Inundation Simulations for Margate City, New Jersey

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Civil Engineering CE560

Coastal Remote Sensing

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INTRODUCTION and BACKGROUND

Margate City is a coastal town situated on Absecon Island in Atlantic County, NJ, which it shares with the municipals Atlantic City, Ventnor, and Longport.[1][2] The island's 8.1-mile coastline bears the Atlantic Ocean to the southeast, and is flanked by Absecon Inlet to the northeast and Great Egg Harbor to the southwest (Figure 1). The town of Margate is a popular beach destination in summer, and is home to Marven Gardens (of *Monopoly* board game) and Lucy, a 65-ft tall wooden elephant.[2][3]

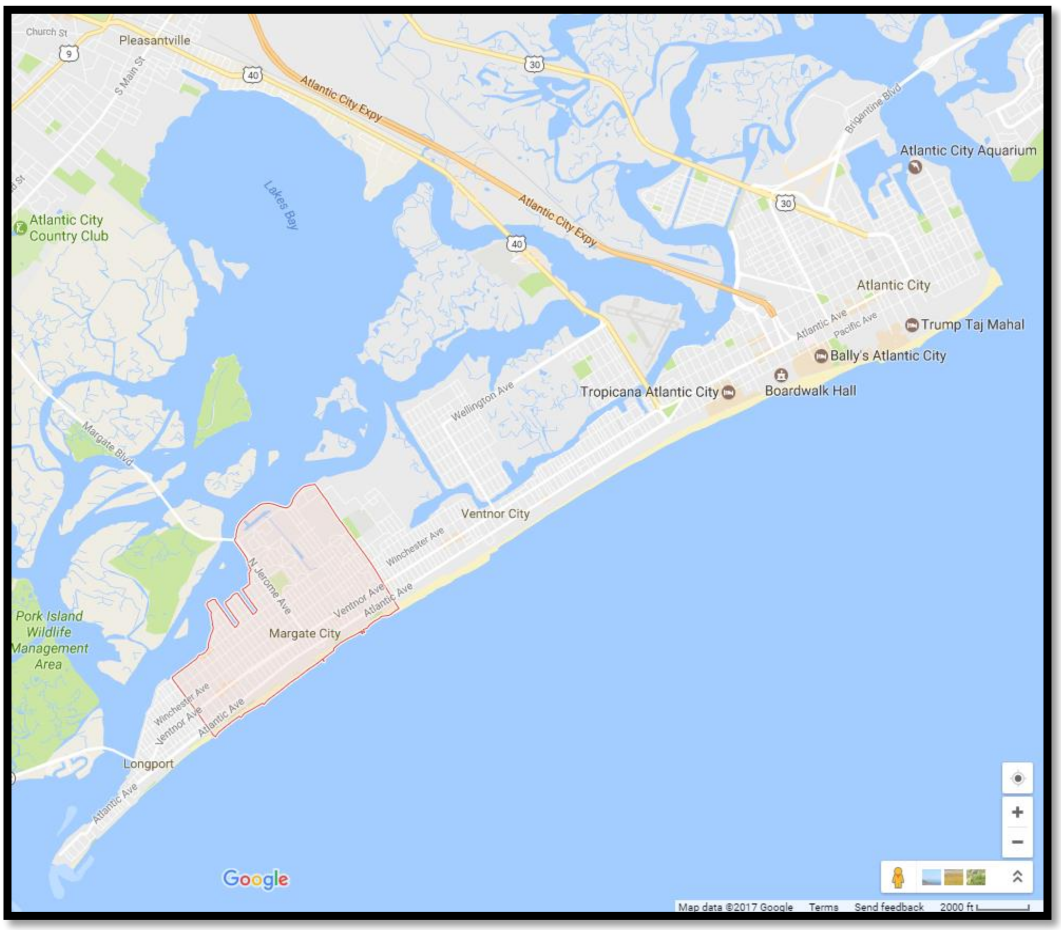


Figure 1. Margate City, New Jersey (Map data ©2017 Google)

Absecon Island is a barrier island, and is constantly affected by erosion especially from hurricanes and nor'easter storms.[4] Hurricane Sandy, the largest recorded tropical cyclone in extended best track record (since 1988),[5] struck NJ on October 29, 2012.[6][7] In response to extensive storm damage along the eastern seaboard including an assessed $36.9 billion in damages in New Jersey,[8] the state's Department of Environmental Protection (NJDEP) and the United States Army Corps of Engineers (USACE) will undertake a $63.3 million project to install beach dunes along the island's seaward coastline, from Absecon Inlet to Great Egg Harbor Inlet.[9] The plan calls for creating a 100ft-wide berm and constructing sand dunes rising to 12.75ft above sea level, walling off the ocean with 1,000ft-long segments of sand (Figure 2).[9][10] According to USACE, the dunes are "designed to reduce storm damage to homes and infrastructure from high waves, high tides and storm surges associated with coastal storms."[9] This rise in water-level due to the combination of storm surge and astronomical tide is defined by the National Oceanic and Atmospheric Administration (NOAA) as "storm tide,"[5][see also 11] and is expressed as height relative to a vertical datum (e.g. NAVD88).

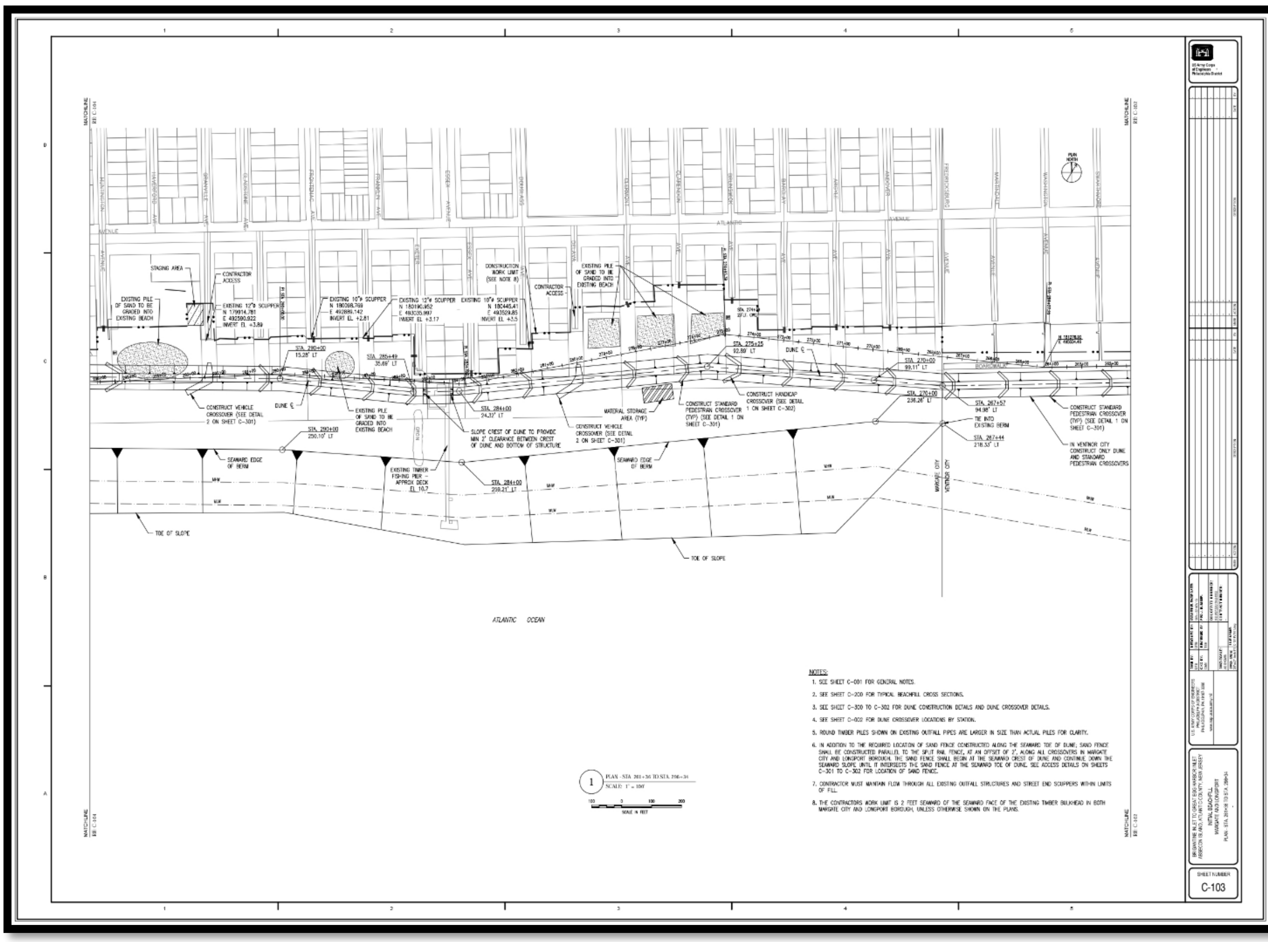


Figure 2. Initial beachfill Dune Plan for oceanfront coastline. Full plan (IFB W912BU-14-B-0002) available here

In this investigation, inundation simulations are modeled under various sea level rise (SLR) scenarios in order to map historical and hypothetical flood events in Margate City, NJ. Selected levels of SLR represent the Intergovernmental Panel on Climate Change (IPCC) high and low predictions of SLR by year 2100; storm tide water level recorded during Hurricane Sandy in 2012; storm tide level plus maximum wave height recorded during Hurricane Sandy; potential dune-breaching water levels; and cataclysmically high SLR.

