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Economic Valuation of Shoreline Protection within the Jacques Cousteau National Estuarine Research Reserve

NOAA National Centers for Coastal Ocean Science
Marine Spatial Ecology

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LIST OF ACRONYMS

ADCIRC	Advanced Circulation
AEP	Annual Exceedance Probability
ASCII	American Standard Code for Information Interchange
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
C-CAP	Coastal Change Analysis Program
CRS	Community Rating System
CZM	Coastal Zone Management
DEM	Digital Elevation Model
EDF	Expected Damage Function
ENC	Electronic Navigational Chart
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GWCE	Generalized Wave Continuity Equation
HFA	Habitat Focus Area
HURDAT2	Hurricane Data 2nd generation
IPCC	International Panel on Climate Change
JC NERR	Jacques Cousteau National Estuarine Research Reserve
LiDAR	Light Detection and Ranging
LULC	Land Use Land Cover
MLLW	Mean Lower Low Water
MPC	Marginal Propensity to Consume
NACCS	North Atlantic Coast Comprehensive Study
NAVD 88	North American Datum 1988
NAICS	North American Industry Classification System
NCCOS	National Centers for Coastal Ocean Science
NED	National Elevation Dataset
NERR	National Estuarine Research Reserve
NERRS	National Estuarine Research Reserve System
NFIP	National Flood Insurance Program
NFIPD	Total NFIP Discount
NMS	National Marine Sanctuary
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NWI	National Wetlands Inventory
OCM	Office for Coastal Management
OSP	Open Space Preservation
POCs	Points of Contact
RIMS	Regional Input-output Modeling System
SFHA	Special Flood Hazard Area
SLAMM	Sea Level Affecting Marshes Model
SLR	Sea Level Rise
SWAN	Simulating Waves Nearshore
TNC	The Nature Conservancy
UN-CSD	United Nations Commission on Sustainable Development
US	United States
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Executive Summary

Photo credit: Jane Thomas, IAN Image Library

Ecosystem service valuation provides natural resource managers with the ability to place values on natural ecosystems and to more completely assess the costs and benefits of different management alternatives. Healthy coastal ecosystems produce a vast array of services, such as food production, carbon storage, aesthetically pleasing views, water purification, and shoreline stabilization. This study focuses on the ecosystem of coastal habitats (e.g., seagrass beds, marshes, and coastal forests), which operate as natural infrastructure, and can benefit coastal communities, other types of human development, and economic activity by reducing the impacts of coastal hazards. For example, in a given storm event, the presence of marsh can attenuate wave height and flooding impacts, and, in turn, mitigate property damages.

This study used the "damages avoided" method, in which the ameliorating benefits of a natural habitat are measured by using either the value of property protected or the cost of actions taken to avoid damages (i.e. storm surge, flooding, etc.) as a measure of the benefits provided by an ecosystem. Additionally, a second, market-based, method was used to quantify the value of open space preservation (OSP) in terms of its effect on flood insurance premiums. This included insurance premium savings made possible by the preservation of open space through the National Flood Insurance Program (NFIP) Community Rating System (CRS). The area of interest for this project was the Jacques Cousteau National Estuarine Research Reserve (JC NERR), which encompasses approximately 115,000 acres in southeastern New Jersey in parts of Atlantic, Burlington, and Ocean Counties.

By utilizing coastal hydrodynamic and wave models (i.e., the Advanced Circulation (ADCIRC) model and the Simulating Waves Nearshore (SWAN) model), three storm events (Hurricane Sandy event[1], a 50-year storm event[2], and a 25-year storm event[3]) were simulated for two land cover scenarios. In the first scenario, the selected storm events were modeled in an environment in which current marsh cover was present in the model, and for the second scenario, the marsh cover was removed and replaced by open water to evaluate the change in flooding and respective flood damages. This method provided flood depth outputs for each storm event illustrating property damages for both "marsh present" and "marsh absent" scenarios, with the difference between these two figures representing the storm damage reduction value of the marsh in a given storm event. In order to understand how the storm damage reduction value of the marsh within the JC NERR may change over time, the Sea Level Affecting Marshes Model (SLAMM) was utilized to create a GIS environment that projects how shoreline habitats will be altered in the face of sea level rise (SLR) in the area of interest[4] by the year 2050. The three storm events were again modeled in this projected 2050 environment in both "marsh present" and "marsh absent" scenarios.

Then, by utilizing CRS credit point and NFIP discount data for the communities within the area of interest, the economic impact of individual expenditures resulting from flood insurance premium savings due to OSP (as defined by the CRS) was calculated. OSP is a community activity that can provide flood insurance discounts to households within a CRS-participating community. These savings represent extra discretionary income for NFIP policyholders, which can then be spent in the local community, inducing economic stimulus for the surrounding area.

For this study's area of interest, it was found that the marsh in the JC NERR resulted in ~$8.34 million in avoided damages during a simulated Hurricane Sandy event, ~$13.08 million in avoided damages during a simulated 50-year storm event, and ~$9.83 million in avoided damages in a simulated 25-year storm event to residential property owners (Table 4.1). When the three storm events were modeled under future projected marsh cover and sea levels for the year 2050, it was found that the marsh would result in ~$32.09 million in avoided damages during a simulated Hurricane Sandy event, ~$19.93 million in avoided damages during a simulated 50-year storm event, and ~$1.54 million in avoided damages during a simulated 25-year storm event to residential property owners (Table 4.4). It was also found that participation in OSP enabled the communities in the area of interest to save ~$1.42 million on their flood insurance premiums in 2013 ($1.44

[1]Hall and Sobel (2013) found that Hurricane Sandy was a "714-year" storm event (a 0.14% chance of occurring in any given year).
[2]A 50-year storm event has a 2% chance of occurring in any given year.
[3]A 25-year storm event has a 4% chance of occurring in any given year.
[4]Area of interest is defined in Figure 2.3.

million in year 2015 dollars) (Table 4.9). By utilizing community-specific marginal propensity to consume[5] data, it was calculated that the savings attributed to OSP led to an extra $1.04 million (year 2015 dollars) in direct expenditures for the area of interest in 2013. Through multiplier effects, the $1.04 million in direct expenditures can be expected to lead to a $938,973 output contribution[6], a $451,500 income contribution, and an employment contribution of 12 full time jobs (Appendix C).

The findings from this work illustrate how natural infrastructure, such as marsh, is beneficial in terms of the storm impact mitigation services it provides. For the area of interest, storm damage reduction value was on the order of millions of dollars for each of the modeled storm events. It is important to keep in mind that each of the storm events selected for this analysis are unique and vary in factors, including direction, track, duration, intensity, landfall location, speed, and rotational velocity. As a result, the analyses in this report are not intended to be representative of other storm events; rather, the findings from this work support the body of literature concerning the economic benefits of coastal habitats in terms of reducing damages to coastal communities in the face of storm events. The property damages in the current/future and presence/absence of marsh scenarios will not change in the same magnitude for each storm event. This analysis also indicates how three unique storm events are distinct in resultant flooding and damages, and illustrates the variability in surge reduction potential of natural features such as marsh.

This report provides insight into the value of natural infrastructure in the JC NERR in terms of its flood mitigation capabilities, and provides evidence of the CRS program value for NFIP policyholders in CRS-participating communities. Here, it was shown that preserved open space provides economic benefits in the form of reductions of impacts to coastal communities from storms and NFIP premium savings.

[5]The marginal propensity to consume is the proportion of a change in disposable income that individuals spend on consumption, rather than saving.
[6]In economics, output is defined as the total value of goods or services produced by a given firm, industry, or geographic region.

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Chapter 1
Introduction

Photo credit: Jarrod Loerzel, NOAA

Healthy ecosystems provide an array of benefits and services ("ecosystem services") to people, including food, carbon storage, protection from natural disasters, and places to recreate (Costanza et al., 1997). Coastal erosion and inundation pose threats to these ecosystems and ecosystem services, as well as to nearby human populations, activities, and infrastructure. This is especially true within the context of a changing climate and increasing coastal populations (Schröter et al., 2005). Coastal habitats (e.g., seagrass beds, marshes, coastal forests) operate as natural infrastructure and can help reduce damages to human development and economic activity. For example, coastal vegetation has been shown to attenuate wave height, moderate the strength of wave-inducing currents, and decrease the extent of wave run-up on beaches (Lovas and Torum, 2001; Bridges, 2008; Luhar et al., 2010). It is important for natural resource managers to understand how management action or land use change may affect the storm damage reduction provided by coastal habitats.

Natural resource economists use a variety of techniques to estimate the value that ecosystems provide to people, which, in turn, allows environmental managers to assess the true costs and benefits of different management alternatives, as well as effectively communicate the importance of these ecosystems to their constituents and other decision makers (Granek et al., 2009). Values might include the amount of money potentially saved in property damages due to the presence of natural coastal infrastructure in a given storm event(s) or the amount of economic benefit accrued to local economies due in part to the habitat's presence (Badola and Hussain, 2005; Barbier, 2007; Costanza et al., 2008). Placing values on these ecosystems can lead to an increase in public awareness about the importance of these natural resource areas (Cooper, Burke and Bood, 2009; Waite, Burke and Gray, 2014).

This particular study uses the "damages avoided" method, in which the storm damage reduction benefits of a natural habitat are measured by considering the property damage costs that would be incurred if the flood control provision (e.g. the storm damage reduction value provided by a natural habitat) was absent (King, Mazzotta and Markowitz, 2000). Additionally, a second, market-based method was used to quantify the value of open space preservation (OSP) in terms of its effect on flood insurance premiums. This included insurance premium savings made possible by the preservation of open space through the National Flood Insurance Program (NFIP) Community Rating System (CRS).

This document describes the specific approach, data, tools, and techniques used, as well as the methods required to conduct this study. The report is organized as follows: Chapter 1 provides introduction and background; Chapter 2 describes the methods for data preparation and analysis; Chapter 3 outlines the data requirements and datasets used; Chapter 4 describes the study's results; and Chapter 5 provides discussion and conclusions.

1.1. STUDY AREA: JACQUES COUSTEAU NATIONAL ESTUARINE RESEARCH RESERVE

The region of interest for this project is the Jacques Cousteau National Estuarine Reserve (JC NERR), which encompasses approximately 115,000 acres in southeastern New Jersey and includes a great variety of terrestrial, wetland, and aquatic areas within the Mullica River-Great Bay ecosystem. The JC NERR is a concentrated patchwork of federal and state lands managed in partnership through a variety of agencies. Since only approximately 1% of the land within the JC NERR has been subjected to human development, this area is regarded as one of the least disturbed estuaries in the highly populated Northeastern United States (US) urban corridor (JC NERR, 2014a). The Reserve contains a wide range of different habitats for plants, animals, and endangered species, including: upland forested areas of pines and oaks; lowland forested areas of Atlantic white cedar swamps; pitch pines and red maples; fresh and salt-water marshes; barrier islands; sandy beaches; dune habitats; and, shallow bays (JC NERR, 2014b). Three New Jersey counties lie within/adjacent to the JC NERR: Atlantic County, Burlington County, and Ocean County (Figure 1.1).

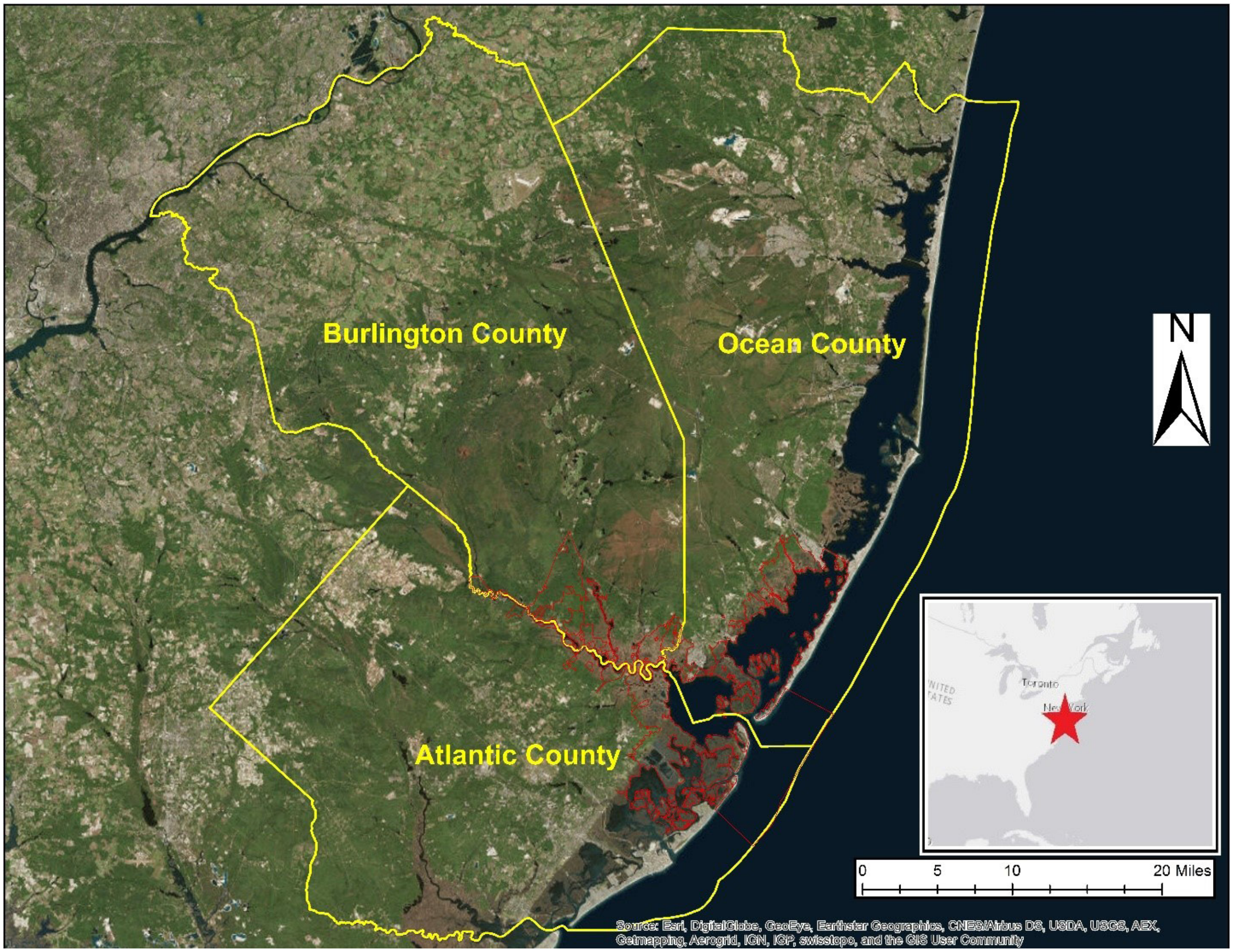

Figure 1.1. JC NERR boundary highlighted in red along with the three adjacent New Jersey counties highlighted in yellow.

1.2. WHY INTEGRATED METHODS TO ASSESS AND VALUE ECOSYSTEM SERVICES MATTER

1.2.1. Coastal Zone Management

Coastal zone management (CZM), as a discipline, covers many concerns, ranging from habitat protection to public access, and from climate change to water quality (NOAA, 2016). The broad scope of CZM necessitates an integrated approach to coordinate strategies to allocate available coastal resources in such a way as to provide sustainable multiple uses of coastal areas (Mumby et al., 1995). A major part of the coordinated strategies is gathering enough information to balance environmental stewardship, economic opportunity, human health, and human activities sustainably, effectively, and efficiently. Information regarding coastal habitat condition, as well as information concerning the economic benefits of coastal habitats, can be used by coastal zone managers when communicating to the public; for example, this might include the amount of money potentially saved in property damages in a given storm event due in part from the habitats under their jurisdiction. Additionally, communicating the information obtained from ecosystem valuation studies can increase public awareness about the importance of these ecosystems (Turner et al., 2000; Bingham et al., 1995).

1.2.2. Sea Level Rise

According to past research, global mean sea level has risen at the rate of approximately 3.2 mm per year from 1993 to 2010 (IPCC, 2014). By the year 2100, total accumulated sea level rise (SLR) is projected to be somewhere between 90 mm to 880 mm (IPCC, 2014). With human population density the highest in the coastal zone, this amount of SLR could have very significant effects, ranging from habitat conversions to losses in key ecosystem services (UN-CSD, 2008).

From a regional point of view, data from the three New Jersey sea level monitoring stations indicate an upward average mean sea level trend at a rate of ~4.22 mm per year[7] (NOAA, 2013). While these rates are strictly relative to the region, SLR amounts of this magnitude can influence the distribution, density, and coverage of coastal wetland types, particularly marsh grasses (Craft et al., 2009). These impacts could result in habitat migration and marsh submersion (Park et al., 1989; Moorhead and Brinson, 1995), which could, in turn, affect the delivery of key ecosystem services provided by these habitats (Craft et al., 2009).
Coupled with SLR, coastal erosion and inundation pose threats to human populations, activities and infrastructure. This is especially true within the context of a changing climate and increasing coastal populations. Coastal habitats (e.g., seagrass beds, marshes, coastal forests) can protect human development and economic activity by reducing the impacts of these coastal hazards through reducing wave height, moderating the strength of currents, and decreasing the extent of waves' effect on beaches (Lovas and Torum, 2001; Möller, 2006; Bridges, 2008; Luhar et al., 2010). Management actions and land use change can affect the storm damage reduction benefits provided by coastal habitats; therefore, it is critical for natural resource managers to have the best available science when evaluating decisions.

1.2.3. Various Tools and Techniques Used in Ecosystem Services Valuation

Ecosystem service values are used to measure the importance of ecosystem services to people (i.e. what they are worth). Economists quantify the value of ecosystem services to people by estimating the amount people are willing to pay to preserve or enhance the services; however, this is not always straightforward, and for several reasons. Whereas some ecosystem services, like fish for food or lumber for construction, are bought and sold in markets, many ecosystem services, like a day of bird watching or an aesthetically pleasing view of the ocean, are not. As a result, people do not pay directly for many ecosystem services. Additionally, because people are not familiar with purchasing such goods, their willingness to pay may not be clearly defined, but this does not mean that ecosystem services not traded in markets have no value or cannot be valued in dollar terms. Economists bring several different approaches to the practice of ecosystem service valuation (i.e. the replacement cost method, the hedonic pricing method, the travel cost method, the benefit transfer method, etc.), including the "damages avoided method," in which the value of the property protected by the coastal habitat is a measure of the storm damage reduction benefits (Farber, 1987; Costanza, 2008; Cooper, Burke and Bood, 2009; Barbier, 2013). For the economic valuation component of this project, the "damages avoided method" was used to calculate the storm damage reduction benefits of the marsh within the area of interest.

1.2.4. Integrated GIS Modeling

Over the years, Geographic Information System (GIS) modeling has become an invaluable tool for coastal zone managers. Moreover, integrated techniques involving a combination of methods to determine the impacts of SLR on coastal zone habitats have shown promise in aiding coastal zone managers in their decision-making (see NOAA's Digital Coast: Stories from the Field for examples).

This study builds upon previous studies (Walls et al., 2017; Narayan et al., 2016; Boutwell and Westra, 2015; Boutwell and Westra, 2014) to utilize an integrated approach to determine the value of coastal natural infrastructure. The research conducted by Walls et al. (2017) looked at a coupled version of the Advanced Circulation and Simulating Waves Nearshore (ADCIRC+SWAN) models implemented for the Chesapeake Bay to estimate the flood depth for both a 'with wetland' scenario (where wetlands and marshes were kept as is during the occurrence of storm events) and for a 'without wetland' scenario. Five historical storms were modeled to capture a range of storms making landfall in the Bay region. Parcel level property data were combined with the simulated results to calculate the avoided damage by the presence of wetlands in the coastal counties of Maryland. The researchers found that for the coastal areas of Maryland, the storm

[7]Refers to relative sea level rise. Relative sea level rise is any sea level change that is observed with respect to a land-based reference frame. This differs from eustatic sea level rise in that the volume or mass of water does not change (Rovere, Stocchi, and Vacchi, 2016).

damage reduction services provided by the wetlands and marshes can range in value from $55 to $454 million. On a per-square kilometer basis, the value varied from $65,000 to as high as $383,000.

Narayan et al. (2016) combined two studies: one examining flood losses from a Hurricane Sandy event with "marsh present" and "marsh absent" scenarios, and another which investigated the annual damages avoided due to saltmarsh presence and absence from 2000 historical storm events. The former study is more closely aligned with the research presented here while the latter is more closely aligned with those studies using multiple storm events in a regression analysis (e.g., Walls et al., 2017; Boutwell and Westra, 2015). Narayan et al. 2016 found that wetlands in New Jersey saved ~$625 million in flood damages by reducing damages more than 10% on average.

Boutwell and Westra (2015) used data from 24 storms making landfall in the Gulf of Mexico coupled with an expected damage function (EDF) approach to determine the economic value of wetlands in the region. An ordinary least squares model described the storm damages as a function of storm intensity, socio-economic situation, and wetland area. The researchers found that wetlands are valuable for storm damage mitigation, and that where wetlands are scarce, changes in the area of wetlands is the most impactful.

Boutwell and Westra (2014) presented a method that used predictive modelling coupled with observed damages to estimate localized damages to the parish-level from storms making landfall in Louisiana between 1997 and 2008. The researchers then used factor analysis to determine the extent that wetlands reduced economic damages. Through this process, the researchers found that while wetlands are valuable for reducing damages during coastal storms, there is a "storm intensity threshold" which limits the flood mitigation services provided by wetlands.

One key difference in this study when compared to other studies of this type is the use of the Sea Level Affecting Marshes Model (SLAMM) GIS tool. This tool allows researchers to project future impacts and migration of marsh in the face of SLR. This project also focuses more closely on the individual parcel-level property damages by utilizing specialized tools found in the Geospatial Modeling Environment software package to determine precise estimates of flood inundation, and by calculating damages at the individual parcel scale using the given parcel's improvement value rather than using an average area of interest-wide improvement value.

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Chapter 2
Methods

Photo credit: Angela Orthmeyer, NOAA

2.1. ECOSYSTEM SERVICE VALUATION

The ecosystem service valuation methodology involved the following steps. These steps are then described in greater detail throughout this chapter.

1. **Identify storm events:** Storm events were selected using information from previous studies, stakeholder input, and data from the US Army Corps of Engineer's (USACE) Storm Track Database (Cialone et al., 2015).
2. **Identify natural infrastructure in the area of interest:** Researchers identified and mapped the extent and types of shoreline habitats in the area of interest. Based on this data and information from the literature and model requirements, natural infrastructure was defined as those with known coastal storm damage reduction qualities (e.g., marsh, estuarine wetlands, palustrine wetlands).
3. **Model storm scenarios within the area of interest:** Researchers and colleagues conducted model runs of identified storm events with and without chosen natural infrastructure using a combination of the ADCIRC+SWAN models.
4. **Determine the migration of marsh habitat due to future sea level rise projections:** The protective habitat was adjusted using the results of the SLAMM analysis and the relative protection was recalculated (using methods found in Step 3). This exercise was done to examine how the value of natural infrastructure in the area of interest is expected to change by the year 2050.
5. **Estimate "damages avoided" due to presence of the habitat:** The building footprint value (improvement value) of each parcel inundated in a given storm event in the model was multiplied by the expected percentage of the parcel damaged given by USACE's depth damage functions (USACE, 2003). This value was used to calculate a damage dollar value for each parcel in both scenarios -- with scenarios being 1) presence of natural infrastructure and 2) absence of natural infrastructure. These parcel-level damage dollar estimates were aggregated across all inundated parcels for each scenario. The "storm damage reduction value" was calculated as the difference in residential property damages with and without natural infrastructure in a given storm event.

2.2. STUDY SITE SELECTION

A rigorous selection process was conducted in order to select a site that would best fit the project's goals and objectives, the steps of which are outlined in the following subsections.

2.2.1. Determination of Potential Study Sites

After consulting with NOAA's Office for Coastal Management (OCM) leadership and other agency members, the research team compiled a list of potential sites to conduct the analysis. One of the priorities of the National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS) is place-based conservation, which focuses on NOS "special places." Special places are defined as "those marine areas that are designated, reserved or in some way set aside for particular use(s), including conservation, and are managed by NOAA or long term NOAA partners (states and territories)" (NOS, 2016). The research team began the site selection process with a comprehensive list of National Marine Sanctuaries (NMSs), National Estuarine Research Reserves (NERRs), and Habitat Blueprint Focus Areas (HFAs) (Table 2.1). These entities were recently or potentially affected by coastal (marine) hazards such as storm surge and sea level rise, and were known to be close to areas with significant human development.

Jacques Cousteau NERR at dusk. Photo credit: Matt Gorstein, NOAA.

Table 2.1. NOS "Special Places" considered for the project.

NERRS sites (marine coastal)	Habitat Blueprint Focus Areas (marine coastal)	National Marine Sanctuaries (near development)
Wells (Maine)*	Choptank River	Florida Keys*
Guana Tolomato Matanzas (Florida)*	Kachemak Bay, Alaska (also a NERR)	
North Carolina (Rachel Carson area) (North Carolina)*	Manell-Geus watershed, Guam	
North Carolina (Masonboro Island area) (North Carolina)*	West Hawaii	
Tijuana River (California)*	Northeast Reserves and Culebra Islands, Puerto Rico*	
Rookery Bay (Florida)*	Russian River, California*~	
Jacques Cousteau (New Jersey)*	Biscayne Bay, Florida*	
Weeks Bay (Alabama)	St. Louis River Estuary*~	
Grand Bay (Mississippi)	Penobscot River watershed, Maine	
Waquoit Bay (Massachusetts)		
San Francisco Bay (California)		
Great Bay (New Hampshire)		
Chesapeake Bay (Virginia)		
Chesapeake Bay (Maryland)		
Kachemak Bay (Alaska)		
Padilla Bay (Washington)		
South Slough (Oregon)		
Elkhorn Slough (California)		
Mission-Aransas (Texas)		
Apalachicola (Florida)		
Jobos Bay (Puerto Rico)		
Sapelo Island (Georgia)		
ACE Basin (South Carolina)		
North Inlet-Winyah Bay (South Carolina)		
Delaware (Delaware)		
Narragansett Bay (Rhode Island)		
Hudson River (New York)		

*Ranked as having a "high" level of development within a 1-mile buffer of the site's boundary.
~Removed from consideration due to being located in riverine/estuarine ecosystems with little likelihood of being impacted by coastal natural hazards such as storm surge or sea level rise.

2.2.2. Development of Criteria for Site Selection

By soliciting feedback from NOAA's OCM and others, the research team developed a set of criteria for site selection. The team expanded the list to include data requirements for a suite of models that would be used in the analysis, as well as other criteria that the team deemed appropriate for site selection based on project goals and objectives. The overarching categories for site selection were:

- Management interest in the project;
- Anticipated community interest in the project;
- Proximity to coastal development; and
- Data availability for the models.

A full list of criteria for site selection is found in Table 2.2.

2.2.3. Proximity to Development Analysis

Beginning with the sites recommended by OCM and partners, and later extending to the rest of the sites on the list (Table 2.1), researchers conducted a "proximity to development" analysis. Researchers ranked sites as having "low," "medium," or "high" levels of development within a 1-mile buffer of the site boundary. This ranking was established through a visual analysis. The visual analysis took into consideration the number of towns/cities and the size/extent of total urban development within each site. Twelve sites were determined as being proximate to relatively "high" development (Table 2.1).

2.2.4. Initial Contact with Site Managers

After two of the sites (St. Louis River and Russian River) were removed from consideration, the research team sent out a site selection criteria questionnaire (Table 2.2) to points of contact (POCs) (determined through feedback from OCM) at the refined list of ten sites that passed the "proximity to development" test, and were deemed to be vulnerable to coastal natural hazards. Six completed questionnaires were returned from site managers (five contacts, one group representing the two parts of the North Carolina NERR that were under consideration). The six final sites were:

- Guana-Tolomato-Matanzas NERR
- North Carolina NERR (Rachel Carson area)
- North Carolina NERR (Masonboro Island area)
- Jacques Cousteau NERR
- Florida Keys NMS
- Northeast Reserves and Culebra Islands HFA

Phone calls were held with the POCs from each of the six above sites in order to collect more detailed information about the site selection criteria questionnaire, to review the project's goals and objectives, and to discuss how the project may fit in with managers' goals and objectives for management of the areas of interest.

Example of raised housing for flood mitigation adjacent to the JC NERR. Photo credit: Sarah Gonyo, NOAA.

Table 2.2. The site-selection criteria in questionnaire format.

Criteria Questions	Yes/No/Maybe/Unsure (Circle one)	Comments
Management Interest		
Does your management plan have goals related to ecosystem service valuation?	Yes No Maybe Unsure	
Do you think that this project is relevant to current management concerns?	Yes No Maybe Unsure	
Do you think that this study would have any direct policy or management implications?	Yes No Maybe Unsure	
Do you feel that ecosystem valuation projects will be useful in reaching management goals/ have they been useful in the past?	Yes No Maybe Unsure	
Can you provide in-kind funds or human resources to the effort?	Yes No Maybe Unsure	
Community Interest		
Do you feel that the surrounding community understands the protection benefits provided by coastal ecosystems?	Yes No Maybe Unsure	
Do you feel that this project would be of interest to the surrounding community?	Yes No Maybe Unsure	
Do you feel there are other community organizations that would be interested in or benefit from this project? If so, please list them in the space provided.	Yes No Maybe Unsure	
Has your surrounding community been negatively affected by a coastal natural disaster in the last 10-20 years?	Yes No Maybe Unsure	
Proximity to Development		
Do you think the developed areas around your site are in need of shoreline protection measures?	Yes No Maybe Unsure	
Is there development (residential, etc.) nearby your site?	Yes No Maybe Unsure	
If yes to above, would you classify it as HIGH, MEDIUM, or LOW density development?	Yes No Maybe Unsure	
Are there businesses nearby your site that are particularly important to the local economy?	Yes No Maybe Unsure	
Are there cultural or historical assets nearby or within your site that are important to the surrounding community?	Yes No Maybe Unsure	
Data Availability		
Digital shoreline habitat maps?	Yes No Maybe Unsure	
Property values?	Yes No Maybe Unsure	
Flood insurance information/participation?	Yes No Maybe Unsure	
Digital Land Use/Land Cover?	Yes No Maybe Unsure	
Digital shoreline delineations?	Yes No Maybe Unsure	
Sea level rise calculations?	Yes No Maybe Unsure	
Anthropogenic influences?	Yes No Maybe Unsure	

2.2.5. Development of Refined Site Selection Criteria and Weighting Scheme

After the phone calls, researchers refined the site selection process by developing an objective decision process and weighted scoring mechanism based on the site-selection criteria questionnaire (Figure 2.1). This allowed the research team to begin filtering through the sites based on data availability (necessary for model input) and proximity to development. A second, refined proximity to development analysis was conducted for five sites, using a 1-km buffer and quantifying the amounts of habitat types and development within the buffer range using land use/land cover data from the Coastal Change Analysis Program (C-CAP) (Figure 2.2). Once any sites were removed from consideration through the filtering process outlined in the decision diagram (Figure 2.1), the remaining sites were evaluated based on their responses to questions in the site selection criteria list, as well as the researchers' refined evaluations based on conversations with site managers.

