03

Geographic Information System (GIS) Modeling for Structures of Coastal Resilience

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3.1 Overview

For the Structures of Coastal Resilience (SCR) study, geospatial models were created to understand the consequences of flooding and its potential impact on our infrastructure, ecosystems, and coastal communities. These models incorporate information about water depth, land elevation and resiliency features and were created as a framework to support the individual SCR design teams. Elevation and coastal feature data were initially collected and combined with the use of Geographic Information Systems (GIS) to form topobathy models. A topobathy or digital elevation model (DEM) is a single surface combining the land elevation with the seafloor surface, which can be used to examine processes that occur across coastal and near shore areas.[1] These models were then analyzed with static and hydrodynamic models and GIS analyses to determine potential impacts and consequences from flooding events and simulations. Geospatial analysis provides a high level of detail for analyzing how natural and manmade threats such as sea level rise, drought, storm flooding, and development may interact with natural and nature-based coastal resiliency features.

3.2 Projections, Datums, Reference Systems

In surveying and geodesy, a datum is a reference point on the earth's surface against which position measurements are made and associated in a model of the earth for computing positions. SCR uses the North American Datum of 1983 (NAD 83) State Plane Projection in feet as its horizontal datum and the North American Vertical Datum of 1988 (NAVD 88) (Figure 3.1) in feet as its vertical datum. The topographic and hydrographic data are referenced to this datum of NAD 83 so that manipulation and analyses are consistent.

The SCR study regions are defined and referenced to quarter-quadrangle (QQ) and quarter-quarter quadrangle (QQQ) grid reference systems. These grid systems are related to the USGS 7½ minute quadrangle index maps divided into quarter quadrangles. Each quarter quadrangle is designated as NW, NE, SW, or SE. QQ and QQQ are common spatial references for the USGS, FEMA, the Department of Homeland Security (DHS), and many others (Figures 3.2, 3.3 and 3.6).

Quad	GCS scale	Scale	Approx - M	Approx - Ft
Q	7.5 min	1:24k	10k x 14k	35k x 45k
QQ	3.75 min	1:12k	5k x 7k	17k x 22k
QQQ	1.875 min	1.6k	2.5k x 3.5k	8.5k x 11k

Figure 3.1: Reference Scale and Geographic Coordinate System (GCS)

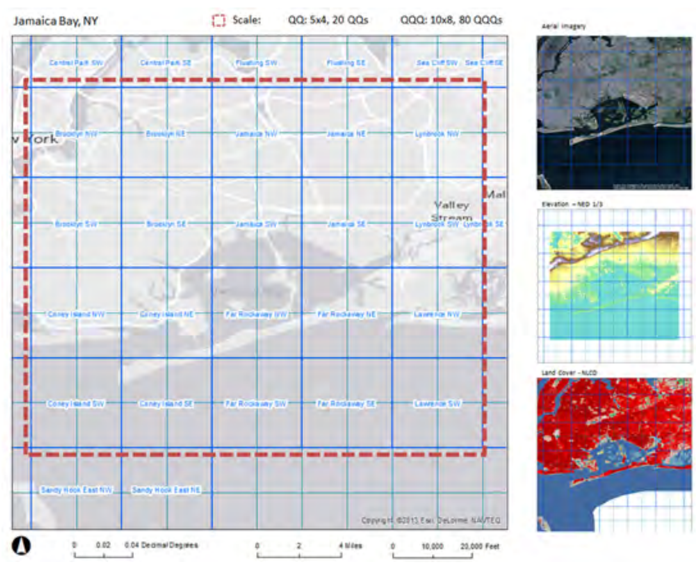
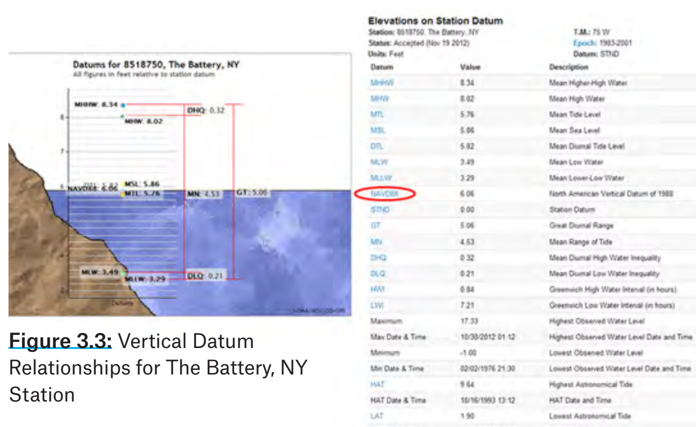


