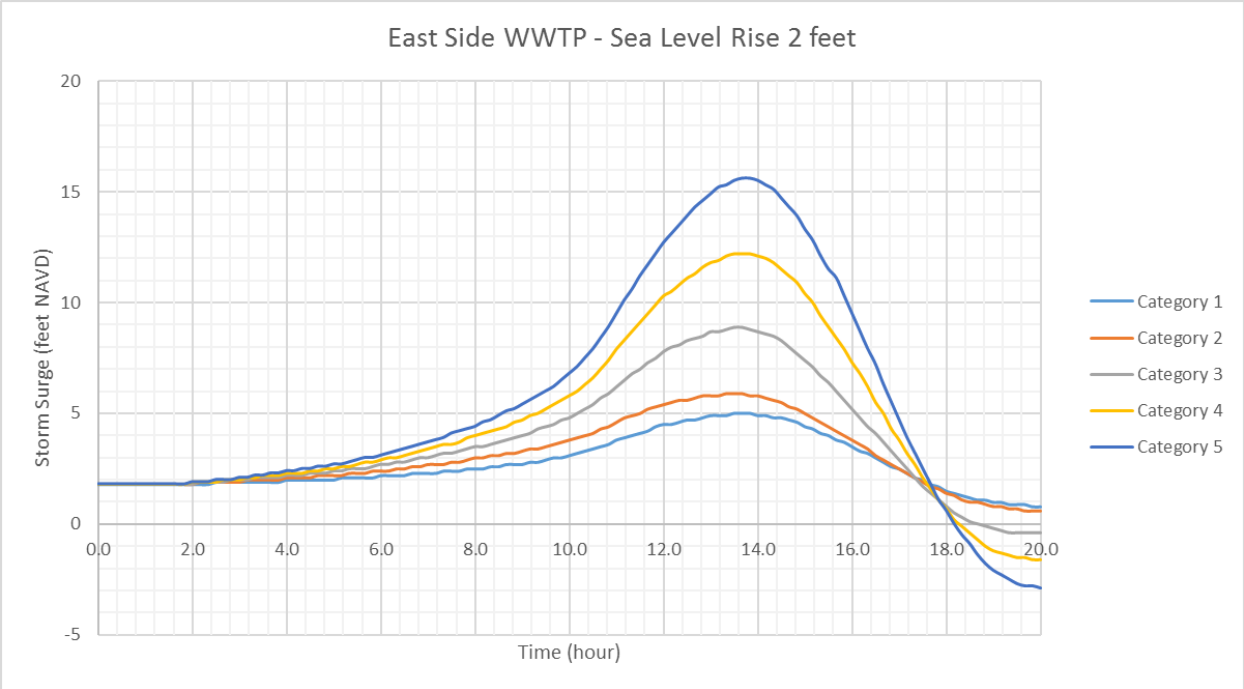
G:\Enterprise\Massachusetts\77500645_SLOSH_Modeling_Phase_2\mxd\Hampton_slr6_cat5.mxd