An analysis is also performed comparing inundation models under the presence or absence of land subsidence. Subsidence is the gradual sinking of the land surface, often due to human-caused extraction of groundwater or petroleum.[12][13] Land subsidence exacerbates SLR and flooding potential through shoreline retreat,[13] and global SLR measurements ought to include land elevation changes when indicating absolute changes in sea level relative to the land.[14] The low-lying topography of coastal plains (such as the mid-Atlantic) make these regions even more vulnerable to SLR, since small changes to either land elevation or sea level can increase the risk of coastal flooding.[13][14] Although rates of land subsidence in the mid-Atlantic are not as high as in other parts of the country (e.g. CA, TX, LA), in coastal areas from New York to North Carolina, "tide-gauge observations indicate that relative sea-level rise (the combination of global sea-level rise and land subsidence) rates were higher than the global mean and generally ranged between 2.4 and 4.4 millimeters per year, or about 0.3 meters (1 foot) over the twentieth century".[14, p.2] Other projections of centennial land subsidence rates consistently fall at or over 12 inches (Karegar et. al 2016 – 12 inches [15]; Eggleston and Pope 2013 – 12.2 inches[13]; Titus et. al 2009 – 15.67 inches[14]). Although rates and locations of land subsidence change over time,[13] this study will assume a subsidence of 12 inches (by 2100) to assess differences in inundation model outputs of the 2100 maximum predicted SLR.

METHODS and RESULTS

The first step of this investigation involved examining all available LiDAR (Light Detection and Ranging) datasets downloaded from NOAA CSC's Digital Coast Data Access Viewer, in order to determine the most suitable pre- and post- Hurricane Sandy Digital Elevation Models (DEMs). Airborne LiDAR can provide high-resolution topographic maps for use in identifying flood risk hazard.[16] The selection process consisted of subjectively examining specifications of each dataset's spatial footprint, first-return spatial density, and horizontal and vertical accuracy (Table 1). Three DEMs were selected for three different trials: (1) EAARL-B Coastal Topography—Eastern NJ, Hurricane Sandy: First Surface, Pre-Sandy; (2) USGS EAARL-B Coastal Topography: Post Sandy First-Surface (NJ); and (3) NOAA Post Hurricane Sandy Topobathymetric Lidar (highlighted in blue, green, red, Table 1, and hereafter referred to as "2012 Pre-Sandy," "2012 Post-Sandy," and "2014 Post-Sandy," respectively).

The 2012 Pre-Sandy and 2012 Post-Sandy data were collected by the same organization, have identical point-return densities and accuracies, and make for convenient comparison. 2012 is also the first available year for data taken by NASA's enhanced Experimental Advanced Airborne Research Lidar (EAARL-B) instrument, which is designed to measure coastal land elevations and shallow submerged topography in a single raster scan of pulses.[17][18] The third LiDAR dataset, 2014 Post-Sandy, has comparable accuracy specifications to the other two, but was obtained more recently and has a larger (city-wide) coverage.

Table 1. Specifications of LiDAR datasets available at NOAA CSC's Digital Coast Data Access Viewer. Chosen DEMs are highlighted in spectral sequence blue (Trial I), green (Trial II), and red (Trial III).

TITLE	SOURCE	YEAR	SIZE	Density	Vertical Accuracy	Horizontal Accuracy
Fall East Coast Airborne LiDAR Assessment of Coastal Erosion	DOC/NOAA/NOS/OCM	2000	811Cx802R	N/A	15cm	80cm
USACE Topo/Bathy Lidar: DE, MD, NJ, NY, NC, VA	USACE	2005	811Cx823R	1.3m	20cm	75cm
FEMA RiskMAP Atlantic	DOC/NOAA/NOS/OCM	2010	812Cx1018R	1m	18.5cm	60cm
USACE JALBTCX Lidar: New Jersey	USACE	2010	811Cx798R	N/A	20cm	75cm
NOAA NGS Lidar: Cape May to Absecon Inlet, NJ	DOC/NOAA/NOS/NGS	2011	812Cx1042R	N/A	30cm	100cm
EAARL-B Coastal Topography—Eastern NJ, Hurricane Sandy: First Surface, Pre-Sandy	DOC/NOAA/NOS/OCM	2012	811Cx771R	.5-1.6m	20cm	100cm
USGS EAARL-B Coastal Topography: Post Sandy. First-Surface (NJ)	DOC/NOAA/NOS/OCM	2012	811Cx783R	.5-1.6m	20cm	100cm
NOAA NGS Topobathy Lidar: Great Egg (NJ)	DOC/NOAA/NOS/NGS	2013	N/A	N/A	15cm	100cm
NOAA Post Hurricane Sandy Topobathymetric Lidar	DOC/NOAA/NOS/NGS	2014	N/A	N/A	6-22cm	100cm
CoNED Topobathymetric Model for NJ & DE	DOC/NOAA/NOS/OCM	2015	2431Cx3121R	1m	15/20cm	N/A

MATLAB (R2016b) was utilized to create a flat grid to be used as a reference water surface (0m vertical Z values) for the model. This 1400x1400m (3x3m-cell) grid spanned the area of interest (AOI) Margate City from coordinates UTM Zone 18N 541570mE 4351710mN to 545767mE 4355907mN. The file output from MATLAB was then processed through NOAA's VDatum software, in order to reference the water surface to the AOI's Mean Higher High Water (MHHW) in the NAVD88 vertical datum. This resulted in the uniform 0m elevation Z values adjusting to between 0.6157m - 0.6388m. MHHW is the daily average of the highest extent of the higher high waters each day over a 19-year period.[19] Modeling SLR with respect to the highest tides yields worst-case, maximum potential flooding, so MHHW was used as the reference for all inundation scenarios. The MHHW tidal surface was brought into ArcMAP (10.4.1) as X,Y point data in NAD83 2011 UTM 18N and converted to a raster layer (Figure 3).

Figure 3. Mean Higher High Water (MHHW) digital tile overlaid on ArcGIS basemap of Margate, NJ

Next, each LiDAR-derived DEM was added to a satellite image basemap and transformed from point to raster, then the symbology adjusted by applying custom histogram filtering to accentuate distinction among the lower elevations. The histogram stretch increased visual interpretability of detailed elevation changes on the ground, which indicates the direction of waterflow (Figure 4). [20]

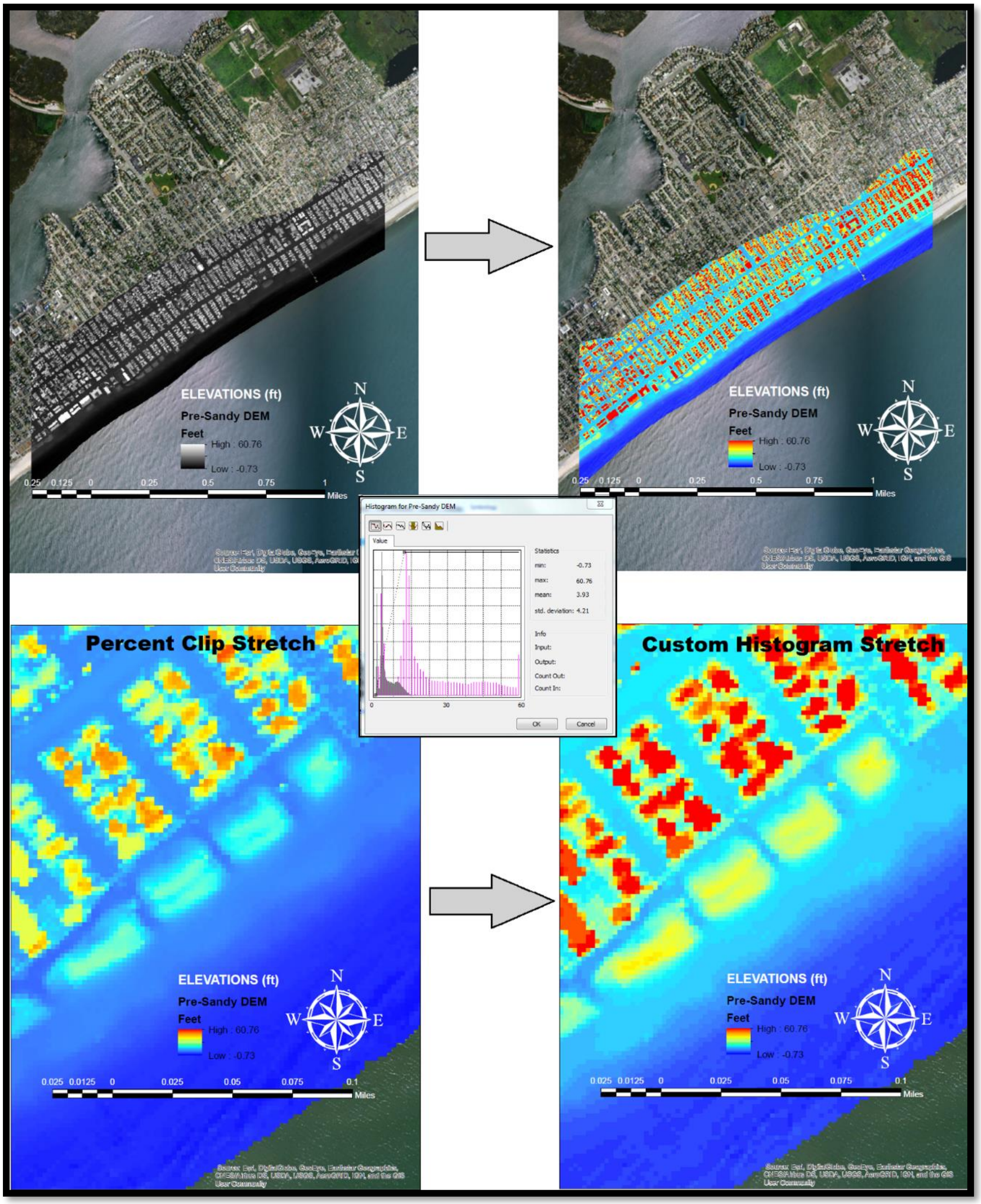


Figure 4. LiDAR-derived Digital Elevation Model (DEM) of Margate, NJ, with custom histogram filter applied

TRIAL I

2012 Pre-Sandy

Selected Levels of Sea Level Rise

SLR for **TRIAL I** was chosen at levels of 1ft (0.305m), 2.5ft (0.762m) 4ft (1.22m), 8.43ft (2.57m), and 40.43ft (12.32m).