Figure 3.2: Sample QQ (light blue) and QQQ (heavy blue) indices for Jamaica Bay Study Region with Imagery, Elevation and National Land Cover Data (NLCD)



Datum	Value	Description
MHHW	8.34	Mean Higher-High Water
MHW	8.02	Mean High Water
MTL	5.76	Mean Tide Level
MSL	5.86	Mean Sea Level
DTL	5.82	Mean Diurnal Tide Level
MLW	3.49	Mean Low Water
MLLW	3.29	Mean Lower-Low Water
NAVD88	6.06	North American Vertical Datum of 1988
STND	0.00	Station Datum
GT	5.06	Great Diurnal Range
MN	4.53	Mean Range of Tide
DHQ	0.32	Mean Diurnal High Water Inequality
DLQ	0.21	Mean Diurnal Low Water Inequality
HWI	0.84	Greenwich High Water Interval (in hours)
LWI	7.21	Greenwich Low Water Interval (in hours)
Maximum	17.33	Highest Observed Water Level
Max Date & Time	10/30/2012 01:12	Highest Observed Water Level Date and Time
Minimum	-1.00	Lowest Observed Water Level
Min Date & Time	02/02/1976 21:30	Lowest Observed Water Level Date and Time
HAT	9.64	Highest Astronomical Tide
HAT Date & Time	10/16/1993 13:12	HAT Date and Time
LAT	1.90	Lowest Astronomical Tide
LAT Date & Time	01/21/1996 20:06	LAT Date and Time