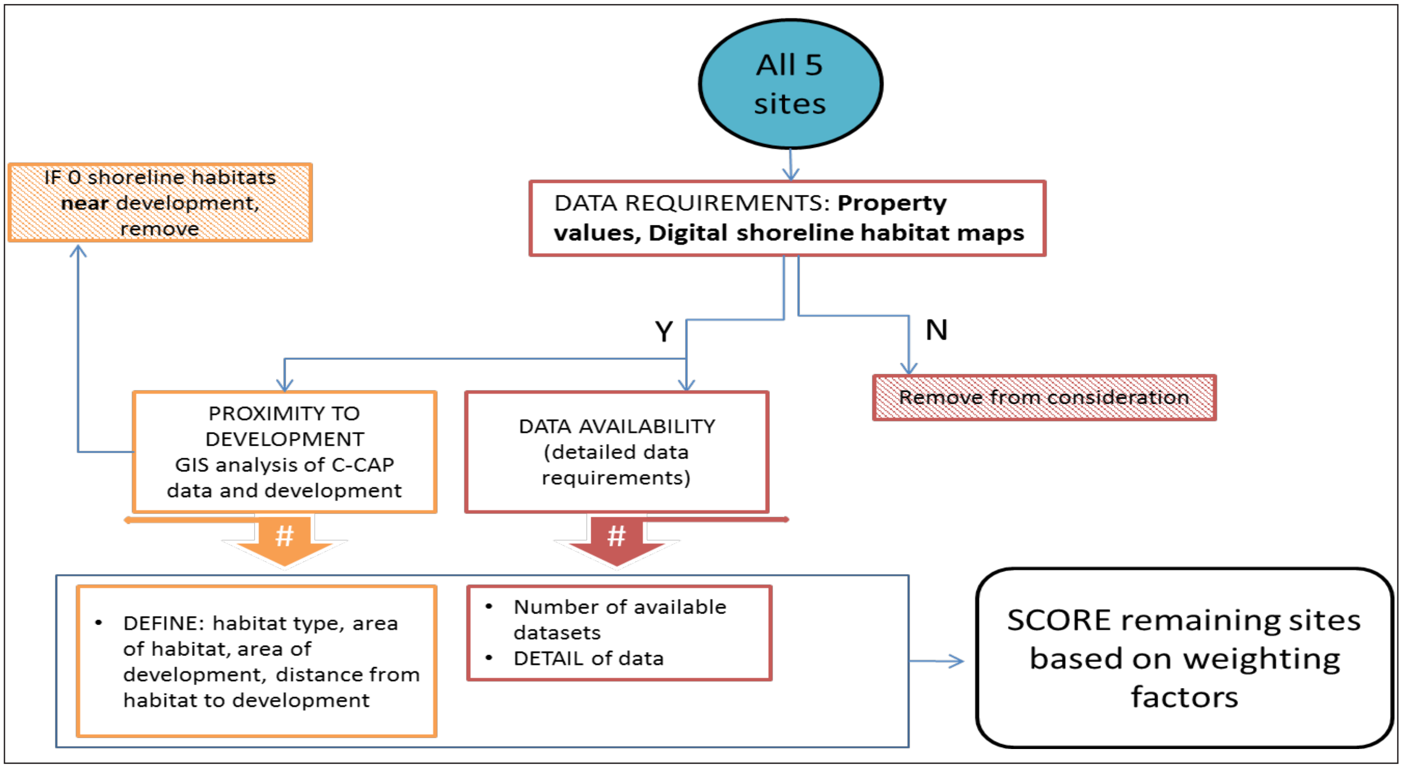


Figure 2.1. Decision diagram.

Marina on a foggy day. Photo credit: Matt Gorstein, NOAA.

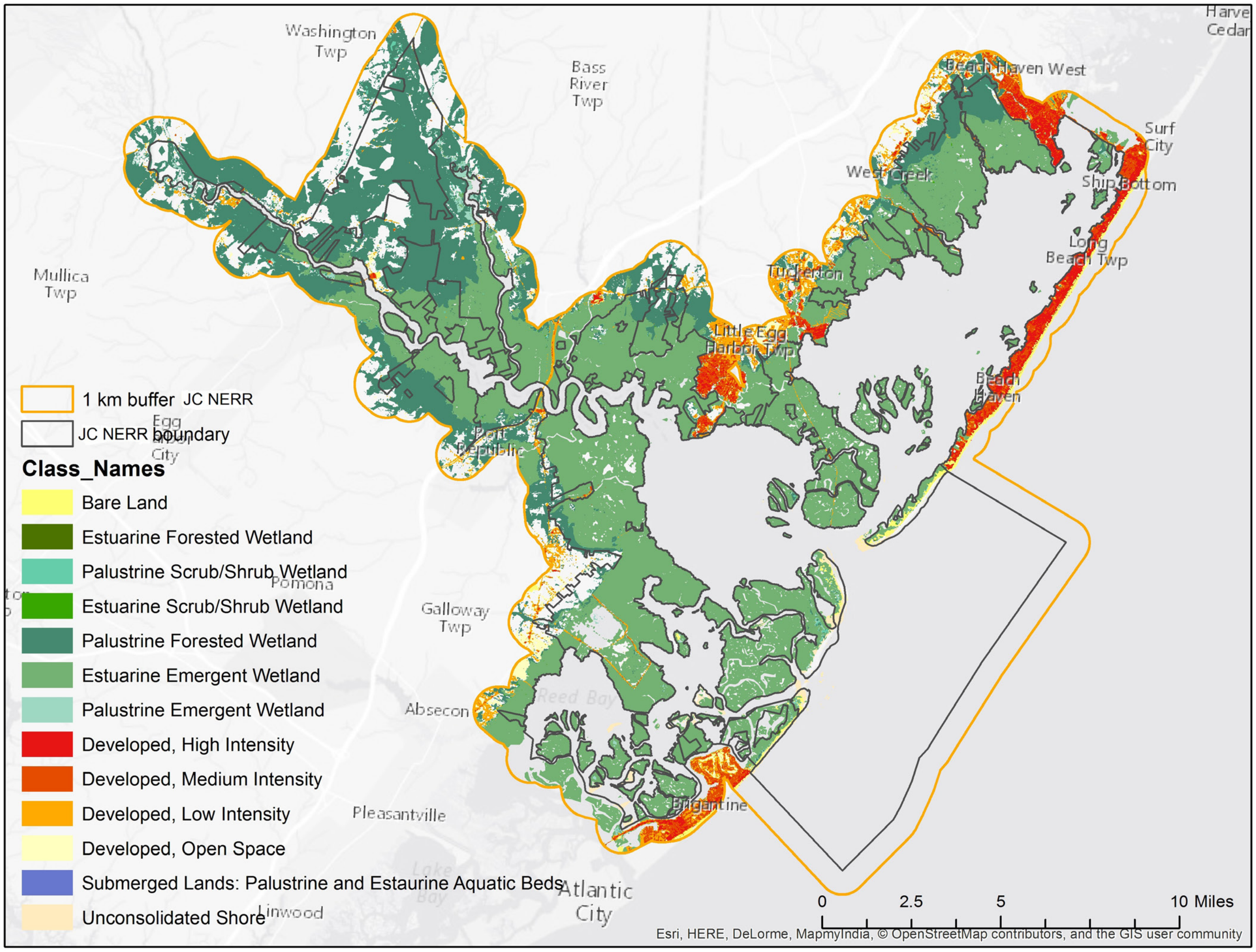


Figure 2.2. Example of refined proximity to development analysis using a 1 km buffer and C-CAP data.

2.2.6. Final Site Selection

For the four sites remaining (the two North Carolina NERR sections considered as one site), an expanded list of data requirements for the models was sent back to the POCs in the form of a checklist. POCs at each site checked off boxes for each dataset that they had available or could obtain to run the two models (Table 2.3).

The data requirements for the SLAMM and the ADCIRC+SWAN models are quite extensive, and requiring more complete data sets before beginning analysis proved to be beneficial by saving time during the data collection stage of the project. The final four sites were evaluated based on their professed management interest in the project, their data availability from the expanded list, and their proximity to development from the refined analysis. The team reviewed this information and decided on the JC NERR as the best site to conduct the analysis.

2.3. STAKEHOLDER ENGAGEMENT AND SCENARIO SELECTION

In the fall of 2015, members of the project team met with members of the JC NERR staff and other stakeholders, including researchers from Rutgers University, NJ Future, and The Nature Conservancy (TNC). The purpose of this meeting was to provide an overview of the project goals and research methods, to elicit input on weather event and shoreline habitat management scenarios, and to determine which communities were of interest for this project. Based on meeting discussions, potential modeling scenarios were developed and categorized into one of three types: habitat, hazard, or community (Table 2.4). By combining these types in different arrangements, potential modeling scenarios were created. For example, Sedimentation + Progressive storm events + Route 9 = How would progressive storm events impact sedimentation patterns along Route 9?

Table 2.3. Expanded data availability checklist.

Modeling Data Requirements	Yes/No
Polyline with attributes about local coastal geomorphology along the shoreline	
Polygons representing the location of natural habitats (e.g., seagrass, kelp, wetlands, etc.)	
Rates of (observed) net sea-level change	
A depth contour that can be used as an indicator for surge level (the default contour is the edge of the continental shelf)	
Digital Elevation Model (DEM) representing the topography and (optionally) the bathymetry of the coastal area	
A point shapefile containing values of observed storm wind speed and wave power	
Polygon shapefiles representing residential parcel data for the area of interest with information as to the improvement value of the parcel	
Near shore bathymetry (water depths) and topography (land elevation) - a sort of DEM/ bathymetry combination	
Back shore characteristics: elevation relative to Mean Lower Low Water (MLLW) of both the submerged (underwater) and emerged (above water) portions of the cross-shore profile (cross-shore profile ideally using the Emery board method); sand size information along the cross-shore profile transects	
Offshore wave height and period values	
Location and descriptions and physical characteristics of natural habitats: sub-tidal (always submerged), inter-tidal (between high and low tides) and supra-tidal (above the high-water mark) habitats [i.e., seagrass beds, marshes, mangroves or coastal forests, coral reefs and oyster reefs]; and representative density, height and diameter of the habitat elements; distance from the shoreline of the natural habitats that will become submerged during a storm	
Land Use Land Cover, from both National Wetlands Inventory (NWI) and C-CAP	

Table 2.4. Potential scenarios determined through stakeholder input.

Habitat	Hazard	Community
Sedimentation	Progressive storm events	Route 9
Pilings	Cold fronts	Mystic and Osborn Islands
Seagrass	Storm surge	Raised homes
Maritime forests	Sea level rise (5-year)	Tuckerton community
Marsh	Sea level rise (10-year)	Marsh level communities (Osborn Island, Tuckerton Beach, Bass River)
Upland areas	Wind velocity, direction and fetch	Lagoon communities
Dunes	100 year flood event	Great Bay
Mosquito ditching	Nor’easter	
Barrier islands	Sandy event (500 year flood or beyond)	
Wetlands	Ice ("bulldozing effect")	
Bulkheads or other hardened shoreline		

In an effort to address as many of the above scenarios as possible while managing time constraints and stakeholder needs, the project team focused on three simulated storm events: A Hurricane Sandy event; a 25-year storm event (4% annual rate of occurrence); and, a 50-year storm event (2% annual rate of occurrence). The project partners at the JC NERR indicated that a Hurricane Sandy event, a 25-year storm event, and a 50-year storm event were of high interest, and being that marsh is the dominating natural infrastructure within the JC NERR area, this was the natural feature that was analyzed in the storm damage reduction analysis. Each of these unique storm events were modeled with both current baseline marsh conditions and with marsh habitat virtually removed (“marsh present” and “marsh absent” scenarios) using a GIS framework. To take future area of interest environmental conditions into account, each of these storm events were also modeled under projected SLR and marsh migration conditions in the year 2050 (again modeled with marsh present and with marsh absent) in an effort to understand how the distribution of natural infrastructure and its storm damage reduction value is projected to change over time. As a result, the chosen events, scenarios, and conditions were operationalized in the following manner for the purposes of modeling (Table 2.5).

Table 2.5. Modeled storm and habitat scenarios.

Hurricane Sandy storm event	25-year storm event	50-year storm event
Under current baseline conditions (marsh present)	Under current baseline conditions (marsh present)	Under current baseline conditions (marsh present)
Under current baseline conditions (marsh absent)	Under current baseline conditions (marsh absent)	Under current baseline conditions (marsh absent)
Under future projected conditions of sea level rise and marsh migration in the year 2050 (marsh present)	Under future projected conditions of sea level rise and marsh migration in the year 2050 (marsh present)	Under future projected conditions of sea level rise and marsh migration in the year 2050 (marsh present)
Under future projected conditions of sea level rise and marsh migration in the year 2050 (marsh absent)	Under future projected conditions of sea level rise and marsh migration in the year 2050 (marsh absent)	Under future projected conditions of sea level rise and marsh migration in the year 2050 (marsh absent)

After developing storm and habitat scenarios, stakeholders were consulted to provide their input on the spatial extent for which they wanted the inundation modeling and economic analysis to encompass. An area of interest was chosen to include the JC NERR and extend south to include Atlantic City, north to include Barnegat Bay, and inland to include other Mullica River watershed communities (Figure 2.3). This area of interest formed the polygon to which all analytical results were clipped.

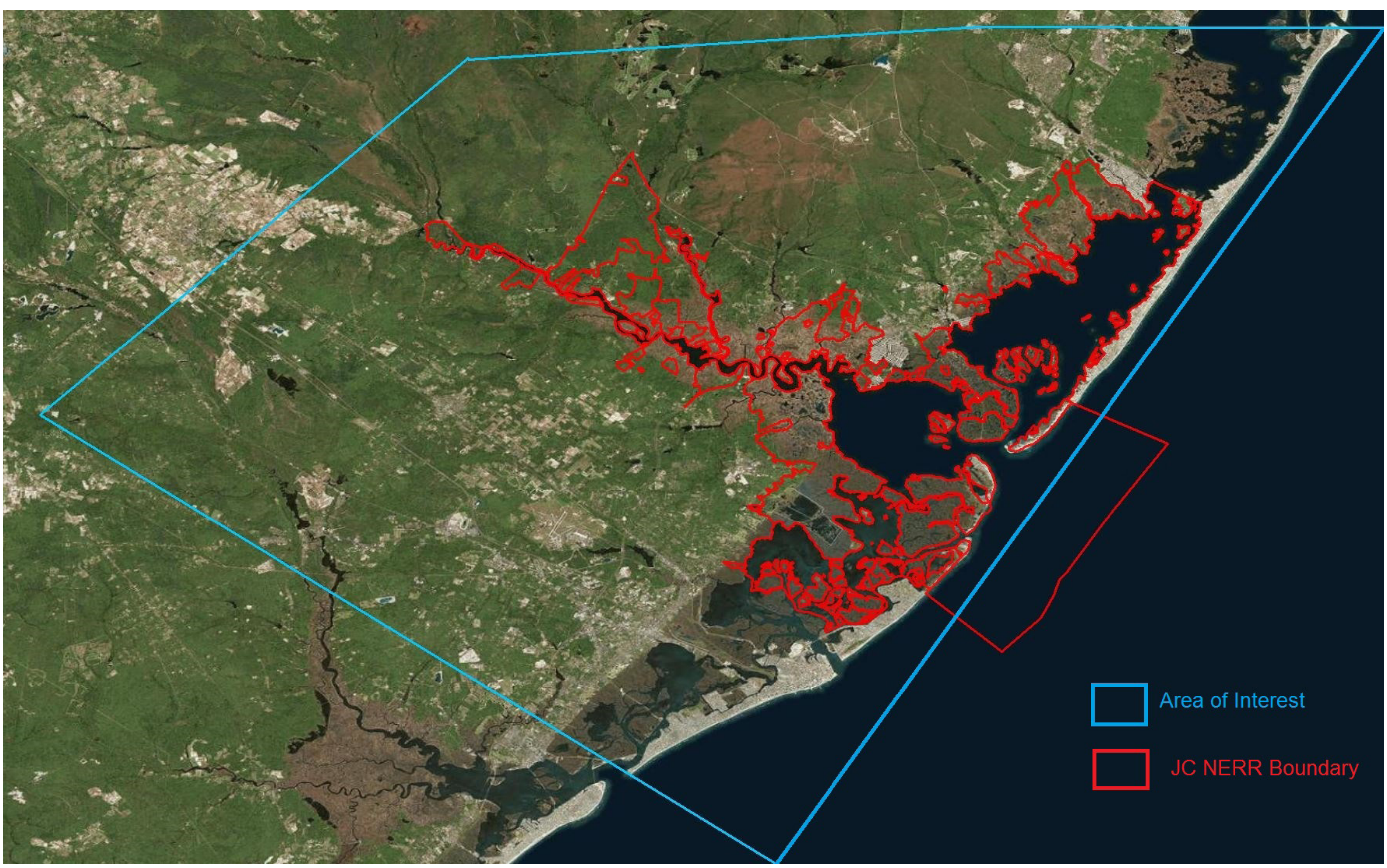


Figure 2.3. Area of interest chosen with partner consultation.

2.4. SPATIAL ANALYSES

For the spatial component of the project, a number of methods were used and will be discussed in this section. The methods used will reference the aforementioned data requirements (See Table 2.5 for modeled scenarios). For a more nuanced explanation of the spatial data manipulation methodology, please see Appendix A.

2.4.1. Sea Level Affecting Marshes Model (SLAMM)

SLAMM was developed to simulate the primary processes influencing wetland conversions and shoreline fluctuations in the face of long-term sea level rise (Clough, 2016). SLAMM utilizes a complex decision-tree that incorporates qualitative and geometric relationships to represent the shoreline conversions and habitat fluctuations vis-à-vis SLR (Clough, 2016). In the SLAMM, SLR is offset by user supplied values of accretion and sedimentation. Due to limited literature references as to the rates of accretion or sedimentation in the study area, for this implementation, the value of 4 mm/yr accretion was used as an average for the entire area of interest (Lathrop, 2016).

For projected SLR in the area of interest, researchers used the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios A1 storyline and the F1 scenario. That is,

> "[t]he A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies)." (IPCC, 2001)

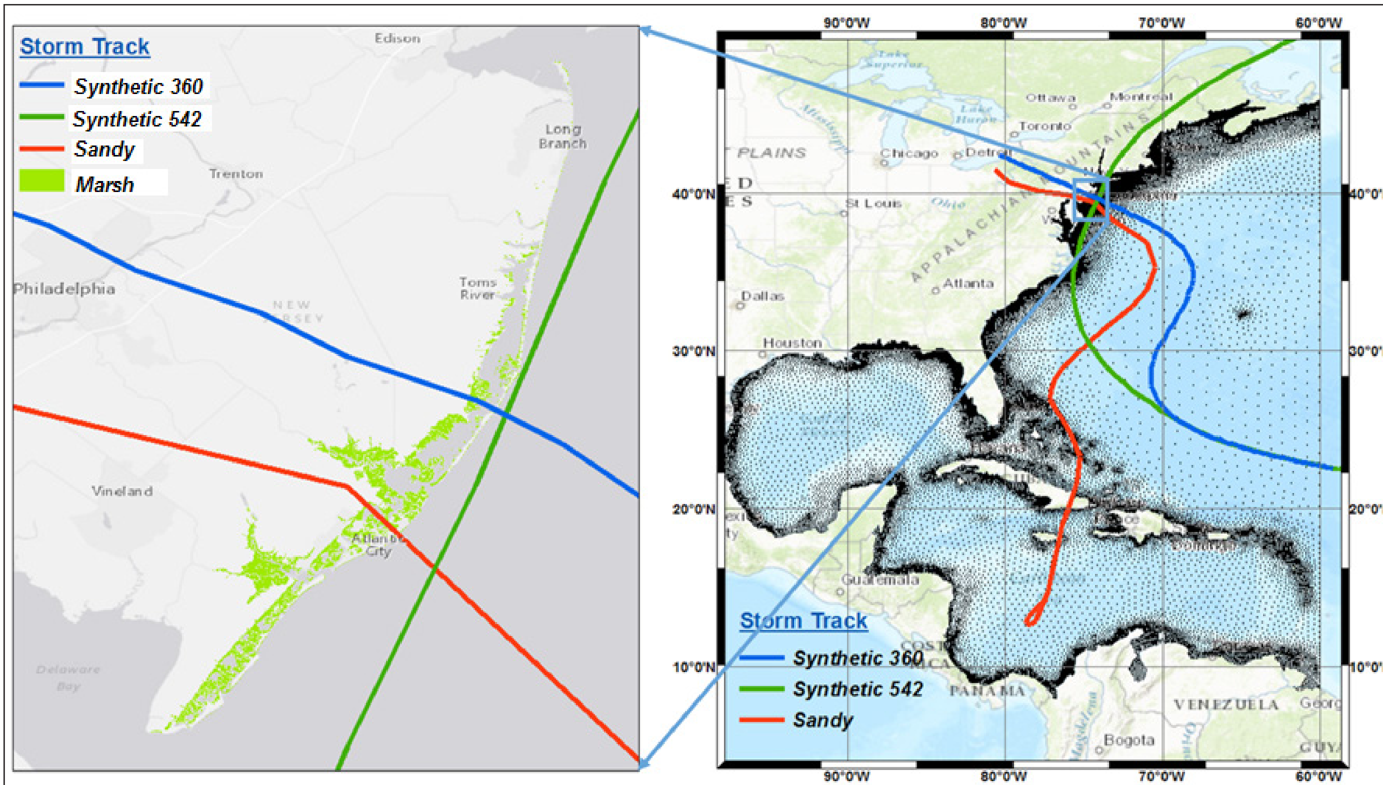
Due to partner request and project timeline restrictions, the researchers limited the future projections of SLR to the year 2050. Using the projected SLR value of 0.1332 m for the year 2050, SLAMM simulated the future land cover changes in the study area. This provided an estimation of how land use and land cover types, especially wetlands and marshes, will change within the study area.

2.4.2. Advanced Circulation (ADCIRC) + Simulating Waves Nearshore (SWAN) Models

To estimate the flooding in the area of interest due to selected storm event storm surge, researchers applied the coastal hydrodynamic model ADCIRC dynamically coupled with the nearshore wind wave model SWAN. ADCIRC (Luettich, Jr., Westerink,and N.W.S., 1992; Westerink et al., 1994) is a computer model that solves two-dimensional, depth integrated shallow water equations in generalized wave continuity equation (GWCE) form. The model uses the finite element method in an unstructured mesh (Luettich, 2004) to compute water level and current velocity at each computational node. SWAN is a third generation numerical wave model that solves the action balance equation (Booij, Ris and Holthuijsen, 1999) to estimate the random short-crested waves in the nearshore coastal regions. In the coupled version of ADCIRC+SWAN (Dietrich et al., 2010; Dietrich et al., 2011), both models use the same computational mesh such that in each time step ADCIRC transfers the computed water level and currents to SWAN. SWAN, in turn, computes the wave radiation stress gradient and passes the information back to ADCIRC as a forcing component (Dietrich et al., 2011; Dietrich et al., 2012; Bilskie et al., 2016; Mattocks and Forbes, 2008). The model requires tides, winds, and pressure fields to simulate hurricane induced storm surge. In addition to the forcing conditions, the model incorporates the impact of different land use and land cover types though *Manning's n* bottom friction coefficients, roughness lengths, and canopy cover (for further details see Appendix A). While *Manning's n* accounts for the resistance to flow due to sea surface roughness, the land roughness length and surface canopy address the wind blocking effect of vegetation (Atkinson et al., 2011; Ferreira, 2014). For this study, *Manning's n* values were taken from the previous literature that applied ADCIRC for storm surge simulations in the United States (Dietrich et al., 2010; Dietrich et al., 2011; Atkinson et al., 2011; Ferreira, Olivera, and Irish, 2014). *Manning's n* values of 0.07, 0.75 and 0.2 were used for the palustrine[8] wetlands (forested, shrub, and emergent, respectively), and for the estuarine[9] wetlands, 0.15, 0.07 and 0.05 were applied accordingly. The difference in the friction co-efficient values for wetland types vary with existing vegetation types, canopy density, soil type, alignment of the vegetation or plants to the flow, and fraction of wetted perimeter by the vegetation (Arcement and Schneider, 1989). Additionally, for the "marsh absent" land cover scenario where both estuarine and palustrine wetlands were replaced with open water, a 0.025 *Manning's n* value was used for assigning the friction parameter for open water. Both the current land use types and SLAMM projected future land use information were incorporated into the surge and wave models using the geospatial parameterization described earlier in this paragraph.

Harmonic tides were used in the open ocean boundary as the tidal forcing for the modelling. Major diurnal tidal constituents and all of its semidiurnal constituents were incorporated in the forcing from the Le Provost database (Le Provost et al., 1994). To incorporate SLR, the study used the 'eustatic' approach, which offsets the mean sea water level in the model by the selected value of SLR. This should yield conservative flood estimates as river and stream discharge were not accounted for in any scenario.

When simulating coastal flooding, one historical and two synthetic storms were selected. The selected storm tracks in the model domain and their location within the area of interest are shown in Figure 2.4. Hurricane Sandy was selected as the historical storm, having been one of the deadliest and costliest regional storms. The wind and track information for Hurricane Sandy was collected from the National Hurricane Center Hurricane Data 2nd generation (HURDAT2) database. The selected synthetic storms (S360 and S542) were generated under the North Atlantic Coast Comprehensive Study (NACCS) by the USACE (Cialone et al., 2015). Based on the storm surge and meteorological measurements related to historical tropical and extratropical storm events for the 1938–2013 period, the USACE conducted a modified joint probability method to develop



Note: Synthetic 360 refers to the 25-year storm event, and Synthetic 542 refers to the 50-year storm event.

Figure 2.4. Selected storm tracks used in the project scenarios.

[8]Palustrine wetlands include any inland wetlands that lack flowing water, contain ocean-derived salts in concentrations of less than 0.5 parts per thousand, and are non-tidal.

[9]Estuarine wetlands are tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land.

an extensive database of future storms (Cialone et al., 2015). These storms were simulated to carry out Annual Exceedance Probability (AEP) (yr-1) and average recurrence interval (yr) analysis for multiple storm responses along the east coast of the United States. Using the NACCS results on storm response such as surge and waves, two synthetic storms - one with a 4% (25-year storm event) and the other with a 2% (50-year storm event) probability of making landfall in, or otherwise impacting the area of interest - were selected for this analysis. In the report, Synthetic storm S360 and S542 refer to the 25-year storm and 50-year storm, respectively. Storm wind intensity and pressure information are also provided in Table 2.6, which shows that in terms of storm intensity and strength, the selected storms represent low to high strength hurricanes that hit or are likely to hit within the study area. It should be noted that the researchers were limited in their ability to select storms that tracked perpendicular to the study area (Figure 2.4) while maintaining the 25-year storm event, 50-year storm event, and Hurricane Sandy event requirements.

Table 2.6. Characteristics of the storm events used in the scenarios.

Storm Event	Minimum Central Pressure (mb)	Maximum Wind Speed (kt)	Radius of Maximum Wind
Hurricane Sandy	940	85	80
Synthetic 542 (50 year storm)	970	84	22
Synthetic 360 (25 year storm)	985	64	26

The coupled version of ADCIRC+SWAN provides maximum flood elevation due to each storm events for both current/baseline and future/SLR scenarios. Using a GIS tool, ArcStormsurge (Ferreira, Olivera and Irish, 2014), simulated maximum water/flood elevation at each computational node in the model were imported in ArcGIS. An interpolation technique in ArcGIS was employed to prepare a flood elevation raster for the selected study area. Furthermore, using a seamless DEM of 10m resolution for the selected areas, a flood depth raster was calculated by subtracting the land elevation values from the maximum flood elevation raster. Consequently, this resulted in generating a 10m resolution depth raster for the three counties near the JC NERR areas for all cases.

2.5. ECONOMIC ANALYSES

2.5.1. Damages Avoided

The damages avoided method uses either the value of property protected, or the cost of actions taken to avoid damages as a measure of the benefits provided by an ecosystem. For example, if a wetland protects adjacent property from flooding, the flood protection benefits may be estimated by the damages that would occur if the wetland were not present. This approach does not provide strict measures of economic values, which are based on people's willingness to pay for a product or service, but it assumes that society is willing to pay at least as much as they would avoid losing if no natural infrastructures were to exist.

The inputs to this method are:

- Identification of residential property parcels on lands that are vulnerable to wave induced erosion and/or storm damage
- Identification of residential parcels that are inundated (and to what level they are inundated in feet[10]) in a storm event under current baseline conditions (with marsh present)
- Identification of residential parcels that are inundated (and to what level they are inundated in feet) in a storm event under scenario conditions (with marsh absent)
- Property values of residential parcels of interest
- The number of stories in each residential parcel of interest
- Whether or not each residential parcel of interest is a split level property[11]
- Depth damage functions, or plots of floodwater depth versus percent of the structure damaged (USACE)

[10]Computed as the area weighted mean flood depth for each parcel.

[11]A split-level home is a style of house in which the floor levels are staggered. There are typically two short sets of stairs, one running upward to a bedroom level, and one going downward toward a basement area.

Combining these inputs, the avoided residential property damages for an individual structure under a given storm scenario were calculated by multiplying the percent of structure damaged, based on the estimated floodwater depth, by the structure's property value. The total residential damages avoided value was then calculated by aggregating the individual property damages in the current baseline scenario ("marsh present" scenario), and subtracting this value from the aggregate of property damages calculated in the "marsh absent" scenario.

This analysis was specifically focused on residential property parcels in the research team's area of interest (see Figure 2.3). When analyzing the data, a few decisions were made:

- Only residential properties in the area of interest were considered in the damages avoided calculations; therefore, the monetary damages in a given storm scenario do not take the contents of the residential structure, commercial property damage, business interruption, gross domestic product (GDP) loss, job loss, or industry effects into account.
- Due to the absence of consistent data across the area of interest as to the presence/absence of a basement in each parcel, the depth damage functions for residential properties without basements (see Appendix B) were utilized. This is in line with anecdotal evidence from local partners that basements are rare in the area of interest (Phil Reed, pers. comm., 2017; Mike Fromosky, pers. comm., 2017). These "without basement" depth damage functions are more conservative in nature with their percent damage estimates at each flood height.
- The research team did not apply the content depth damage functions, due to the varying nature of the value of a structure's contents and to the unavailability of data concerning the value of each structure's contents.
- The ADCIRC+SWAN modelling provides outputs of maximum flood elevation (height of water plus height of land) and using the maximum flood and land elevation information flood depth (height of water = height of maximum flood elevation minus height of the land) can be calculated. For the purposes of calculating the percent damage to a residential structure, the area weighted mean flood depth per parcel was used (Kousky and Walls, 2014).
- A rule was established for parcels that were only partially inundated in the model. The research team utilized a centroid approach in this analysis (Kousky and Walls, 2014; Seidel, Richards and Beitch, 2013), which denoted that a partially inundated parcel was included in the economic analysis if and only if the inundation layer intersected the parcel's centroid.
- The monetary value of interest for each parcel was the "improvement value" (i.e. the assessed value of the building portion of a parcel) (Kousky and Walls, 2014).
- Any residential parcel without any "improvement value" was removed from the economic analysis.
- Any residential parcel without building description information indicating the number of stories and whether or not the building is split level was removed from the economic analysis.
- Any residential property listed as having 1.5[12] or 1.75 stories[13] was considered to have 2 or more stories,[14] and any residential property listed as having 0.5 stories[15] was considered to have 1 story for the purposes of applying depth damage functions.