- 1ft, 2.5ft, 4ft
  - Inundation simulations were chosen at these levels in accordance with the National Climate Assessment's 2014 report containing predictions of SLR by between 1-4ft by 2100.[21][22]

- 8.43ft
  - A USGS tide gauge in Longport, NJ (UTM Zone 18N 39940.2mE 4350704.8mN) measured the non-wave-affected high water mark at 8.43ft during the peak of Hurricane Sandy. This sensor was decidedly the closest measurement to the AOI (Figure 5). Hurricane Sandy storm tide was unusually high because "the combination of storms, timed with the full-moon high-tide on October

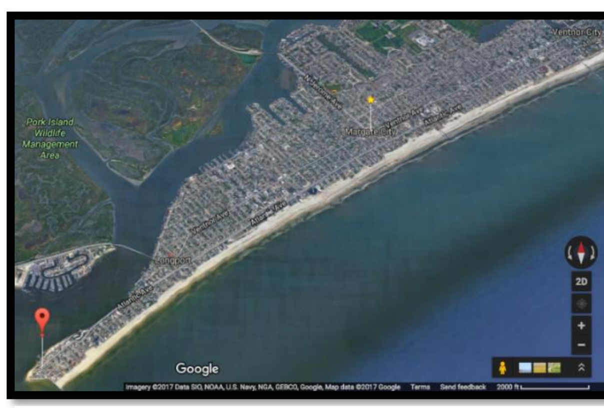


Figure 5. Location of storm tide sensor (red pin) during Hurricane Sandy

29, exacerbated storm-tide flooding along the New Jersey, New York, and Connecticut coastlines." [11 p.1] [see also 5]

- 40.43ft
  - The second-highest recorded maximum significant wave height (H_s) during Hurricane Sandy measured over 32ft (9.9m),[23][24] which was added to the Sandy non-wave storm tide of 8.43ft to arrive at 40.43ft. Although wave height may not necessarily correspond to where an area will become inundated, and the measurement was not taken near the AOI (Buoy 44065 is at the entrance of NY Harbor, approximately 100 miles north), this simulation represents a hypothetically much more violent landfall, or a tsunami, whelming this area.

Models for Mapping Hydrologic Connectivity in GIS

Three different inundation models were tested during **TRIAL I** to determine the best representation of how and where incoming water will flow.

- "Dumb" Model
  - This model adds the desired height of SLR (e.g. 1ft) to the MHHW sea level, then finds all areas of the DEM with an elevation less than the adjusted MHHW and considers these flooded (Figure 6). Since the model counts all sub-MHHW pixels -- even those that are not hydrologically connected to the ocean -- it was named for its interpretation of reality.

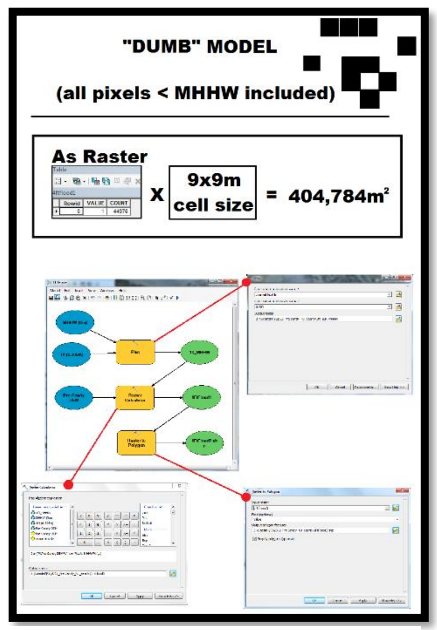


Figure 6. Workflow process for hydrologically unconnected "Dumb" Model

- 4-Neighbors Model
  - Using the output from the previous model, I converted the raster (grid) of flooded pixels into a vector polygon, then selected for all polygons that intersected with a digitized polyline of all Margate's land-water interfaces (Figure 7a). This method considers the conditions of hydrologic connectivity to be met if two adjacent flooded pixels share a common edge, and therefore water can flow between pixels in 4 directions.

- Digitization in Geographic Information Systems (GIS) is the manual drawing and creation of digital features to represent true objects, such as boundaries. The digitized coastline and bay were drawn through interpretation of the satellite image basemap (Figure 7b). In this way, bridges and piers could be drawn over so as to ensure the model not misinterpret these structures as impediments to water flow.[see 25]
- Margate contains marshland areas, in which water levels fluctuate depending on tides and seasons. Marshes are particularly difficult to map using LiDAR, which tends to overestimate elevations.[26] The satellite basemap imagery of the marsh at different scales also shows drastic vegetation change, perhaps with fluctuating water levels (Figure 7c). For the purpose of simulations in this study, marshes were counted as a potential avenue of water entry, and therefore were digitized as if a discrete land-water interface.

Figure 7a. Workflow process for 4-Neighbor Model

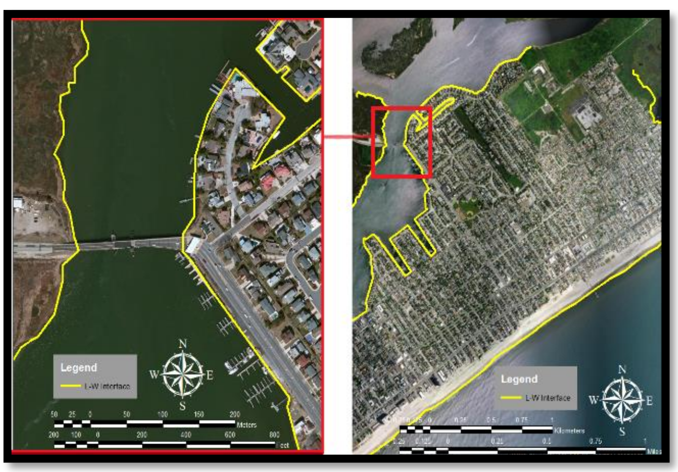


Figure 7b (left). Digitization of land-water interface through a bridge
Figure 7c (right). Digitization of marsh area

- <u>8-Neighbors Model</u>
  - The 8-Neighbors model counts hydrologic connectivity as satisfied if flooded pixels share a common side and/or corner. This model allows water to flow between pixels in one or more of the 8 cardinal and diagonal directions.[20]
  - The unfiltered raster output from the Dumb Model was again used as the input for calculating 8-Neighbor connectivity (Figure 8). This process was adopted from the

methods used by NOAA's Office for Coastal Management for mapping SLR inundation.

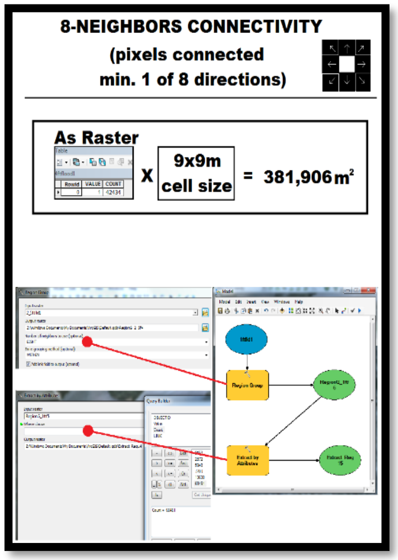
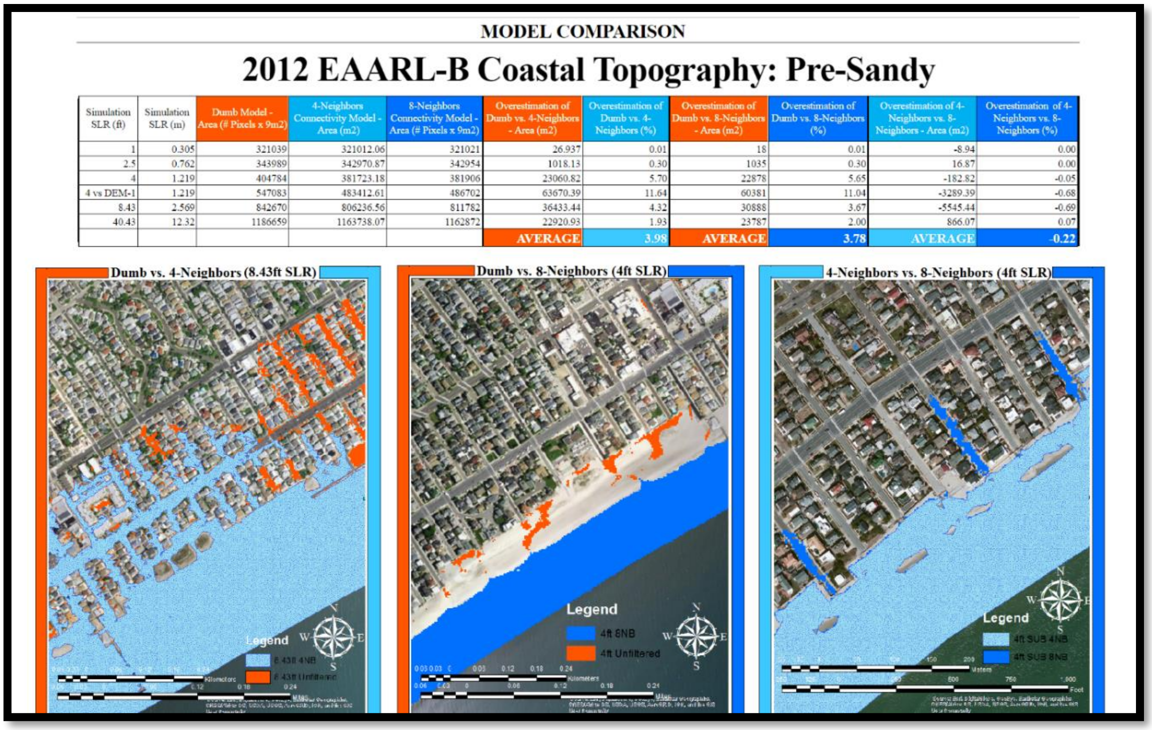