Figure 3.3: Vertical Datum Relationships for The Battery, NY Station

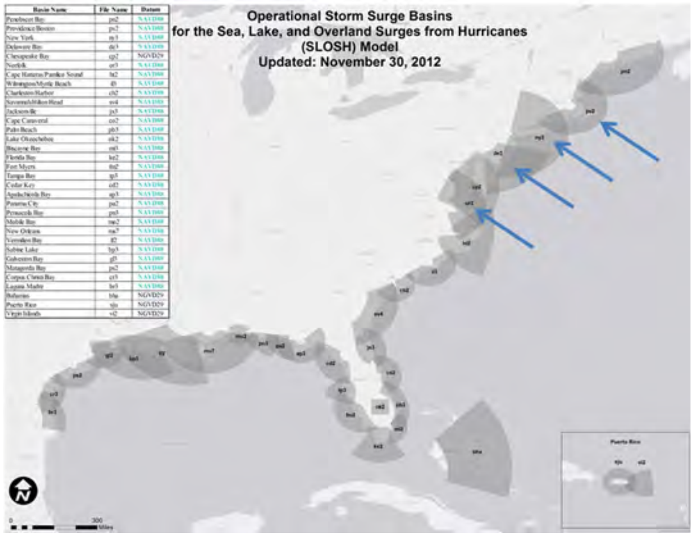


Figure 3.4: SLOSH Computation Basin Indices

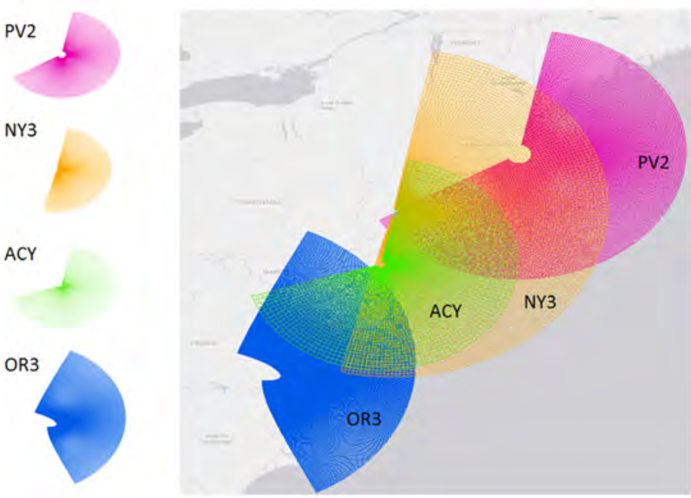


Figure 3.5: Study Region Slosh Computation Basins for the Jamaica Bay (NY), Providence (RI), Atlantic City (NJ) and Norfolk (VA) study regions

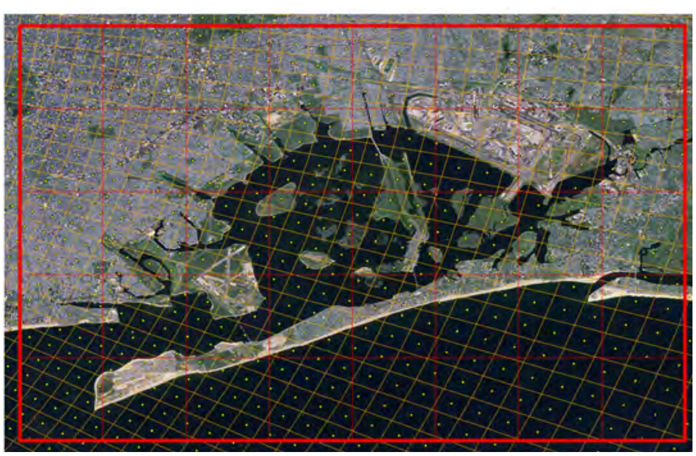


Figure 3.6: A Sample Relationship between SLOSH Computational Indices (Orange) and SCR QQ (Red) indices for Jamaica Bay

Additionally, pre-defined computational index basins were used for storm surge analyses. SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model coverages are subdivided into 37 regions or basins; four of these were selected for the SCR regions. Figures 3.4 and 3.5 show computational SLOSH basin indices used for the Jamaica Bay (NY), Providence (RI), Atlantic City (NJ) and Norfolk (VA) study regions. These basins are centered upon particularly susceptible features: inlets, large coastal centers of population, low-lying topography, and ports.

3.3 Topobathy Models

The physical features of the earth's surface—whether offshore, underwater or on land—are important in determining the response of the coastal ocean to strong storm events.

Bathymetric and topographic features block waves and currents, dissipate energy, channel water movement, and generally affect the ability of a strong storm to move water. To understand the effects of a change in coastal water level or the impacts of inundation, a seamless surface that represents both the topography of the land and the bathymetry of the seafloor is necessary.[1] Such a seamless topobathy surface can require high-resolution data and is an important factor when modeling processes (such as storm surge) that occur across the land-water interface. It is therefore critical to create accurate databases of this information for use in modeling storm surge.

This study uses two hydrodynamic models: SLOSH (Sea, Lake, and Overland Surges from Hurricanes) and ADCIRC (the Advanced Circulation Model). More information about these two models is available in Section 2.0.

SLOSH is a computerized model run by the National Hurricane Center to estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes.[3] With SLOSH analysis, the Maximum of the Maximum Envelope of High Water (MEOW), or MOM, provides a worst case snapshot for a particular storm category under "perfect" storm conditions.

Each MOM considers combinations of forward speed, trajectory, and initial tide level. These products are compiled when a SLOSH basin is developed or updated.