Residential structure depth damage functions from the USACE are on a per integer basis, and considering that flood depths in a given storm event will not necessarily affect properties on an integer basis (i.e. not all properties will be inundated by exactly 2 feet or exactly 3 feet of water, etc.), cubic regressions were run for each depth damage function (see Appendix B). The resulting functional regression coefficients were applied to calculate the percent of each structure expected to be damaged given each structure's area weighted mean flood depth in a given storm scenario. It must also be noted that a flood depth of zero feet is still associated with some form of structural damage, and that structures inundated with zero feet of water are distinct from structures that are not inundated at all. The USACE depth damage functions specify that some proportion of a structure is damaged given a flood depth of zero feet (Appendix B). For example, wood sub-

[12] 7,212 of the residential parcels with improvement value and a building description.
[13] 280 of the residential parcels with improvement value and a building description.
[14] FEMA (2012) considers 1.5 story buildings to be 2 story buildings for damage calculation purposes.
[15] 2 of the residential parcels with improvement value and a building description.

flooring is found in pier homes, and will warp when touched with floodwater at the zero foot level. This, in turn, causes total damage to the finished floor. In slab structures, finished floors (such as wood floors, ceramic tile, vinyl tile, or carpet) are a total loss at zero flood level. Total damages occur to carpets and tiles as soon as floodwaters soak them. This can occur at zero feet depending on structure type and flooding condition (USACE, 2006), and therefore, parcels that experience a flood depth of zero are included in all inundation and damage calculations.

Table 2.7 illustrates the decisions described above in terms of their effect on the population of parcels in the economic analysis. The total number of parcels considered for this economic analysis is 103,927. Table 2.8 then displays the building characteristics of the parcels considered in the economic analysis and Table 2.9 displays summary statistics of the parcels considered in the economic analysis.

Table 2.7. Parcel population.

Delineation	Number of parcels
Number of parcels in 3 county area (2015)[1]	629,277
Number of parcels in area of interest[2]	199,219
Number of parcels in area of interest that have parcel characteristics associated with it	158,498
Number of residential parcels in area of interest	111,866
Number of residential parcels with improvement value in area of interest	111,774
Number of residential parcels with improvement value and information concerning the number of building stories in area of interest	103,927

[1]Atlantic, Burlington, and Ocean Counties in New Jersey
[2]A parcel was considered to be in the area of interest if any part of the parcel's boundary intersected within the area of interest boundary.

Table 2.8. Parcel population building characteristics.

Characteristic	Number of parcels
One story	42,039
2+ stories	60,823
Split level	1,065
Total	*103,927*

Table 2.9. Parcel population summary statistics.

Characteristic	Value[1]
Mean	$151,898
Median	$120,700
Standard deviation	$127,158
Minimum	$15
Maximum	$5,687,300

[1]These values represent the improvement value of the parcel (the assessed value of the building portion of the parcel).

2.5.2. Community Rating System

The NFIP CRS was implemented in 1990 as a voluntary program for recognizing and encouraging community floodplain management activities exceeding the minimum NFIP standards. Any community in full compliance with the minimum NFIP floodplain management requirements may apply to join the CRS (FEMA, 2016a). As a result, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from community actions that help to meet the three goals of the CRS:

1. To reduce flood losses;
2. To facilitate accurate insurance rating; and
3. To promote the awareness of flood insurance.

The CRS uses a class rating system that is similar to fire insurance rating to determine flood insurance premium reductions for residents. Class ratings are determined by a community's commitment to and engagement in flood risk mitigation practices. For CRS participating communities, flood insurance premium rates are discounted in increments of 5%. Table 2.10 illustrates these class ratings and discounts within and outside of the special flood hazard area (SFHA).

Several communities in the area of interest participate in this program. The analysis of the CRS program in this context was focused on "Open Space Preservation" (OSP) (Activity 420 in the CRS). NFIP policyholders in CRS-participating communities receive discounts on their flood insurance prices and the preservation of open space in the community factors into this discount. In all, communities can receive a maximum of 2,020 credit points for OSP. Specific activities under OSP include:

Table 2.10. CRS ratings and discounts.

CRS Class	Credit Points (cT)	Premium Reduction	
		In SFHA[1]	Outside SFHA[1]
1	4,500+	45%	10%
2	4,000-4,499	40%	10%
3	3,500-3,999	35%	10%
4	3,000-3,499	30%	10%
5	2,500-2,999	25%	10%
6	2,000-2,499	20%	10%
7	1,500-1,999	15%	5%
8	1,000-1,499	10%	5%
9	500-999	5%	5%
10	0-499	0%	0%

[1]SFHA is defined as Special Flood Hazard Area
Source: 2013 CRS Coordinator's Manual

- OSP: Up to 1,450 points for keeping vacant lands vacant through ownership by a public agency, non-profit organization (such as a church camp), or restrictive regulations. To qualify, a property must be open, meaning there are no buildings, filling, or storage of materials.
- Deed restrictions: Up to 50 points extra credit for legal restrictions that ensure that parcels credited for OSP will never be developed. This is done via a legal restriction that prevents subsequent owners from changing the use of the property.
- Natural functions open space: Up to 350 points extra credit for OSP-credited parcels that are preserved in or restored to their natural state.
- Special flood-related hazards open space: Up to 50 points if the OSP-credited parcels are subject to one of the special flood-related hazards or if areas of special flood-related hazards are covered by low density zoning regulations.
- Open space incentives: Up to 250 points for local requirements and incentives that keep flood-prone portions of new development open through techniques such as density transfers.
- Low-density zoning: Up to 600 points for zoning districts that require lot sizes of 5 acres or larger, resulting in fewer buildings constructed in the floodplain.
- Natural shoreline protection: Up to 120 points for programs that protect natural channels and shorelines, the areas most valuable for protecting the natural functions of floodplains. The programs can be local policies that are adhered to on public lands and/or regulations that govern development on private lands. This credit can be based on shoreline protection practices put in place by property owners or on protection requirements embodied in local regulations.

The objectives of OSP, as defined by the CRS, are to prevent flood damage by keeping flood-prone lands free of development, and to protect and enhance the natural functions of floodplains. Floods are natural processes, and floodplains are necessary to every riverine and coastal system. The CRS defines a floodplain as any land susceptible to being inundated by flood waters. Floodplains can also be regarded as the land needed by a river or stream to convey and store flood waters. Preserving the floodplain as open space allows it to serve these primary natural functions and many other important functions. Keeping the floodplain free of development—free of buildings and infrastructure—means that there will be no flood insurance claims, no closed businesses, no homeless residents, and will help ensure that the community can return to normal quickly after flooding occurs (FEMA, 2013).

The JC NERR is open space that includes protective habitats such as wetlands, marshes, sand dunes, and beaches. These preserved open space habitats provide protection to nearby and adjacent communities in the form of storm surge, flood, and wave mitigation. Since the JC NERR has vacant land that is kept as such through regulations and it protects natural channels/shorelines, its presence can help nearby and adjacent communities qualify for flood insurance discounts through OSP, as defined by the CRS. Researchers sought to quantify the annual economic contribution of OSP discounts in the communities surrounding and encompassed by the JC NERR by examining CRS discounts and credit points received for OSP. The logic behind this exercise was that:

- Preserved open space leads to a better CRS class rating;
- A better CRS class rating leads to more savings on NFIP premiums;
- More savings on premiums lead to extra discretionary income for households with flood insurance in CRS-participating communities;
- The extra discretionary income leads to additional consumption expenditures; and
- Additional expenditures lead to economic stimulus.

The methodology outlined below quantitatively illustrates the above concept.

Based on the area of interest for the spatial analysis (see Figure 1.1), if any part of a CRS-participating community's boundary intersected the boundary of the area of interest, it was included in this analysis. The communities taken into account by this analysis included:

- Atlantic City
- Barnegat Light
- Beach Haven
- Brigantine
- Harvey Cedars
- Long Beach
- Longport
- Margate City
- Ship Bottom
- Stafford
- Surf City
- Ventnor City

The New Jersey CRS state profile provides information for each participating community, including: the total number of CRS credit points received; the total number of credit points received associated with OSP; the CRS class rating; the percent discount received by NFIP policy holders inside the SFHA;[16] the percent discount received by NFIP policy holders outside the SFHA; and the total NFIP discount (community-wide annual figure in dollars). Since different levels of discount are received by NFIP policyholders inside and outside the SFHA (see Table 2.10), these two populations must be treated separately; therefore, the total NFIP discount (*NFIPD*) received in 2013 is distributed across NFIP policyholders based on the percentage of NFIP policies that fall within the SFHA (*p*) and outside the SFHA (*1-p*).

$$D_{SFHA_i} = p_i * NFIPD_i$$

$$D_{NONSFHA_i} = (1-p)_i * NFIPD_i$$

Where D_{SFHA} *is the total discount received by policyholders inside the SFHA zone in 2013 in community* i*, and* $D_{NONSFHA}$ *is the total discount received by policy holders outside the SFHA zone in 2013 in community* i*.*

After the total discount was distributed into the SFHA and non-SFHA zones accordingly, a discount value attributable to OSP in the SFHA and in the non-SFHA zones was then derived. To accomplish this, researchers developed a scenario in which all else was held constant and each CRS-participating community received zero credit points associated with OSP. This allowed comparison between a given community's "real" CRS class rating and its "hypothetical" CRS class rating in a scenario without OSP credit points, while also taking the step-wise nature of CRS classes into account. If removing the OSP credit points increased a community's class rating, and therefore reduced its discount rate, then the change in discount rate was attributed to OSP.

[16]The SFHA is defined as zones A, AO, AH, A1-30, AE, A99, AR, AR/A1-30, AR/AE, AR/AO, AR/AH, AR/A, VO, V1-30, VE, and V in the FEMA flood map (FEMA, 2016b).

The percent change in discount rate was multiplied by the community's total discount to estimate the value of OSP (this process was done separately for the SFHA and the non-SFHA zones).

$$DOSP_i = [(D_{with_i} - D_{without_i})/D_{with_i}] * NFIPD_i$$

Where i *is a particular CRS-participating community,* DOSP *is annual CRS discount dollars attributed to OSP in 2013,* D_{with} *is the annual NFIP discount rate in reality,* $D_{without}$ *is the annual NFIP discount rate in a hypothetical scenario without OSP credit points, and* NFIPD *is the total NFIP discount received in dollars in 2013.*

These savings on insurance premiums due to OSP represent extra discretionary income that goes back into the hands of NFIP policy holders, which may, in turn, impact the local community on an annual basis. Additional income has been shown to increase consumer expenditures (Keynes, 1936). It was in this book, that Keynes articulated the concept of the marginal propensity to consume (MPC)[17]. In order to determine how much of the annual discount will be spent, community-specific MPC values were calculated by dividing each community's annual average household expenditure by its annual average household income. These MPCs were then multiplied by each community-specific OSP related annual discount value. This represents the increase in annual expenditures due to NFIP premium savings attributed to OSP that can be expected for each community. When summed for each community, an annual total increase in annual expenditures figure was derived for the entire area of interest.

$$\sum_{i=1}^{n}(DOSP_i * MPC_i) = EI$$

Where i *is a particular CRS-participating community,* DOSP *is annual CRS discount dollars attributed to open space preservation in 2013,* MPC *is the annual marginal propensity to consume in 2014, and* EI *is the expected annual increase in expenditures due to open space preservation-related CRS savings for the entire area of interest.*

This aggregate "increase in expenditures" figure is the starting point for annual economic contribution calculations. To calculate the total annual economic contribution of these expenditures, a method was employed that utilized a series of ratios on economic measurements, input-output multipliers, and a regional purchase coefficient (the percent of inputs locally; used to delineate the local effect of these expenditures instead of the total effect) (Leeworthy, 2010). The ratios utilized were:

- Wages to sales
- Wages to employment
- Proprietor income to proprietor employment
- Total income to wages and salaries
- Proprietor income to wages and salaries

Each of these ratios was calculated for Atlantic, Burlington, and Ocean Counties in New Jersey and then transformed into a weighted average (based on county population) composite ratio representing the tri-county area. The wages to sales ratio was derived from the 2012 Economic Census (US Census Bureau), and the other ratios were derived using US Bureau of Economic Analysis (BEA) regional economic information system 2013 data on personal income and employment. Input-output multipliers representative of the same tri-county area were derived from the BEA's regional input-output modeling system (RIMS) corresponding to the year 2013. The multipliers utilized included an output multiplier, an income multiplier, and an employment multiplier. Multipliers were calculated on a North American Industry Classification System (NAICS) industry-by-industry basis, so composite multipliers representative of all industry in the area of interest were calculated by using a weighted average technique. Each industry-specific income multiplier was weighted by the amount of income generated by that industry in the tri-county area of interest, and each industry-specific employment

[17]The marginal propensity to consume is the proportion of a change in disposable income that individuals spend on consumption, rather than saving.

multiplier was weighted by the level of employment in that industry in the tri-county area of interest. Output-by-industry data were not available at the county level (only available at national and regional level), however, so the composite industry-wide output multiplier for the area of interest was merely an average of each industry-specific multiplier, while the income and employment multipliers were industry-wide, area of interest-specific weighted average multipliers. The figure utilized for the regional purchase coefficient was derived from Rutgers University's input-output modeling system, and represents a statewide coefficient for all of New Jersey (Irving, pers. comm., 2016).

Before calculation, all dollar figures were inflation adjusted to 2015 dollars using the annual average consumer price index for all urban consumers. The calculation method was employed as follows:[18]

1. Total expenditures * Wages to sales ratio = Direct wages and salaries income
2. Direct wages and salaries income ÷ Wages to employment ratio = Direct wages and salaries employment
3. Total expenditures * Percent of inputs purchased locally = Direct output
4. Direct output * Output multiplier = **Total Output Contribution**
5. Direct wages and salaries income * Total income to wages and salaries ratio = Direct income
6. Direct income * Income multiplier = **Total Income Contribution**
7. Direct wages and salaries employment * Employment multiplier = Total wage and salary employment
8. Proprietor's income to wages and salaries ratio * Direct wages and salaries income = Proprietor's direct income
9. Proprietor's direct income ÷ Proprietor's income to employment ratio = Proprietor's direct employment
10. Proprietor's direct employment * Employment multiplier = Total proprietor's employment
11. Direct wages and salaries employment + Proprietor's direct employment = Total direct employment
12. Total wage and salary employment + Total proprietor's employment = **Total Employment Contribution**

Employing the above calculations resulted in estimates of the total annual output contribution, annual income contribution, and annual employment contribution of CRS flood insurance discounts attributed to OSP for the year 2013 (represented in year 2015 dollars). Consumers spend a portion of these flood insurance discounts in the local economy, which, in turn, creates economic stimulus. These annual economic contribution values and the increase in expenditure values can then be illustrated on an area of interest scale, a community scale, a per-household scale, and a per-policyholder scale, depending on the needs of the investigators.

[18] See Leeworthy (2010) for a detailed description of these calculations.

Chapter 3
Data

Photo credit: Angela Orthmeyer, NOAA

3.1. SPATIAL COMPONENT

In general, this section will describe the data requirements of the various spatial models. These requirements must be met before model initialization may proceed. For more detail as to the origination and the manipulation of specific spatial datasets required for this project, please see Appendix A.

3.1.1. Advanced Circulation (ADCIRC) + Simulating Waves Nearshore (SWAN) Models

A package of datasets specific to the study area was required for the analysis. The package included the following:

- Two digital elevation models (DEMs)
- Bathymetry data
- Categorical raster of land use land cover (LULC) obtained from NOAA's 2010 Coastal Change Analysis Program (C-CAP) database

The first DEM was seamless with a 10-m horizontal resolution developed from multiple sources, including NOAA Hydrographic Surveys and Electronic Navigational Chart (ENC) data and USACE Topographic and Bathymetric Light Detection and Ranging (LiDAR) data. The second DEM was derived from the results of the SLAMM analysis (detailed in Chapter 2 and Appendix A), and used the aforementioned seamless DEM as an input.

A validated version of Federal Emergency Management Agency (FEMA) Region II mesh that has 604,790 nodes and 1,188,640 elements with a maximum of 500m and minimum of 80m inland spacing was also used in the models. The model domain extended from Mid-Atlantic Ocean to an inland boundary defined by the 25-foot (NAVD 88) contour including the Atlantic Ocean side of New Jersey, New York City, Westchester County, New York, and the Hudson River up to the Troy, NY "tidal dam." For the terrain data, a seamless DEM with a 10-m horizontal resolution was developed from multiple sources including NOAA Hydrographic Surveys and Electronic Navigational Chart (ENC) data and USACE Topographic and Bathymetric LiDAR data. Detailed description of the mesh development and terrain processing are described in Region II Coastal Storm Surge Study reports (FEMA, 2014b-d).

3.1.2. Sea Level Affecting Marshes Model (SLAMM)

The following data were required for SLAMM:

- DEM
- Tidal information
- Slope of the study area
- Raster datasets of land cover
- Vertical level of marsh accretion
- Projected SLR

The DEM was used by the SLAMM to determine the lower elevation range at which various habitats change to a different type, and to determine inundation frequency for marsh and wetlands. It was derived from the National Elevation Dataset (NED) provided by the United States Geological Survey (USGS). Tidal information was used to adjust the elevation data to ensure that the mean tide level was zero. Tidal information was provided by the NOAA Tides & Currents website.[19] Raster datasets were required for the determination of marsh classification. These datasets came from two sources: NOAA's OCM C-CAP,[20] and the United States Fish & Wildlife Service (USFWS) National Wetlands Inventory (NWI). To counter-balance the effects of SLR on the landscape, the vertical level of marsh accretion was used. A value of 4 mm per year was derived using information from Lathrop (2016) to reflect a "moderate" level of vertical marsh accretion specific to the study area. Finally, projections of SLR were used to aid in the determination of habitat conversion. Numerous projections

[19] National Oceanic and Atmospheric Administration (NOAA). 2013. "NOAA Tides & Currents, Mean Sea Level Trends – Station Selection – New Jersey." Retrieved October 2, 2016, from: https://tidesandcurrents.noaa.gov/sltrends/sltrends_states.htm?gid=1246.

[20] National Oceanic and Atmospheric Administration (NOAA). 2010. "C-CAP Land Cover Atlas, New Jersey." Retrieved January 24, 2017, from: https://coast.noaa.gov/digitalcoast/tools/lca

for SLR exist; however, this analysis used the global historic trend of 1.778 mm per year as reported by the International Panel on Climate Change (IPCC, 2014).

Example of raised housing for flood mitigation with incorporated storage space. Photo credit: Sarah Gonyo, NOAA.

3.1.3. Property Parcel Data

Year 2015 property parcel data for Atlantic, Ocean, and Burlington Counties in the area of interest were obtained from the State of New Jersey Department of the Treasury's Division of Taxation.[21] These data contain information on each parcel in terms of its geographic location, the parcel's improvement value, property class (i.e. residential, commercial, etc.), the year the property was constructed, and a description of any building present on the parcel (i.e. the number of stories, the structure style), amongst a variety of other variables. New Jersey parcel data were used to understand which residential properties will be inundated during the simulated storm events, and, in turn, calculate aggregated residential property damages resulting from a given storm event in the area of interest.

3.2. ECONOMIC COMPONENT

3.2.1. Avoided Property Damages

Depth damage functions for residential structures were obtained from the USACE Economic Guidance Memorandum 04-01 (USACE, 2003). These functions depict the cubic relationship between flood depth (in feet) and the expected percent of structural damage for various structure types. The three structure types used in this analysis were:

- Residential structure – one story – without basement
- Residential structure – two or more stories – without basement
- Residential structure – split level – without basement

3.2.2. Community Rating System

Several data sources were consolidated in order to calculate the economic contribution of CRS savings attributed to OSP. These data sources are discussed generally in this section; for a more detailed explanation of the data manipulation methodology for calculating the economic contribution of OSP-related CRS savings, please see Appendix C.

CRS credit point and class rating data by community were obtained through the 2013 New Jersey CRS state profile (FEMA, 2014a). The file contains information for each CRS-participating community in New Jersey, including the number of credit points received for each CRS activity, the number of NFIP policies held by

[21]http://www.state.nj.us/treasury/taxation/lpt/TaxListSearchPublicWebpage.shtml

residents, the total NFIP premium collected by FEMA, the CRS class rating, and the total CRS discount at the community level.

Data concerning the proportion of NFIP policies inside and outside the SFHA zones were obtained from FEMA (2016a). Data were unavailable at the county and community level; therefore, the New Jersey statewide figure for the proportion of NFIP policies inside the SFHA zones (82.93%) was used to distribute the CRS discount dollars across the SFHA and non-SFHA zones in each CRS-participating community.

Data on the MPC for each CRS-participating community were obtained from consumer expenditure data provided by Mapinsite, an Applied Geographic Solutions affiliate. Average household spending patterns and income characteristics for the year 2014 were pulled for each CRS-participating community in the area of interest to calculate the spent proportion of an average household's income (as opposed to savings) (Table 3.1).

Table 3.1. Community marginal propensity to consume; 2014$.

Area of interest Community that Participates in the CRS	Average Household Income	Average Household Expenditure	Marginal Propensity to Consume (MPC)
Atlantic City	$47,132	$41,812	0.8871
Barnegat Light	$104,727	$73,168	0.6987
Beach Haven	$118,773	$80,391	0.6768
Brigantine	$85,852	$63,620	0.741
Harvey Cedars	$172,721	$104,999	0.6079
Long Beach	$146,643	$94,148	0.642
Longport	$151,752	$96,500	0.6359
Margate City	$109,181	$75,003	0.687
Ship Bottom	$85,242	$63,421	0.744
Stafford	$84,972	$63,187	0.7436
Surf City	$85,883	$63,565	0.7401
Ventnor	$84,631	$62,350	0.7367

Five weighted ratios were estimated for this analysis (Table 3.2). The data needed for calculation of these ratios were obtained from the US Census Bureau's Economic Census and the US BEA regional economic information system. The data were obtained at the county level for Atlantic, Burlington, and Ocean Counties, and were then transformed into weighted averages[22] to represent all three counties adjacent to the JC NERR. The data sources, formulas, and values for the ratios are shown in Table 3.2.

Table 3.2. Economic contribution ratios; constant 2015$.

Type of ratio	Data source	Formula	Value
Wages to sales	US Census Bureau - 2012 Economic Census	Aggregate annual payroll for each industry divided by aggregate value of sales, shipments, receipts, revenue, or business done for each industry	0.189
Wages to employment	US BEA 2013 Regional Economic Information System – Table CA4 Personal income and employment by major component	Wages and salaries divided by total employment	$35,141.55
Proprietor income to proprietor employment	US BEA 2013 Regional Economic Information System – Table CA4 Personal income and employment by major component	Proprietor's income divided by proprietor's employment	$29,166.75
Total income to wages and salaries	US BEA 2013 Regional Economic Information System – Table CA4 Personal income and employment by major component	The sum of wages and salaries, supplements to wages and salaries, and proprietor's income divided by wages and salaries	1.47
Proprietor income to wages and salaries	US BEA 2013 Regional Economic Information System – Table CA4 Personal income and employment by major component	Proprietor's income divided by wages and salaries	0.202

Source: US Census Bureau, US BEA

[22]Weighted by the population of each county in the year 2013.

Multiplier data were obtained from the US BEA's RIMS, and reflect industry data from 2013 aggregated across Atlantic, Burlington, and Ocean Counties. These Type II Keynesian multipliers are designed to capture the indirect and induced effects of spending as expenditures make their way through a local economy (i.e. for every dollar of output, we would expect the direct[23], indirect[24], and induced[25] effects to equal more than one dollar as this one dollar makes its way through industries in the local economy).

A regional purchase coefficient (i.e. the percent of inputs purchased locally) was obtained from Rutgers University's input-output modeling system and is representative of the entire state of New Jersey (Irving, pers. comm., 2016). Researchers were unable to obtain a regional purchase coefficient at the county level, as this information was not available. All multiplier values are shown in Table 3.3.

Table 3.3. Multiplier values.

Multiplier	Value
Output multiplier	1.56
Income multiplier	1.566
Employment multiplier	1.745
Regional purchase coefficient	0.58

Source: BEA RIMS, Will Irving

The figures used to inflation adjust all dollar values to the year 2015 (to match the damages avoided results) were obtained from the US Bureau of Labor Statistics Consumer Price Index for all urban consumers (US BLS, 2015).

[23]Direct effects are the results of the money initially spent in the area of interest. This includes money spent to pay for salaries, supplies, raw materials, and operating expenses.

[24]Indirect effects are the results of business-to-business transactions indirectly caused by the direct effects. Businesses initially benefiting from the direct effects will subsequently increase spending at other local businesses. The indirect effect is a measure of this increase in business-to-business activity (not including the initial round of spending, which is included in the direct effects).

[25]Induced effects are the results of increased personal income caused by the direct and indirect effects. Businesses experiencing increased revenue from the direct and indirect effects will subsequently increase payroll expenditures (by hiring more employees, increasing payroll hours, raising salaries, etc.). Households will then increase spending at local businesses. The induced effect is a measure of this increase in household-to-business activity.

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Chapter 4
Results

Photo credit: Jane Thomas, IAN Image Library

4.1. DAMAGES AVOIDED – CURRENT CONDITIONS

Three storm events (Hurricane Sandy event, a 50-year storm event, and a 25-year storm event) were modeled under current baseline conditions (i.e. current marsh cover and current sea levels) in the selected area of interest. Under current conditions, there are 61,318.71 acres of marsh in the area of interest. Each of these storm events were modeled in an environment in which all marsh cover was present in the model, and were again modeled with the marsh layers virtually removed in a GIS. Table 4.1 below tabulates the results.

Table 4.1. Residential property damage by storm event under current conditions.

Event	Residential Property Damage; 2015$ (Marsh Absent)	Residential Property Damage; 2015$ (Marsh Present)	Damages Avoided (Value of the Marsh)	Percent Reduction in Damages Due to Marsh Presence[1]	Per Acre Value of the Marsh
Hurricane Sandy	$2,331,067,963	$2,322,731,031	$8,336,932	-0.36%	$136
50 Year Storm	$107,972,822	$94,888,388	$13,084,434	-13.79%	$213
25 Year Storm	$91,894,099	$82,062,657	$9,831,442	-11.98%	$160

[1]This is computed as damages avoided divided by residential property damage with marsh present.

As expected, the area of interest is impacted the most by a Hurricane Sandy event and progressively less impacted by the 50-year event and the 25-year event. Marsh in the area of interest was found to reduce storm damages by approximately $8.3 million (0.36%), $13.1 million (13.79%), and $9.8 million (11.98%) for a Hurricane Sandy, 50-year, and 25-year storm event, respectively. The first takeaway from these results is that the marsh was worth millions of dollars in storm damage reduction benefits in each of these storm events. Secondly, the marsh was shown to be of highest value in the simulated 50-year storm event in terms of absolute value, the proportion of damages that were avoided due to marsh presence, and in the per acre value of the marsh. This suggests threshold effects for marsh storm damage reduction benefits.

Table 4.2 illustrates the number of residential parcels impacted by each storm event, and Table 4.3 illustrates average flood depths and proportional structure damages under current conditions. Again, it must be noted that only residential properties with improvement value and information on the number of stories were included in these calculations; therefore, the term "parcels" in Tables 4.2-4.3 refers only to these types of properties. Figures 4.1-4.6 display the spatial extent of inundation and mean flood depth per parcel for the simulated Hurricane Sandy event in the area of interest under current marsh cover and sea level conditions. For maps of the spatial extent of inundation and mean flood depth per parcel for the simulated 50-year storm event and 25-year storm event, please see Appendix D.

Table 4.2. Inundated parcels in each storm event under current conditions.

	Hurricane Sandy		50-year storm event		25-year storm event	
	Marsh Present	Marsh Absent (percent change)	Marsh Present	Marsh Absent (percent change)	Marsh Present	Marsh Absent (percent change)
Parcels inundated	47,591	47,885 (1%)	5,081	5,878 (16%)	4,695	5,538 (15%)
Parcels in which inundation crossed the parcel's centroid	46,598	46,820 (<1%)	3,932	4,723 (20%)	3,592	4,423 (19%)

Table 4.3. Flood depths and proportional structure damages in each storm event under current conditions.

	Hurricane Sandy		50-year storm event		25-year storm event	
	Marsh Present	Marsh Absent	Marsh Present	Marsh Absent	Marsh Present	Marsh Absent
Mean flood depth per parcel in feet (SD [1])	3.4624 (1.9107)	3.4928 (1.9429)	0.0952 (0.2641)	0.0961 (0.2506)	0.0680 (0.1632)	0.0728 (0.1632)
Mean percent of structure damaged (SD [1])	32.32% (13.16%)	32.45% (13.22%)	11.55% (3.18%)	11.69% (3.02%)	11.42% (2.73%)	11.86% (2.90%)

SD [1] = Standard Deviation
Note: The statistics in this table represent only those residential parcles in which the inundation layer intersected the parcel's centroid.

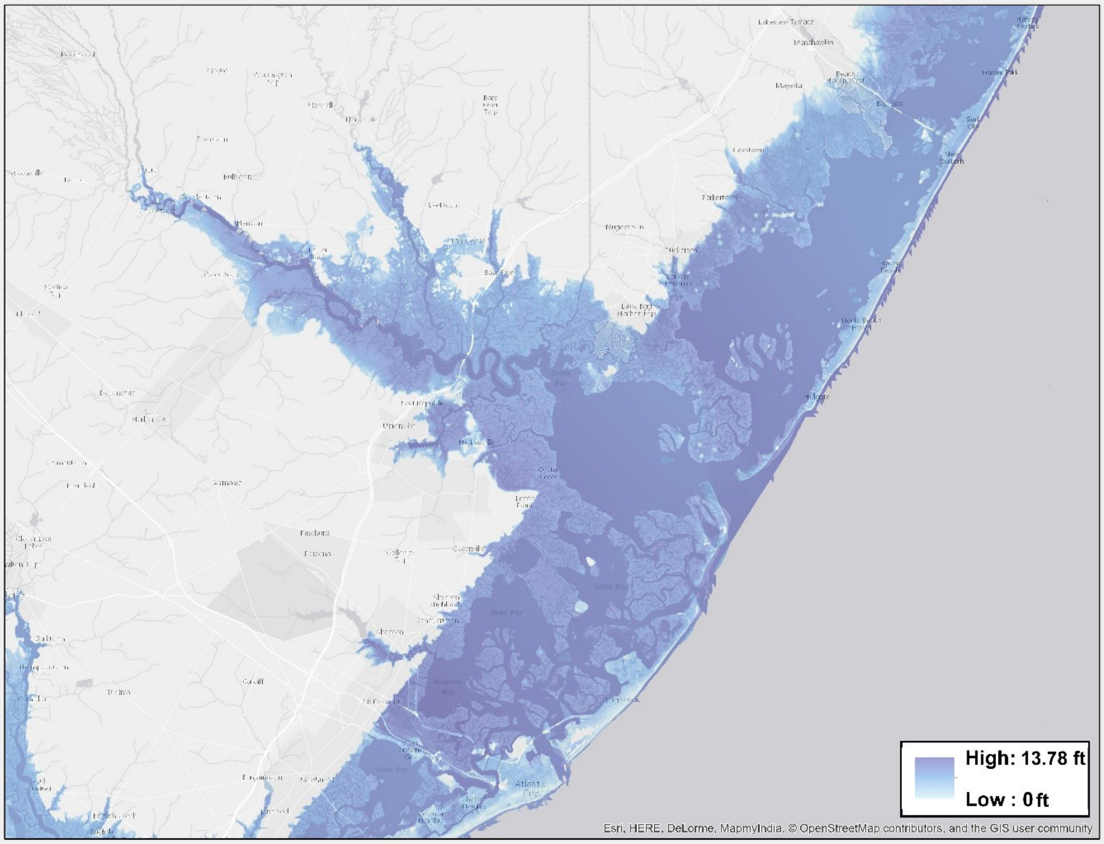

Figure 4.1. Hurricane Sandy event flood depth (ft) under current conditions/marsh present.