Figure 8. Workflow process for 8-Neighbors Model

Model Comparison

Out of the three tested inundation models, the 8-Neighbor model was deemed to be the most realistic for use in flood mapping. This is because liquid water will flow in any downhill direction rather than in four restricted cardinal directions, and also cannot jump to other areas without hydrologic connectivity.

Comparisons of inundation maps between models (Figure 9) revealed that the "Dumb" model overestimated flooding; the 4-Neighbor model's assessment of flooded area was the lowest of the three models overall; and the 8-Neighbor model's estimation of total flooded area tended to fall between the predictions from the other two models. In several areas, the sharing of a corner by two submerged pixels opened up pathways to flooding in the 8-Neighbor model that the 4-Neighbor model did not recognize. Since the 8-Neighbor model was deemed to be the most realistic model for SLR inundation here, it was attempted as the preferred method for the remaining trials.



MODEL COMPARISON

2012 EAARL-B Coastal Topography: Pre-Sandy

Simulation SLR (ft)	Simulation SLR (m)	Dumb Model - Area (# Pixels x 9m2)	4-Neighbors Connectivity Model - Area (m2)	8-Neighbors Connectivity Model - Area (# Pixels x 9m2)	Overestimation of Dumb vs. 4-Neighbors - Area (m2)	Overestimation of Dumb vs. 4-Neighbors (%)	Overestimation of Dumb vs. 8-Neighbors - Area (m2)	Overestimation of Dumb vs. 8-Neighbors (%)	Overestimation of 4-Neighbors vs. 8-Neighbors - Area (m2)	Overestimation of 4-Neighbors vs. 8-Neighbors (%)
1	0.305	321039	321012.06	321021	26.937	0.01	18	0.01	-8.94	0.00
2.5	0.762	343989	342970.87	342954	1018.13	0.30	1035	0.30	16.87	0.00
4	1.219	404784	381723.18	381906	23060.82	5.70	22878	5.65	-182.82	-0.05
4 vs DEM-1	1.219	547083	483412.61	486702	63670.39	11.64	60381	11.04	-3289.39	-0.68
8.43	2.569	842670	806236.56	811782	36433.44	4.32	30888	3.67	-5545.44	-0.69
40.43	12.32	1186659	1163738.07	1162872	22920.93	1.93	23787	2.00	866.07	0.07
					AVERAGE	3.98	AVERAGE	3.78	AVERAGE	-0.22

Figure 9. Model Comparison of three inundation models on 2012 Pre-Sandy DEM

Inundation maps for all **TRIAL I** simulations of SLR are shown below (Figure 10). A GIF animation of these maps can be viewed here.

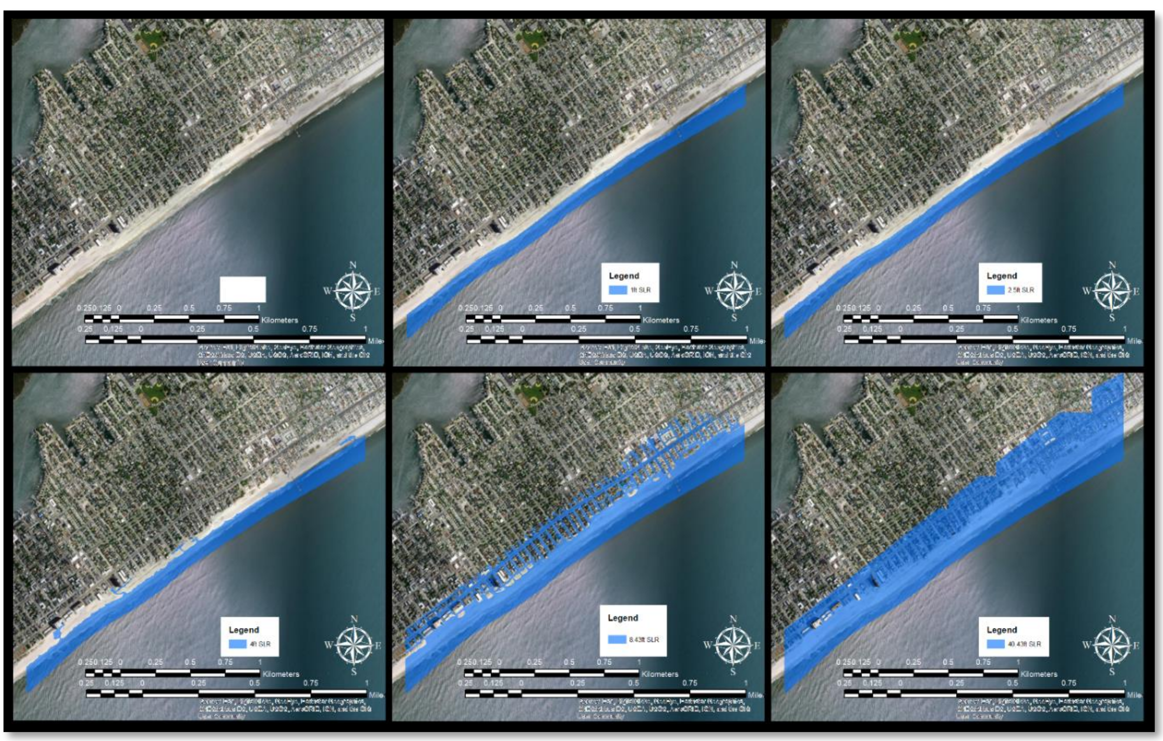


Figure 10. 2012 Pre-Sandy DEM Inundation Simulations (8-Neighbor Model)

TRIAL II

2012 Post-Sandy

Selected Levels of Sea Level Rise

Rising sea levels were again simulated at 1ft, 2.5ft, 4ft, 8.43ft, and 40.43ft, using the 2012 Post-Sandy DEM. A SLR of 13ft was also simulated, and will be analyzed later on. Inundation maps for all **TRIAL II** simulations of SLR are below (Figure 11). An animation of the images as a GIF can be viewed [here].

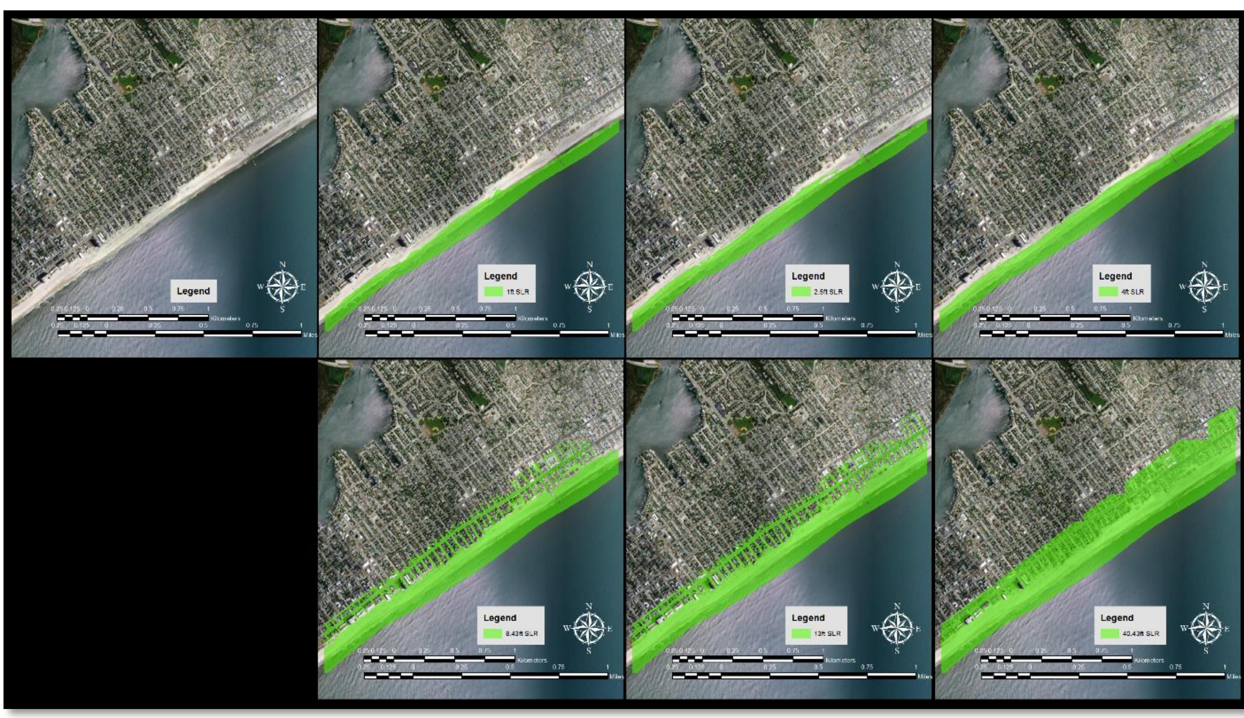


Figure 11. 2012 Post-Sandy DEM Inundation Simulations (8-Neighbor Model)

TRIAL III

2014 Post-Sandy

Selected Levels of Sea Level Rise

The 2014 Post-Sandy DEM covers of the entire municipality of Margate, which is hemmed by water on several sides (above). 1ft, 2.5ft, 4ft SLR simulations were performed again, and this time compared to NOAA's SLR and Coastal Flooding Impacts user-manipulated inundation modeler (Figure 12).