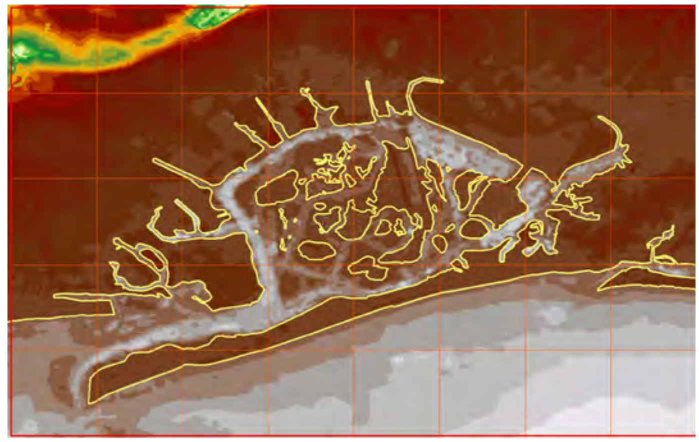


Figure 3.7: A Sample Topobathy Model for the Jamaica Bay (NY) Study Region

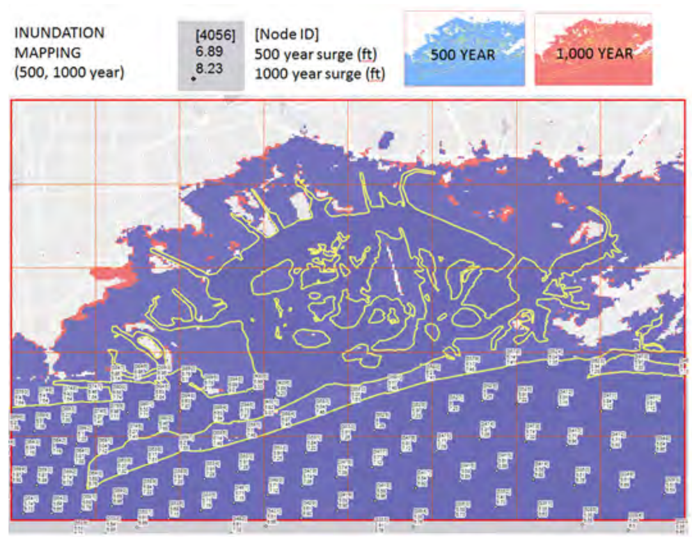


Figure 3.8: Sample Inundation Model Results Using ADCIRC model

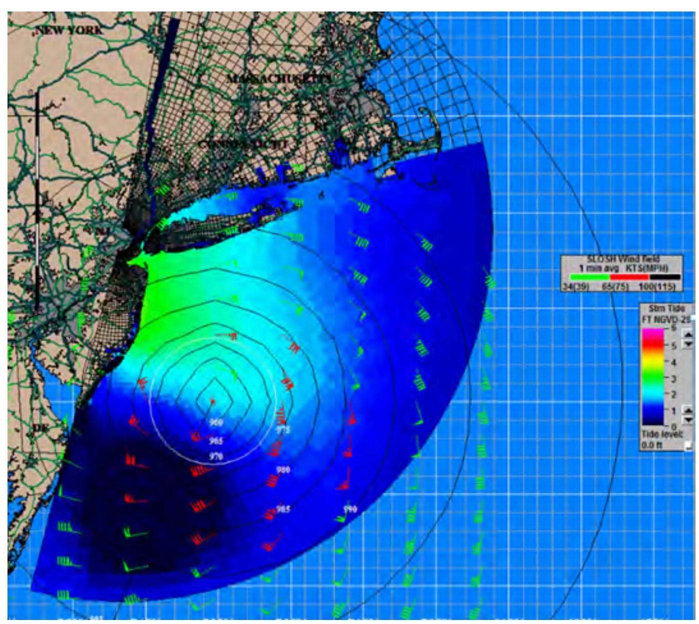


Figure 3.9: Sample Slosh Simulation Using the NY3 Basin Displaying Wind Field and Tidal Data

Commonly, the MOMs are also used to develop the nation's evacuation zones.

ADCIRC is a system of computer programs for solving time-dependent, free-surface circulation and transport problems in two and three dimensions. These programs utilize the finite element method in space, allowing the use of highly flexible, unstructured grids.[3] Typical ADCIRC applications have included modeling tides and wind-driven circulation, and analysis of hurricane storm surge and flooding. The ADCIRC code system is freely available but is typically run by universities and federal agencies.[3] Therefore, the output may be made available from a variety of sources.

