New Jersey's Coastal Community Vulnerability Assessment and Mapping Protocol

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Office of Coastal Management

New Jersey Department of Environmental Protection

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Foreword

New Jersey is truly a coastal state, encompassing 127 miles of Atlantic coastline and nearly 1,800 miles of estuarine shoreline. The coastal zone is comprised of multiple shoreline types, including spits, headlands, high-energy barrier island systems, mixed-energy barrier island systems, and bays, all of which sustain habitat and wildlife, support viable maritime and tourism industries, and harbor a way of life for many New Jersey residents. Approximately 1.8 million people live within the coastal counties of New Jersey.[1] These numbers drastically increase during the summer months as visitors travel from a wide region to enjoy the pleasures of the State's recreational resources and vacation destinations, supporting a $16 billion annual tourism industry.[2] The same resources and scenic views that support recreation and tourism provide a nursery for the State's $2.1 billion commercial fishing industry[3] and a $50 billion maritime industry.[4] While the coastal zone is a financial engine for the State, it also provides critical habitat for endangered and threatened species, serves as a host for migratory birds, and sustains ecosystem services such as flood control and stormwater filtration. Unfortunately, much of New Jersey's coastal landscape is threatened by the impacts of episodic and chronic erosion, subsidence, shallow coastal flooding, nor'easters, tropical storms and hurricanes.

Historically, coastal communities have merely responded to the impacts of natural hazards. In recent decades, the federal government has proactively attempted to protect people and property from natural disasters by improving coastal construction standards, developing incentives to reduce flood losses, and requiring mitigation planning in order for local governments to obtain pre- and post-disaster mitigation funding. New Jersey has further strengthened floodplain construction standards by requiring all new development to be constructed two feet above base flood elevation. Despite federal and state efforts, coastal development continues to be sited in high hazard areas, increasing property damage losses and

May 2008 Nor'easter
Photo credit: Andrew King 2008,
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"People typically are unaware of the hazards they face, underestimate those of which they are aware, overestimate their ability to cope when disaster strikes, often blame others for their losses, underutilize pre-impact hazard strategies, and rely heavily on emergency relief when the need arises."

--Dennis S. Mileti,
  Disasters by Design, 1999

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[1] US Census Bureau. (2010).
[2] NJDEP: CMP. (2002).
[3] NOAA. (2006).
[4] NJDEP: CMP. (2002).

recovery costs for coastal communities. Since 1960, New Jersey coastal counties have experienced over $970 million in property damage and crop loss as a result of coastal storms and flooding.[5] Climate change threatens to exacerbate the impacts of coastal hazards by increasing the frequency and intensity of coastal storms, accelerating rates of sea level rise, increasing coastal erosion, and inundating low-lying portions of the shore.[6] As a result, more people, development, and natural resources will be vulnerable to the impacts of coastal hazards than in the past. While communities will have ample time to plan for increases in sea level, they will be challenged by stronger and more frequent coastal storms. Projections indicate that Atlantic City will likely be impacted by 100-year storms every 5 to 30 years,[7] and similar increases in storm patterns will likely occur in coastal regions throughout the state. Local decision-makers continue to have the greatest influence on their community's resiliency through land use planning and permitting, floodplain management, disaster preparedness, and public education. Unfortunately, few communities are aware of their existing vulnerabilities to coastal hazards, let alone, the potential impacts of climate change and sea level rise.

The ability of coastal communities to remain resilient to coastal hazards is rooted in understanding their potential exposure and vulnerabilities. However, there is currently a lack of clear guidance to assess existing and future hazard vulnerabilities on the local level. Existing all-hazard mitigation plans are typically developed on the county level and do not provide vulnerability assessments of cultural and historic properties, businesses, critical natural resources, or other features that are integral to a community's character, nor do they typically address the potential impacts of climate change. Without baseline information, it is difficult for communities to identify and implement hazard mitigation and climate adaptation strategies.