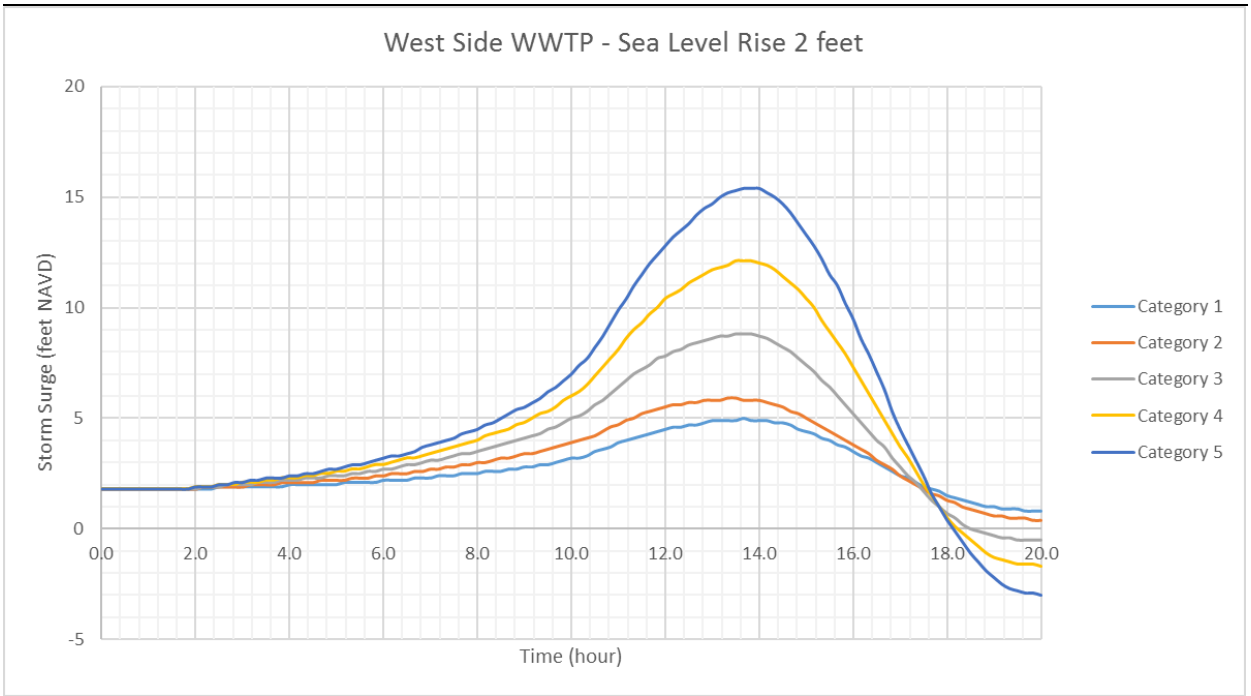
Appendix B-1

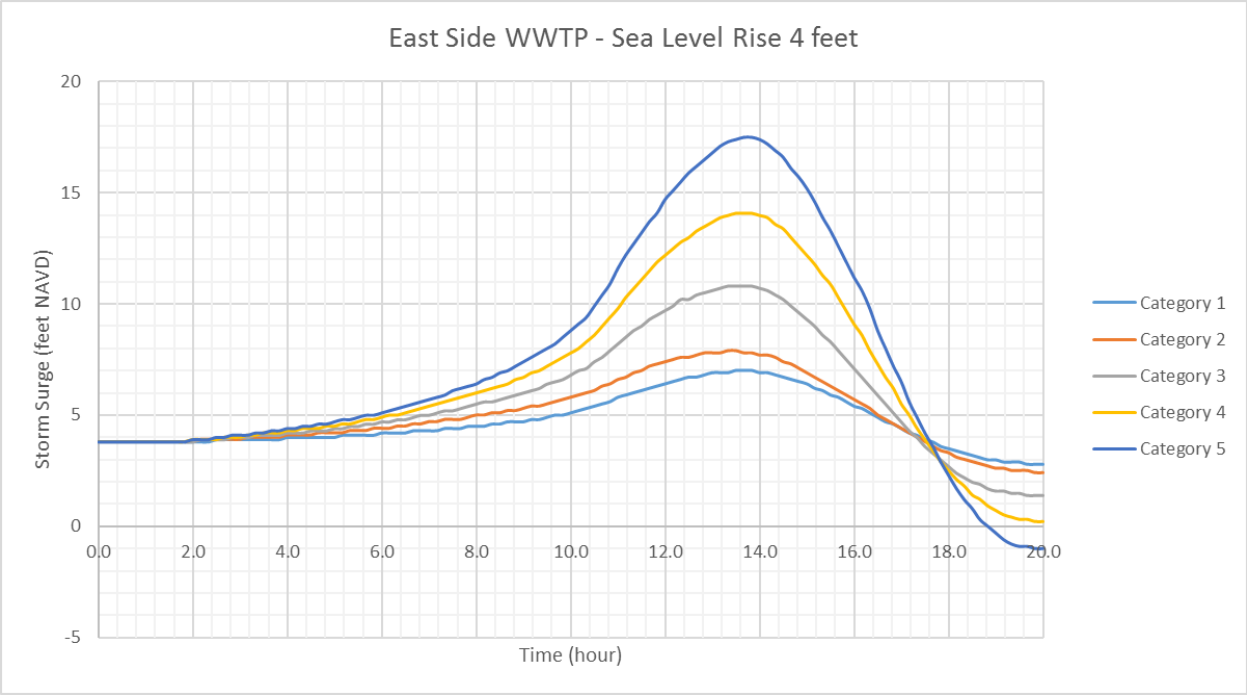
Time Series Plot for Bridgeport, CT

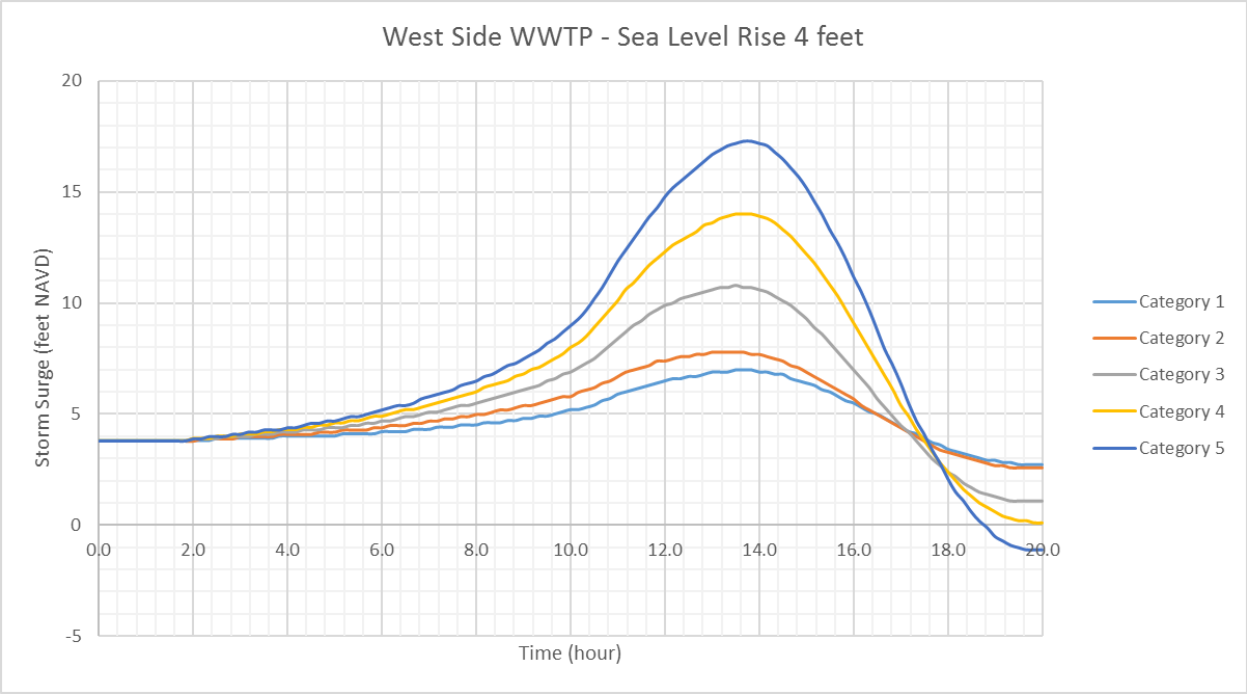

East Side WWTP - Sea Level Rise 0 feet
Storm Surge (feet NAVD)
Time (hour)
20
15
10
5
0
-5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Category 1
Category 2
Category 3
Category 4
Category 5

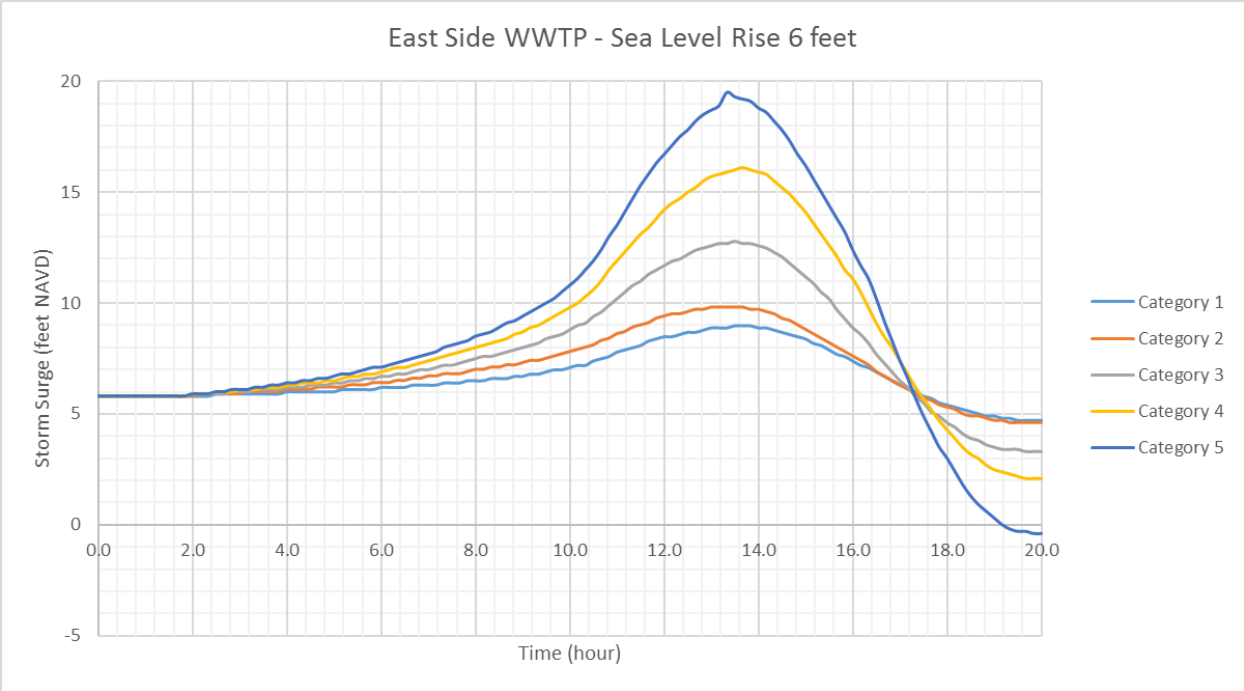

West Side WWTP - Sea Level Rise 0 feet
Storm Surge (feet NAVD)
Time (hour)
20
15
10
5
0
-5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Category 1
Category 2
Category 3
Category 4
Category 5

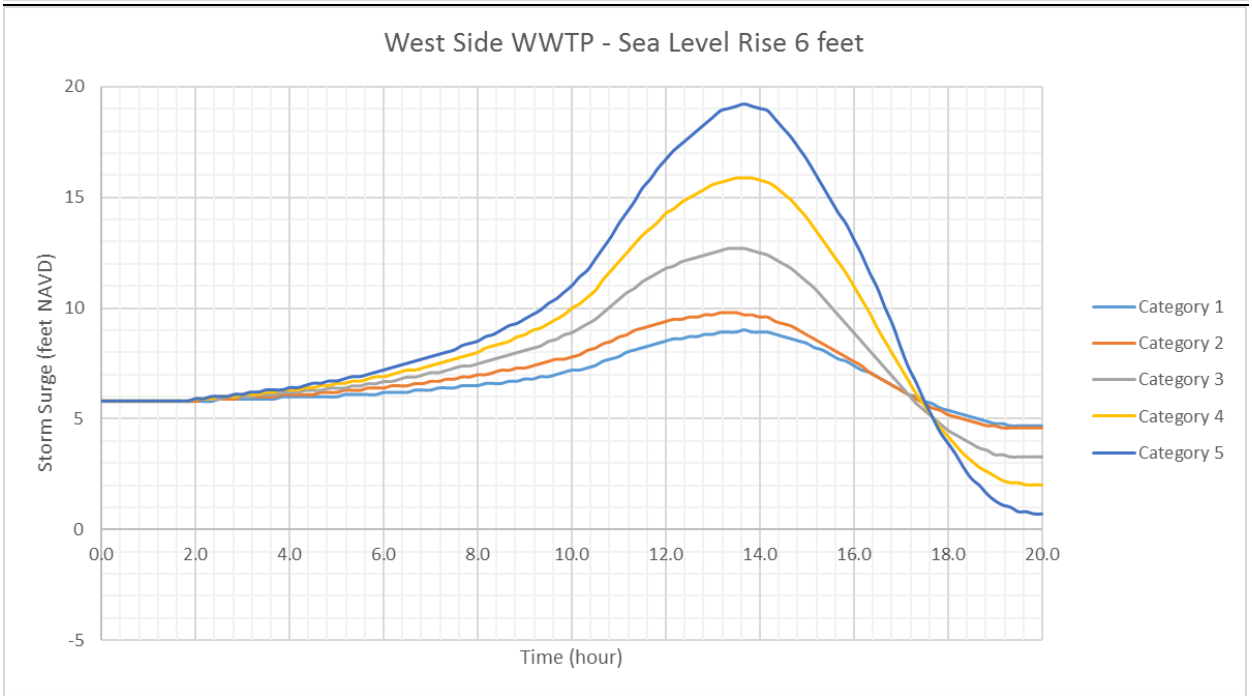

East Side WWTP - Sea Level Rise 2 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