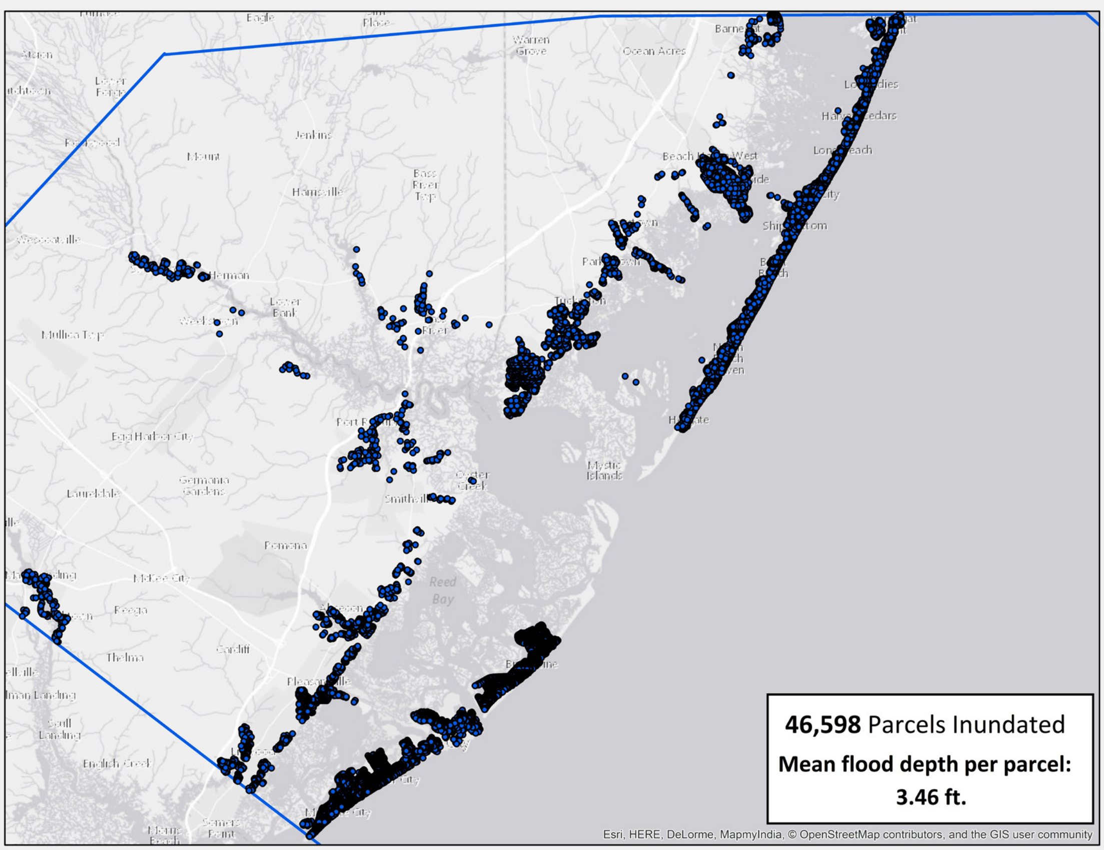

Figure 4.2. Hurricane Sandy event number of parcels inundated and mean flood depth per parcel under current conditions/marsh present.

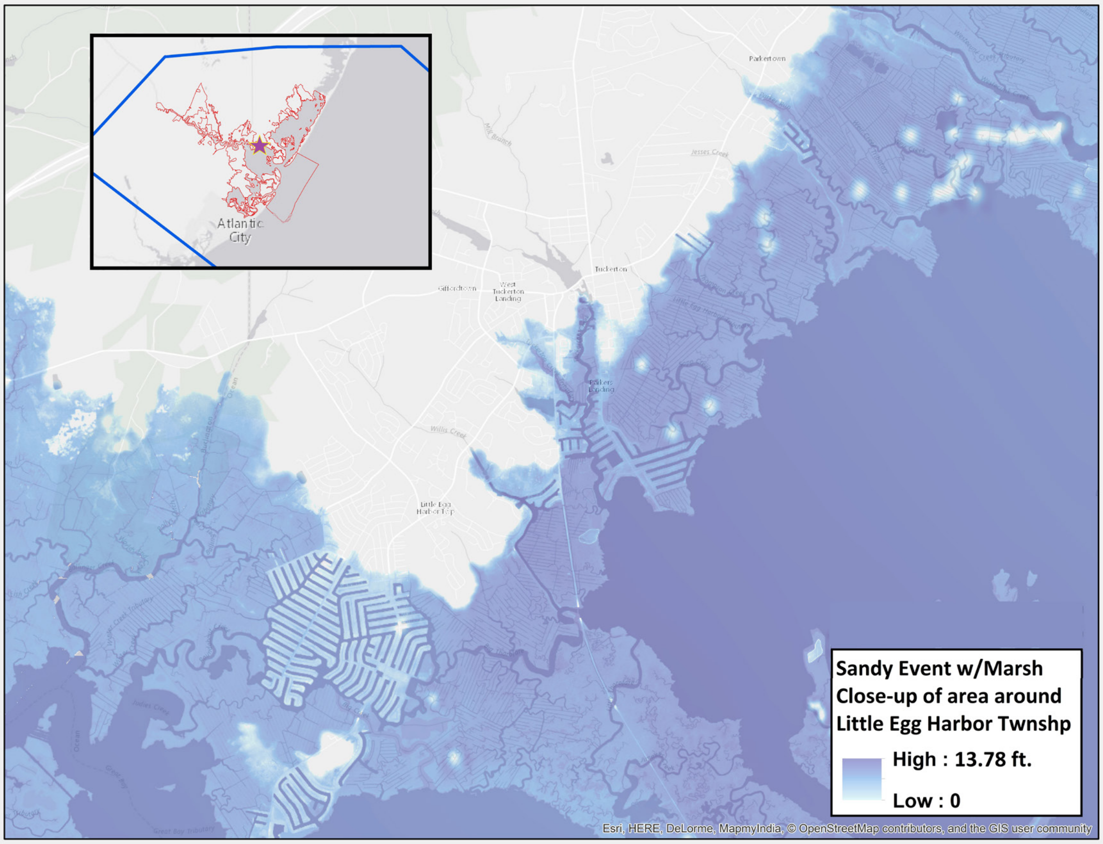

Figure 4.3. Hurricane Sandy event flood depth (ft) under current conditions/marsh present: Little Egg Harbor Township.

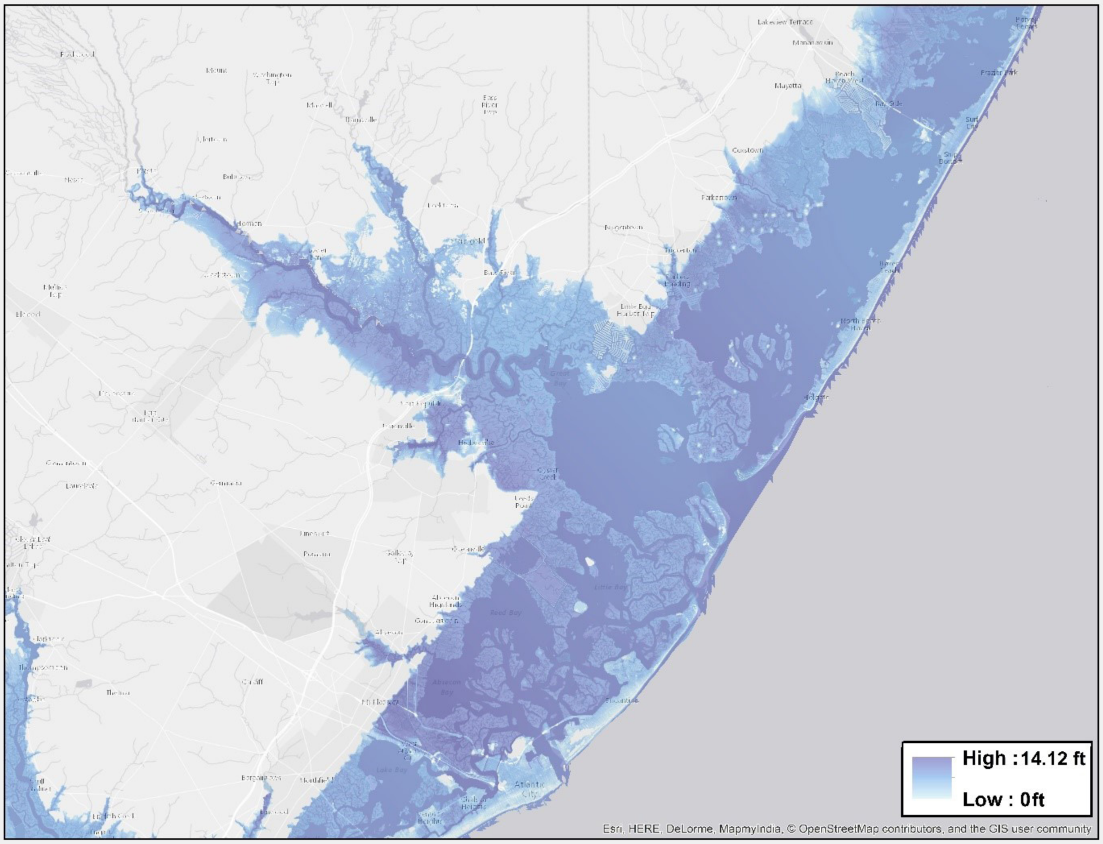

Figure 4.4. Hurricane Sandy event flood depth (ft) under current conditions/marsh absent.

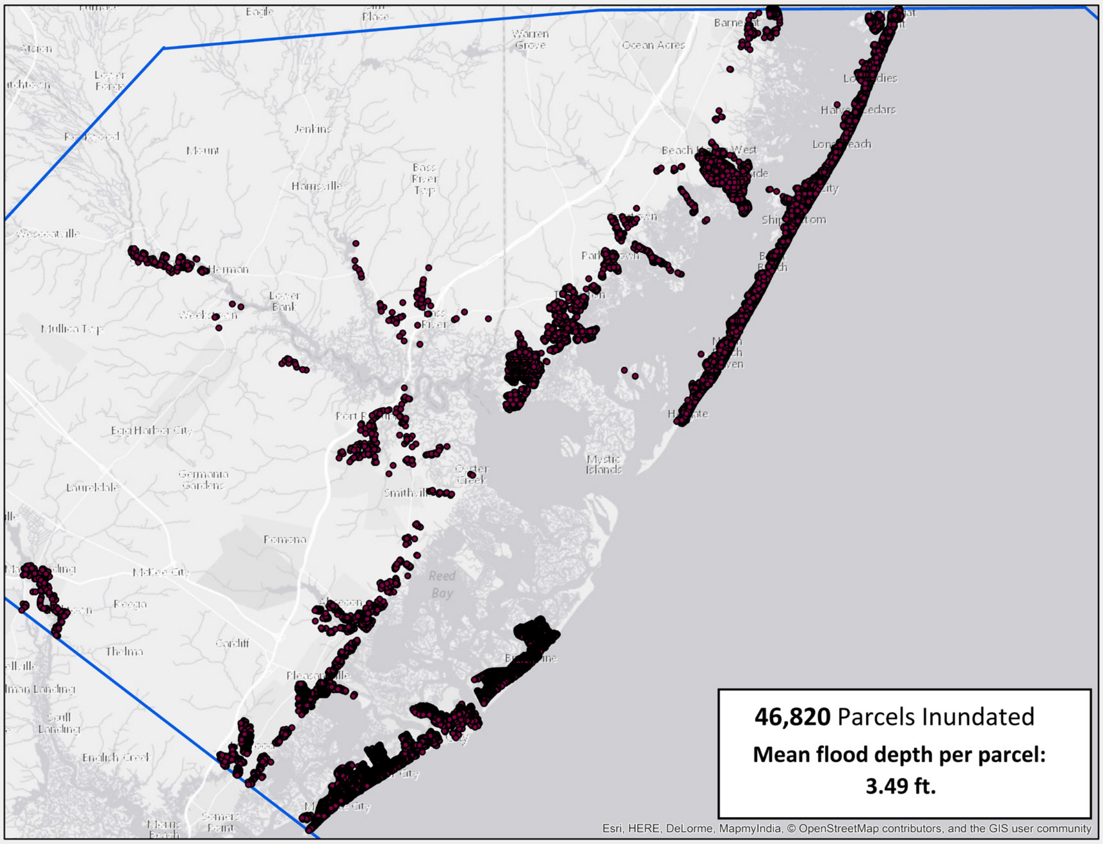

Figure 4.5. Hurricane Sandy event number of parcels inundated and mean flood depth per parcel under current conditions/marsh absent.

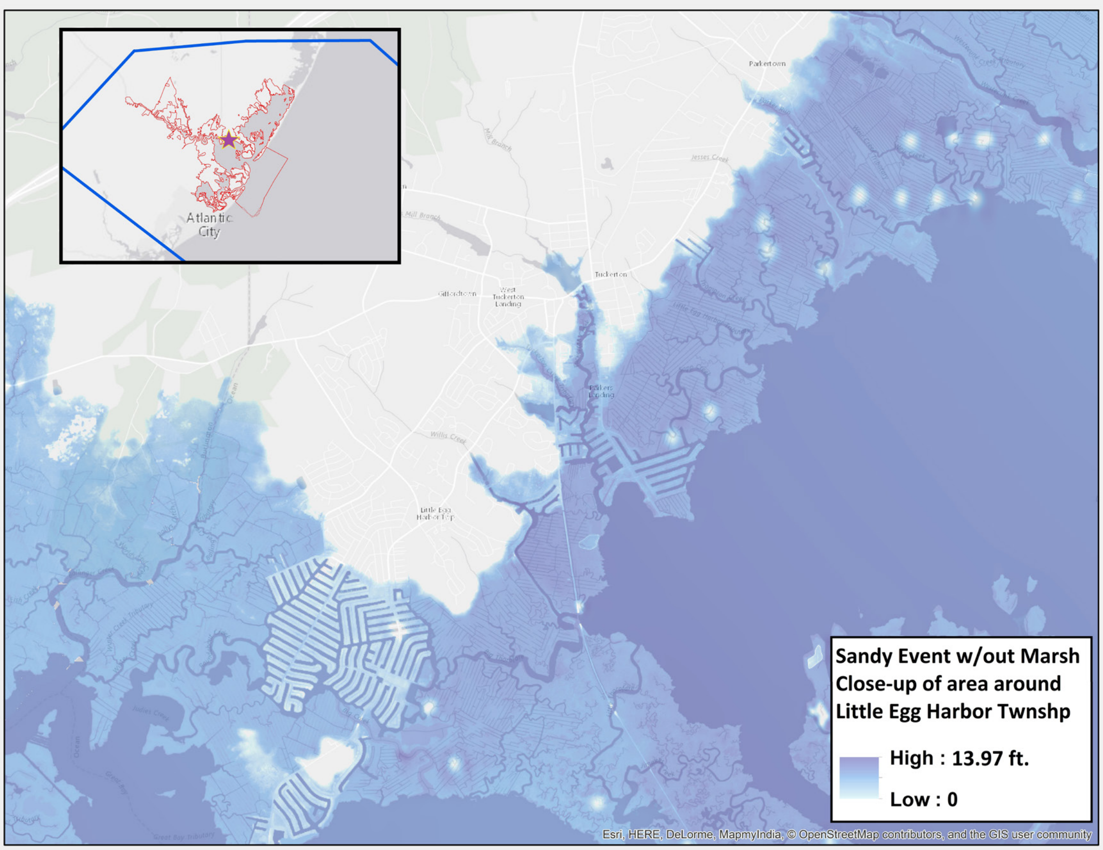

Figure 4.6. Hurricane Sandy event flood depth (ft) under current conditions/marsh absent: Little Egg Harbor Township.

Overall, the results are as expected. In general, the number of parcels inundated, the average flood depth, and the average proportional structure damage all increase with marsh absent under current marsh cover and sea level conditions. The storm damage reduction effect of marsh on parcels peaks under a 50-year storm event.

4.2. DAMAGES AVOIDED – FUTURE PROJECTED 2050 CONDITIONS

Three storm events (Hurricane Sandy event, a 50-year storm event, and a 25-year storm event) were again modeled for this exercise, except this time the modeling was done in a future environment of projected marsh cover and sea levels in the year 2050 in the area of interest. The SLAMM predicts that in 2050, there will be 57,662.21 acres of marsh in the area of interest (a decrease of 3,656.5 acres (-6%) from current conditions). Each of these storm events were modeled in an environment in which all marsh cover was present in the model, and were again modeled with the marsh layers virtually removed in a GIS. Table 4.4 below illustrates the results.

Table 4.4. Residential property damage by storm event under 2050 conditions.

Event	Residential Property Damage; 2015$ (Marsh Absent)	Residential Property Damage; 2015$ (Marsh Present)	Damages Avoided (Value of the Marsh)	Percent Reduction in Damages Due to Marsh Presence[1]	Per Acre Value of the Marsh
Hurricane Sandy	$2,594,648,892	$2,562,559,835	$32,089,057	-1.25%	$557
50 Year Storm	$349,122,514	$329,190,819	$19,931,695	-6.05%	$346
25 Year Storm	$126,980,226	$125,436,468	$1,543,758	-1.23%	$27

[1]This is computed as damages avoided divided by residential property damage with marsh present.

Similar to the storm events modeled under current conditions, the area of interest in 2050 is expected to be impacted the most by a Hurricane Sandy event, and progressively less impacted by the 50-year event and the 25-year event. An analogous result was found when comparing these results to the current baseline results: The marsh is expected to reduce storm damages by millions of dollars in each of these storm events in the future as well. Marsh in the area of interest was found to reduce storm damages by approximately $32.1 million (1.25%), $19.9 million (6.05%), and $1.5 million (1.23%) for a Hurricane Sandy event, 50-year storm event, and 25-year storm event, respectively. Under future projected conditions, the marsh was shown to provide the greatest reduction in damages for the 50-year storm event in terms of the proportion of damages, again suggesting a threshold. The per acre value of the marsh, however, is expected to be the highest in a Hurricane Sandy event under 2050 conditions.

View of the JC NERR. Photo credit: Jane Thomas, IAN Image Library.

Figure 4.7 illustrates each of the storm events in terms of the storm damage reduction benefits that the marsh provides in each event for both current and 2050 conditions in terms of absolute value. Figure 4.8 illustrates the storm damage reduction benefits in terms of percent change, and Figure 4.9 illustrates the per acre storm damage reduction value of the marsh in each storm event.

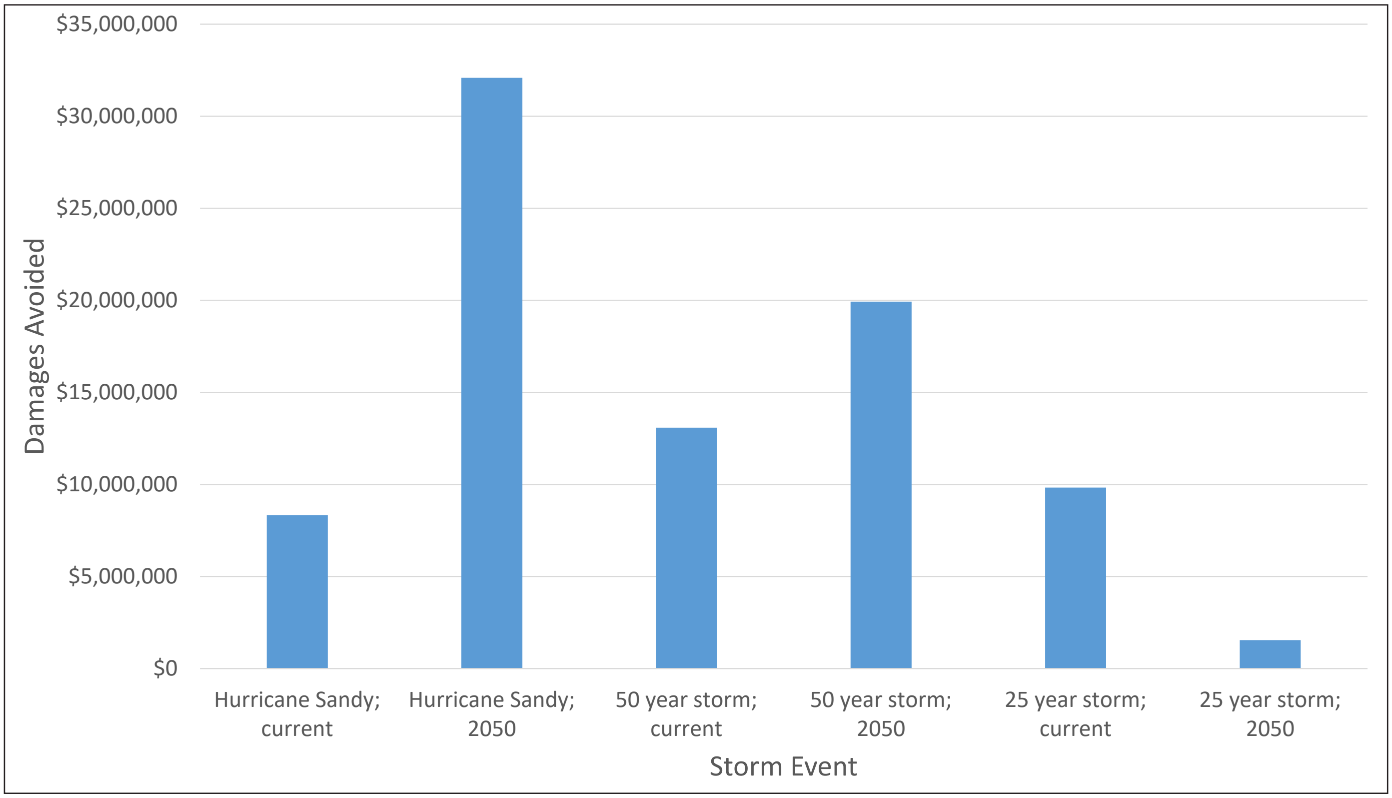

Figure 4.7. Damages avoided in each storm event under current and 2050 conditions.

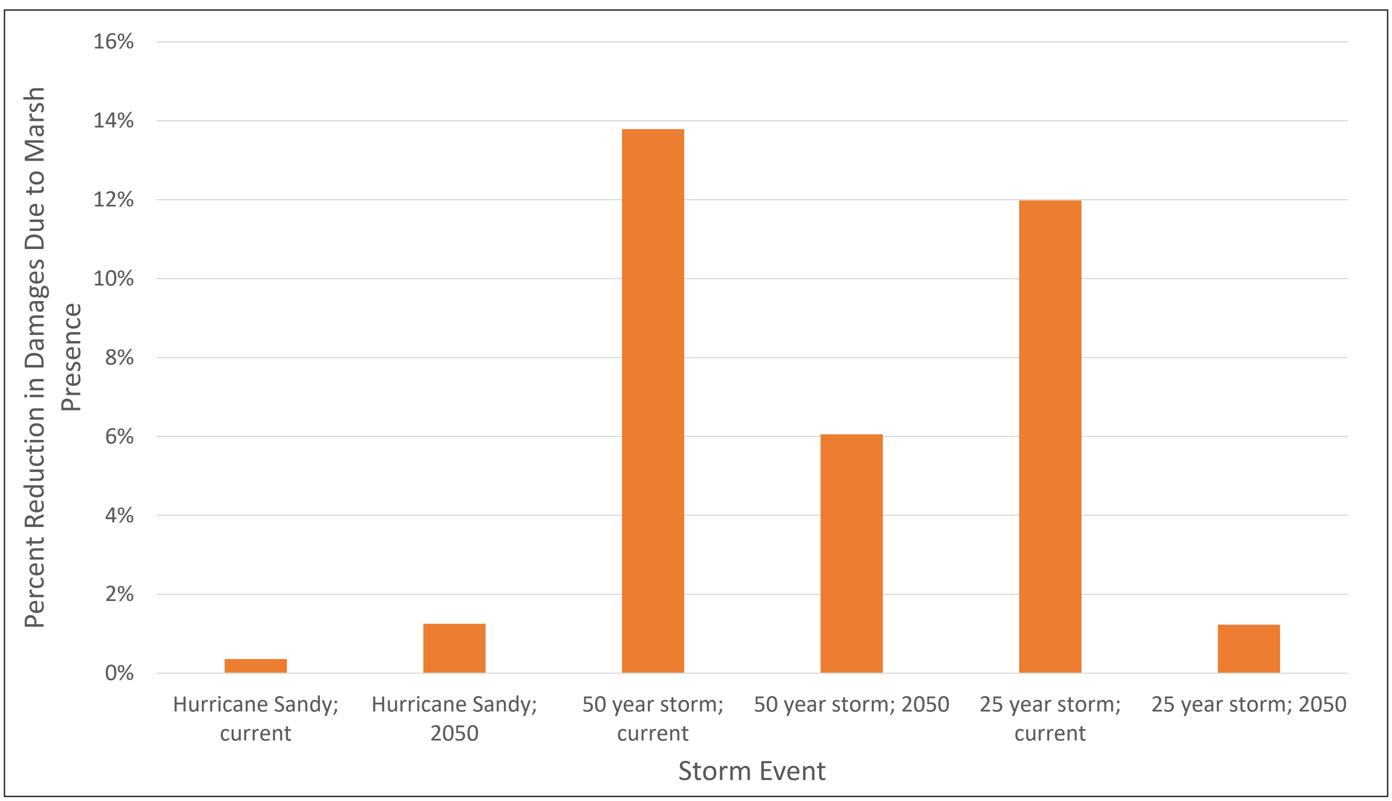

Figure 4.8. Percent reduction in damages avoided in each storm event under current and 2050 conditions.

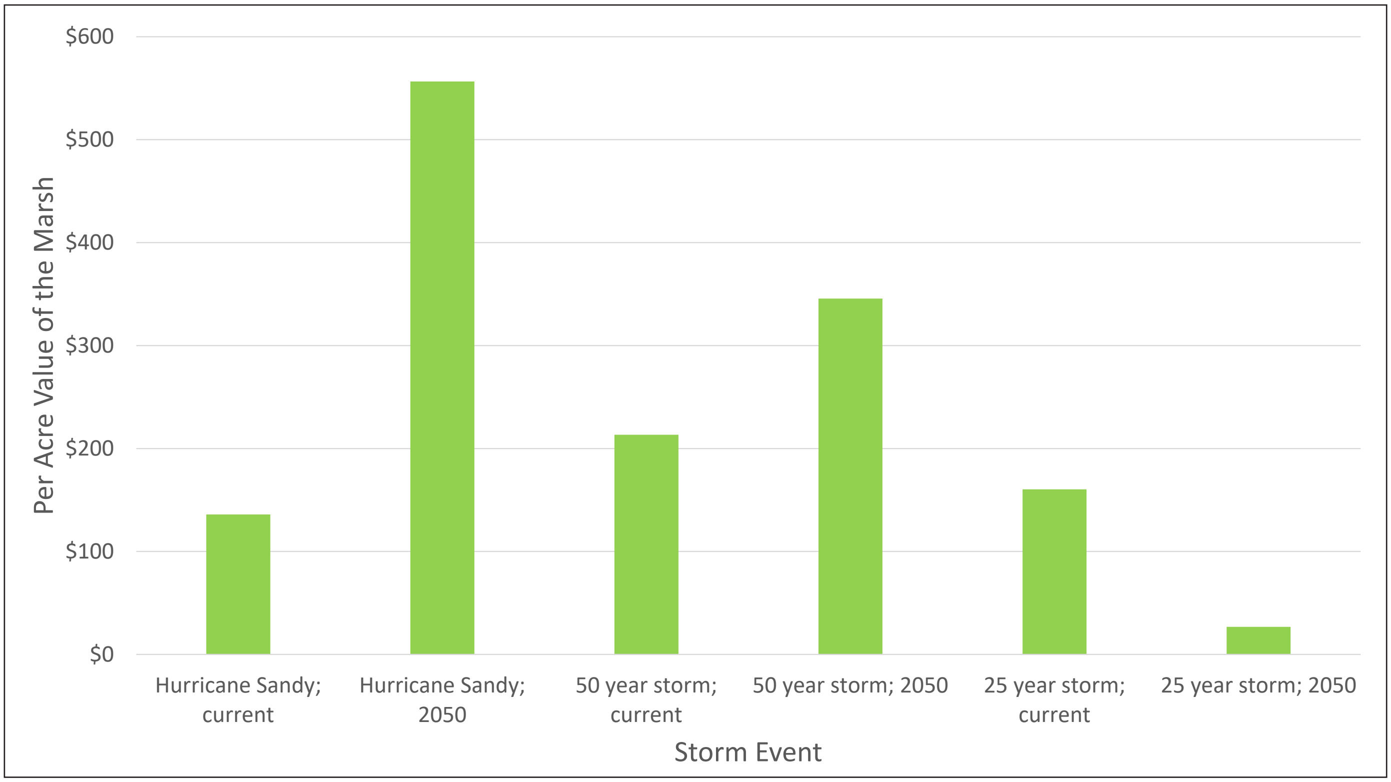

Figure 4.9. Per acre value of the marsh in each storm event; current and 2050 conditions.

Table 4.5 illustrates the number of residential parcels impacted by each storm event, and Table 4.6 illustrates average flood depths and proportional structure damages under future projected conditions. Figures 4.10-4.15 display the spatial extent of inundation and mean flood depth per parcel for a Hurricane Sandy event in the area of interest under projected 2050 marsh cover and sea level conditions. For maps of the spatial extent of inundation and mean flood depth per parcel for the simulated 50-year storm event and 25-year storm event under projected marsh cover and sea level conditions, please see Appendix D.

Table 4.5. Inundated parcels in each storm event under 2050 conditions.

	Hurricane Sandy		50 year storm event		25 year storm event	
	Marsh Present	Marsh Absent (percent change)	Marsh Present	Marsh Absent (percent change)	Marsh Present	Marsh Absent (percent change)
Number of parcels inundated	47,502	47,976 (1%)	17,158	17,762 (4%)	7,001	7,085 (1%)
Number of parcels in which inundation crossed the parcel's centroid	46,577	47,017 (1%)	15,903	16,490 (4%)	5,895	5,973 (1%)

Table 4.6. Flood depths and proportional structure damages in each storm event under 2050 conditions.