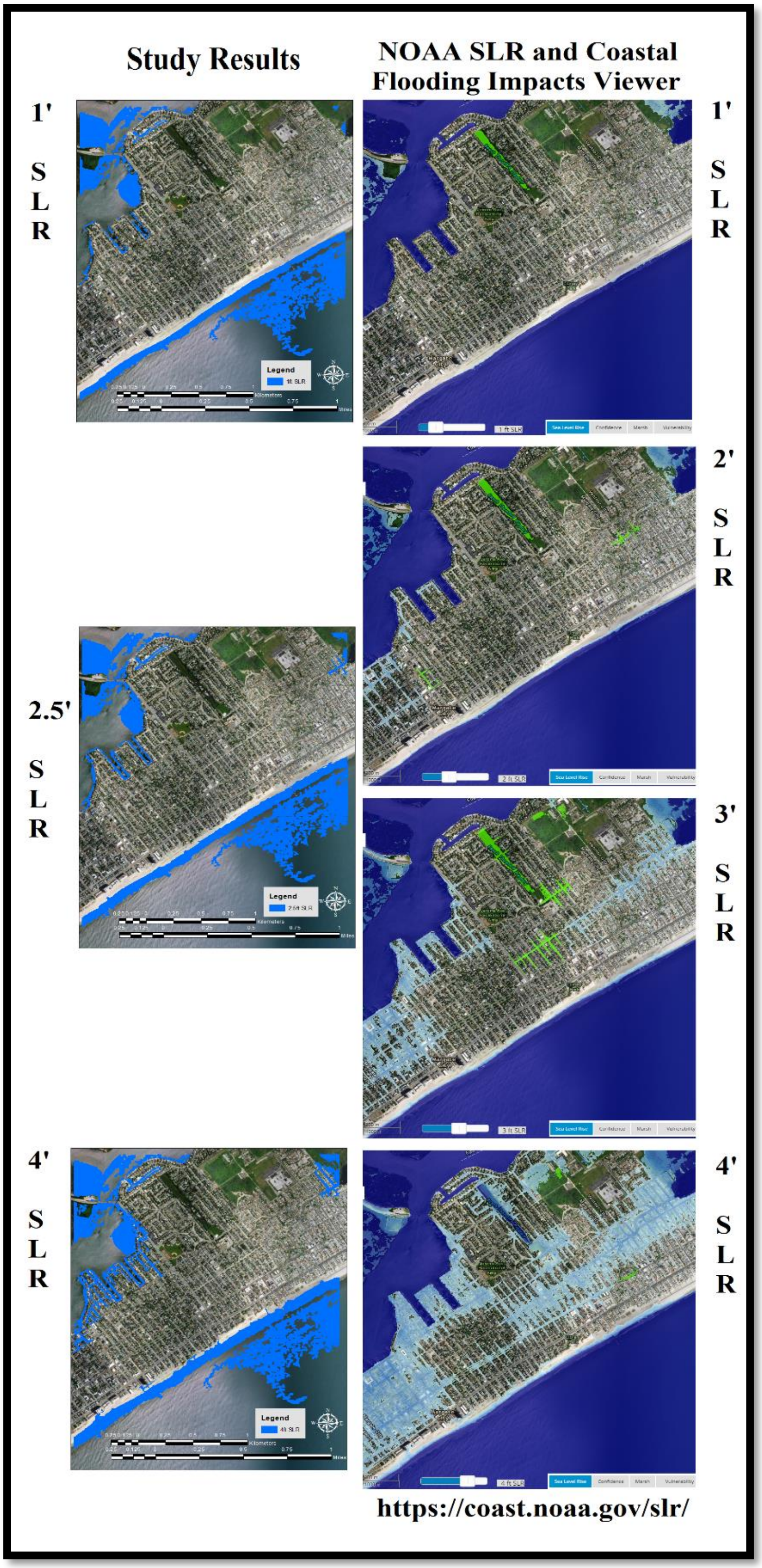


Figure 12. Comparison of inundation maps, this study and NOAA.

The gap in the reference sea-level 0m MHHW layer (Figure 3) became discerningly problematic in this trial. GIS was unable to interpret inundated pixels of the DEM where the 0m MHHW layer dropped out, so large sections of the city are unrepresented in the flood map output. Where the 0m MHHW layer disappears, NOAA's SLR online viewer shows these parts of Margate heavily inundated under 3ft and 4ft of SLR, with significant inundation sourced from the marsh and inlet; beachfront properties remain hardly affected by the ocean.

Considering the fault in the 0m MHHW layer, it should not be interpreted that certain sections of the town would remain dry under the doomsday scenario of unmitigated melting of the world's polar icecaps, estimated to raise sea levels by 229.66ft (70m).[27] The maximum height of everything in Margate, NJ (measured via LiDAR DEM) is 199.1ft (60.7m), so it can be assumed that complete global ice melt would safely sink the town.

In addition to the above issue, the process flowchart shortcuts that were adapted to NOAA's [OCM 8-Neighbor Connectivity algorithm](#) were unable to computationally handle the (previously mosaicked) city-wide spatial extent of the 2014 Post-Sandy DEM, and the inundation maps were deemed unfit to service the questions of this investigation. Because of this, the 4-Neighbor model was reverted to as the next best alternative to a hydrological connectivity model (Figure 13). It should be noted, therefore, that although the 2012 Post-Sandy DEM (**TRIAL II**) is two years more outdated, the 8-Neighbor simulation outputs may yield more realistic representations of 1ft, 2.5ft, 4ft, 8.43ft, and 13ft change in sea level along the ocean-side area of Margate.

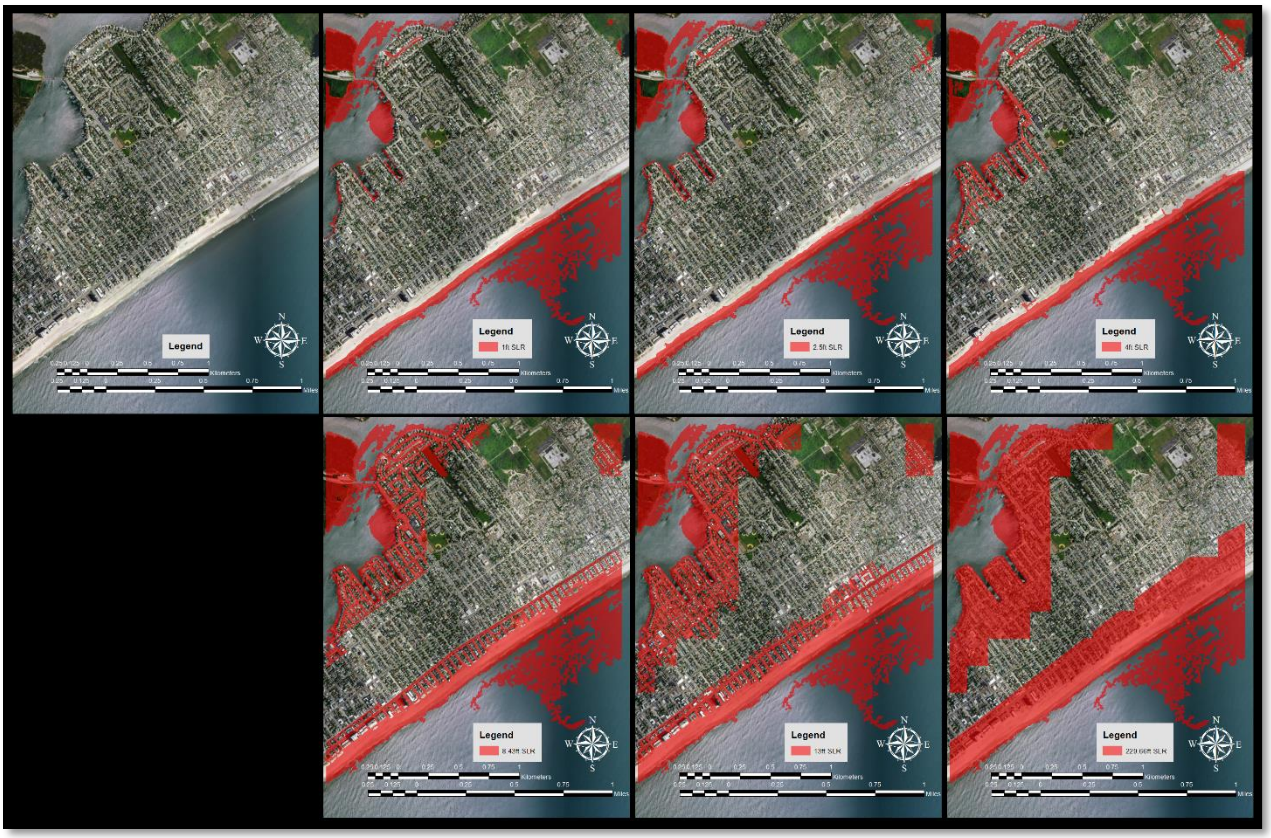


Figure 13. 2014 Post-Sandy DEM Inundation Simulations (4-Neighbor Model).
A GIF animation of **TRIAL III** *simulations is available [here](#).*

ADDITIONAL ANALYSES

Subsidence

Inundation maps were created for examining the effect of subsidence on model predictions and whether it matters to consider in SLR modeling. This comparison tested the 2100 predicted maximum change in sea level (4ft) on the 2012 Pre-Sandy DEM, then on the same DEM vertically reduced by the 100-yr estimation of 1ft subsidence (Figure 14).