West Side WWTP - Sea Level Rise 2 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


East Side WWTP - Sea Level Rise 4 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5

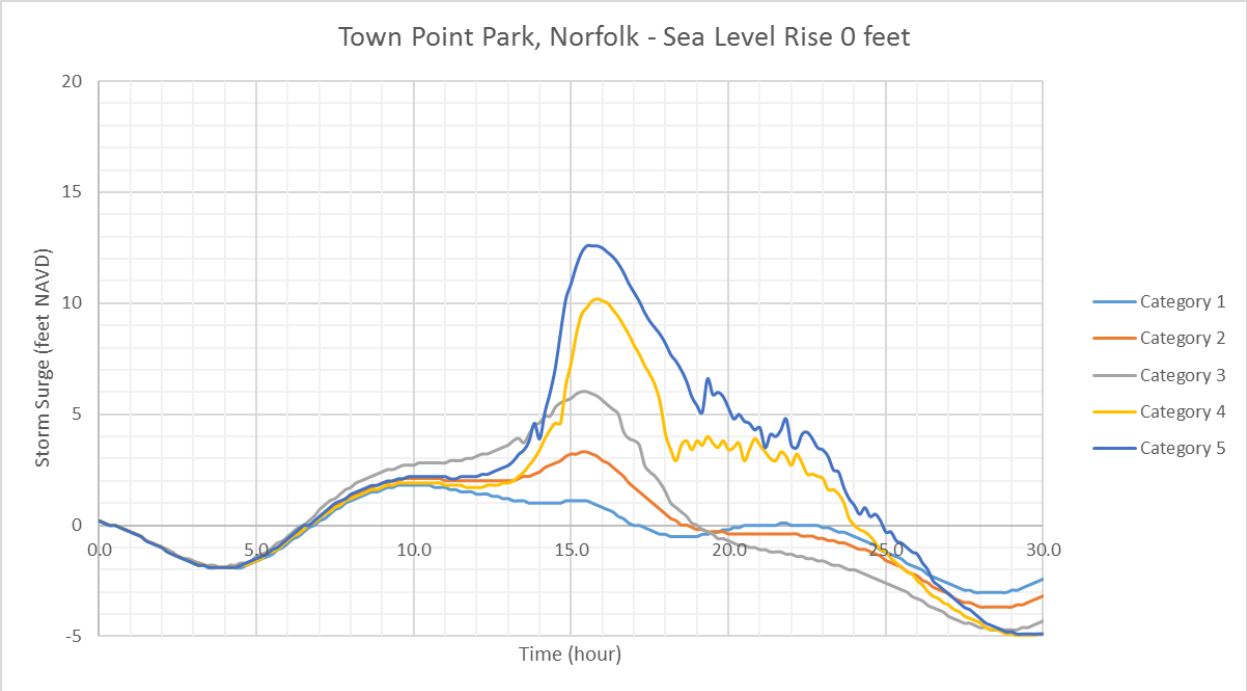

West Side WWTP - Sea Level Rise 4 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5

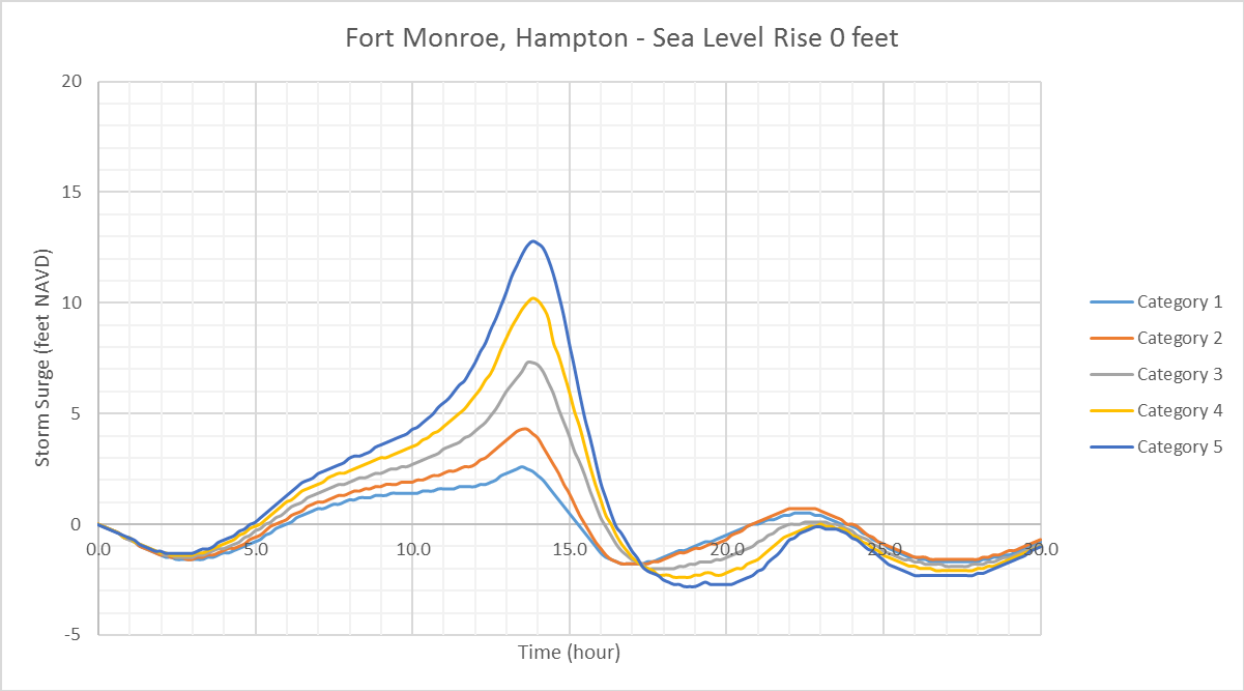

East Side WWTP - Sea Level Rise 6 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5