	Hurricane Sandy		50 year storm event		25 year storm event	
	Marsh Present	Marsh Absent	Marsh Present	Marsh Absent	Marsh Present	Marsh Absent
Mean flood depth per parcel in feet (SD)	4.0236 (2.0477)	4.0889 (2.0789)	0.6617 (1.4558)	0.7534 (1.5901)	0.1009 (0.2896)	0.1076 (0.2993)
Mean percent of structure damaged (SD)	35.33% (13.79%)	35.66% (13.93%)	14.99% (8.95%)	15.58% (9.63%)	11.89% (3.46%)	11.96% (3.56%)

Note: The statistics in this table represent only those residential parcels in which the inundation layer intersected the parcel's centroid

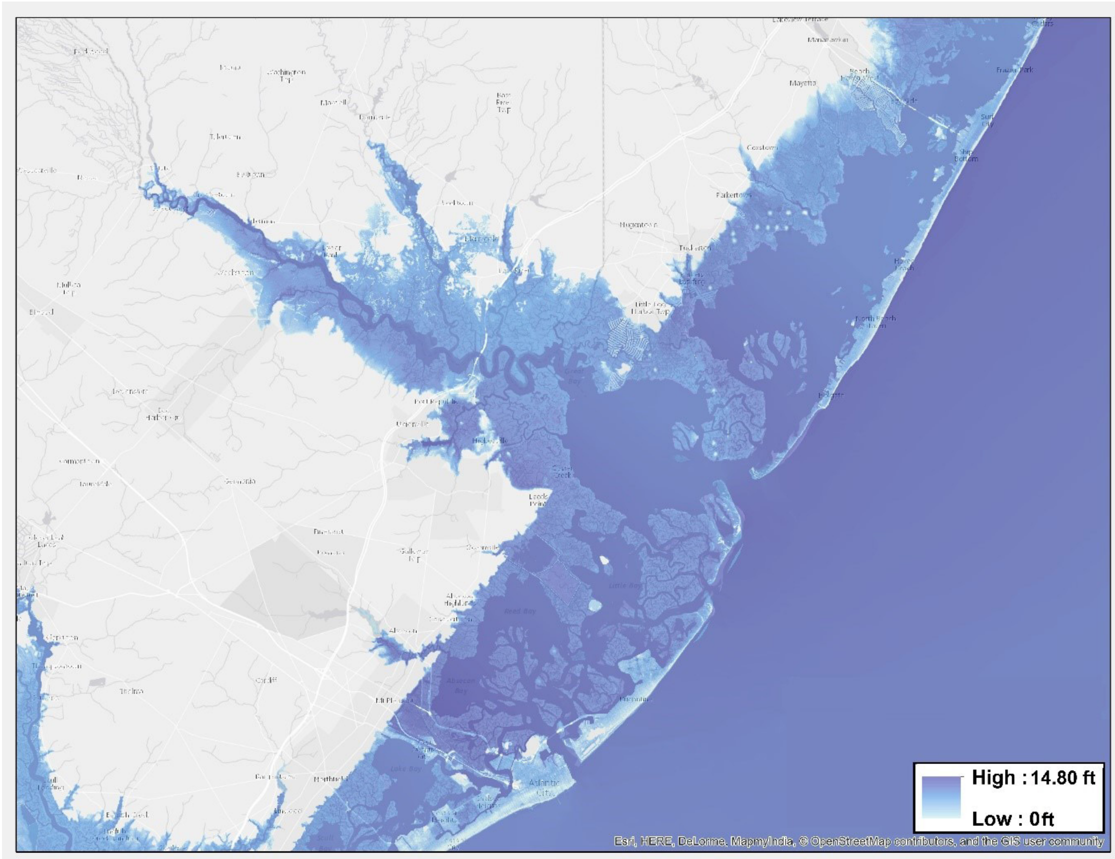

Figure 4.10. Hurricane Sandy event flood depth (ft) under 2050 conditions/marsh present.

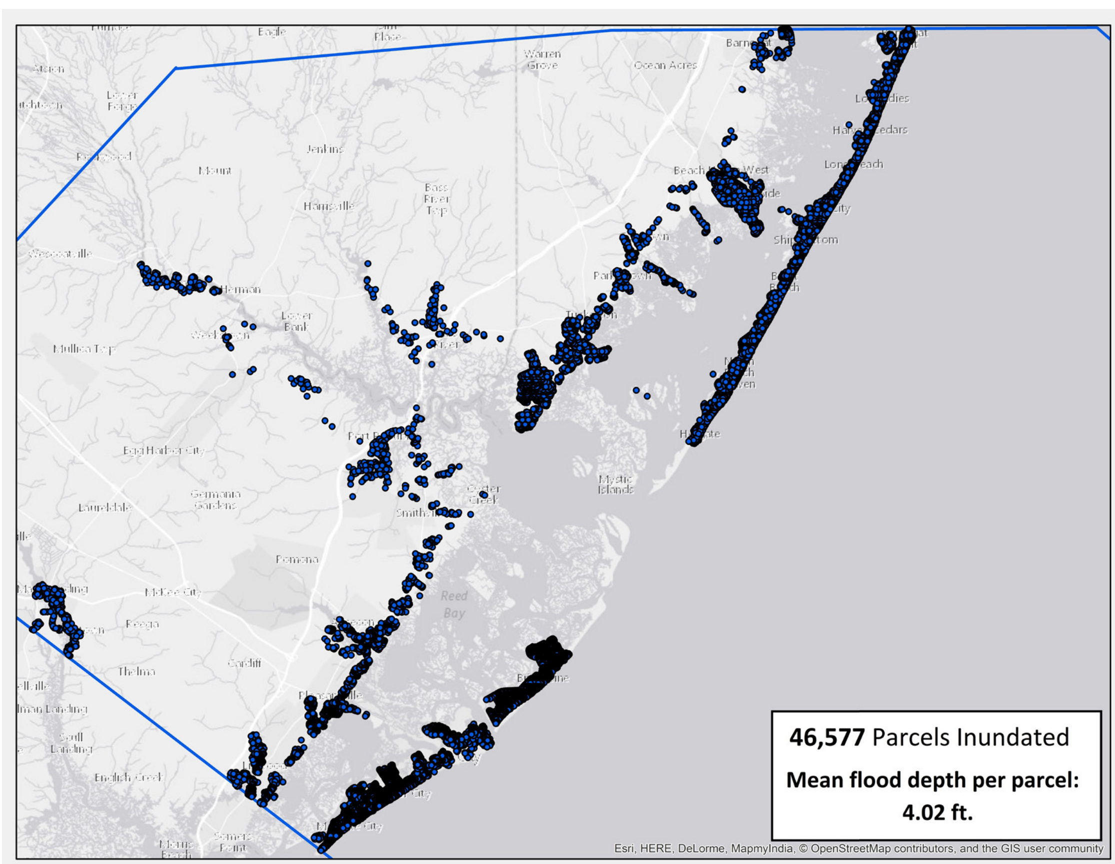

Figure 4.11. Hurricane Sandy event number of parcels inundated and mean flood depth per parcel under 2050 conditions/marsh present.

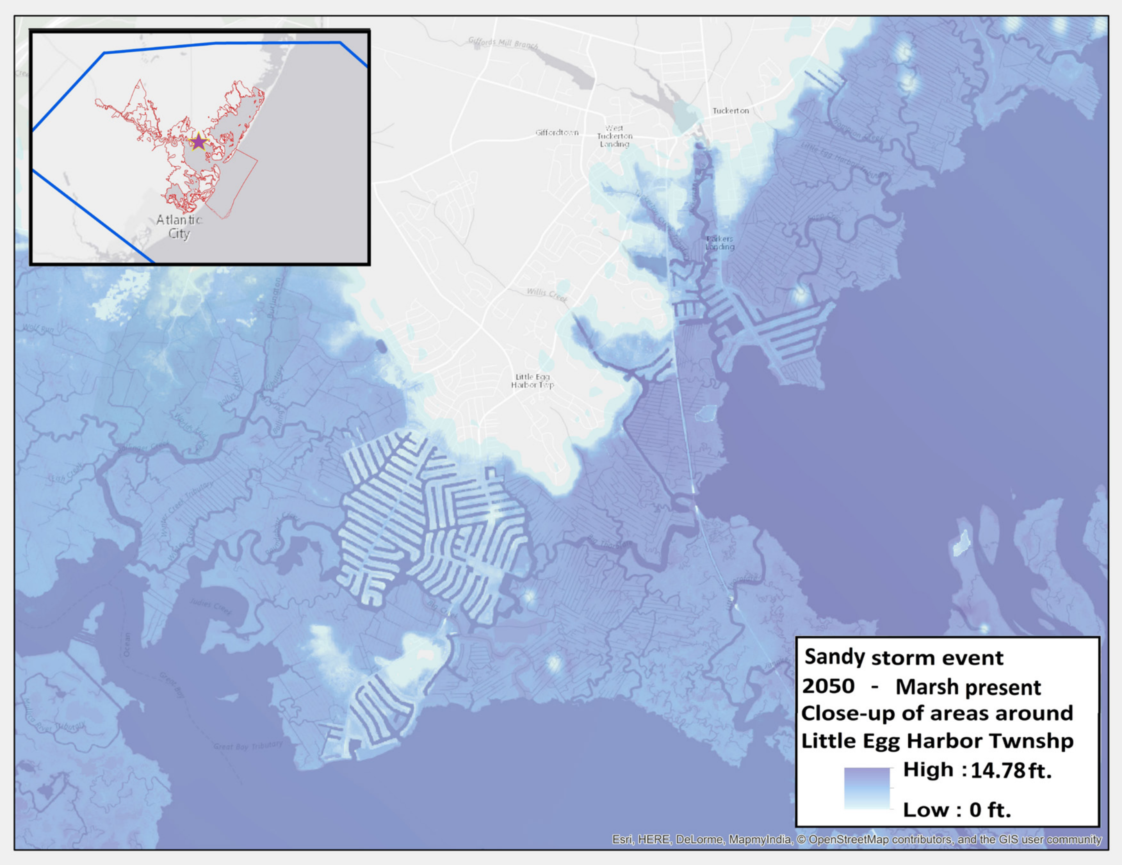

Figure 4.12. Hurricane Sandy event flood depth (ft) under 2050 conditions/marsh present: Little Egg Harbor Township.

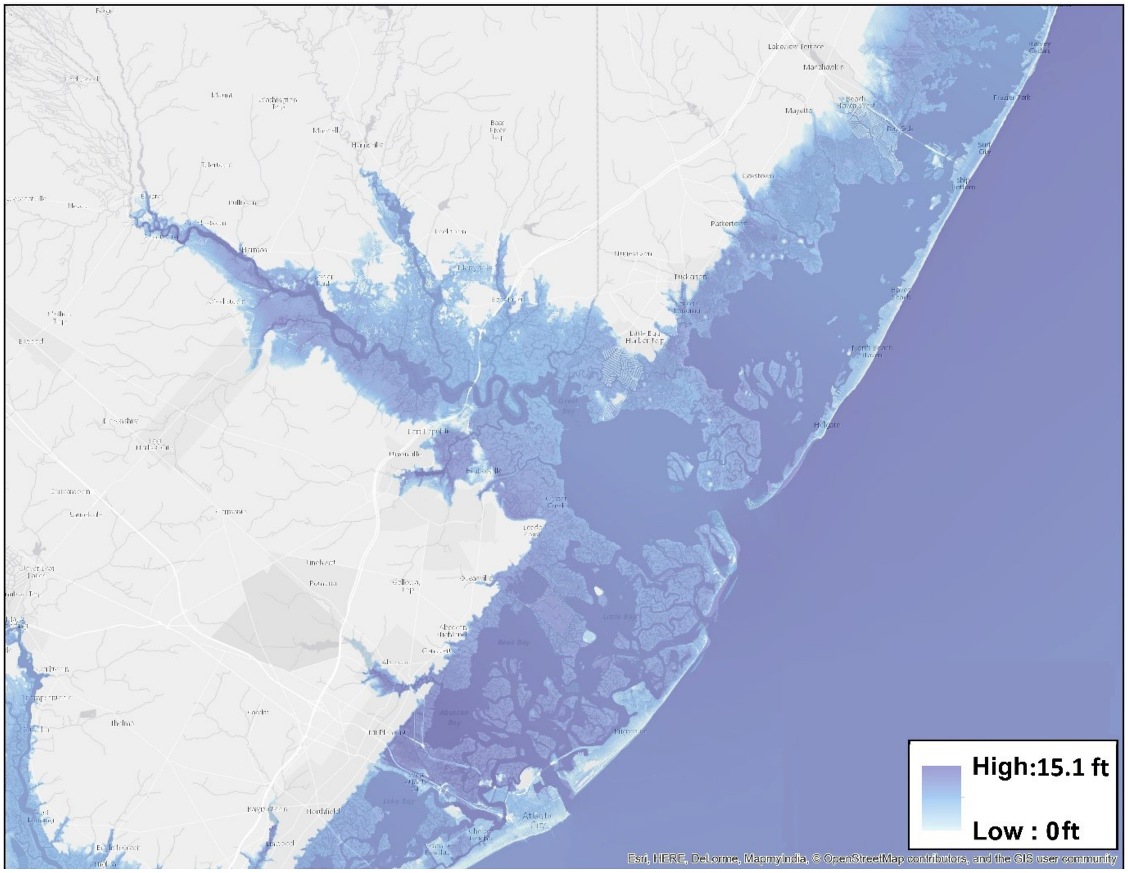

Figure 4.13. Hurricane Sandy event flood depth (ft) under 2050 conditions/marsh absent.

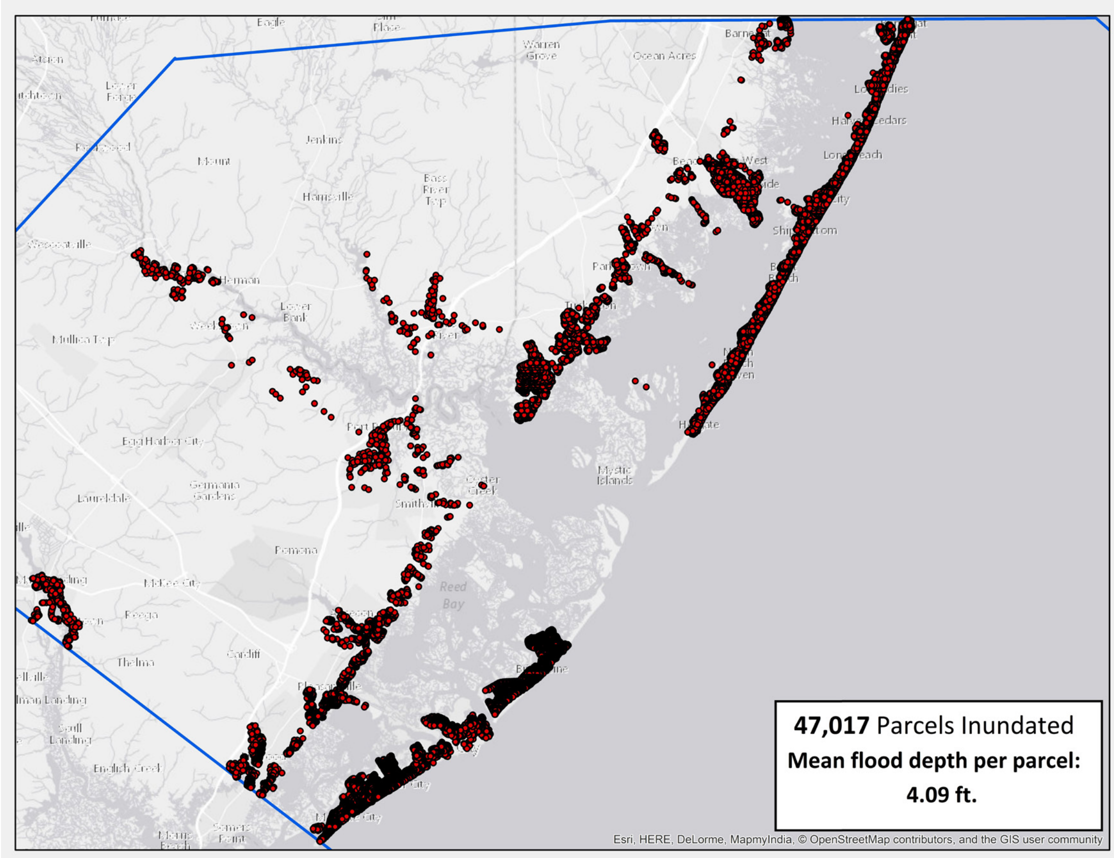

Figure 4.14. Hurricane Sandy event number of parcels inundated and mean flood depth per parcel under 2050 conditions/marsh absent.

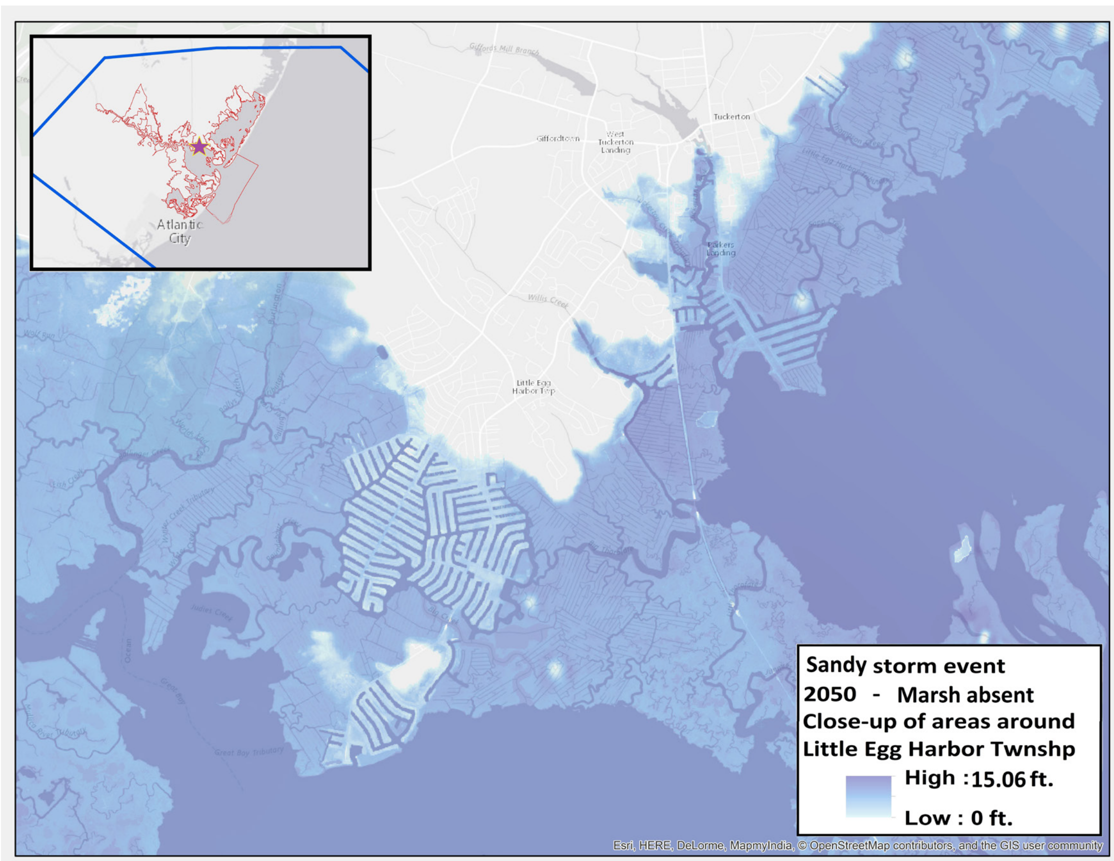

Figure 4.15. Hurricane Sandy event flood depth (ft) under 2050 conditions/marsh absent: Little Egg Harbor Township

The results are similar under future projected conditions. The number of parcels inundated, average flood depth, and average proportional structure damage all increase with marsh absent. The storm damage reduction effect of marsh on parcels peaks under a 50-year storm event.

4.3. ANALYSIS OF STORM EVENTS, MARSH SCENARIOS, AND TEMPORAL CONDITIONS

The results were analyzed further with paired T-tests and chi-square tests to determine if statistically significant differences existed in the number of parcels inundated, mean parcel flood depths of inundated parcels, and mean proportional structural damage of inundated parcels. These differences were investigated across presence/absence of marsh scenarios, storm events, and current vs. 2050 marsh cover and sea level conditions (Tables 4.7 and 4.8).

Table 4.7. Analysis across marsh presence/absence and across current/2050 conditions.

	Effect of Marsh Presence		Effect of SLR and Marsh Migration	
	Current Conditions	2050 Conditions	Marsh Present	Marsh Absent
Number of parcels inundated (25-year storm)	DECREASE ($p<0.01$)	N/A	INCREASE ($p<0.01$)	INCREASE ($p<0.01$)
Number of parcels inundated (50-year storm)	DECREASE ($p<0.01$)	DECREASE ($p<0.01$)	INCREASE ($p<0.01$)	INCREASE ($p<0.01$)
Number of parcels inundated (Hurricane Sandy storm)	N/A	DECREASE ($p=0.05$)	N/A	N/A
Mean parcel inundation depth (25-year storm)	N/A	N/A	INCREASE ($p<0.01$)	INCREASE ($p<0.01$)
Mean parcel inundation depth (50-year storm)	N/A	DECREASE ($p<0.01$)	N/A	N/A
Mean parcel inundation depth (Hurricane Sandy storm)	DECREASE ($p = 0.01$)	DECREASE ($p<0.01$)	N/A	N/A
Mean proportional structural damage (25-year storm)	DECREASE ($p<0.01$)	N/A	INCREASE ($p<0.01$)	N/A
Mean proportional structural damage (50-year storm)	DECREASE ($p=0.02$)	DECREASE ($p<0.01$)	N/A	INCREASE ($p<0.01$)
Mean proportional structural damage (Hurricane Sandy storm)	N/A	DECREASE ($p<0.01$)	N/A	INCREASE ($p<0.01$)

Notes: Entries of "N/A" indicate no statistical significance; Increases and decreases are considered statistically significant at a p-value ≤ 0.05

4.3.1. Presence of Marsh and Absence of Marsh Scenarios

Under current conditions, the presence of marsh, on average, statistically significantly decreased the number of parcels inundated during a 25-year (chi2=89.61, p=0.00) and a 50-year (chi2=75.43, p=0.00) storm event; and, on average, statistically significantly decreased the mean parcel inundation depth during a Hurricane Sandy event (t=2.41, p=0.01). That is, current marsh presence would cause statistically significantly fewer properties, on average, to be affected by a 25-year or a 50-year storm event, but not statistically significantly affect the number of properties affected by a Hurricane Sandy event. On average, however, properties affected by a Hurricane Sandy event would experience a statistically significantly lower inundation depth.

Under current conditions, the presence of marsh, on average, statistically significantly decreased the mean proportional structural damage during a 25-year (t=7.00, p=0.00) and a 50-year storm event (t=2.09, p=0.02), but did not statistically significantly affect the mean proportional structure damage in a Hurricane Sandy event. Under 2050 conditions, the presence of marsh, on average, statistically significantly decreased the number of parcels inundated (50-year: chi2=12.60, p=0.00; Sandy: chi2=3.76, p=0.05), the mean parcel inundation depth (50-year: t=5.41, p=0.00; Sandy: t=4.84, p=0.00), and the mean proportional structural damage (50-year:

Table 4.8. Analysis across storm events.

	From a 25-year storm to a 50-year storm	From a 25-year storm to a Hurricane Sandy storm	From a 50-year storm to a Hurricane Sandy storm
Number of parcels inundated (Current conditions, marsh present)	INCREASE (p<0.01)	INCREASE (p<0.01)	INCREASE (p<0.01)
Number of parcels inundated (Current conditions, marsh absent)			
Number of parcels inundated (2050 conditions, marsh present)			
Number of parcels inundated (2050 conditions, marsh absent)			
Mean parcel inundation depth (Current conditions, marsh present)	INCREASE (p<0.01)	INCREASE (p<0.01)	INCREASE (p<0.01)
Mean parcel inundation depth (Current conditions, marsh absent)			
Mean parcel inundation depth (2050 conditions, marsh present)			
Mean parcel inundation depth (2050 conditions, marsh absent)			
Mean proportional structure damage (Current conditions, marsh present)	INCREASE (p=0.03)	INCREASE (p<0.01)	INCREASE (p<0.01)
Mean proportional structure damage (Current conditions, marsh absent)	DECREASE (p<0.01)		
Mean proportional structure damage (2050 conditions, marsh present)	INCREASE (p<0.01)		
Mean proportional structure damage (2050 conditions, marsh absent)	INCREASE (p<0.01)		

Notes: Entries of "N/A" indicate no statistical significance; Increases and decreases are considered statistically significant at a p-value ≤ 0.05

t=5.63, p=0.00; Sandy: t=3.72, p=0.00) during 50-year and Hurricane Sandy events. That is, the presence of marsh under 2050 conditions would cause statistically significantly fewer properties to be affected by a 50-year and a Hurricane Sandy event, and those properties would experience statistically significantly lower inundation depths.

4.3.2. Storm Events

Storm intensity,[26] on average, statistically significantly increased the number of parcels inundated as well as the mean inundation depth of inundated parcels. Under all conditions and scenarios, statistically significantly more parcels were inundated and mean parcel inundation depth was statistically significantly higher in a Hurricane Sandy event when compared to a 50-year storm event, and in a 50-year storm event when compared to a 25-year storm event.

Under current conditions with marsh present, mean proportional structure damage statistically significantly increased, on average, from a 25-year to a 50-year storm event, and from a 50-year to a Hurricane Sandy event. Under current conditions with marsh absent, mean proportional structure damage statistically significantly decreased, on average, from a 25-year to a 50-year storm event, while it statistically significantly increased, on average, from a 50-year to a Hurricane Sandy event, and from a 25-year to a Hurricane Sandy event. Under 2050 conditions, regardless of marsh presence/absence, the mean proportional structure damage statistically significantly increased, on average, from a 25-year to a 50-year storm event, and from a 50-year to a Hurricane Sandy event.

[26]Storm intensity increases from a 25-year storm event to a 50-year storm event, and increases from a 50-year storm event to a Hurricane Sandy event.

4.3.3. Current and Year 2050 Marsh Cover and Sea Level Conditions

Under current conditions, regardless of the presence/absence of marsh, statistically significantly fewer parcels were inundated, on average, during a 25-year and a 50-year storm event, and mean parcel inundation depth is predicted to be statistically significantly lower, on average, during all three storm events. That is, 2050 conditions would cause statistically significantly more properties to be inundated, on average, in a 25-year or a 50-year storm event, but not statistically significantly affect the number of properties inundated in a Hurricane Sandy event. Those affected by any of the three storm events would, on average, experience statistically significantly lower parcel inundation depths under current conditions, however.

Under current conditions with marsh present, the mean proportional structural damage was statistically significantly less, on average, when compared to 2050 conditions. Under current conditions with marsh absent, the mean proportional structural damage was statistically significantly less, on average, when compared to 2050 conditions for the 50-year storm and Hurricane Sandy events.

4.4. COMMUNITY RATING SYSTEM

As stated, another way to examine the economic contribution of preserved open space such as the JC NERR is by using the CRS. Following the methodology outlined in Section 2.5.2, it was found that participation in OSP enabled the area of interest's CRS-participating communities to save a total of $1,419,766 on their flood insurance premiums in 2013 ($1,444,510 in year 2015 dollars). When divided by the number of NFIP policy holders in the communities in the area of interest, this resulted in $31 in savings attributed to OSP per NFIP policyholder. This figure of $1,419,766 in OSP-related flood insurance savings represents 18% of all CRS savings in 2013 for the CRS-participating communities in the area of interest, and represents 4% of all NFIP premiums paid in 2013 by the CRS-participating communities in the area of interest.

By utilizing community-specific MPC data, it was calculated that these savings attributed to OSP led to an extra $1,037,576 (year 2015 dollars) in direct expenditures for the area of interest in 2013. By examining the average annual household expenditures for each of the CRS-participating communities in the area of interest and multiplying by the number of NFIP policyholders in each community, it was found that direct expenditures resulting from OSP-related CRS savings represent 0.03% of all annual expenditures by NFIP policyholders within these communities.

Through multiplier effects, the $1,037,576 in direct expenditures can be expected to lead to a $938,973 output contribution, a $451,500 income contribution, and an employment contribution of 12 full time jobs. While the economic contribution of these expenditures resulting from OSP-related NFIP premium savings is noted, these values represent less than 1% of all output, income, and employment in the tri county area.

Table 4.9 displays each CRS-participating community in the area of interest along with their CRS rating characteristics, and Appendix C details the economic contribution calculation described above.

Table 4.9. CRS OSP economic contribution.

Area of interest community that Participates in the CRS	Number of NFIP policy holders (2013)	Total CRS credit points (2013)	CRS Credit points associated with OSP (2013)	CRS class (2013)	Percent-age discount received for SFHA/ non SFHA	Total CRS Discount aggregated across NFIP policy holders (2013)	Discount dollars attributed to OSP (2013$)	MPC (2014)	Expected increase in expenditures due to OSP CRS savings (2013$)	Expected increase in expenditures due to OSP CRS savings (2015$)
Barnegat Light	1,039	1214	368	8	5-Oct	$100,544	$41,688.16	0.6987	$29,125.66	$29,633.27
Beach Haven	2,485	2108	212	6	20/10	$649,876	$190,210.25	0.6768	$128,743.16	$130,986.91
Brigantine	7,637	2023	543	6	20/10	$1,221,373	$610,686.50	0.741	$452,541.80	$460,428.75
Margate City	5,770	2007	51	6	20/10	$1,194,682	$349,667.89	0.687	$240,208.81	$244,395.20
Stafford	3,675	2076	250	6	20/10	$777,326	$227,513.21	0.7436	$169,183.32	$172,131.87
TOTAL							*$1,419,766*			*$1,037,576*

Note: Section 2.5.2 provides a list of the communities in the area of interest that participated in the CRS in 2013. The communities of Atlantic City, Harvey Cedars, Long Beach, Long-port, Ship Bottom, Surf City, and Ventnor are left absent from this table as their CRS class rating is unchanged in a hypothetical scenario without OSP credit points, and therefore would not change that community's level of NFIP savings, and would not lead to additional expenditures in that community.

Chapter 5
Discussion and Conclusions

Photo credit: Matt Gorstein, NOAA

The purpose of this study was to estimate the coastal property storm damage reduction benefits of marsh in the JC NERR through spatial and economic analyses. The results of this study indicate that marshes in and around the JC NERR provide economic benefit in terms of the storm damage reduction services these natural infrastructure provide to neighboring coastal communities. It was found that the marsh reduced damages the most (proportionally) for the 50-year storm event when compared to the 25-year storm event and the Hurricane Sandy event. Findings from these calculations support past research that says there are storm intensity thresholds (Boutwell and Westra, 2014) and marsh area thresholds (Boutwell and Westra, 2015) for the flood mitigation services provided by these ecosystems. That is, the marsh does not exert as high a protection effect in large, impactful storms such as Sandy, perhaps due to relatively high (compared to the other modeled storm events) levels of storm surge rendering marsh's attenuation effects less impactful. In these more frequent, somewhat weaker storm events, however, the marsh's effect on storm damage reduction is larger in absolute value, as well as in the percent change in damages due to marsh presence (i.e. the 25-year and 50-year storm events). Similar to Wamsley et al. 2010, these results suggest that marshes do have the potential to reduce storm surge and mitigate flood damages to properties, but the magnitude of attenuation is dependent upon the surrounding coastal landscape and the characteristics of the specific storm event.

In the "current conditions" iteration of the model, it was calculated that residential property damages reached $2.3 billion in a Hurricane Sandy event with marsh present for this particular area of interest. This figure is comparable to the $3.7 billion estimated by the New Jersey Department of the Treasury for residential property damage to Atlantic, Burlington, and Ocean Counties due to actual Hurricane Sandy (Gallagher, 2013), especially considering the area of interest does not encompass the entirety of these three counties.

The findings from this work illustrate how natural infrastructure, such as marsh, is of benefit in terms of the storm damage reduction benefits it provides to coastal communities; this is in keeping with past research (Walls et al., 2017; Narayan et al., 2016; Boutwell and Westra, 2015). For the area of interest used in this study, the value is on the order of millions of dollars for each of the modeled storm events. It is important to keep in mind that each of the storm events selected for this analysis are unique, and vary in factors including direction, track, duration, intensity, landfall location, speed, and rotational velocity. As a result, the analyses in this report are not intended to be representative of all possible storm events; rather, the findings from this work support the body of literature on the storm damage reduction value of shoreline habitats. It is not expected that the property damages in the current/future and presence/absence of marsh scenarios will change in the same magnitude for each storm event. This also indicates that three unique storms are distinct in resultant flooding and damages. Trying to explain the phenomenon of a perceived lack of pattern in the damage results of three unique storms for such a large area might be misleading as the coastal processes and surge propagation depend on multiple factors. These facts illustrate the variability in surge reduction potential of natural features such as marsh, and highlight the complex nature of storms in terms of their structure and their impacts to coastal communities.