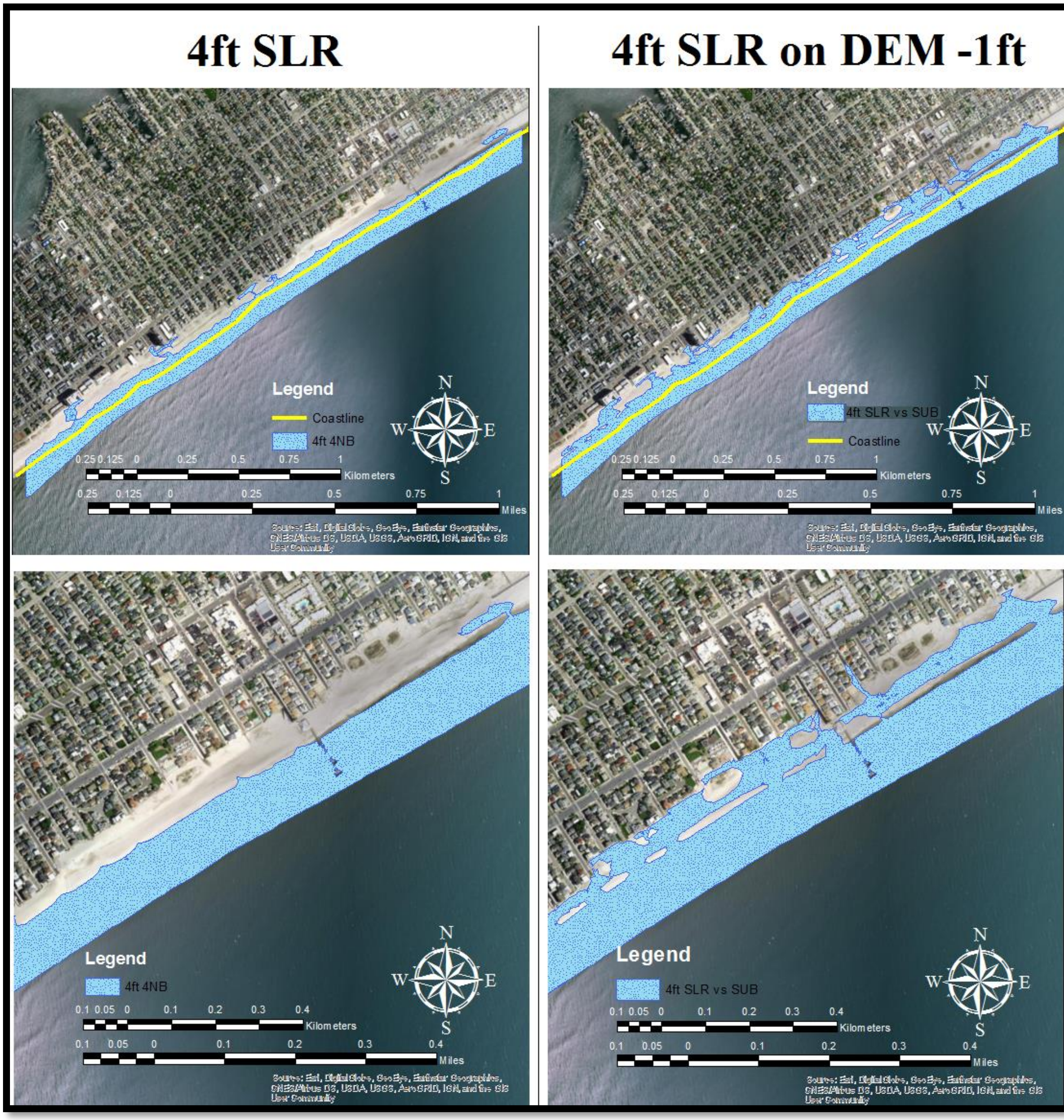


Figure 14. Comparison of flood maps when DEM is, or is not, subject to subsidence (full DEM, top; zoomed in, bottom)

Dune Analysis

In a final scenario, an inundation analysis was performed to assess the protective effectiveness of a 100ft-wide sand dune running the length of the beach. Two levels of SLR were simulated on a DEM either with or without a hypothetical 12.75ft height dune wall. The dune was created by bringing the Dune Plan image file (Figure 15a) into Google Earth and georeferencing it to the satellite base image (Figure 15b). Technical defects prevented the dune's drawn outline from being digitized by overlay, so the image was simply referred to when creating the digital dune in ArcGIS. Since the Dune Plan was only available for a smaller section of Margate's seaside coastline, the remaining coastline was extrapolated given the available map's dune width, direction, and tendency to tie in present-day dunes and sand deposits. The dune was given a constant maximum elevation of 12.75ft, then incorporated into the DEMs of 2012 Post-Sandy and 2014 Post-Sandy (Figures 15c, 15d).

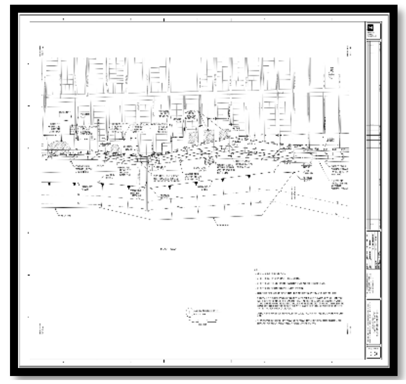


Figure 15a. Dune Plan for Margate, NJ

Figure 15b. Georeferencing of Dune Plan in Google Earth (Map data ©2017 Google)