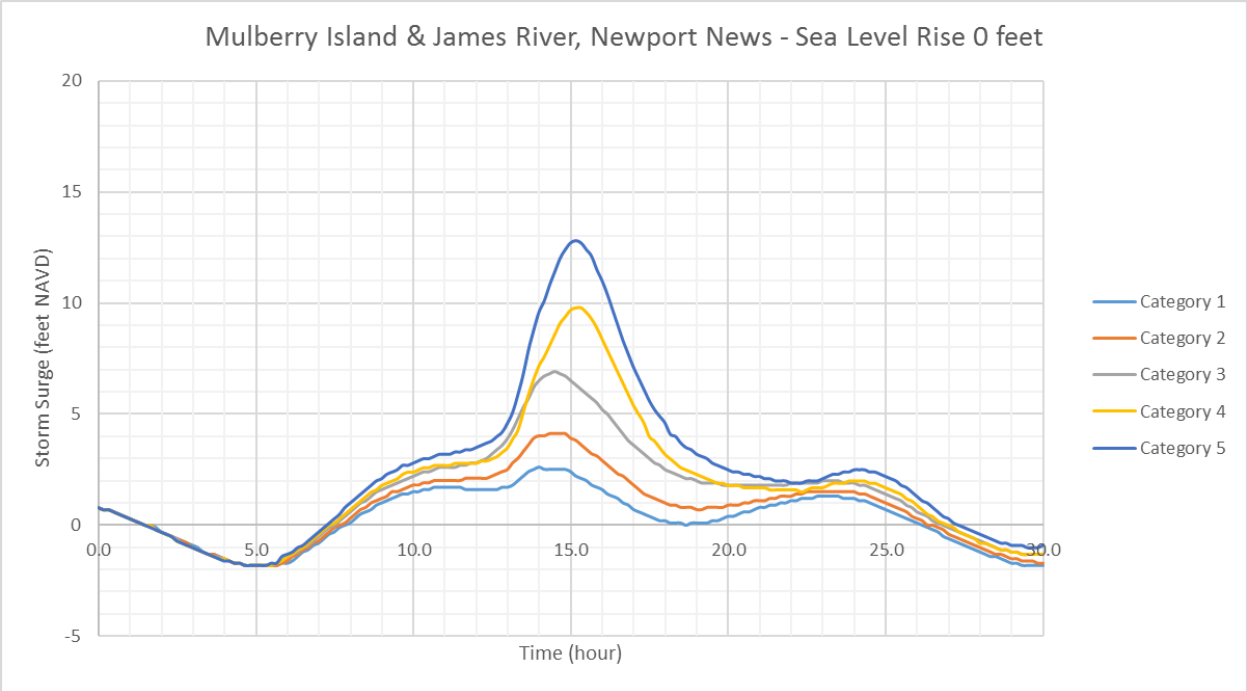

West Side WWTP - Sea Level Rise 6 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5