SLOSH, ADCIRC, and other inundation prediction models use topobathy data as a basis for analysis. This allows the model to accurately predict how deep and how far inland water will surge during a major coastal storm. Numerous, simulated, possible coastal storm tracks are then input into the prediction models to map the extents of surge and inundation, and to evaluate proposed features for coastal resiliency (Figure 3.7).

3.4 Inundation Analysis

Maps that depict inundation are based on output from a hydrodynamic model, or a combination of hydrodynamic and wave models are developed to calculate a total water level surface. Some prevalent examples of this type of map include the FEMA Flood Insurance Rate Maps (FIRMs) and storm surge zone maps. The FIRMs depict the 1% annual chance flood zone based on studies that incorporate several different models, such as the ADCIRC model, Wave Height Analysis for Flood Insurance Studies (WHAFIS), and others. Storm surge zone maps in this study depict the potential extent of storm surge from hurricanes based on model output from SLOSH, ADCIRC, or other models (Figures 3.8, 3.9).

Detailed comparisons were also made between computational simulations (ADCIRC and SLOSH), field verifications from Hurricane Sandy and benchmark results from FEMA's Preliminary Work Maps (PWMs); these comparisons are made for different return periods (Figures 3.10-3.15).

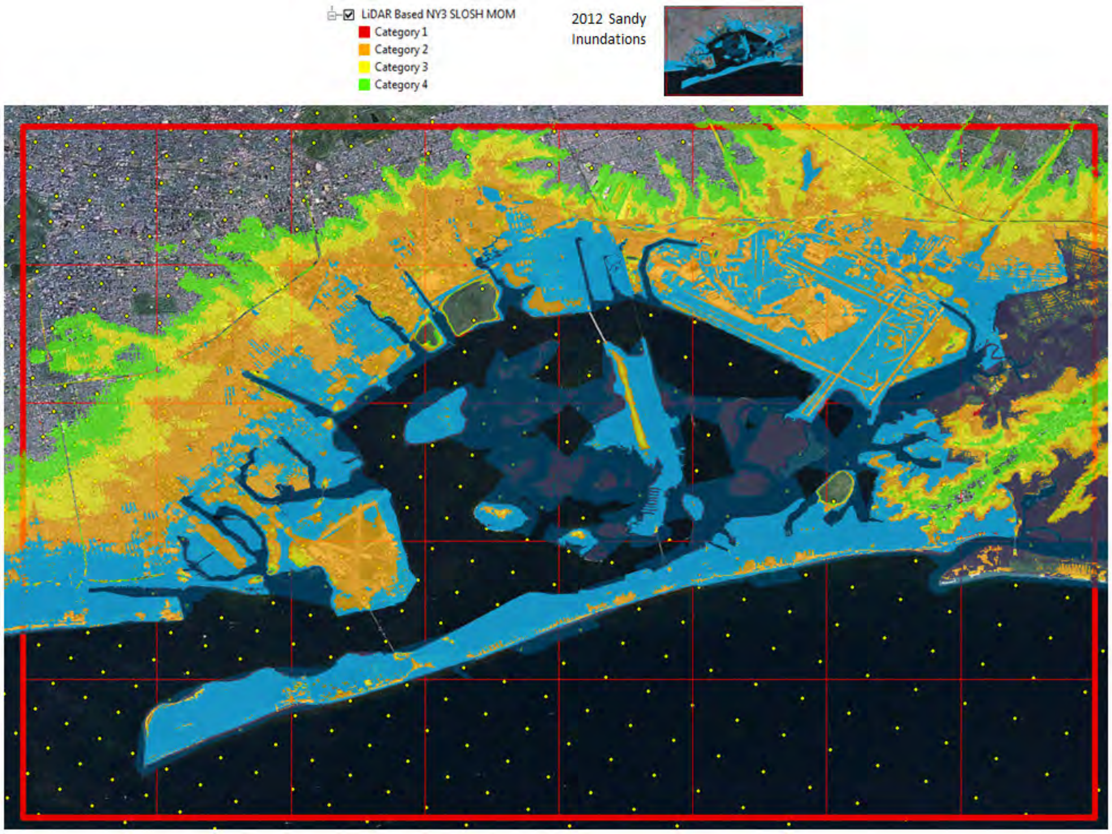
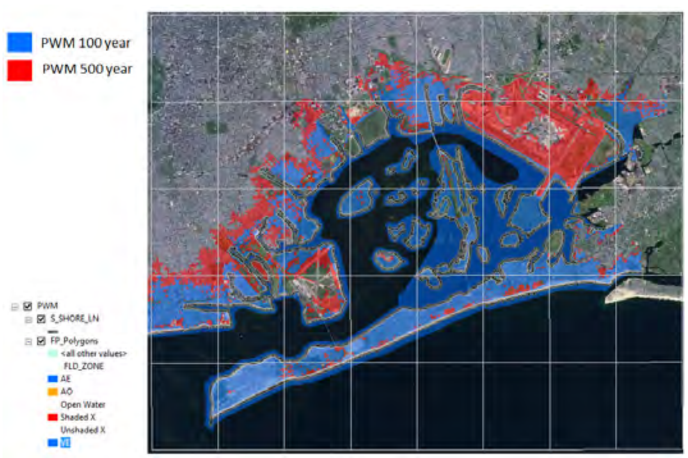
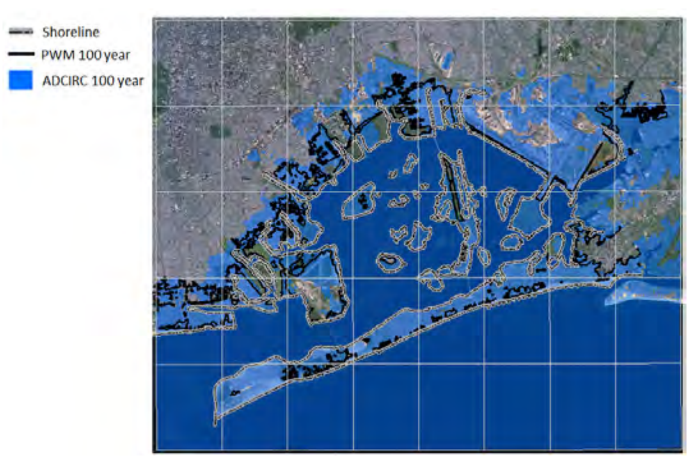