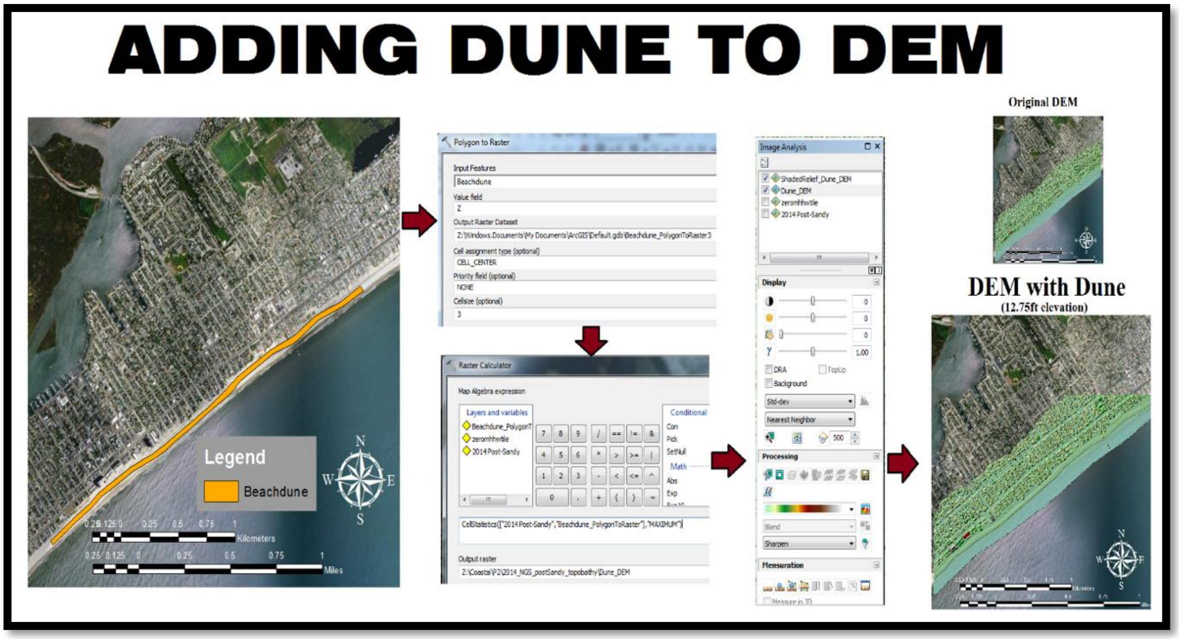


Figure 15c. Workflow process of incorporating a 3D dune into a DEM

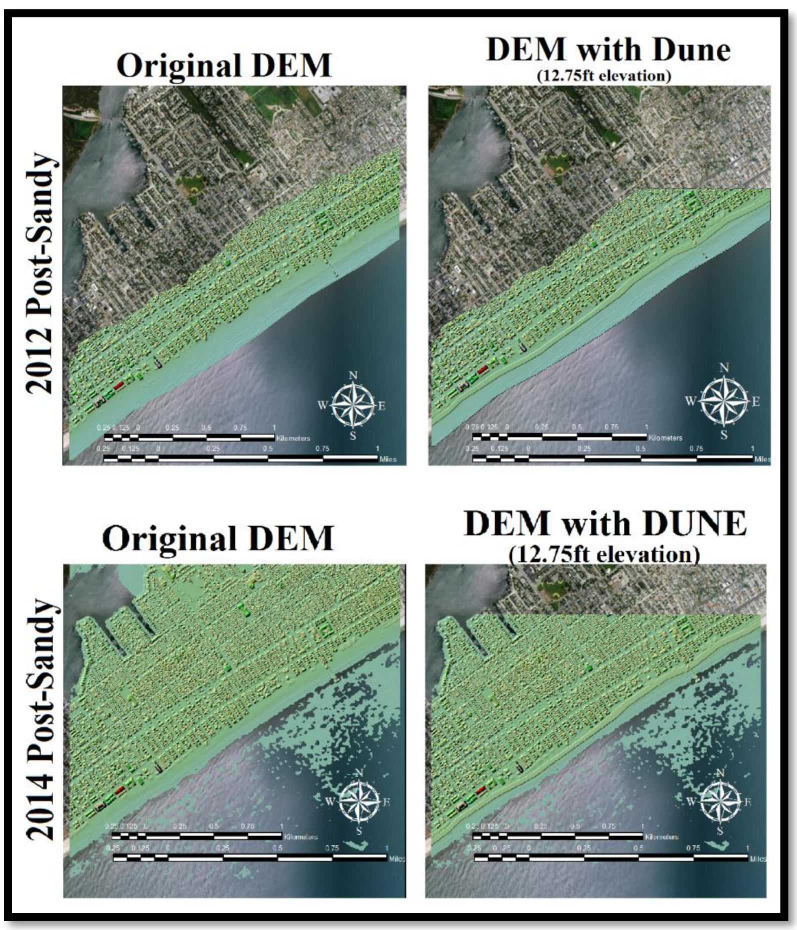


Figure 15d. Two DEMs with and without addition of a 3D dune

The simulations of SLR on the dune-or-not DEMs were run at 8.43ft (Sandy water level measured nearby) and at 13ft (a storm surge, tide, and wave combination that would breach dunes of this height). Hurricane Sandy's storm surge and astronomical tide measured 8.43ft near the AOI, but the addition of wave setup several feet high could exceed the crest of the dune.[28] Therefore, a SLR of 13ft is used to test the efficacy of the state Government's 12.75ft-high dune wall along the ocean-side coast. Simulation maps for the two DEMs are shown below (Figures 16a, 16b).

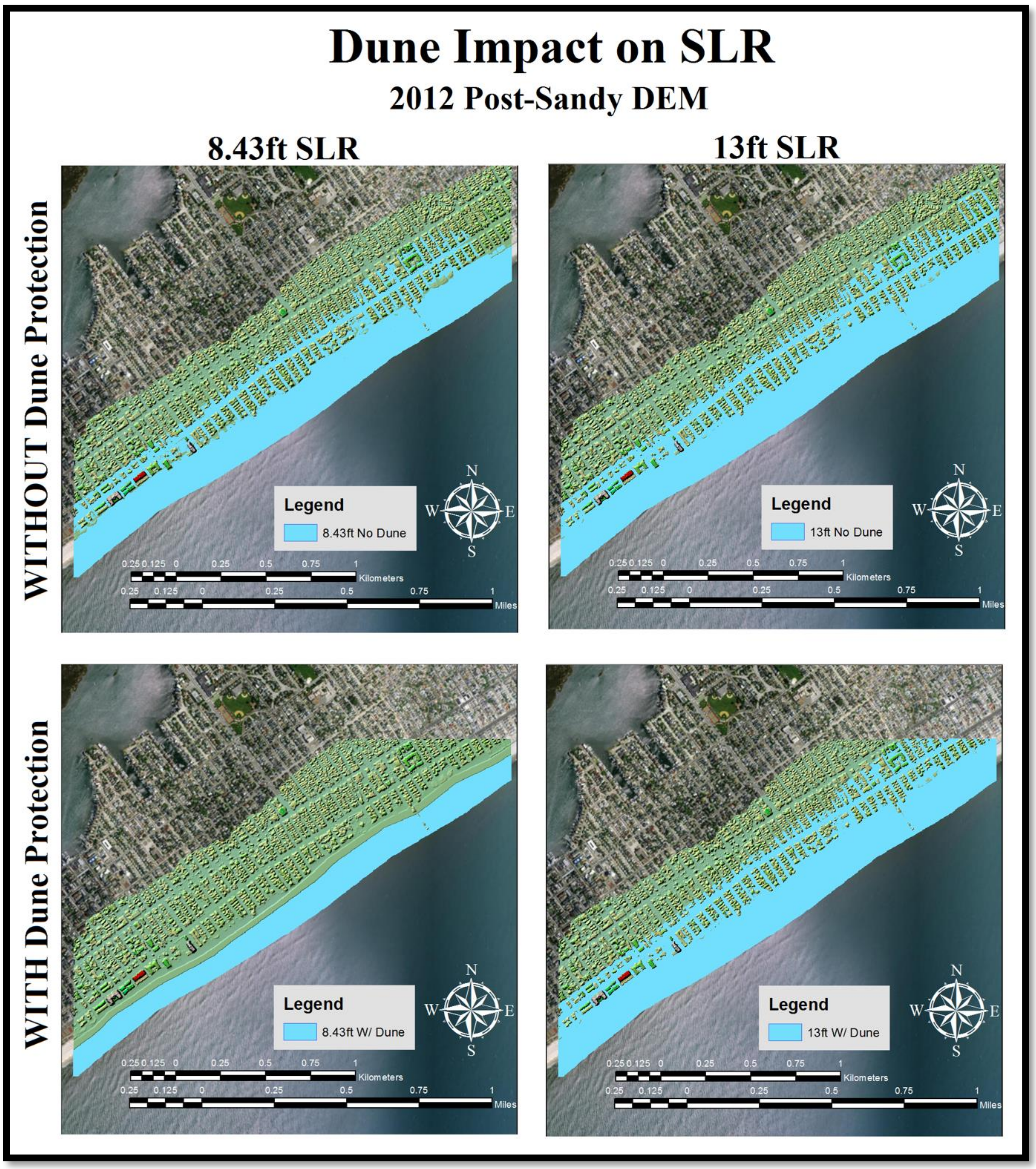


Figure 16a. Inundation simulations at 8.43ft, 13ft SLR on the 2012 Post-Sandy DEM either with or without a 12.75ft-high dune (8-Neighbor Model)

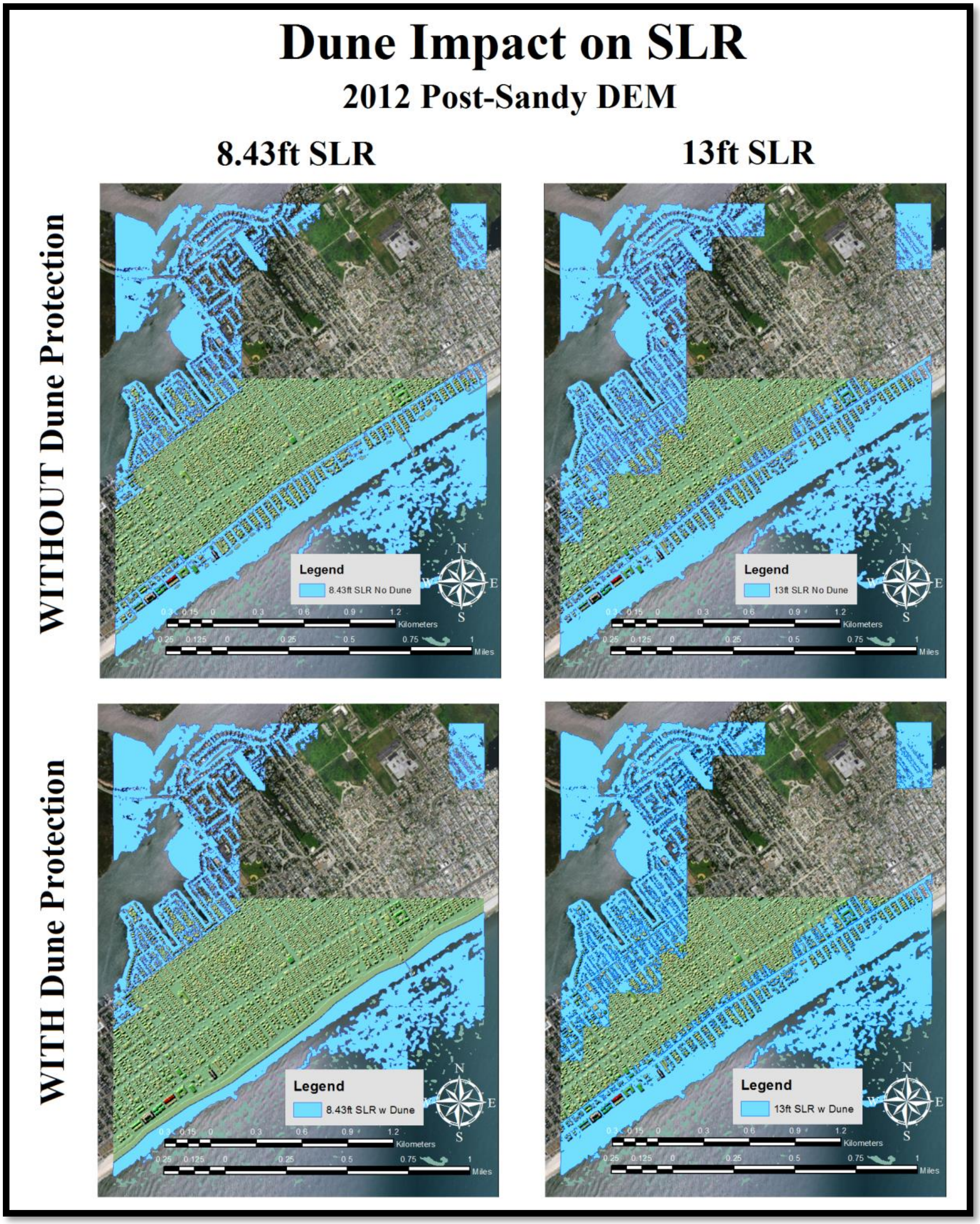


Figure 16b. Inundation simulations at 8.43ft and 13ft SLR on the 2014 Post-Sandy DEM either with or without a dune (4-Neighbor Model)

According to the model, SLR of 8.43ft is always impeded by the dune, but allowed to flood the town in the absence of one. At 13ft SLR, the town is inundated dramatically in both DEMs, with or without the dune.