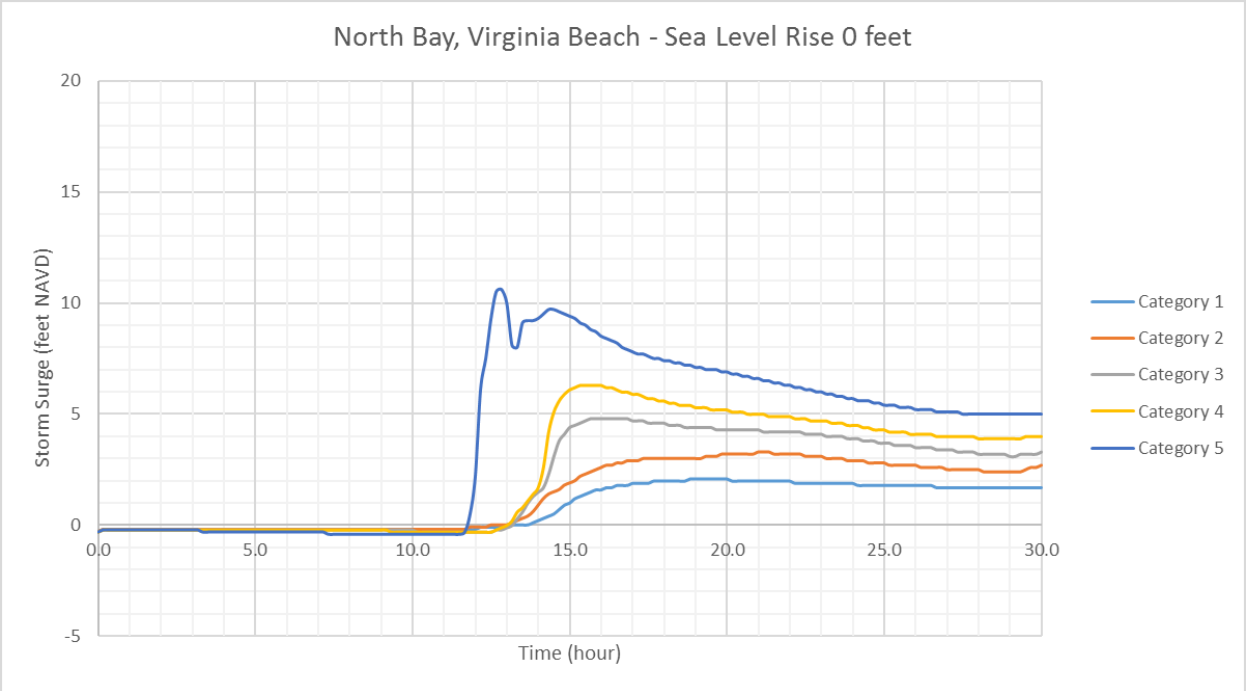
Appendix B-2

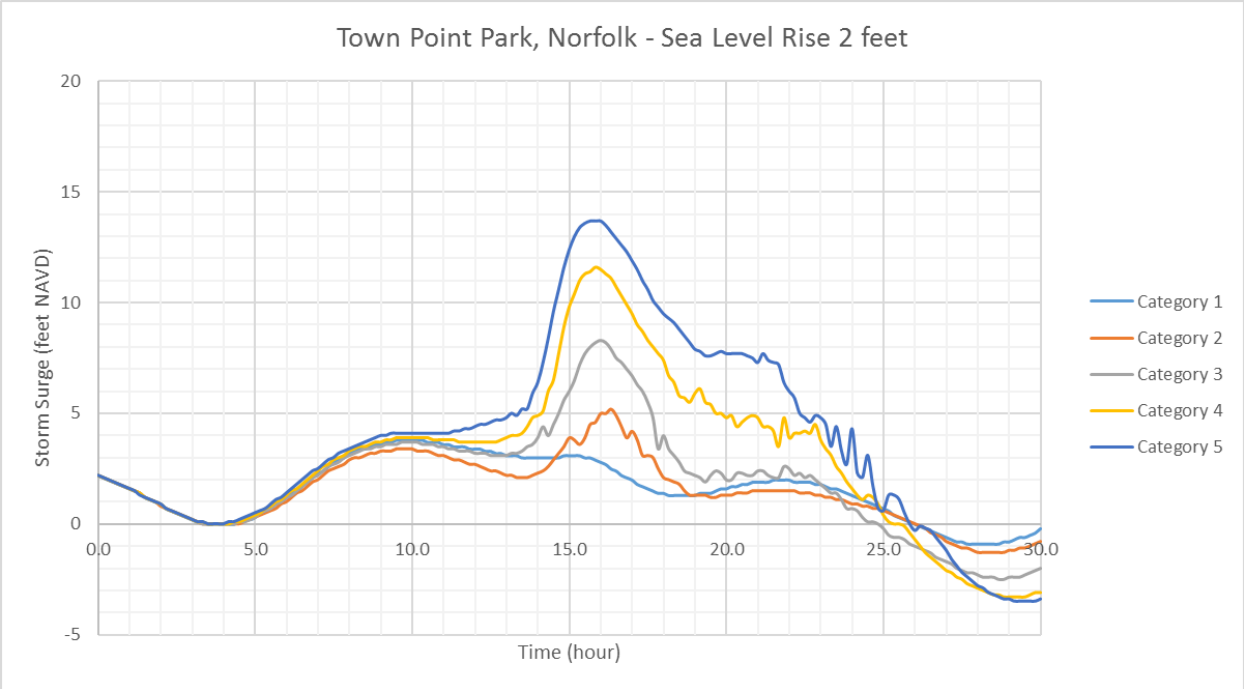
Time Series Plot for Hampton Road, VA

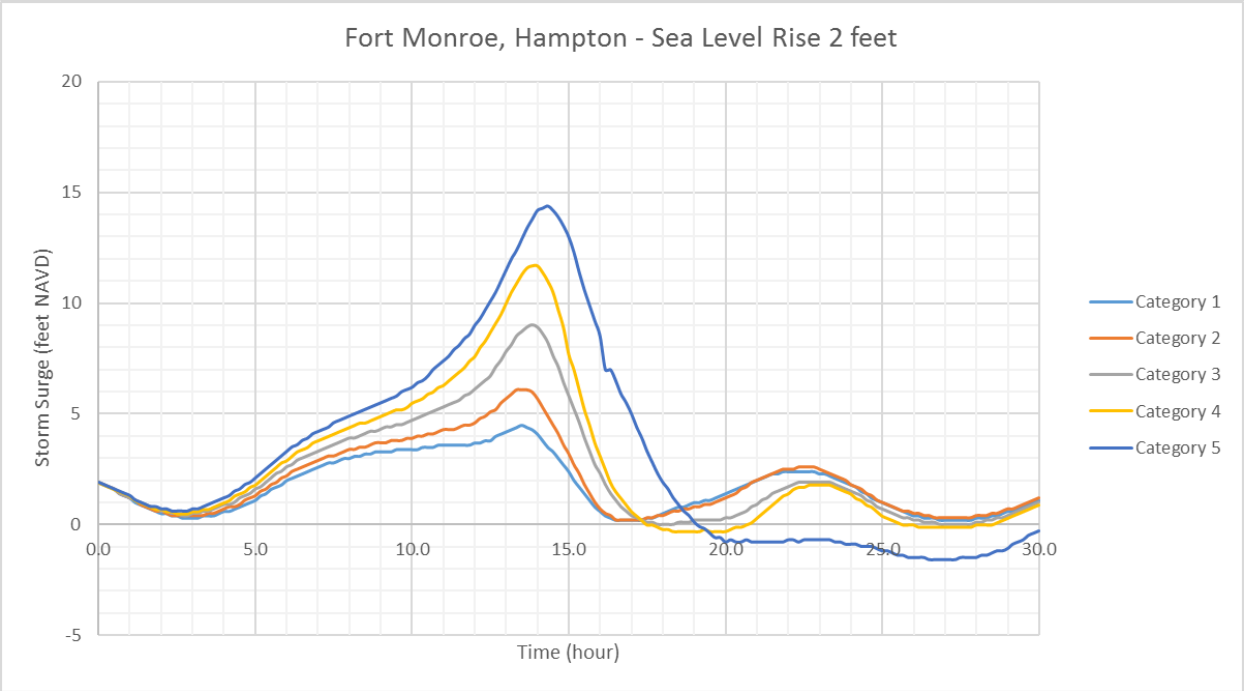

Town Point Park, Norfolk - Sea Level Rise 0 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5

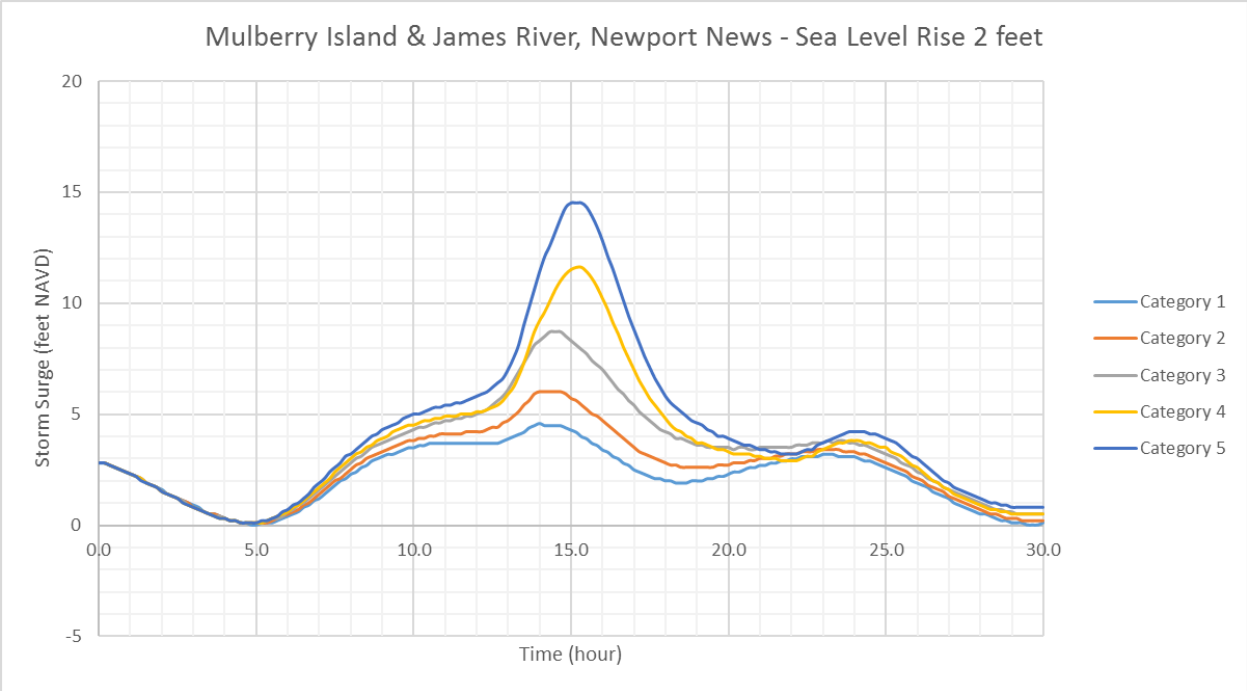

Fort Monroe, Hampton - Sea Level Rise 0 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


Mulberry Island & James River, Newport News - Sea Level Rise 0 feet
Storm Surge (feet NAVD)
Time (hour)
20
15
10
5
0
-5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Category 1
Category 2
Category 3
Category 4
Category 5


North Bay, Virginia Beach - Sea Level Rise 0 feet
Storm Surge (feet NAVD)
Time (hour)
20
15
10
5
0
-5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Category 1
Category 2
Category 3
Category 4
Category 5


Town Point Park, Norfolk - Sea Level Rise 2 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


Fort Monroe, Hampton - Sea Level Rise 2 feet
Storm Surge (feet NAVD)
20
15
10
5
0
-5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


Mulberry Island & James River, Newport News - Sea Level Rise 2 feet
Storm Surge (feet NAVD)
Time (hour)
20
15
10
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5.0
10.0
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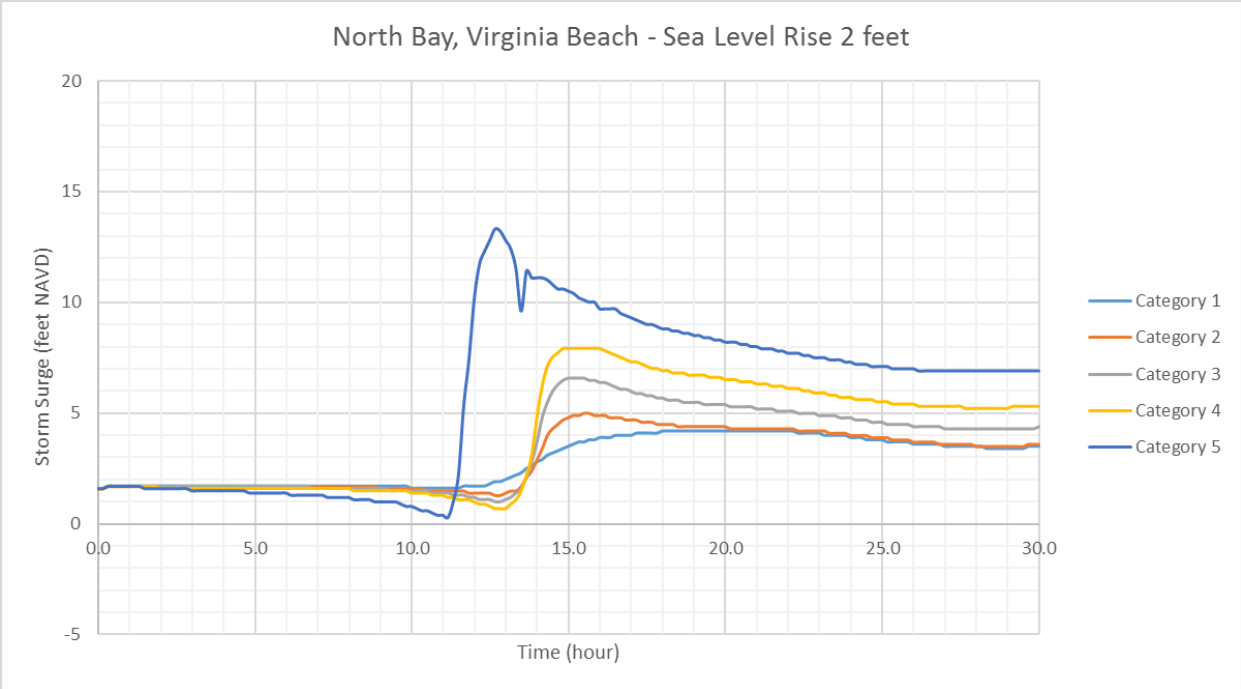
20.0
25.0
30.0
Category 1
Category 2
Category 3
Category 4
Category 5