Figure 3.10: Comparison of SLOSH NY3 MOMs for Categories 1, 2, 3 and 4 and Field Verified Hurricane Sandy Surge Extents

Figure 3.11: PWM inundation – 100 year and 500 year returns

Figure 3.12: Comparison of ADCIRC and PWM inundation –100 year return





3.5 Conclusion

GIS and geospatial modeling are key frameworks for relating numerical models with natural and nature-based features and for understanding coastal resiliency in context. Elevation and coastal feature data were collected and combined with the use of GIS to form topobathy models.

These models were then analyzed using limited scenarios for two hydrodynamic models: SLOSH (Sea, Lake, and Overland Surges from Hurricanes) and ADCIRC (the Advanced Circulation Model). Preliminary output from these models and initial simulations are in the process of being mapped to depict inundation for use in the next phases of the SCR project and use by the design groups in their study regions.

Comparative analyses of computational, benchmark and field measures for inundation for different return periods highlight the variability and sensitivity of analysis methods. Similarly, comparison of these methods and measures can provide an envelope of scenarios for consideration in support of resilient design strategies.

3.6 References

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Figure 3.13: Comparison of ADCIRC and PWM inundation –500 year return

Figure 3.14: Comparison of ADCIRC and PWM inundation –500 year return and Field Verified Hurricane Sandy Surge Extents

Figure 3.15: ADCIRC inundation – 100, 500, 1000, 5000 year returns and worst case of all storms envelope