In September 2006, a "Summit Confronting Climate Change in New Jersey" was convened to examine the economic ramifications of global climate change, sea level rise, and coastal hazard impacts for the State of New Jersey and generate strategic policy options that the State should consider. One of the recommendations stemming from the Summit was the need to develop more accurate information to determine the degrees of vulnerability to coastal hazards in New Jersey's coastal communities. Recognizing that coastal decision-makers need access to resources, tools and science-based information, the New Jersey Coastal Management Program identified coastal hazards as a top priority area in its 2006-2011 Section 309 Strategy. Through the support of federal, state, and local partners, the New Jersey Office of Coastal Management developed the *Coastal Community Vulnerability Assessment and Mapping Protocol* and the *Getting to Resilience* questionnaire to help coastal decision-makers understand and address the full spectrum of factors that influence community resilience. These tools can be used to inform and improve state and local policies and regulations, spur interagency collaboration and educate the public on natural hazards in their community. By providing coastal communities with the criteria they need to assess their vulnerability and resilience to coastal hazards (ie. storm surge and sea level rise), they will have the necessary knowledge to guide their land use, hazard mitigation, emergency management, and conservation efforts in a more holistic and sustainable manner that considers both present and future conditions of the shore.

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[5] Hazards & Vulnerability Research Institute. (2011). Adjusted to 2011 dollars.
[6] U.S. Indian Ocean Tsunami Warning System Program. (2007).
[7] Cooper, M.J.P.; Beevers, M.D.; and M. Oppenheimer. (2005).

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FIGURES, MAPS, AND TABLES

How to Use this Document

This document is intended as a guide for entities interested in assessing their vulnerability to coastal hazards. Coastal vulnerability is a complex topic that requires an understanding of some basic terms, concepts, and historical context to be effectively assessed. This document will navigate through these steps in the following way:

1   Explanation of basic definitions and relevant concepts on hazards that face our coastal areas

2   Explanation of the Assessment Tools developed by the New Jersey Office of Coastal Management

3   The Coastal Community Vulnerability and Mapping Protocol is presented in a 'Cookbook' format that will introduce publically available data and walk the user through the steps to create a Coastal Vulnerability Index (CVI) for their area of interest. Vulnerability can be assessed by overlaying built environment, natural environment, and social vulnerability data over the CVI

Definitions

Risk is the probability of harmful consequences or expected losses (death and injury, losses of property and livelihood, economic disruption, or environmental damage) resulting from interactions between natural or human-induced hazards and vulnerable conditions.[8] Risk from coastal hazards is characterized by the frequency of occurrence and severity of a hazard.[9]

Vulnerability is the degree of exposure and inability of a human or natural system to cope with the effects of a natural hazard, including changing variability and extremes in weather and climate.

Resilience is the capacity of a system, community, or society potentially exposed to hazards to adapt, by resisting or changing, in order to reach and maintain an acceptable level of functioning and structure.[10]
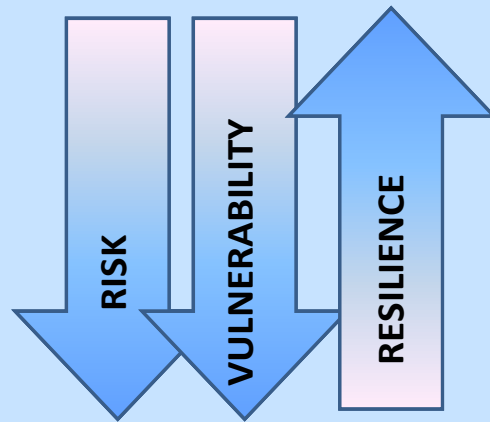
Resilience has an inverse relationship with risk and vulnerability. In a resilient system, change has the potential to create opportunity for development, novelty, and innovation. While in a vulnerable system, even small changes may be devastating. To build coastal community resilience to both chronic and episodic coastal hazards, linkages between community development, coastal management, and disaster management activities are needed. These linkages need to be explicit and driven by community members themselves, working in concert with national and local government programs and NGOs. Community-based planning and assessment of coastal hazards and risks is a fundamental first step in building coastal community resilience. Coastal communities can then take deliberate actions to avoid disaster through improved planning, mitigation, and recovery procedures. Such mitigation and adaptation measures are critical to build resilience and should continuously be updated and improved upon by lessons learned from past hazard events and projections of future hazard scenarios.[11]