North Bay, Virginia Beach - Sea Level Rise 2 feet
Storm Surge (feet NAVD)
Time (hour)
20
15
10
5
0
-5
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10.0
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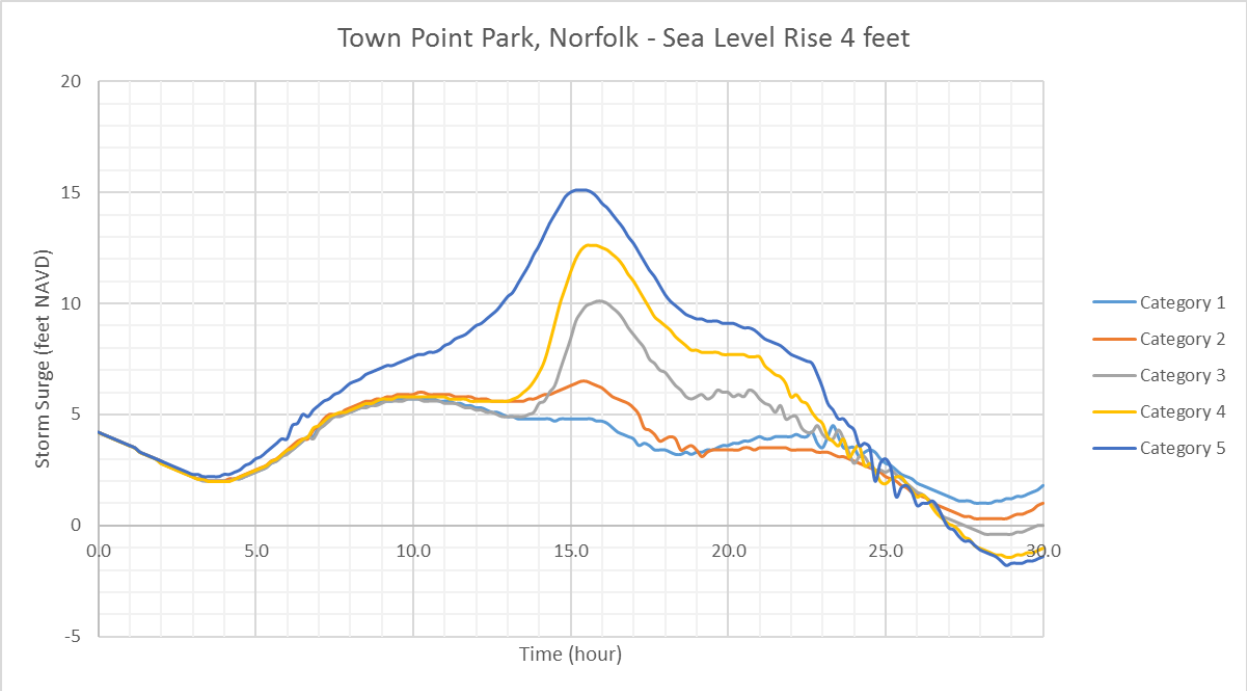
20.0
25.0
30.0
Category 1
Category 2
Category 3
Category 4
Category 5


Town Point Park, Norfolk - Sea Level Rise 4 feet
Storm Surge (feet NAVD)
Time (hour)
20
15
10
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-5
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5.0
10.0
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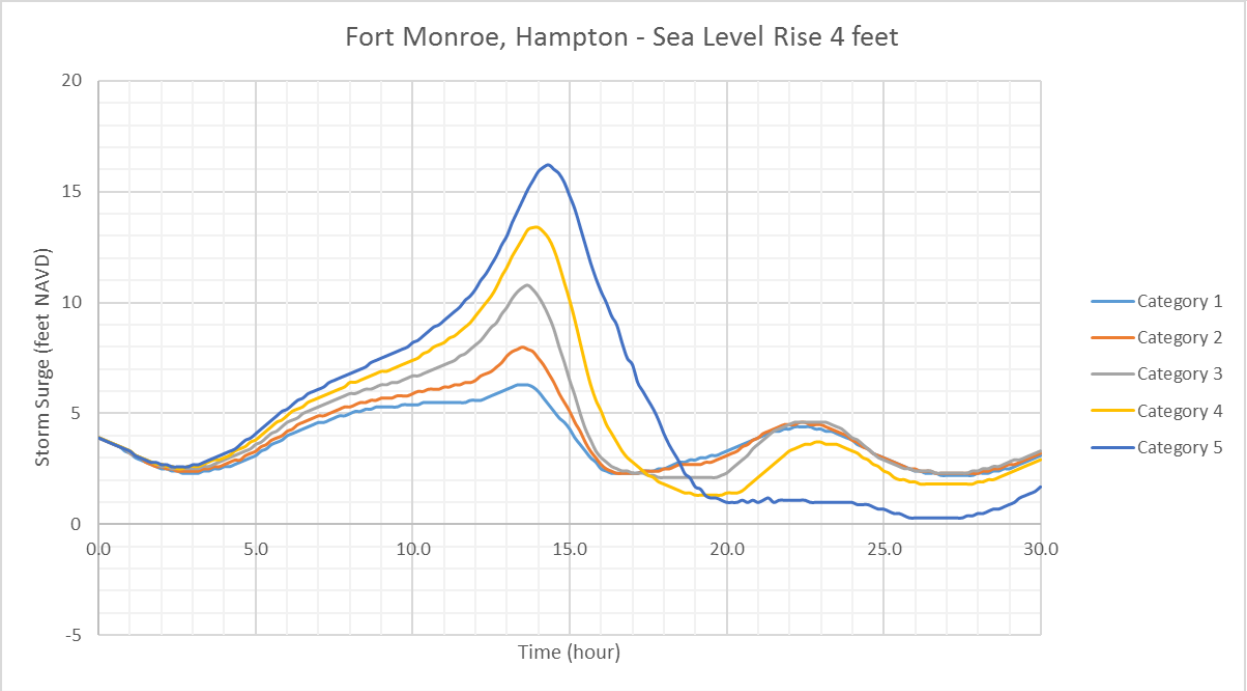
20.0
25.0
30.0
Category 1
Category 2
Category 3
Category 4
Category 5


Fort Monroe, Hampton - Sea Level Rise 4 feet
Storm Surge (feet NAVD)
Time (hour)
20
15
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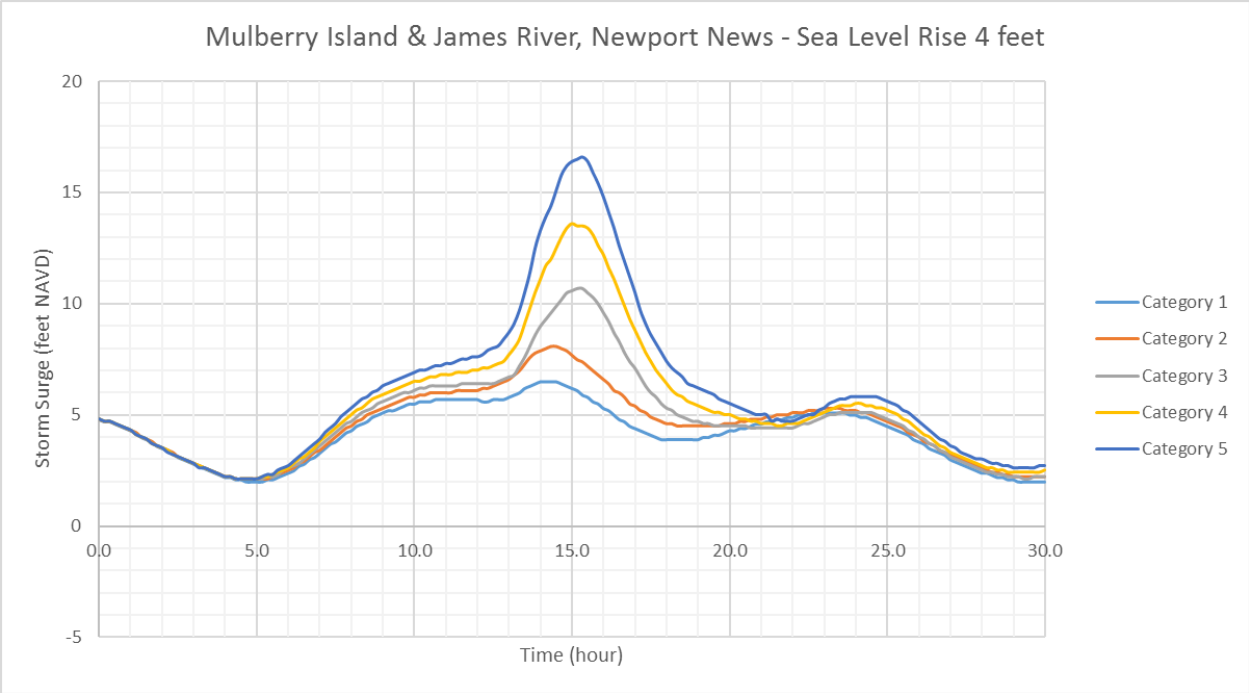
25.0
30.0
Category 1
Category 2
Category 3
Category 4
Category 5