DISCUSSION and CONCLUSION

Dune

A 12.75ft-high dune may have been able to reduce flood damage caused by Hurricane Sandy, but could the dune help mitigate future hurricanes and nor'easters? For some of Margate's residents, it appears so, so long as the storm tide stays below the dune height threshold of 12.75ft above sea level. Hurricane Sandy was the type of superstorm that suggests climate patterns may be changing; but even if storm violence remains constant, rising sea levels alone would make all storms increasingly more dangerous (perhaps by a factor of several feet). In the future, a storm tide water level of 8.43ft may become less uncommon. Indeed, tide gauges at the Battery on southern Manhattan's New York Harbor measured storm tide during Hurricane Sandy at 14.06ft above MLLW.[5]

Weathering and common storms could expectedly wear on the barrier shore's dune wall over time, repetitively eroding the same battered areas; these weaker portions might then give way to a breach of walled-off water during a larger storm, exposing inland areas to the full force of storm surge.[28] In comparing the extent of ocean water at either 2.5ft or 4ft SLR between 2012 Pre-Sandy and 2012 Post-Sandy, one can see the impact that one storm can have on beach topography and contour. Negligence of dune maintenance may be of additional consideration. The most recent USACE beachfill project on Absecon Island was carried out the same summer prior to Hurricane Sandy, but prior to that 2004, as funding was inadequate in 2007, 2008, 2009, and 2010.[10]

It cannot be overlooked that Margate is flanked by water on both its oceanfront eastern coast and western facing waterfront, and the **TRIAL III** inundation maps (and well as those from NOAA's SLR and Coastal Flooding Impacts interactive map) reveal the extent of flooding via Margate's inlet waterfront and contiguous marshes, even under minor SLR conditions. The 2014 Post-Sandy DEM spans the city limits of Margate, and the simulation on that DEM is a reminder that a beachside dune would not completely absolve the town of the effects from global warming and disastrous storms. Recognition of the most vulnerable places for inundation can help decision makers develop appropriate plans for future storm landfall and global SLR. Lastly, if the beachside dunes do successfully hold off storm surge from the ocean, perhaps even more water would be forced to flow around to the back inlet area. The inundation models utilized in this study were unable to predict the possibility of that phenomenon.

Dunes can be highly variable in their structure and elevation, and high-resolution, topographic measurements are essential for detecting vulnerabilities.[28] In light of this, this study's simulation of SLR on a dune of constant thickness and homogenous height may not be an honest representation of reality. Therefore, examining an existing dune of similar elevation and location to the planned dune wall may provide a better forecast of its flood prevention potential. LiDAR-derived heights from the DEM reveal that the majority of this sampled dune is over 12.75ft above sea level, and ranges up to 15.22ft (Figure 17). The inundation maps further reveal that the dune is not submerged in a simulation of 8.43ft SLR, but it is mostly underwater at 13ft. The $63-million dune project may promise an initial maximum dune elevation of 12.75ft, but that does not necessarily mean that the dune will barricade storm tide all the way up to 12.75ft, since any lower depressions would be exploited.

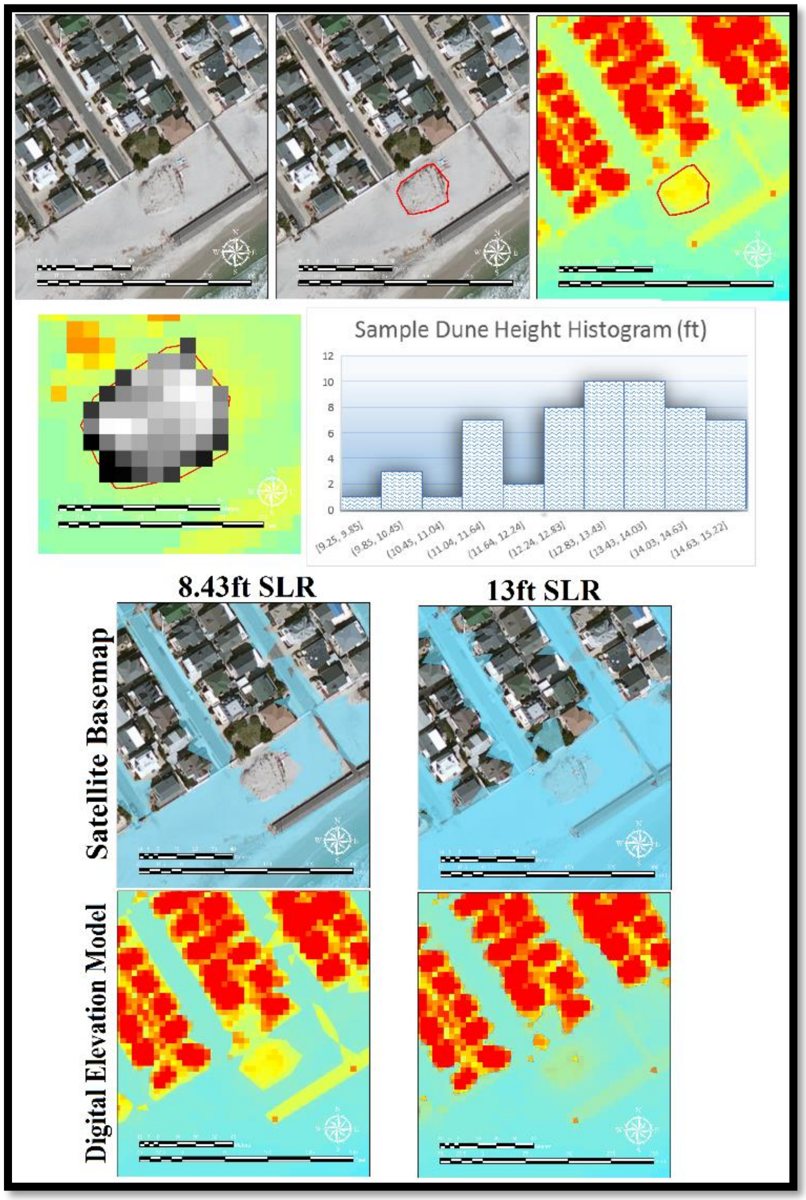


Figure 17. Examination of a present-day dune with similar properties to the proposed dune project

Subsidence

Inundation maps simulating 4ft of SLR with or without the inclusion of 1ft of subsidence predicted considerably inconsistent extents of seawater encroachment; adding 12 inches of sinking into the model leads to a considerable addition of water. In line with the existing consensus that subsidence plays a role in the magnitude of SLR,[12][13][14] it is agreed that subsidence needs to be accounted for in coastal inundation modeling.

Errors

It must not be overlooked that all inundation models are susceptible to inaccuracies and uncertainties. Measurement errors inherent in a LiDAR-derived DEM – tasked with reporting real-world topography – limit inundation models in their ability to predict precisely where water will flow. The three LiDAR datasets employed in this study have vertical accuracies within 20cm or 22cm, and since the study site lacks many dramatic slopes or major changes in elevation, an error of two decimeters could mean the difference of the model predicting water flows one way or the other. It is important that decision-makers and emergency planners understand the potential for errors in inundation model simulations.

Future Studies

For Margate City, NJ, once the dune project is completed new LiDAR-derived DEMs can supply inundation models with updated representations of ground topography for more realistic predictions. Using DEMs to remotely monitor the dune over time may aid in the early recognition of at-risk areas with high breach potential.

One extension related to this study might be to run a spectral classification analysis on images from NOAA's Emergency Response Imagery database to assess where Hurricane Sandy flooding occurred, based on the spatial range of sand deposited by water in the streets.

Other landcover datasets might also provide opportunities for other applications, such as USGS's Flood Event Viewer and USGS's EarthExplorer (although satellite imagery is unavailable before January 2015).

This project explored several different analyses regarding inundation from storms and global SLR, but resources exist for additional investigation – not only for Margate, NJ, but also many coastal regions, along with lists of historical disaster events similar to Hurricane Sandy.

Acknowledgements and Final Remarks

Thank you to Dr. Chris Parrish for passing on so much of the knowledge and skillsets needed to take on this project. Additional thanks go to my parents, whose outspoken opinions toward a pile of sand inspired me to investigate. Although at the time of this paper our family has ties to the study AOI, all research was conducted under strict neutrality.

That being said, this project did remind me of one lesson from my own history down the shore: you can construct an impressive wall of sand in front of your sandcastle, but the tenacious tide ultimately counters with a wave that wrecks it all, and sends you running for your towel.

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