Hazard Mitigation is sustained action taken to reduce or eliminate the long-term risk to human life and property from natural hazards and their effects. Mitigation focuses on breaking the cycle of disaster damage, reconstruction, and repeated damage, creating safer communities, and reducing loss of life and property.[12]

Climate Adaptation is the adjustment of natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.[13]

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[8] Subcommittee on Disaster Reduction. (2005).
[9] US Indian Ocean Tsunami Warning System Program. (2007).
[10] Subcommittee on Disaster Reduction. (2005).
[11] US Indian Ocean Tsunami Warning System. (2007). p 3-8
[12] FEMA. http://www.fema.gov/about/divisions/mitigation.shtm
[13] IPPC. (2007).

Coastal Hazards

New Jersey coastal communities are susceptible to numerous types of coastal hazards, including erosion, coastal storms, and flooding. Despite this susceptibility, people and businesses continue to locate along the shore. Often times, they are unaware of the potential hazards that they face both structurally and financially. Because coastal communities are highly vulnerable to coastal processes and hazards, coastal decision-makers should understand the risks and deter future development and redevelopment away from high hazard areas.

Erosion is one of the most common and persistent hazards along the Jersey shore. Wind, currents, and waves are the main contributors to erosion. While most communities have identified mitigation options to reduce the rate of erosion, some portions of the shore have been lost due to persistent erosion that was not amicable to shore protection methods. Coastal erosion is typically exacerbated by episodic **storm events**, including tropical storms, hurricanes, and nor'easters. Tropical events typically occur between the months of May and November,

Map 2: Historic Shorelines Near Cape May Point

while nor'easters occur during the winter months. Coastal storms are commonly associated with high levels of rainfall, high winds, high seas, and are known to produce powerful storm surges that result in flooding and property loss. Unlike tropical storms and hurricanes, which are typically fast moving storms, nor'easters generally move slowly, tend to stall and cause coastal and riverine flooding over a longer duration than a fast moving tropical storm. **Tides and winds** can heighten the impacts of coastal storms. Barnegat Bay and other semi-enclosed bays are prone to back-bay flooding during storm events because high winds and narrow inlets trap upland rainfall and tidal waters in the bay. Such flooding can overwash barrier islands and spits from both the back bay and ocean, creating new inlets and damaging properties. Normal, episodic spring tides can also cause shallow coastal flooding. Because the Jersey shore is highly developed, coastal flooding not only threatens lives and private property, it threatens roads and bridges, stormwater infrastructure, utilities, and businesses. Understanding inundation patterns in one's community can inform the location or relocation of critical infrastructure, inform evacuation procedures, and guide post-disaster redevelopment.

Map 1: Historic Storm Tracks, 1850-2008

Global climate change is expected to increase the rate of sea level rise resulting in increased saltwater intrusion into coastal aquifers, increase levels of land-based pollutants into coastal waters, and more powerful El Nino and La Nina events.[14] As a result, more people, property, infrastructure, habitat and wildlife will be exposed to coastal hazards than in the past. Due to local geologic factors, including subsidence, depleted sedimentation, and glacial isostatic adjustment, New Jersey already experiences higher than average rates of sea level rise in comparison to global averages. Long-term tide gauge data indicates that the New Jersey coastal zone has experienced sea level rise rates of 3.90 to 4.05 mm/year since the beginning of the twentieth century.[15] If this trend were extrapolated into the future without considering accelerated rates of sea level rise due to global climate change, the New Jersey shore could experience approximately 0.4 meters (1.3 feet) of sea level rise over the next century, nearly twice global averages. But projections indicate