Additionally, the damage estimates presented in this report were calculated based on the mean expected proportional structure damage given a certain flood depth, as specified by the USACE depth damage functions. Each expected proportional structure damage has an associated standard of deviation (margin of error) as well, which indicates that a range of values are possible when calculating a given structures monetary damage in a given storm event.

The utilization of CRS credit point data in conjunction with economic ratios and multipliers is a novel approach for understanding the economic contribution of natural infrastructure. Participation in the CRS leads to discounts on NFIP premiums paid by households. These households, in turn, have more discretionary income due their community's participation in the CRS, and this extra discretionary income leads to more direct expenditures, which then lead to local economic stimulus. It must be noted, however, that there is an opportunity cost associated with not developing open space lands, and this study only takes into account the economic benefits of OSP as it related to NFIP savings. This CRS approach is transferrable to any coastal region of the country that participates in the CRS, and does not require the inundation modeling expertise necessary for discerning the damages avoided due to the presence of natural infrastructure on a parcel level scale. It is entirely based on secondary data, and CRS resources are readily available online.[27] The results from this analysis indicate that there is a community-wide economic benefit in preserving open space for its flood mitigation capabilities, and in a larger sense, these results show that the CRS is a valuable community tool for not only reducing flood impacts, but also for providing NFIP savings to the households within the participating communities.

It was estimated that participation in OSP, as defined by the CRS, led to over $1 million in direct expenditures in the area of interest in 2013. It must be noted that this analysis only examined one CRS activity (OSP), and therefore the total amount of direct expenditures resulting from CRS savings would be expected to be higher, as NFIP premium savings resulting from other CRS activities would be taken into account. This indicates that the CRS is a program that promotes community-wide flood mitigation strategies and flood preparedness, while simultaneously saving households money on their flood insurance premiums.

Another important point of interest is the per acre value of the marsh in a given storm event. These values can be used by natural resource managers in the area of interest as an estimate of the per unit area economic benefits of marsh presence in terms of the habitat's storm damage reduction value. These per acre benefits can then be compared to any costs that may be associated with marsh restoration efforts on a per unit basis in order to conduct cost benefit analyses of possible marsh restoration projects. This may include determining how many acres of marsh to restore/conserve or determining which locations would be best for marsh restoration/conservation projects. It must be noted that not all sections of marsh are "created equal." That is, a given acre of marsh may be more valuable when compared to some other given acre of marsh due to its thickness, proximity to development, and other surrounding habitat. This study approximates a uniform per acre value of the marsh in a given storm event by dividing the value of the marsh by the area of the marsh in the area of interest. This finding again exemplifies the economic benefits of natural infrastructure.

While closely aligning with past research (Walls et al., 2017; Narayan et al., 2016; Boutwell and Westra, 2015), this work can be expanded in several ways. When examining the effects of only three storm events, it became obvious to the researchers involved in this study that each storm event is variable and that the resulting effects of each storm event depend on a wide array of factors. One possible way to alleviate this variability would be to follow past research (Walls et al., 2017; Narayan et al., 2016; Boutwell and Westra, 2015) and pool hundreds (or thousands) of storm events together and then model the average effects (inundation depth, inundation extent, property damages) of this pooled sample of storms. In conjunction with a pooled sample of storm events, a vertical marsh accretion figure, which reflects multiple locations across the study area, would add a level of robustness to the marsh migration modeling. Another extension of this research would be to examine other damages beyond strictly residential structures, such as commercial structures, business interruption, and valuing the contents of structures that may have been damaged in the storm events. Examining a wider array of damage types would provide more information to natural resource managers as to the true economic benefit of coastal habitats. Similarly, this work can be extended to examine other natural habitats that provide storm damage reduction benefits as well (i.e. sand dunes, oyster reefs, mangroves, etc.). There are also a variety of other climate hazards that may arise other than storm events; such as tidal flooding, flash floods, or riverine flooding. These types of hazards can be evaluated in economic terms as well when analyzing natural infrastructure's effect on the climate hazard.

This information can be used by natural resource managers when communicating to the public. For example, they may be able to explain the amount of money potentially saved in property damages due in part from the habitats under their care. Additionally, public awareness about the importance of the natural resource areas can increase by communicating the information obtained from ecosystem valuation studies to the public. The quantification of storm damage reduction benefits in the JC NERR area of interest supports past findings and builds upon the body of literature that states that natural infrastructure provides valuable coastal protection benefits in the face of climate hazards.

[27] CRS fact sheet, CRS Brochure, CRS Coordinator's Manual, List of CRS communities

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Photo credit: Sarah Gonyo, NOAA

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Appendix A: Spatial Data Processing Methodology

Photo credit: NOAA

THE SEA LEVEL AFFECTING MARSHES MODEL (SLAMM)

The Sea Level Affecting Marshes Model (SLAMM) requires a number of other data and datasets formatted or processed in a specific manner. The data processing approach is detailed below.

A 10m resolution digital elevation model (DEM) of the area of interest was prepared for SLAMM input by clipping the file to the area of interest boundary using the Clip tool in the ArcGIS 10.3.1 environment. After the clipping process was complete, the Raster to ASCII tool was used to convert the DEM to an American Standard Code for Information Interchange (ASCII) text file for inclusion into the SLAMM. After the elevation data was clipped to the area of interest, the results were input into the ArcGIS 10.3.1 environment and the Calculate Slope tool was used to determine the slope; the output for the tool was set to degrees. After the slope was calculated, the Raster to ASCII tool was used to create a text-based form of the rasters in order to meet the input requirements of the SLAMM.

The SLAMM documentation calls for using the NWI dataset from the US Fish and Wildlife Service as an input for land cover delineations.[28] Doing so requires aligning the category codes from the NWI dataset to those used in the SLAMM. The SLAMM computer program download includes a file that aids in the crosswalk process. The crosswalk was conducted in Microsoft Excel and ArcGIS 10.3.1. To maintain consistency in assigning the *Manning's n* friction coefficient parameters for the Advanced Circulation and Simulating Waves Nearshore (ADCIRC+SWAN) models, the SLAMM projected land use types for the sea level rise scenario were converted to the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) classifications.

ADVANCED CIRCULATION (ADCIRC) + SIMULATING WAVES NEARSHORE (SWAN) MODELS

In the ADCIRC model, the storm track locations, wind speed, and pressure distribution were provided as inputs for the atmospheric forcing. Using the Holland wind model[29] that is incorporated within ADCIRC, wind velocity and pressure fields were computed at each numerical node. To transfer the wind momentum from atmosphere to surface layer, ADCIRC uses Garratt's drag formulation[30] to estimate the wind shear stress exerted on the open water surface.

The simulated maximum water elevation for the selected storm events were imported into ArcGIS using ArcStormSurge tool[31] to interpolate the flood elevation values for the area of interest. To prepare the flood depth raster, the land topography values were subtracted from the maximum flood elevation raster. The land elevation data were collected from the US Geological Survey National Elevation Dataset.[32] The seamless (DEM) was then used to create a 10m resolution flood depth raster for all storm events and their respective land use and sea level rise (SLR) scenarios. Additionally, both current elevation and future topography obtained from SLAMM were referenced to North American Datum 1988 (NAD88) while the mesh vertical datum was referenced to Mean Sea Level. Using VDatum – a tool designed by NOAA's Office for Coastal Management to adjust the vertical datum of raster-based datasets[33] – the modeled flood elevations were converted to NAVD88 to prepare the final flood depths for selected storm events and scenarios.

These models provided the researchers with the depth and surge elevations from the selected storm events. The results, in raster format, were clipped to the area of interest using the area of interest polygon in the ArcGIS software environment.

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[29]Holland, G.J. 1980. An analytical model of the wind and pressure profiles in hurricanes. Monthly Weather Review 108(8), 1212–1218.

[30]Garratt, J.R. 1977. Review of Drag Coefficients over Oceans and Continents. Monthly Weather Review 105, 915–929.

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[32]Gesch, D., G. Evans, J. Mauck, J. Hutchinson, and W.J.C., Jr. 2009. The National Map - Elevation: U.S. Geological Fact Sheet 2009-3053. Strategies, 4.

[33]Schockraumkonzept, D.B. 2012. Traumapatient, D. Manual, 1–44.

Property Parcel Data

After downloading the parcel data from the various websites of the New Jersey counties within the area of interest, they were clipped to the area of interest using the area of interest boundary polygon file and the Clip tool within the ArcGIS 10.3.1 environment. Once the parcels were clipped to the area of interest, the centroid of each parcel was determined using the Polygon to Point conversion tool in the ArcGIS environment.

GEOSPATIAL MODELLING ENVIRONMENT

Using the raster files output from the ADCIRC+SWAN model runs, the researchers intersected the rasters to the parcel polygon files within the Geospatial Modelling Environment. This allowed the researchers to determine which parcels were impacted by the storm event in terms of surge and flood depth. After this data processing was complete, the researchers then intersected the flood depth rasters with the centroids of the parcel polygons. The researchers performed the analysis for each of the three storm events, both with marsh present and with marsh absent, as well as under current and 2050 projected marsh cover and sea levels. This resulted in a total of 12 storm event/scenario/condition combinations.

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Appendix B
USACE Depth Damage Functions


Photo credit: Matt Gorstein, NOAA

Table B-1. Damage function for single-family one-story, residential structures without basements (USACE 2003).

One Story, No Basement		
Cubic functional relationship:		
$Y = 15.413 + 9.034x - 0.337x^2 - 0.002x^3$		
Depth (X)	**Mean of Damage (Y)**	**Standard Deviation of Damage**
-2	0%	0%
-1	2.50%	2.70%
0	13.40%	2.00%
1	23.30%	1.60%
2	32.10%	1.60%
3	40.10%	1.80%
4	47.10%	1.90%
5	53.20%	2.00%
6	58.60%	2.10%
7	63.20%	2.20%
8	67.20%	2.30%
9	70.50%	2.40%
10	73.20%	2.70%
11	75.40%	3.00%
12	77.20%	3.30%
13	78.50%	3.70%
14	79.50%	4.10%
15	80.20%	4.50%
16	80.70%	4.90%

Table B-2. Damage function for single-family two-or-more-stories, residential structures without basements (USACE 2003).

Two or More Stories-No Basement		
Cubic functional relationship:		
$Y = 10.005 + 5.612x - 0.073x^2 - 0.003x^3$		
Depth (X)	**Mean of Damage (Y)**	**Standard Deviation of Damage**
-2	0%	0%
-1	3.00%	4.10%
0	9.30%	3.40%
1	15.20%	3.00%
2	20.90%	2.80%
3	26.30%	2.90%
4	31.40%	3.20%
5	36.20%	3.40%
6	40.70%	3.70%
7	44.90%	3.90%
8	48.80%	4.00%
9	52.40%	4.10%
10	55.70%	4.20%
11	58.70%	4.20%
12	61.40%	4.20%
13	63.80%	4.20%
14	65.90%	4.30%
15	67.70%	4.60%
16	69.20%	5.00%

Table B-3. Damage function for single-family split level, residential structures without basements (USACE 2003).

Split-Level-No Basement		
Cubic functional relationship:		
$Y = 5.663 + 2.566x + 0.577x^2 - 0.027x^3$		
Depth (X)	**Mean of Damage (Y)**	**Standard Deviation of Damage**
-2	0%	0%
-1	6.40%	2.90%
0	7.20%	2.10%
1	9.40%	1.90%
2	12.90%	1.90%
3	17.40%	2.00%
4	22.80%	2.20%
5	28.90%	2.40%
6	35.50%	2.70%
7	42.30%	3.20%
8	49.20%	3.80%
9	56.10%	4.50%
10	62.60%	5.30%
11	68.60%	6.00%
12	73.90%	6.70%
13	78.40%	7.40%
14	81.70%	7.90%
15	83.80%	8.30%
16	84.40%	8.70%

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Appendix C
Economic Contribution of Expenditures Related to OSP Savings

Photo credit: Jane Thomas, IAN Image Library

ECONOMIC RATIOS

The wages to sales ratio represents the value of a region's workforce as a function of its revenue, and is used to calculate the amount of wage and salary income that is expected to result from extra expenditures in a given economy. The wages to employment ratio represents the value of a region's workforce as function of its amount of employees, and is used to calculate the number of jobs that are expected to be created due to extra wage and salary income. The proprietor income to proprietor employment ratio represents the income of self-employed workers in a region as a function of the number of self-employed workers, and is used to calculate the number of self-employed jobs can be expected to be created as a result of extra expenditures in a given economy. The total income to wages and salaries ratio represents the amount of total income generated in a region (i.e. wages and salary income, supplements to wages and salaries such as investment income, and proprietor's income), in relation to income only from wages and salaries, and is used to calculate the total direct income resulting from wages and salaries income. The proprietor income to wages and salaries ratio represents the proportion of total wages and salaries in a region that is income for self-employed workers, and is used to calculate the income that can be expected to accrue to self-employed workers resulting from extra wage and salary income in the region.

ECONOMIC MULTIPLIERS

Multiplier data were obtained from the US Bureau of Economic Analysis' (BEA) regional input-output modeling system (RIMS), and reflect industry data from 2013 aggregated across Atlantic, Burlington, and Ocean Counties. These Type II Keynesian multipliers are designed to capture the indirect and induced effects of spending as expenditures make their way through a local economy (i.e. for every dollar of output, we would expect the direct, indirect, and induced effects to add up to be more than one dollar as this one dollar makes its way through industries in the local economy). For example, if a consumer spends one dollar at a restaurant, the restaurant can then take this dollar and buy more food from its distributor, and the distributor can then take the money from the restaurant and buy more food from the farmer. The one dollar spent by the original consumer affects the entire supply chain as it moves through the economy. The BEA RIMS provides final demand output, final demand income, final demand employment, final demand value-added, direct effect income, and direct effect employment multipliers (BEA, 2013). This analysis utilizes the final demand output multipliers, the direct effect earnings multipliers, and the direct effect employment multipliers. The final demand output multipliers were used because they form the basis for all other multiplier calculations and represent ratios of the total change in local output (sales) to the change in local output purchased by final users. The direct effect income and employment multipliers were used because they isolate the income and employment effects separately from final output demand. The income multipliers represent the total change in local household earnings per dollar of change in household earnings in the final-demand industry and the employment multipliers represent the total change in local jobs per change in jobs in the final-demand industry. These isolated direct effects are calculated by dividing the final-demand employment multiplier for each industry by the product of the corresponding household-row entry in the regional direct requirements table and the employment-to-earnings ratio for the corresponding industry.

Each industry has a specific output, income, and employment multiplier; therefore, these industry-specific multipliers were averaged to derive industry-wide, area of interest-specific output, income, and employment multipliers. For the income and employment multipliers, researchers were able to obtain county level industry-specific employment and income figures from the BEA's 2013 regional economic information system. These values were then used to calculate weighted average income and employment multipliers to better reflect the local distribution of employees and income across North American Industry Classification System (NAICS) industries in the area of interest. When an employment or income value for an industry was unavailable, a weight of one was assigned. The figures used for the calculation of the weighted average income multiplier were obtained from BEA Table CA5N ("Personal Income by Major Component and Earnings by NAICS Industry"), and the figures used for the calculation of the weighted average employment multiplier were obtained from BEA Table CA25N ("Total Full-Time and Part-Time Employment by NAICS Industry"). Data concerning each NAICS industry's output were not available from the BEA at the county level; therefore, the final demand output multipliers from BEA RIMS were averaged to obtain an industry-wide, area of interest-specific output multiplier.

The specific calculation method along with associated values are illustrated in Tables C1-C4.

Table C-1. Direct wages and salaries income and employment (2015$).

Total Direct Expenditures	$1,037,575.99
(x)	
wages to sales ratio	0.189
=	
Direct Wages and Salaries Income	$196,145.69
(÷)	
wages to employment ratio	$35,141.55
=	
Direct Wages and Salaries Employment	**5.582**

Table C-2. Output contribution (2015$).

Total Direct Expenditures	$1,037,575.99
(x)	
Percent of inputs purchased locally	0.58
=	
Direct output	$601,794.08
(x)	
Output Multiplier	1.56
=	
Total Output Contribution	**$938,973**

Table C-3. Income contribution (2015$).

Direct Wages and Salaries Income	$196,145.69
(x)	
Total income to wages and salaries ratio	1.47
=	
Direct Income	$288,277.54
(x)	
Income Multiplier	1.566
=	
Total Income Contribution	**$451,500**

Table C-4. Employment contribution (2015$).

Wage and Salary Employment:	
Direct Wages and Salaries Employment	5.582
(x)	
Employment Multiplier	1.745
=	
Total wage and salary employment	9.737
Proprietor's employment:	
Proprietor's income to wages and salaries ratio	0.202
(x)	
Direct Wages and Salaries Income	$196,145.69
=	
Proprietor's direct income	$39,647.71
(÷)	
Proprietor's income to employment ratio	$29,166.75
=	
Proprietor's direct employment	1.359
(x)	
Employment multiplier	1.745
=	
Total Proprietor's employment	2.371
Total Employment:	
Direct Wages and Salaries Employment	5.582
(+)	
Proprietor's direct employment	1.359
=	
Total Direct Employment	6.941
Total wage and salary employment	9.737
(+)	
Total Proprietor's employment	2.371
=	
Total Employment Contribution	**12.109**

Appendix D
Scenario Maps

Photo credit: Angela Orthmeyer, NOAA

D.1. CURRENT CONDITIONS RESULTS FOR 25-YEAR AND 50-YEAR STORM EVENTS

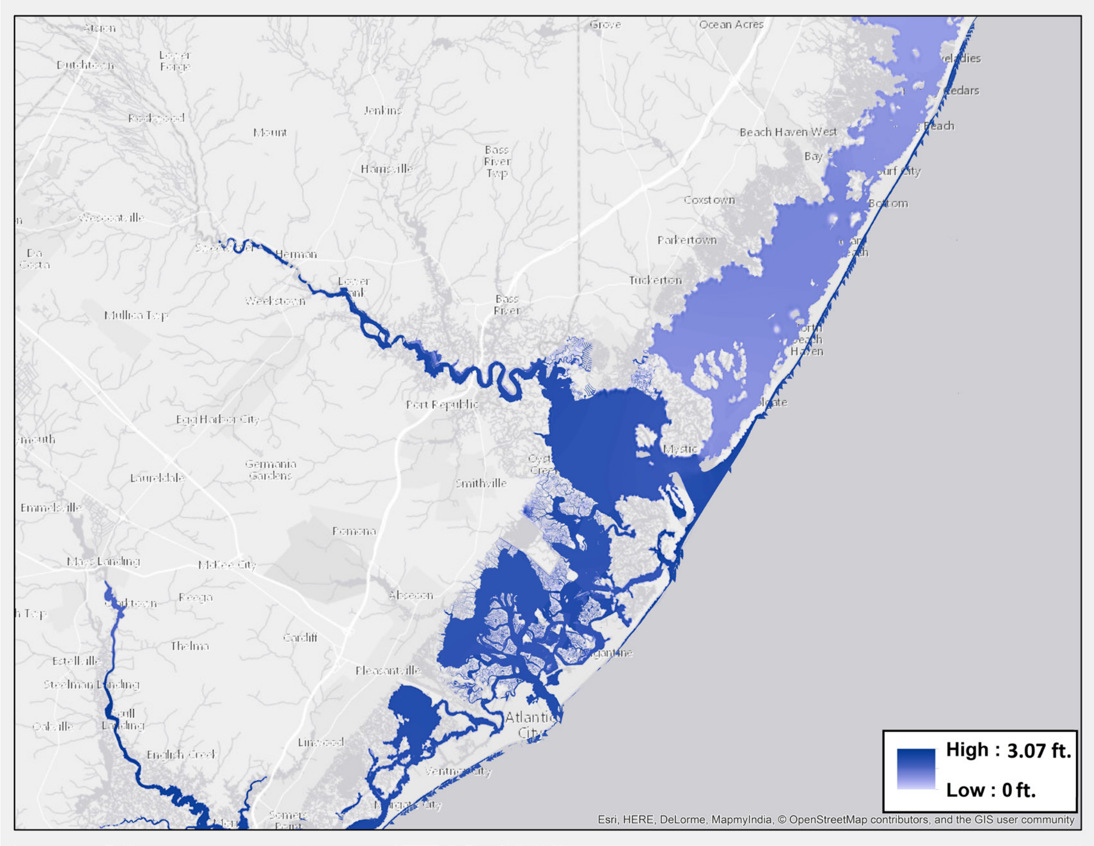

Figure D-1. 25-year storm event flood depth (ft) under current conditions/marsh present.

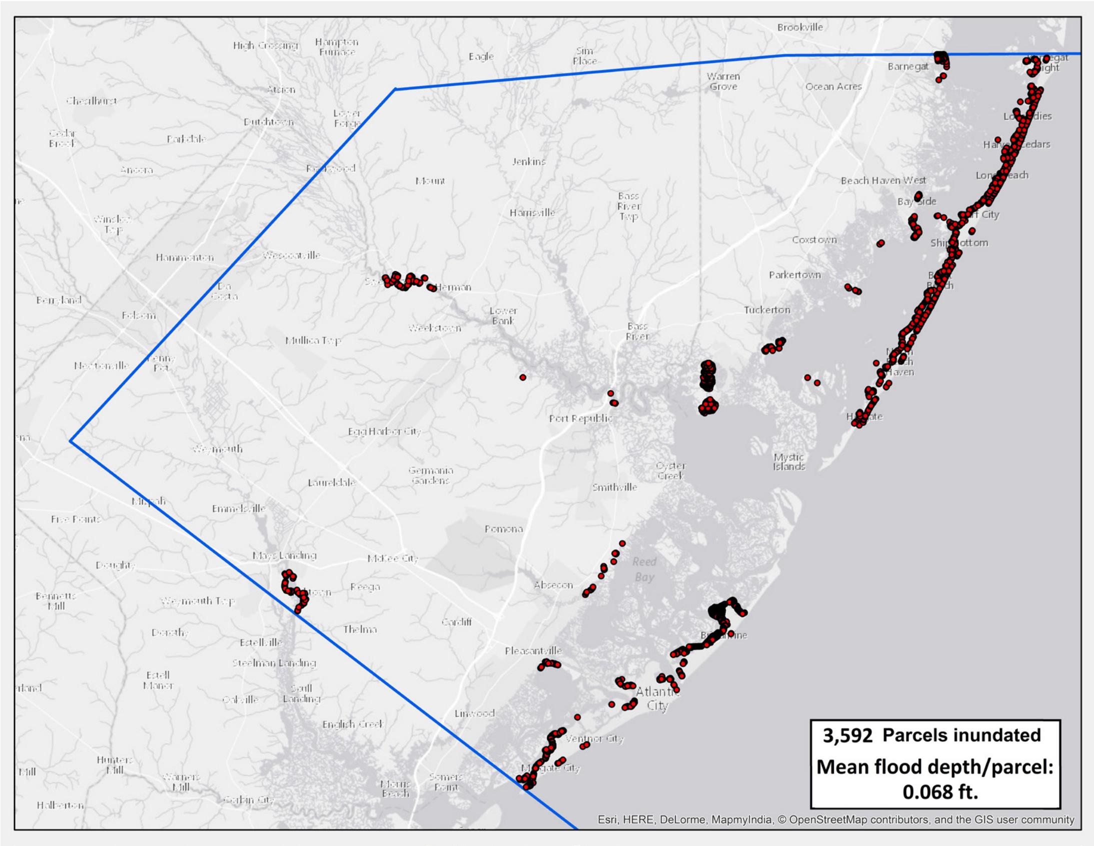

Figure D-2. 25-year storm event number of parcels inundated and mean flood depth per parcel under current conditions/marsh present.

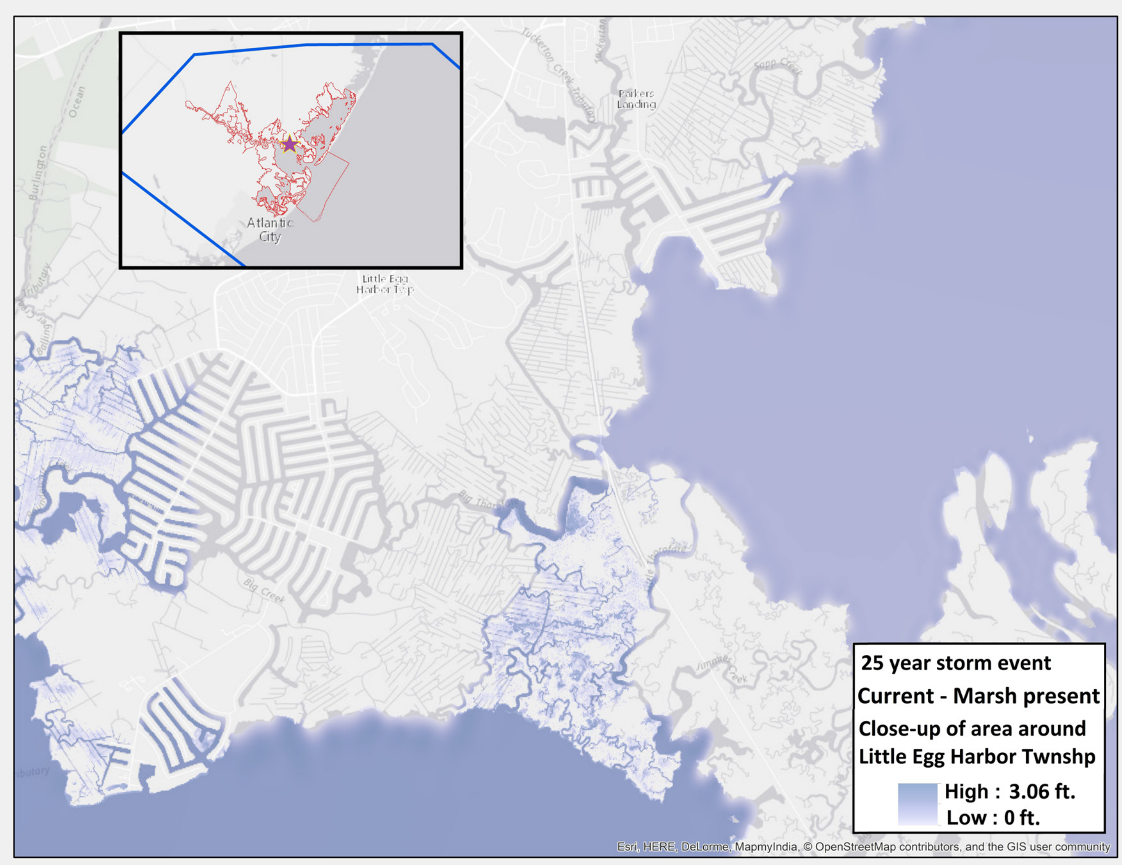

Figure D-3. 25-year storm event flood depth (ft) under current conditions/marsh present: Little Egg Harbor Township.

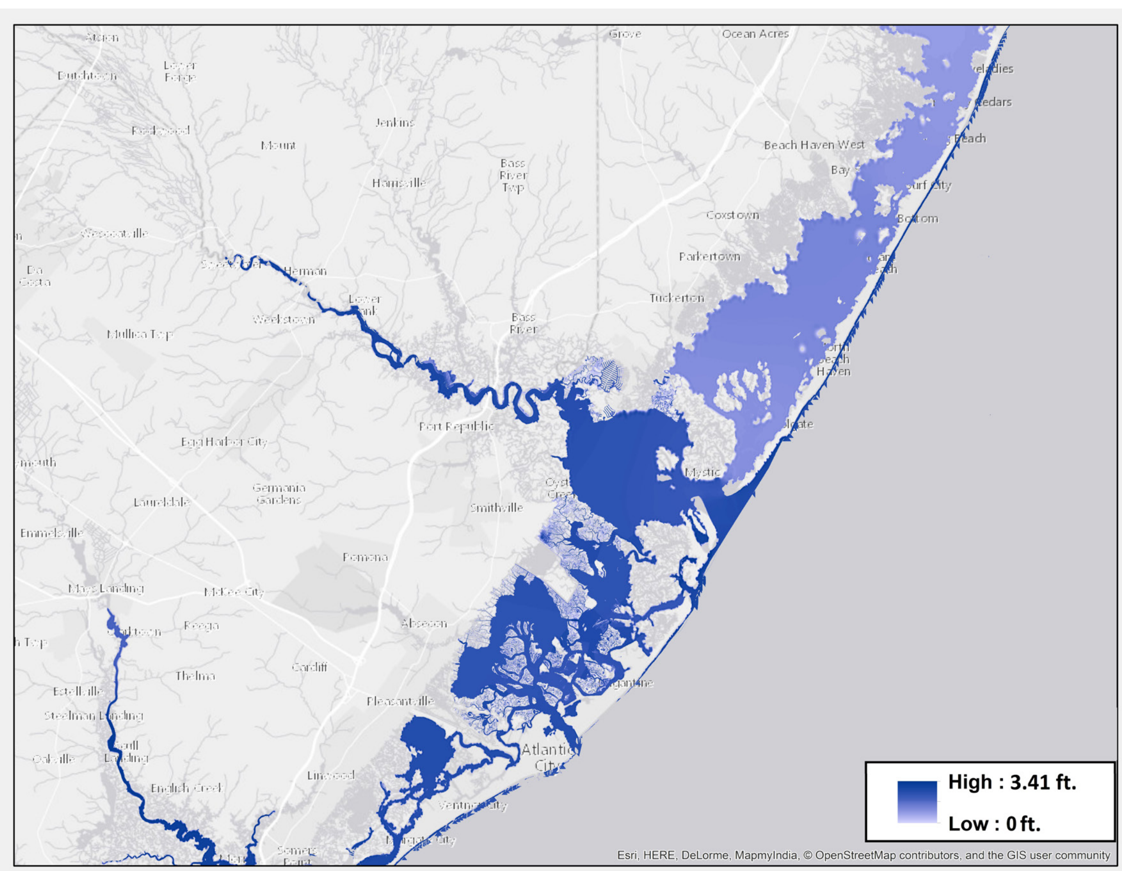

Figure D-4. 25-year storm event flood depth (ft) under current conditions/marsh absent.

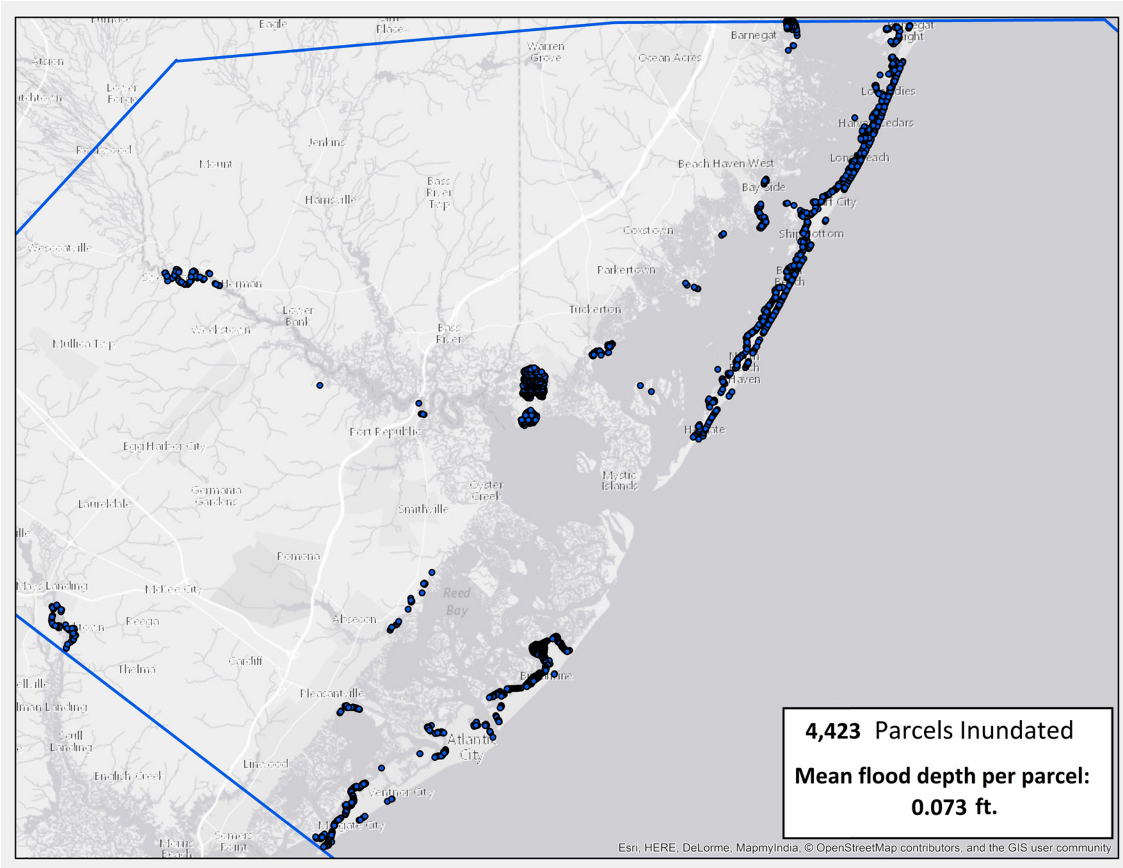

Figure D-5. 25-year storm event number of parcels inundated and mean flood depth per parcel under current conditions/marsh absent.