Mulberry Island & James River, Newport News - Sea Level Rise 4 feet
Storm Surge (feet NAVD)
20
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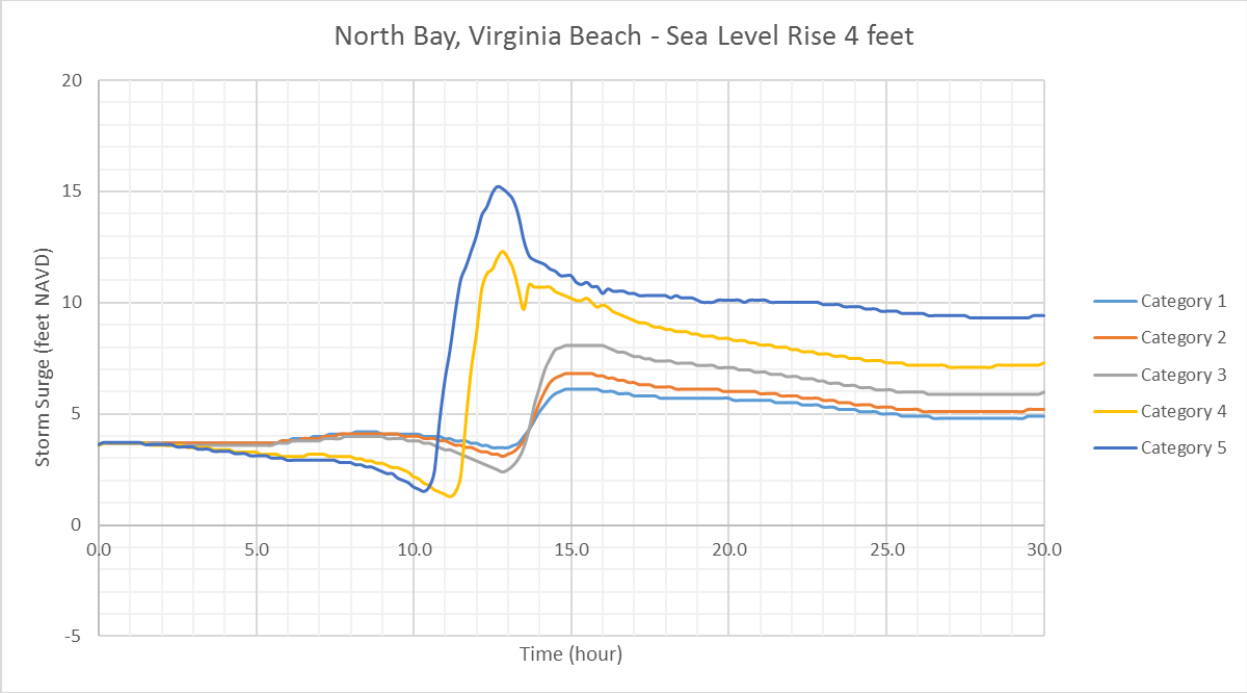
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


North Bay, Virginia Beach - Sea Level Rise 4 feet
Storm Surge (feet NAVD)
20
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5
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-5
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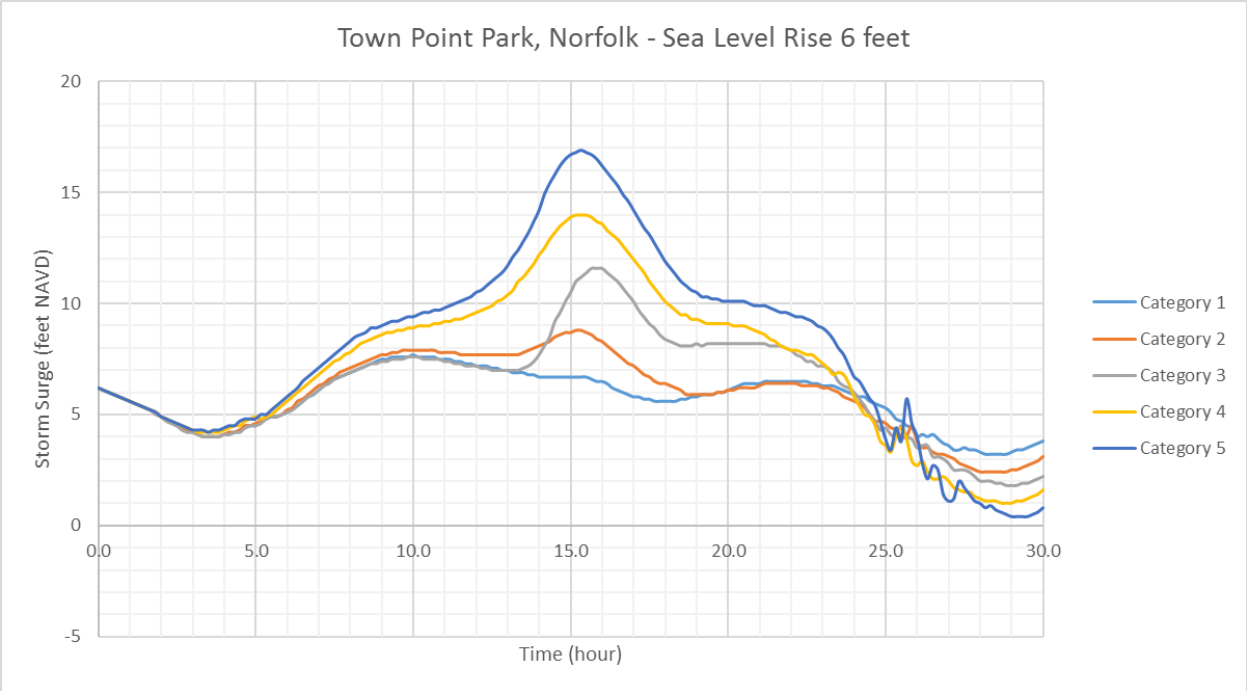
10.0
15.0
20.0
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