Figure 1: Atlantic City's Sea Level Rise Trend
Source: NOAA. 2011. Sea Level Rise Trends

that the seas will vertically rise 0.5 to 1.5 meters (~1.6 to 4.9 feet) by 2100 as a result of increased global temperatures, thermal expansion of water, glacial and Arctic ice sheet melting, and localized conditions.[16] Researchers from Rutgers University and the New Jersey Geological Survey agree that sea level rise along the East Coast will exceed 1 meter (~3 feet) by 2100.[17] As climate change alters the natural processes of the New Jersey shore, coastal communities will likely experience more regular shallow coastal flooding events, greater rates of salinity intrusion into freshwater resources, changes in and loss of critical habitat, and more intense and frequent coastal storms. Additionally, the life expectancy of coastal engineering projects will decrease, the cost of shoreline stabilization will increase, making coastal resource protection harder to achieve.[18]

Because climate change is expected to accelerate overtime, little change will be visible on a year to year basis, making it difficult to make the case to plan for changing coastal conditions. However, as time goes on, the cumulative increase in sea level will become evident. Multiple studies have been undertaken to identify the threat of accelerated sea level rise and exacerbated coastal storms to the Jersey shore.[19] These studies have been effective in providing insight on potential changes in flooding and habitat, but comprehensive hazard and vulnerability assessments have not been performed on the county or municipal scale. The assessment tools identified in this document are intended to provide guidance on how to perform local assessments and take steps to improve resilience to existing and future hazard conditions.

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[14] US Indian Ocean Tsunami Warning System Program. (2007).
[15] NOAA. (2011).
[16] PDE. (2010); Najjar, R., Patterson, L., and S. Graham. (2009); Ramstorf, S. (2007).
[17] Miller, K., Sugarman, P.J., and J.V. Browning. (2011).
[18] Hayes, M. (2004).
[19] PDE. (2010); Lathrop, R. G. and A. Love. (2007); Cooper, M. J.P., Beevers, M. D., and M. Oppenheimer. (2005).

Vulnerability and Resilience Assessment Tools

To help assess their vulnerability and resilience to coastal hazards, coastal decision-makers need access to resources, tools and science-based information. The New Jersey Office of Coastal Management (NJOCM) incorporated elements from numerous tools, guidebooks, and training courses to develop two assessment tools to ensure that coastal communities have consistent and comprehensive guidance to assess their vulnerability and capacity for resilience. The *Coastal Community Vulnerability Assessment and Mapping Protocol* (CCVAMP) was developed to guide communities through the development of a geospatial vulnerability assessment, while the *Getting to Resilience*[20]*(GTR)* questionnaire was assembled to assist local decision-makers review and characterize their existing planning, response and recovery efforts to identify opportunities to support community resilience. These tools provide a consistent means to identify and assess the potential impacts of coastal storms and sea level rise throughout coastal regions of the state; which can then inform local and regional planning, hazard mitigation, and emergency management efforts.

The NJOCM strategically approached the development of vulnerability and resilience assessment tools so they are not only useful for identifying potential exposure to flooding and storm threats, but could identify ways to incorporate hazard mitigation and climate adaptation measures into existing programs and plans, such as local ordinances, master plans, evacuation procedures, and all-hazard mitigation plans.   In order to do so, the NJOCM suggests that the *CCVAMP* and the *GTR* questionnaire be used together to ensure that local decision-makers discover the full spectrum of factors that contribute to their community's resilience. Because coastal communities vary in size and capacity, communities may approach the execution of the vulnerability and resilience assessments in different manners. Some communities may have the staff and the technical capabilities to generate a vulnerability assessment, while others may choose to contract a consultant. While the capabilities of the communities may vary, the NJOCM recommends that the assessments involve the participation of representatives from local government sectors, special interest groups (i.e. business sector and conservation organizations) and the public. By involving a broad group of people in the assessment process, the community will build support around the team's findings and recommendations. Coastal communities should seek partnerships to obtain technical or facilitation assistance. Results of the assessments can be incorporated into all-hazard mitigation plans or climate adaptation plans and may help communities earn Sustainable Jersey™ points and identify ways to improve their Community Rating System scores.