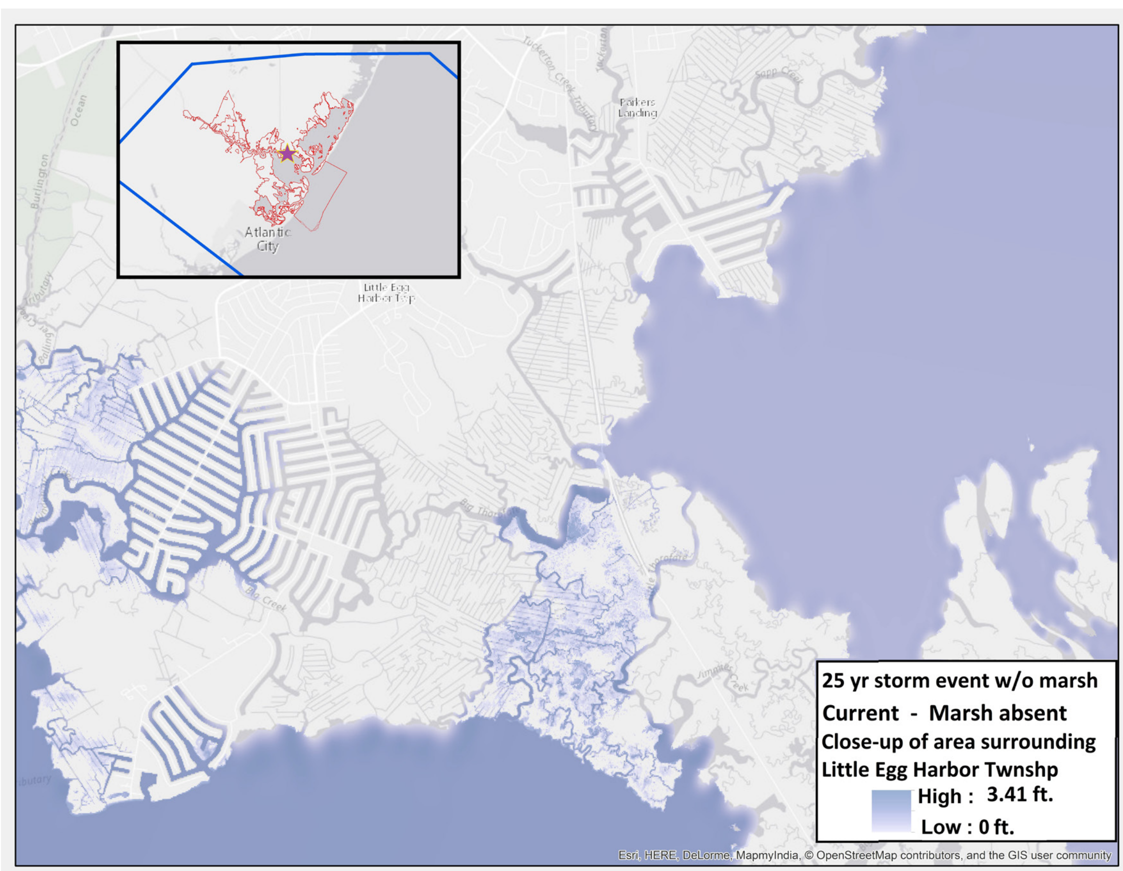

Figure D-6. 25-year storm event flood depth (ft) under current conditions/marsh absent: Little Egg Harbor.

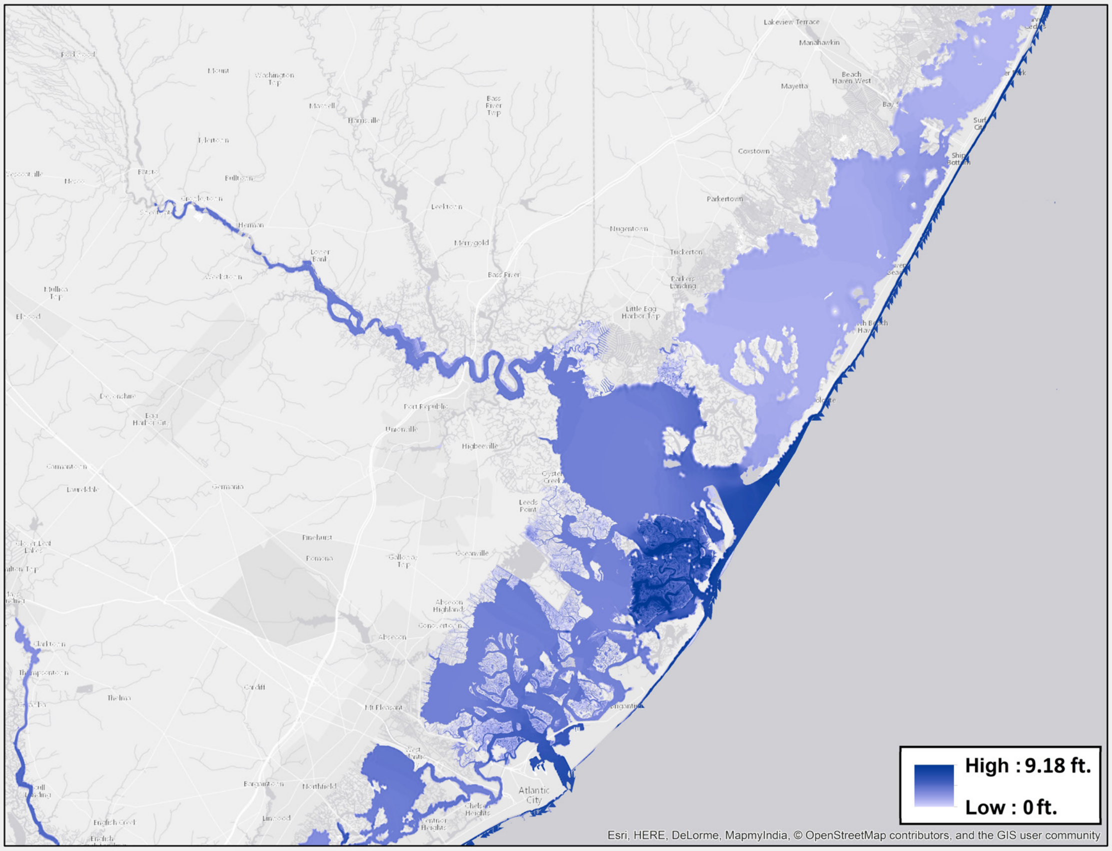

*Figure D-7. 50-year storm event flood depth (ft) under current conditions/marsh present. *Notice the greater depth of flooding to the north of Atlantic City.*

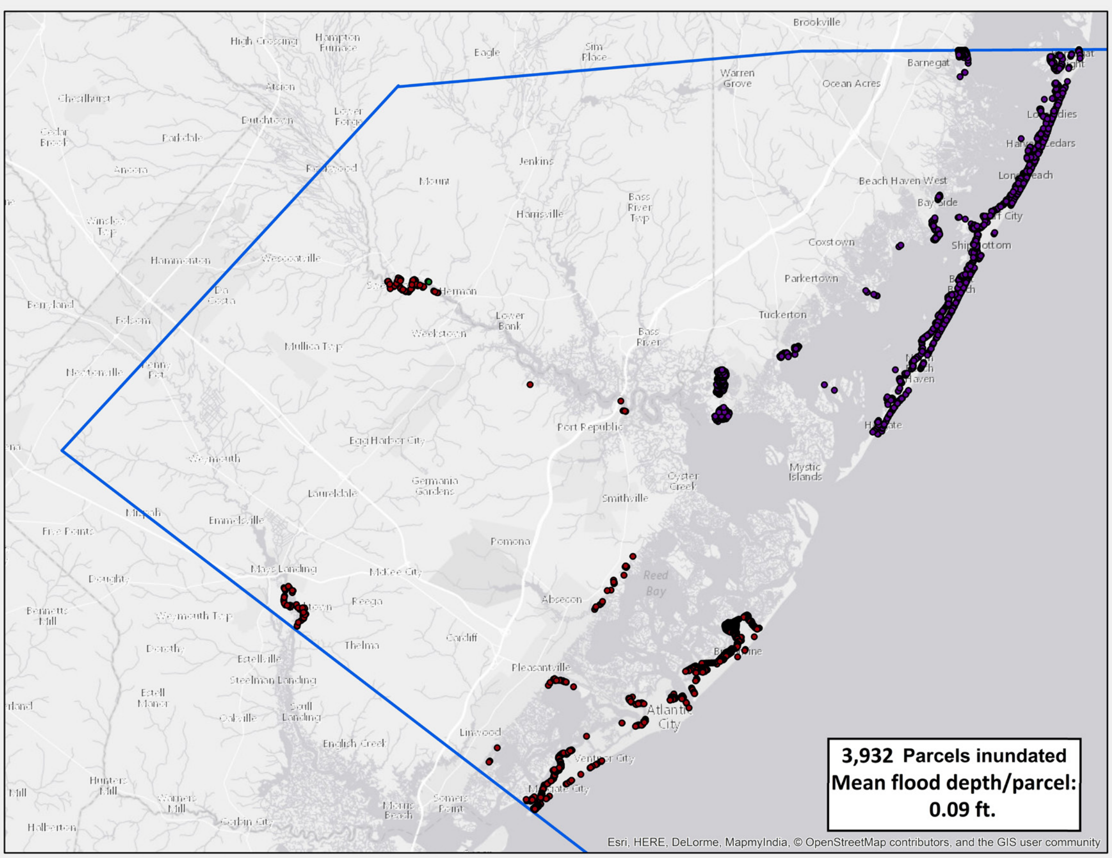

Figure D-8. 50-year storm event number of parcels inundated and mean flood depth per parcel under current conditions/marsh present.

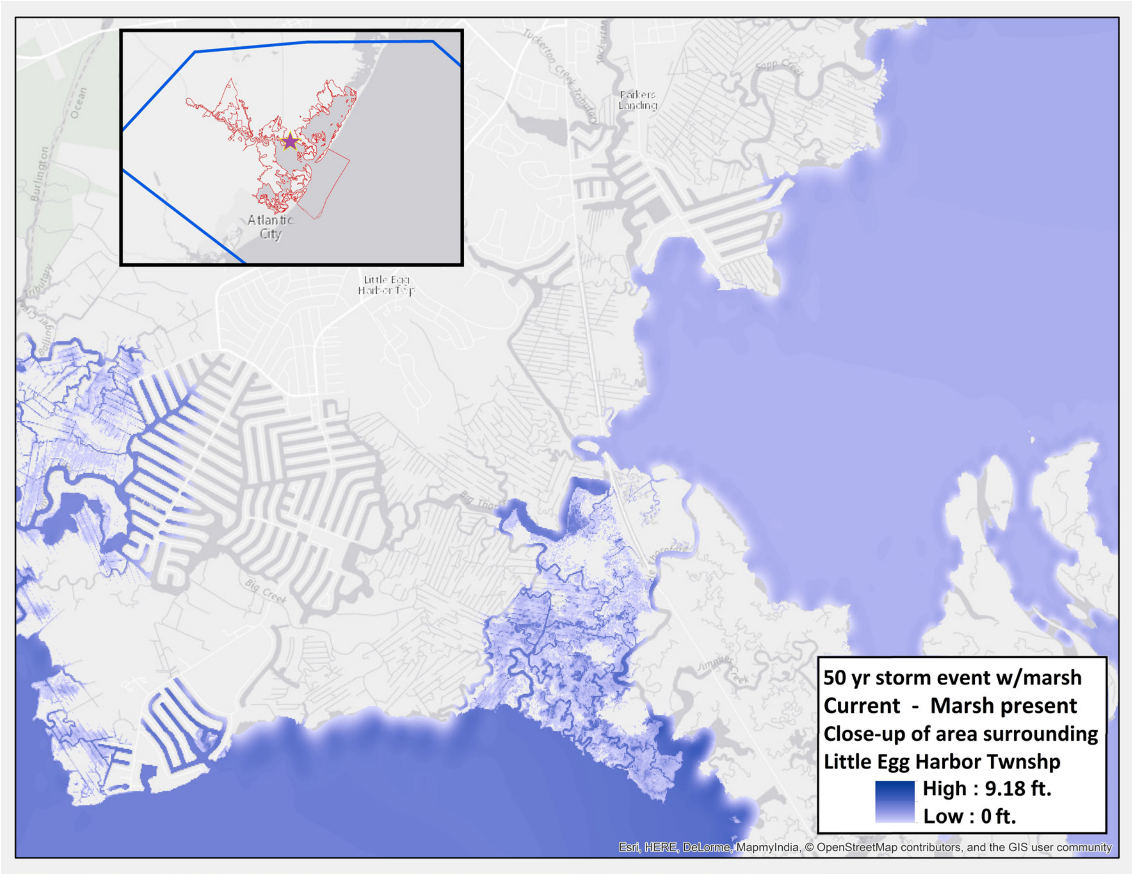

Figure D-9. 50-year storm event flood depth (ft) under current conditions/marsh present: Little Egg Harbor Township.

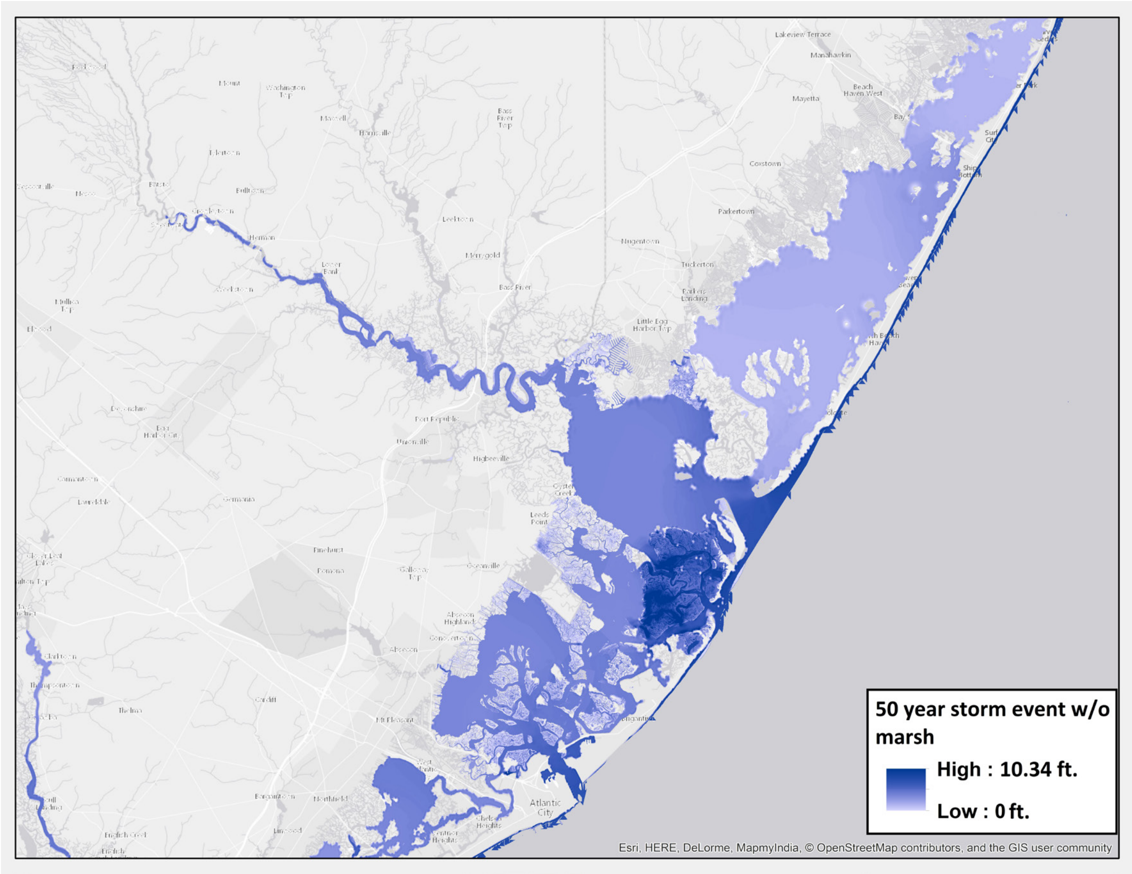

Figure D-10. 50-year storm event flood depth (ft) under current conditions/marsh absent.

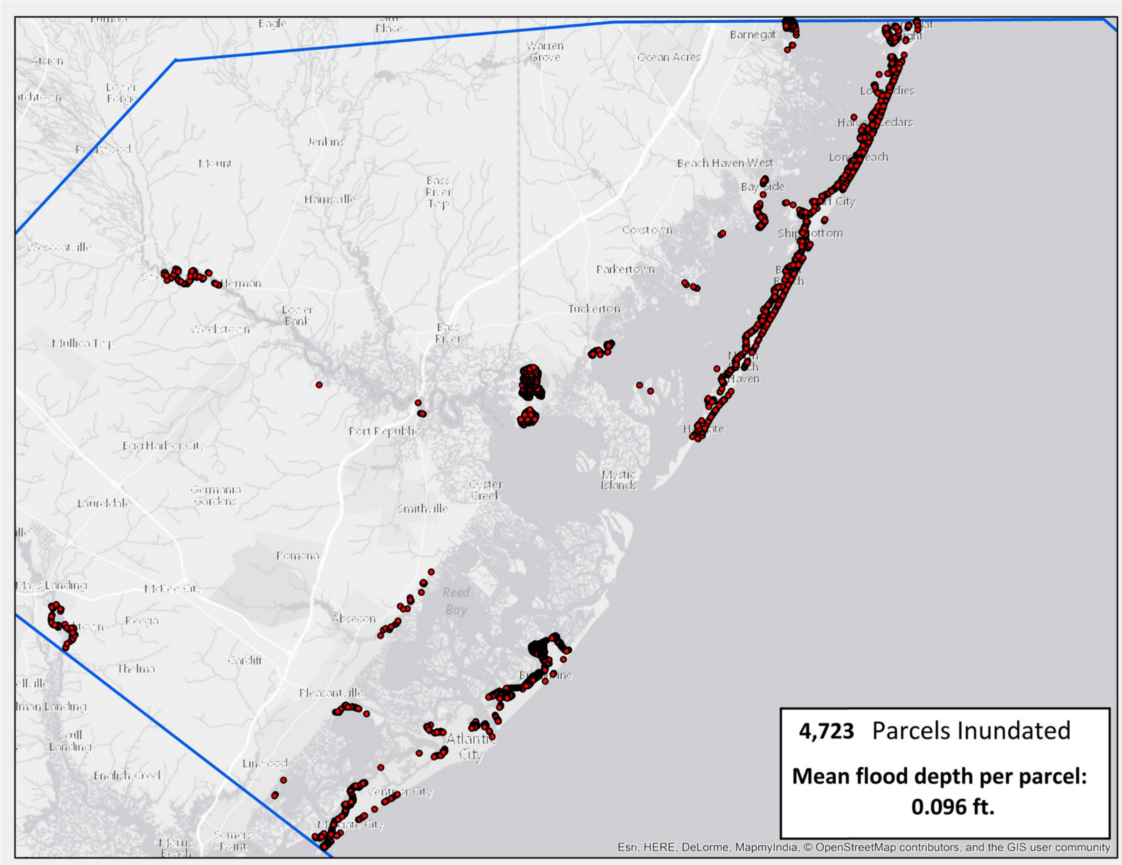

Figure D-11. 50-year storm event number of parcels inundated and mean flood depth per parcel under current conditions/marsh absent.

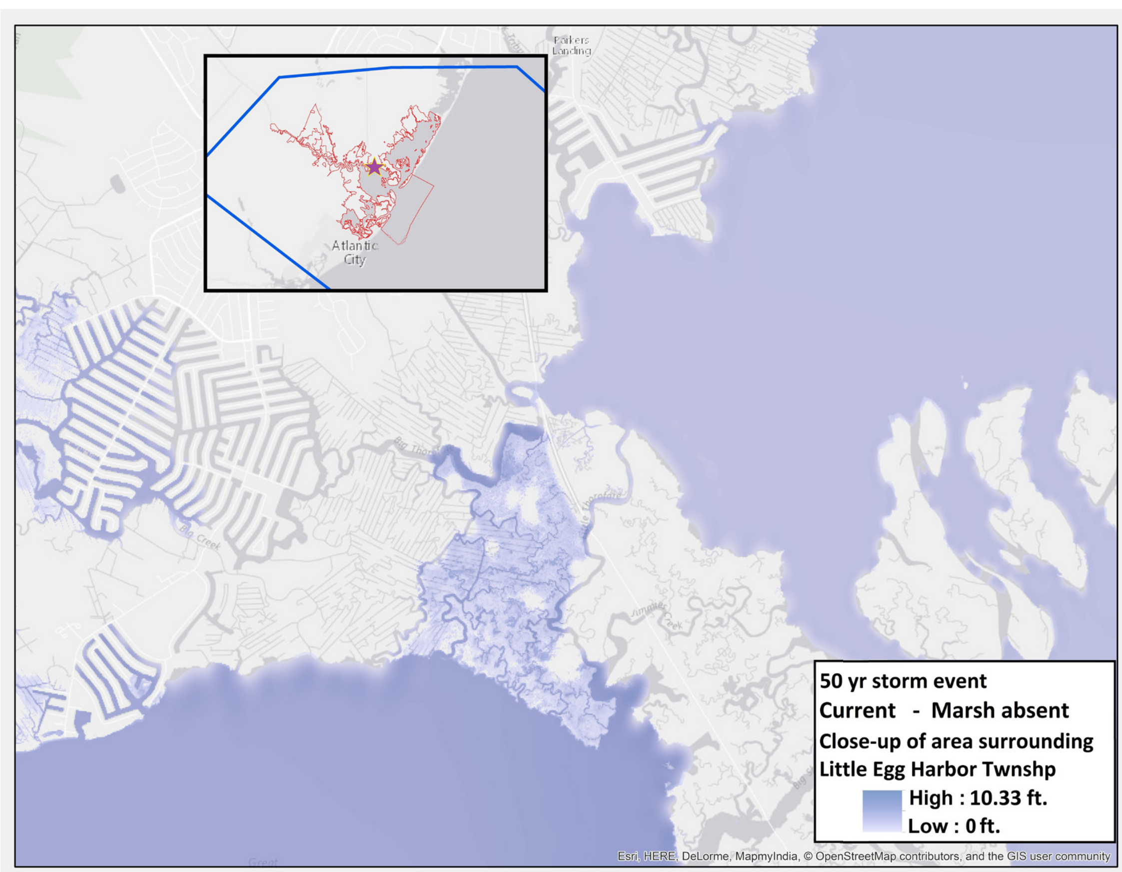

Figure D-12. 50-year storm event flood depth (ft) under current conditions/marsh absent: Little Egg Harbor Township.

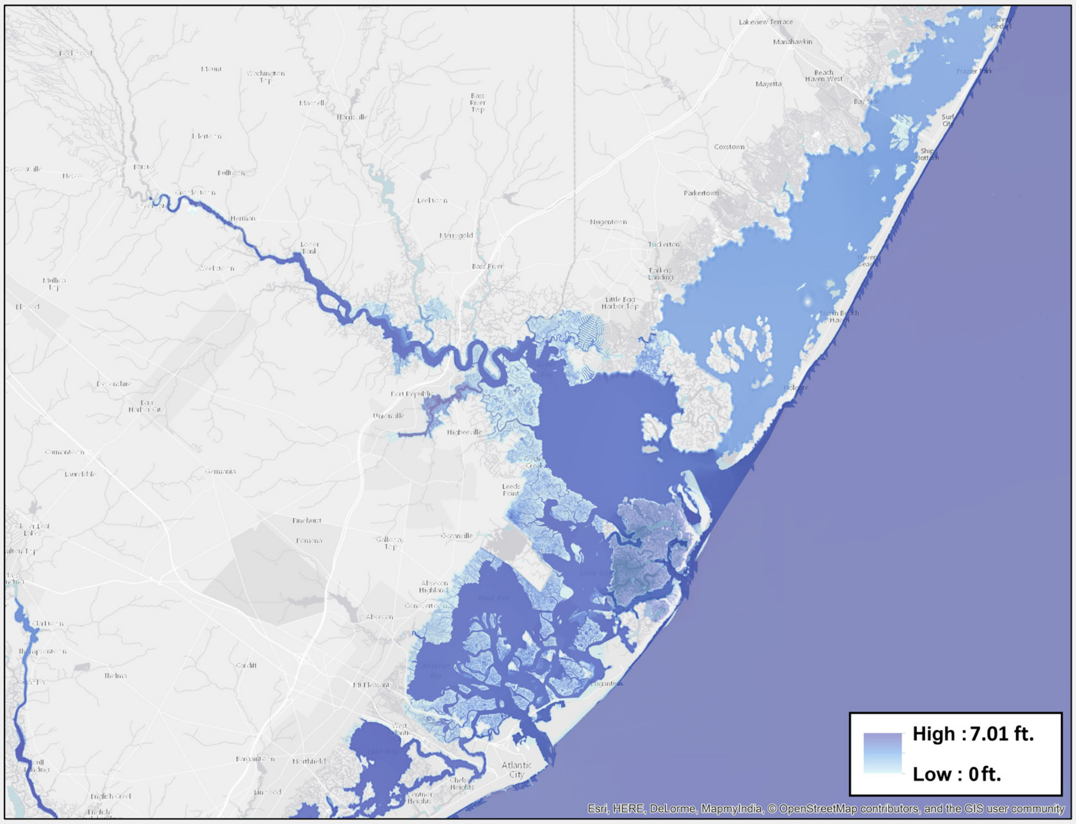

Figure D-13. 25-year storm event flood depth (ft) under 2050 conditions/marsh present.

D.2. 2050 CONDITIONS RESULTS FOR 25-YEAR AND 50-YEAR STORM EVENTS

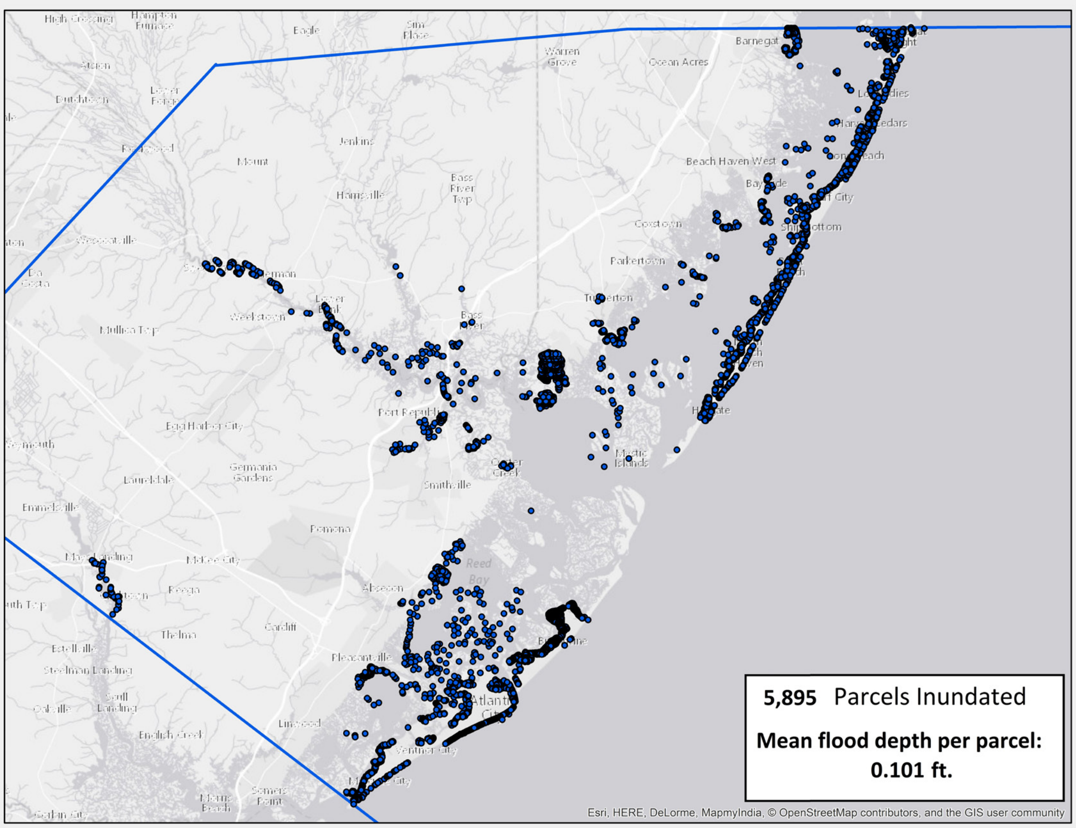

Figure D-14. 25-year storm event number of parcels inundated and mean flood depth per parcel under 2050 conditions/marsh present.