Town Point Park, Norfolk - Sea Level Rise 6 feet
Storm Surge (feet NAVD)
20
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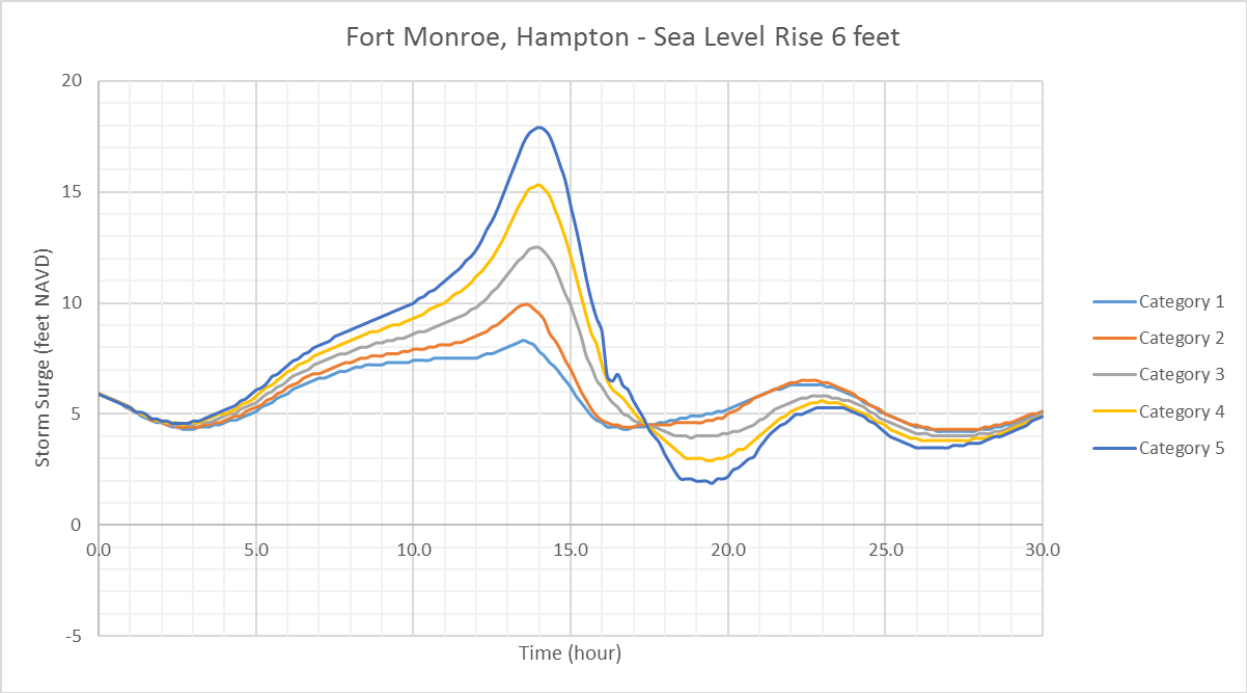
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


Fort Monroe, Hampton - Sea Level Rise 6 feet
Storm Surge (feet NAVD)
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-5
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5.0
10.0
15.0
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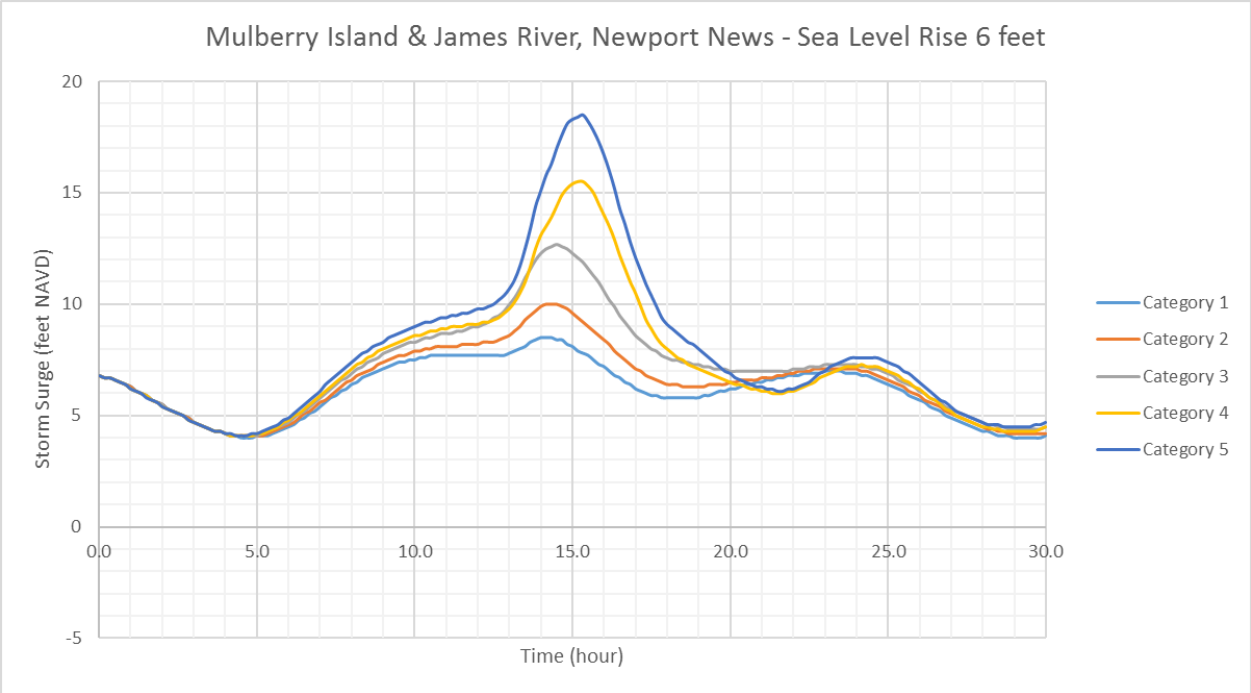
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


Mulberry Island & James River, Newport News - Sea Level Rise 6 feet
Storm Surge (feet NAVD)
20
15
10
5
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-5
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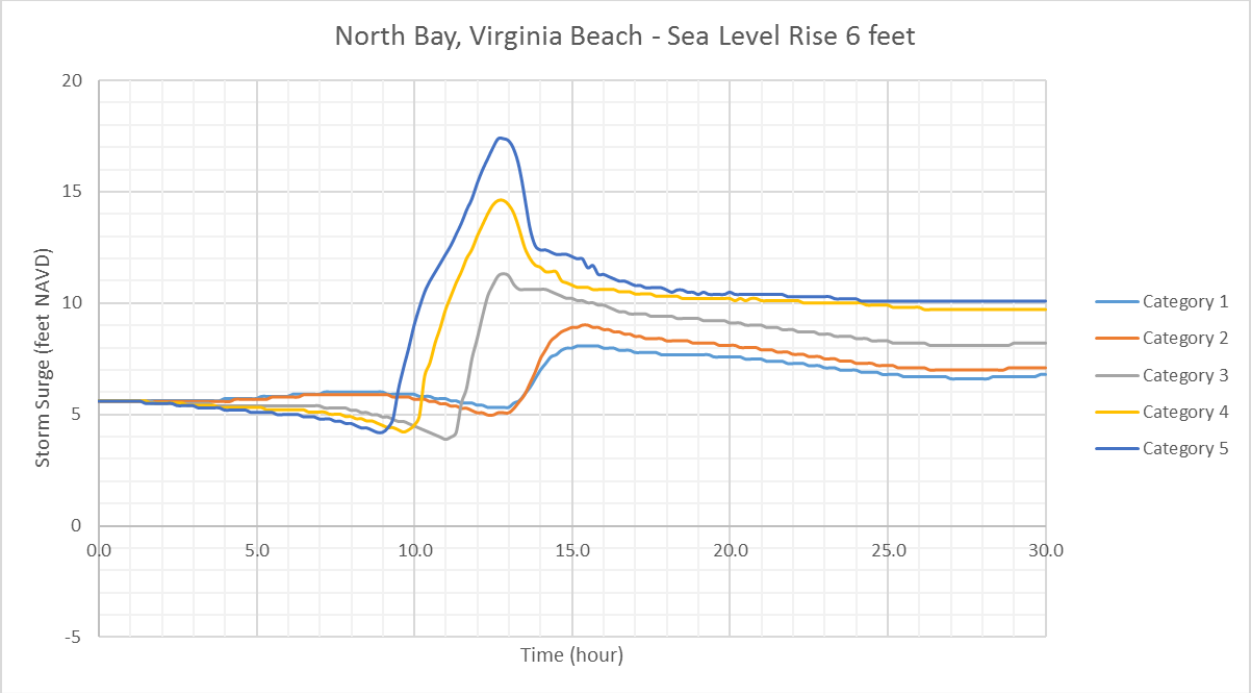
20.0
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5


North Bay, Virginia Beach - Sea Level Rise 6 feet
Storm Surge (feet NAVD)
20
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0
-5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Time (hour)
Category 1
Category 2
Category 3
Category 4
Category 5