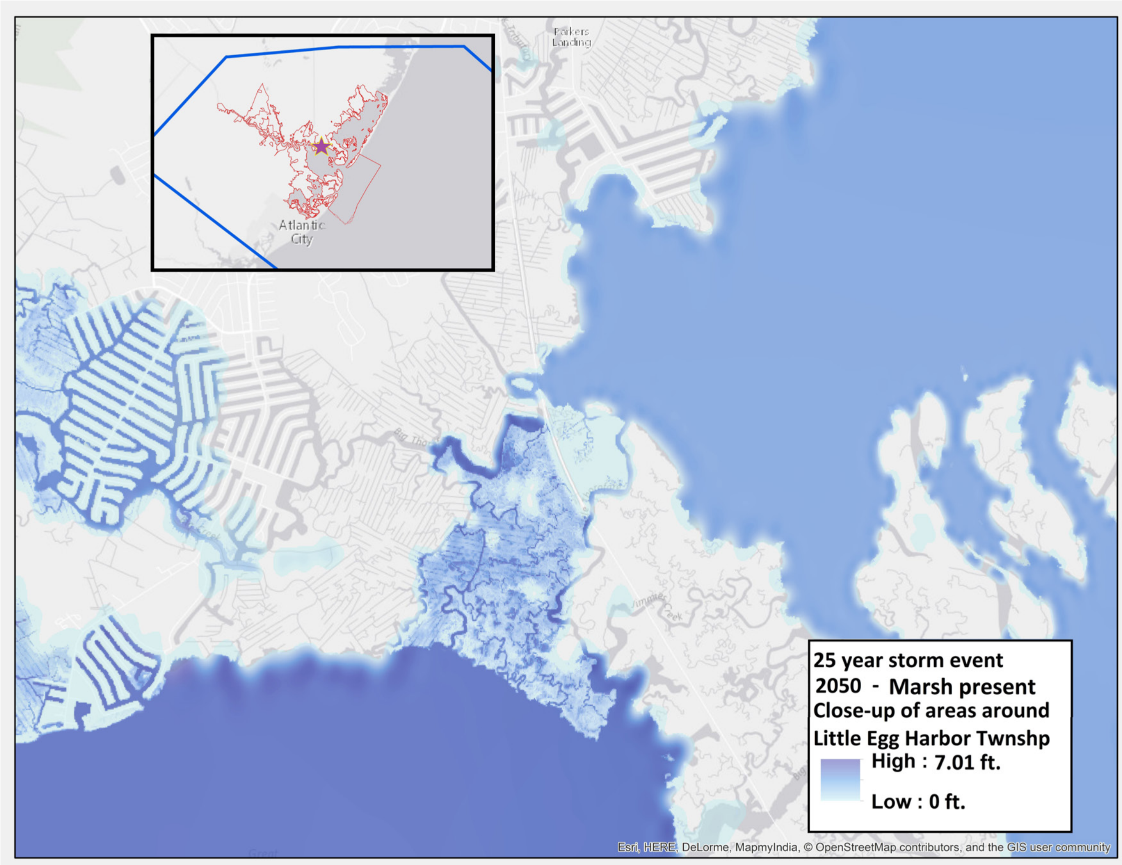

Figure D-15. 25-year storm event flood depth (ft) under 2050 conditions/marsh present: Little Egg Harbor Township.

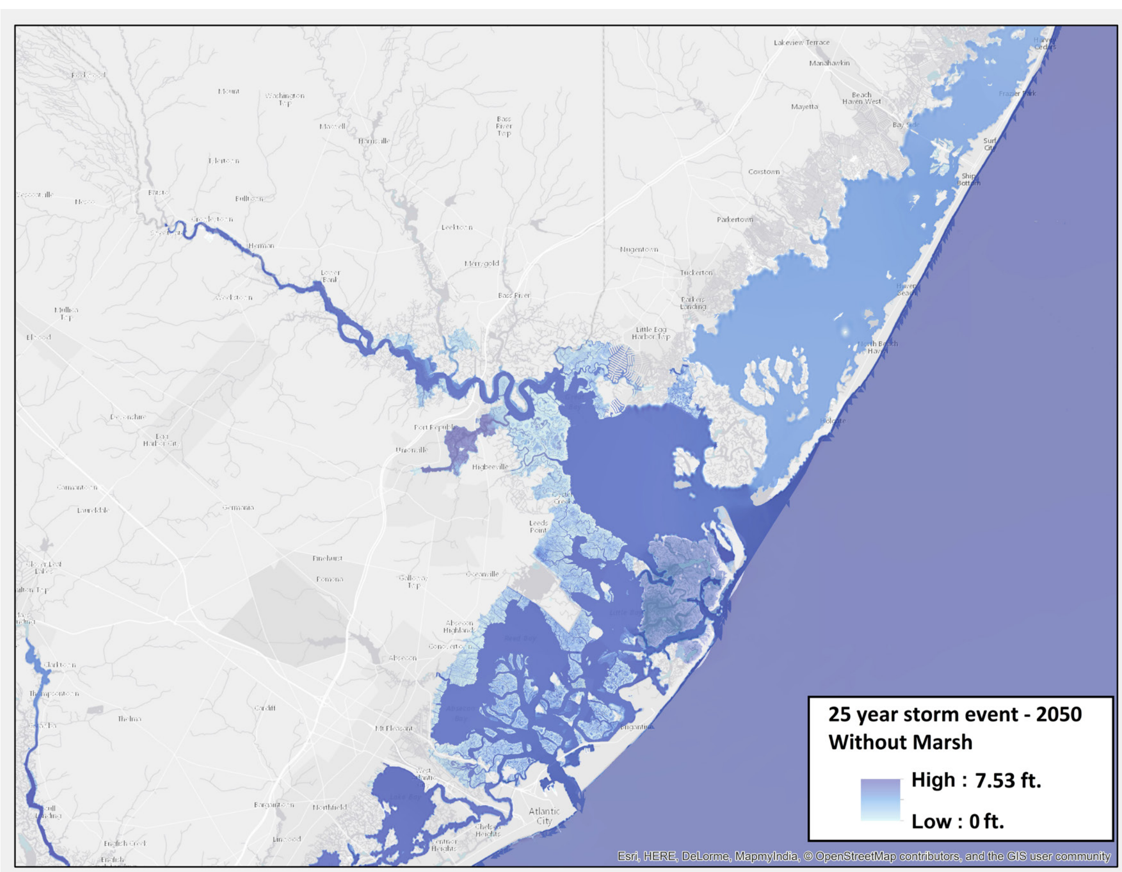

Figure D-16. 25-year storm event flood depth (ft) under 2050 conditions/marsh absent.

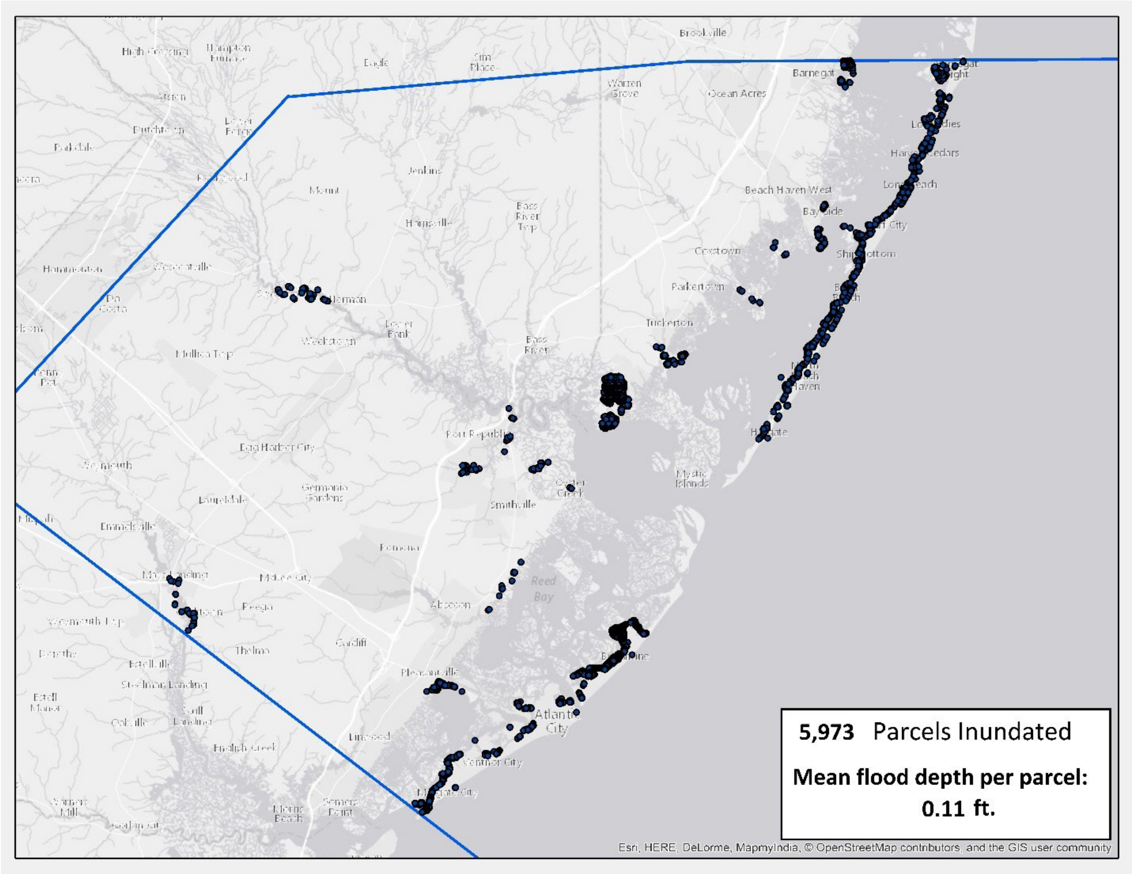

Figure D-17. 25-year storm event number of parcels inundated and mean flood depth per parcel under 2050 conditions/marsh absent.

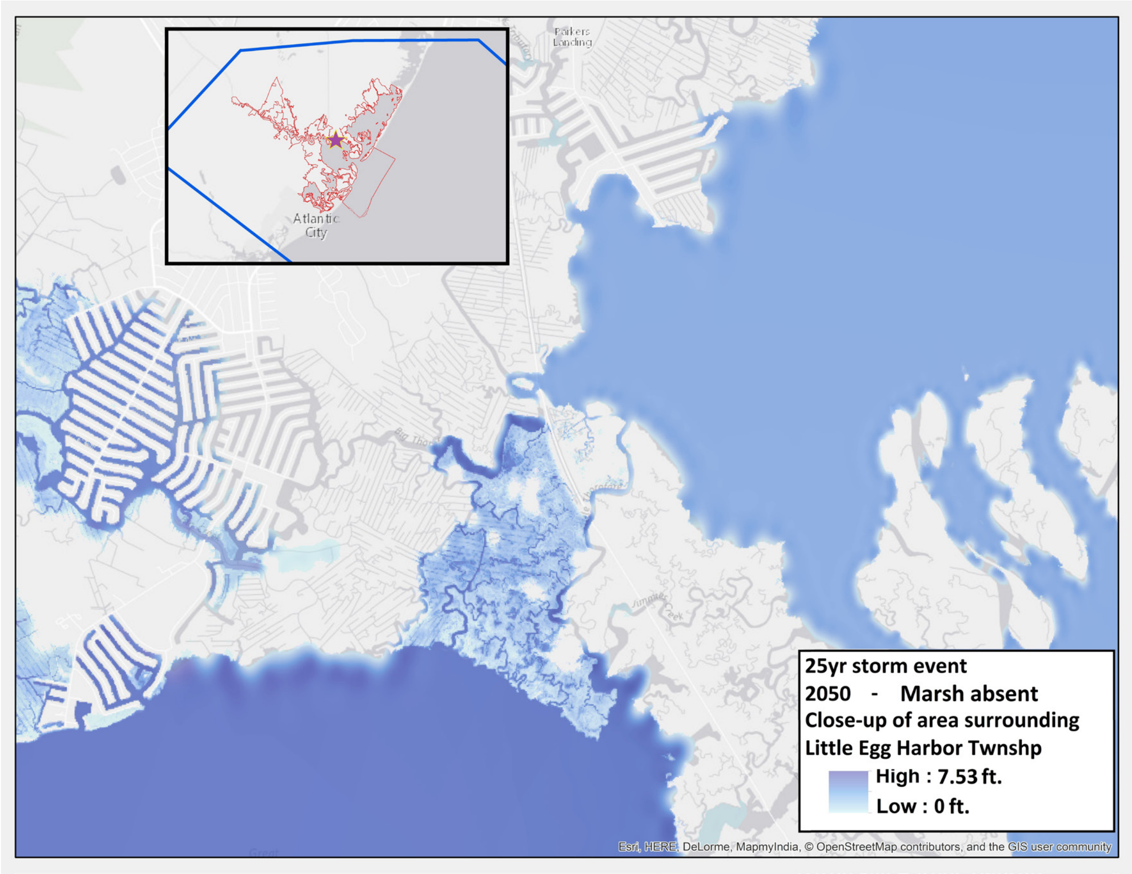

Figure D-18. 25-year storm event flood depth (ft) under 2050 conditions/marsh absent: Little Egg Harbor Township.

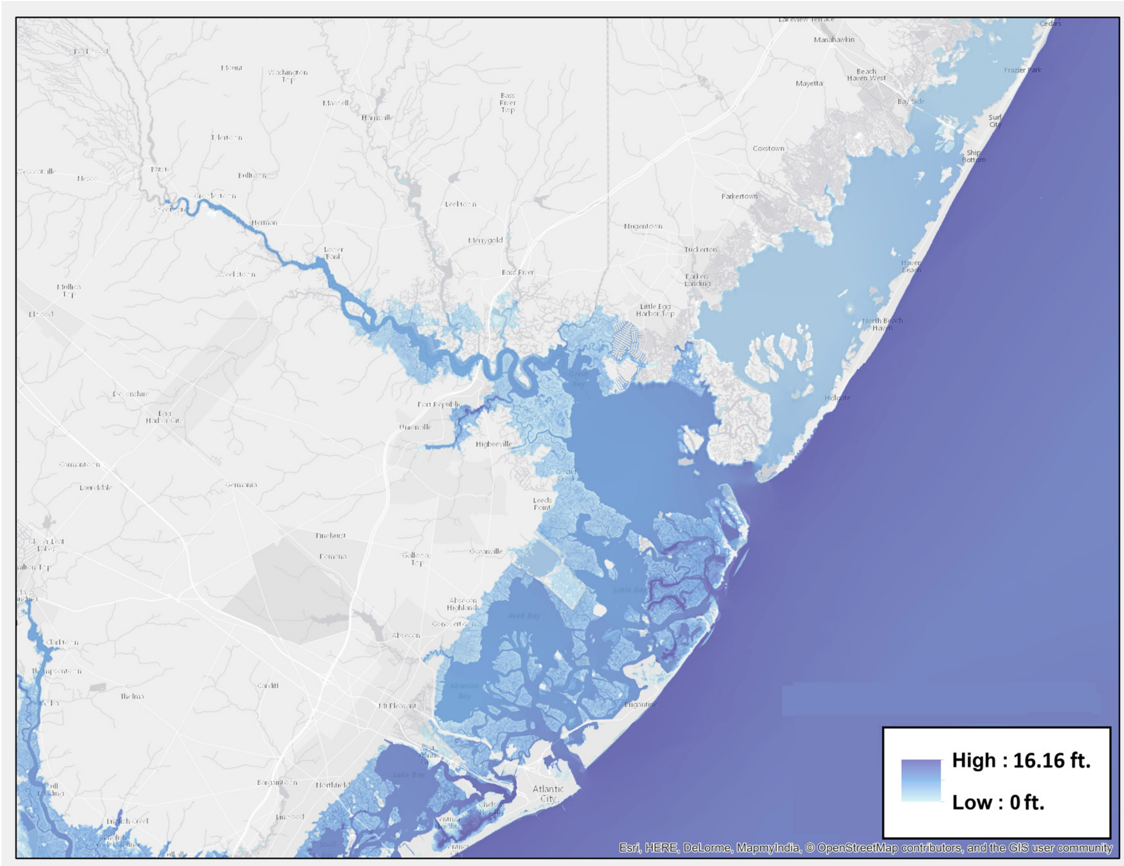

Figure D-19. 50-year storm event flood depth (ft) under 2050 conditions/marsh present.

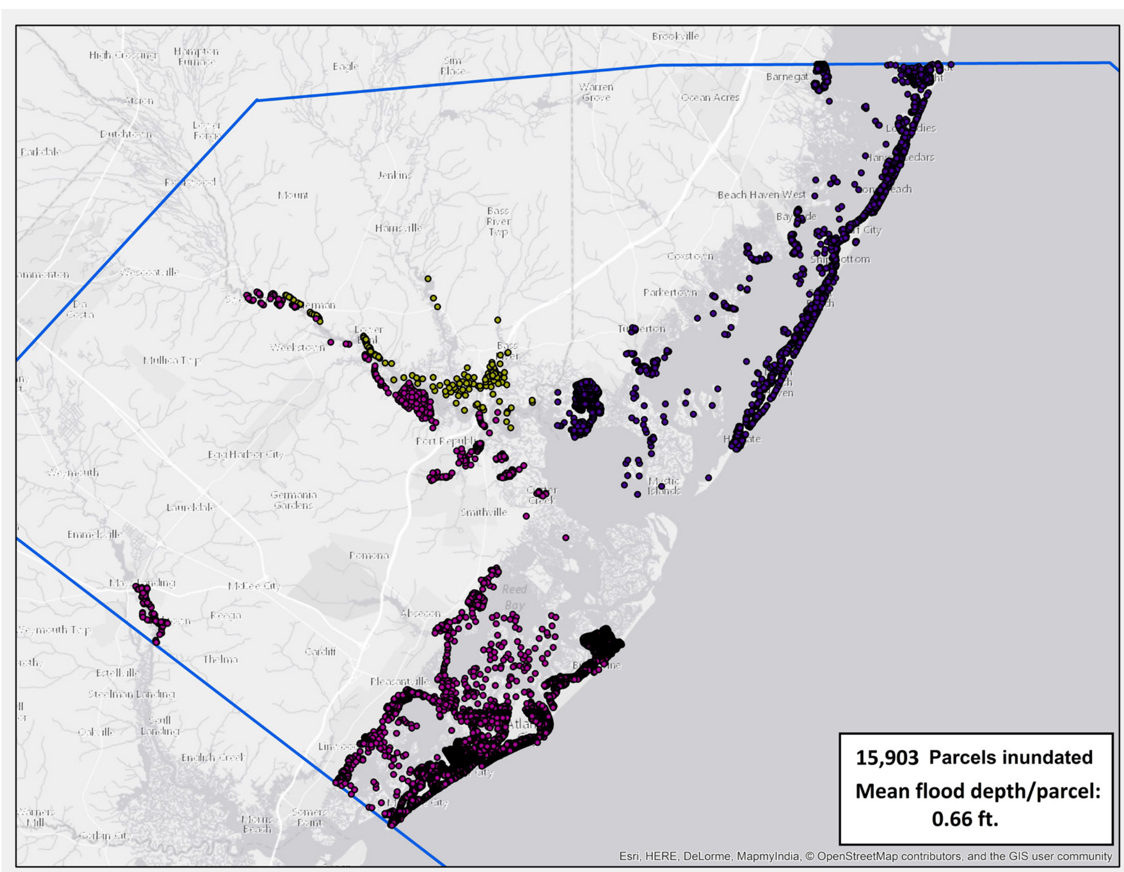

Figure D-20. 50-year storm event number of parcels inundated and mean flood depth per parcel under 2050 conditions/marsh present.

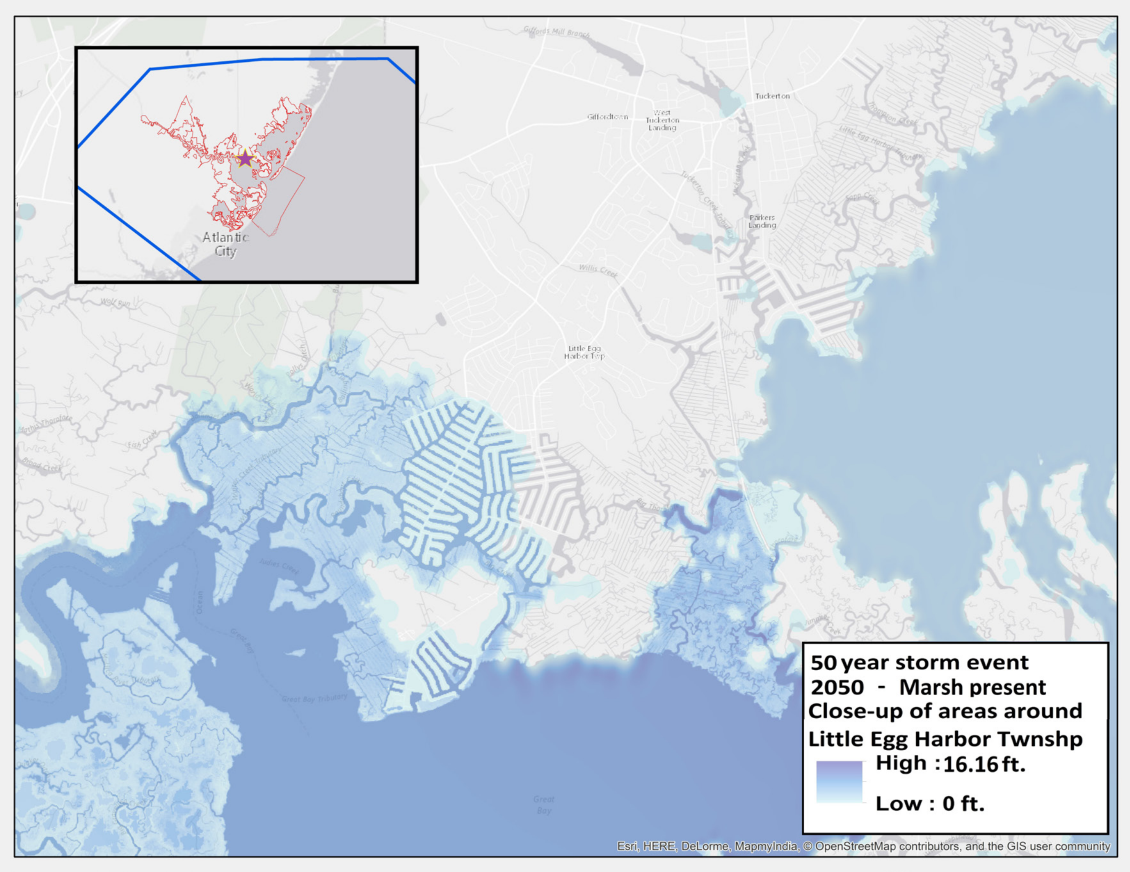

Figure D-21. 50-year storm event flood depth (ft) under 2050 conditions/marsh present: Little Egg Harbor Township.

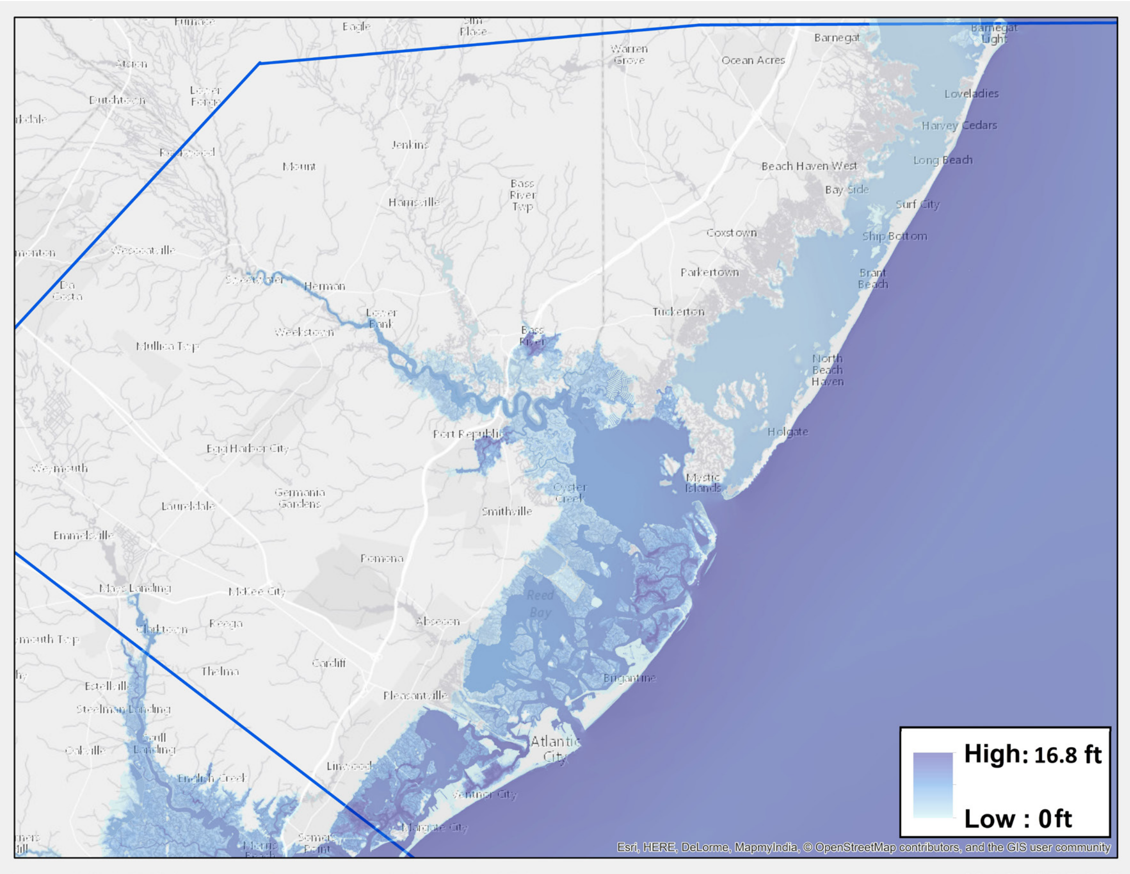

Figure D-22. 50-year storm event flood depth (ft) under 2050 conditions/marsh absent.

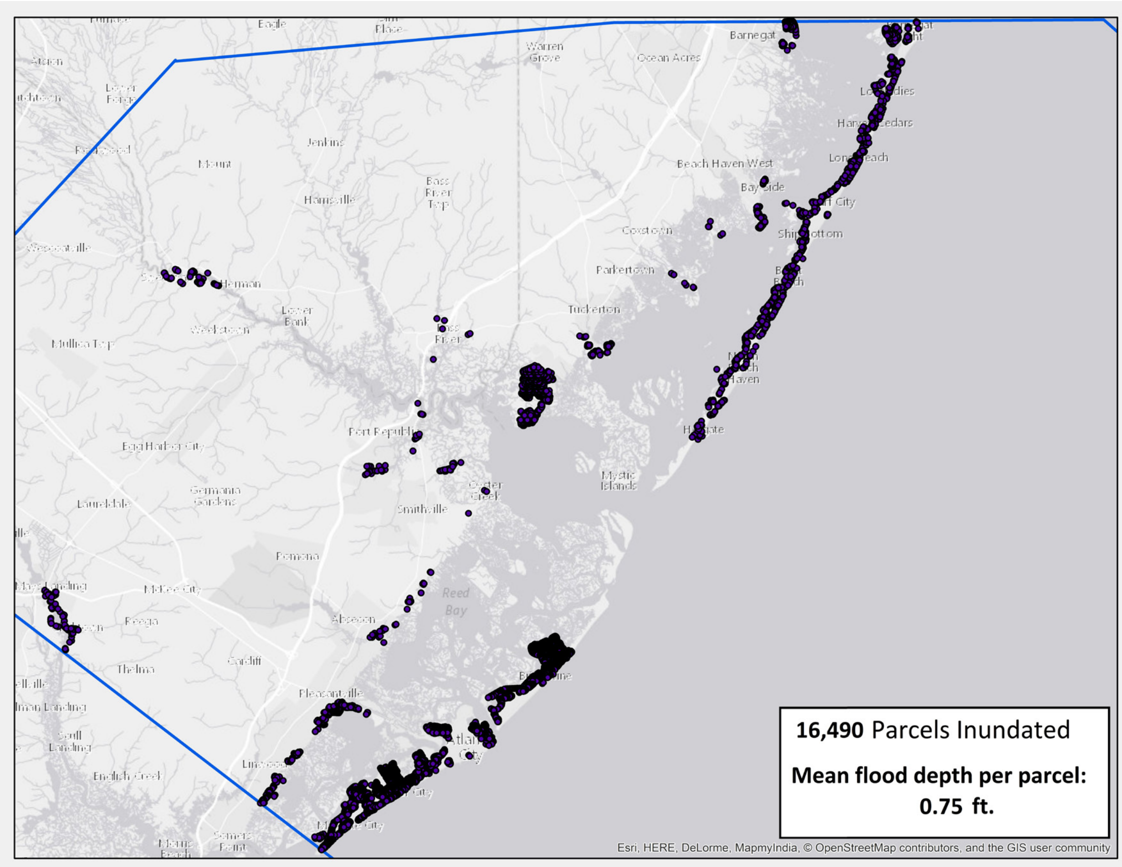

Figure D-23. 50-year storm event number of parcels inundated and mean flood depth per parcel under 2050 conditions/marsh absent.

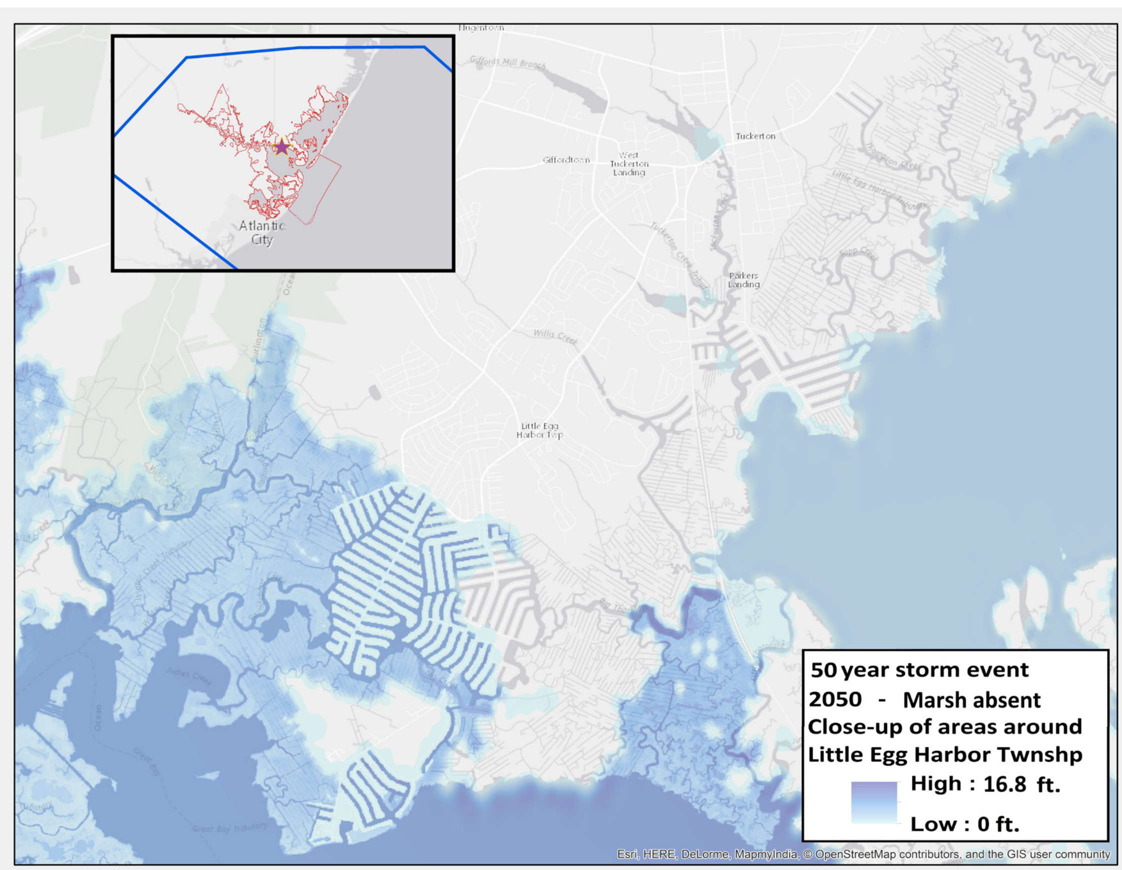

Figure D-24. 50-year storm event flood depth (ft) under 2050 conditions/marsh absent: Little Egg Harbor Township.

U.S. Department of Commerce

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National Oceanic and Atmospheric Administration

Benjamin Friedman, *Deputy Under Secretary for Operations and Acting Administrator*

National Ocean Service

Russell Callender, *Assistant Administrator*

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Economic Valuation of Shoreline Protection within the Jacques Cousteau National Estuarine Research Reserve

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