The methodology outlined in this report is intended to allow its users to identify their existing and future hazard exposure, in addition to the types of factors that a community should consider when embarking on a vulnerability assessment. While the *Coastal Community Vulnerability Assessment and Mapping Protocol* and the *Getting to Resilience* questionnaire are intended to be used together, the vulnerability mapping methodology can be used to assess vulnerability at varying scales, such as the county, watershed, or regional scale. The mapping methodology was first piloted on a regional level along the Delaware Bay to ensure its scalability. The NJOCM then piloted the vulnerability assessment tool and *GTR* in communities along the Jersey shore.

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[20] NJDEP. NJOCM. (2011a).

Coastal Community Vulnerability Assessment and Mapping Protocol

Community resilience is highly dependent upon the location of development in relation to high hazard areas. In order for local governments to take proactive measures to adapt, mitigate, and plan for episodic events or long-term changes in the shoreline, they must first be aware of the hazards they face and the potential exposure of people, property, and resources. As maps are one of the best means to convey information to decision makers, the NJOCM developed the *Coastal Community Vulnerability Assessment and Mapping Protocol* (CCVAMP) to assist land use planners, hazard mitigation planners, emergency managers, and other local decision-makers in the identification of their community's vulnerability to coastal hazards. The *CCVAMP* defines the necessary steps to geospatially identify vulnerable land areas under present and future inundation scenarios, whether it be shallow coastal flooding due to spring tides, storm surge, or sea level rise.
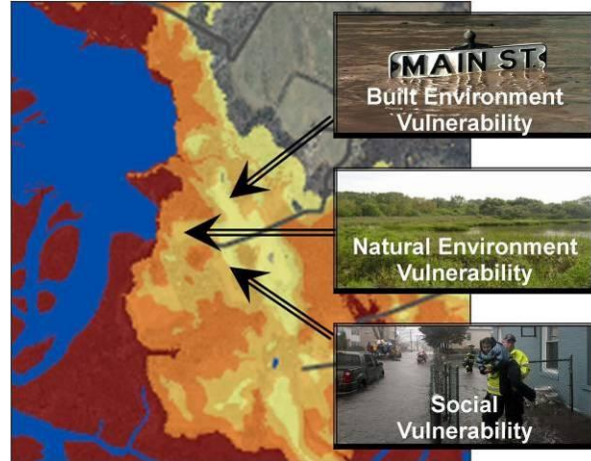
Figure 2: Coastal Community Vulnerability Assessment Protocol

Through the development of inundation scenarios, coastal decision-makers can then determine threats to built infrastructure, sensitive natural resources, and special needs populations. The first step in the analysis is the development of a Coastal Vulnerability Index (CVI), which stratifies high hazard areas in coastal communities by compiling available hazard, elevation, and landscape geospatial data into an environmental constraint model. Armed with the understanding of areas naturally predisposed to risk, coastal decision-makers may guide future development away from high hazard areas and mitigate future losses. The vulnerability assessment methodology is based on numerous risk and vulnerability assessment methodologies,[21] including, but not limited to, NOAA Coastal Services Center's *Roadmap to Adapting to Coastal Risk* and *Inundation Mapping Guidebook.*

Prior to pursuing the development of inundation and vulnerability maps, community leaders should work with a group of engaged decision-makers, special interest groups, and the public to define an acceptable level of risk to various hazard scenarios. While it is suggested that a community develop multiple inundation scenarios to understand the full breadth of their vulnerability, some communities may choose to only assess past hazard scenarios. Other communities may choose to comprehensively assess past storm and future inundation scenarios and local vulnerabilities. After completing a risk and vulnerability assessment, it is recommended that community leaders share the available information as a means to inform community planning, mitigation, response, and recovery strategies.

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[21] Cutter, S.L. (2008). Cutter, S.L.; Mitchell, J.T.; and M.S. Scott. (2000; 1997). NOAA: CSC. (2010b; 1999); PSDS. (2001). Thieler, E.R and E.S Hammar-Klose (1999); Lennon et al (1996); Gornitz, V. M., Daniels, R. C., White, T. W., and Birdwell, K. R. (1994).

Getting to Resilience

Getting to Resilience (GTR) is a facilitated questionnaire that was developed as a non-regulatory tool to assist local decision-makers in the collaborative identification of planning, mitigation, and adaptation opportunities to reduce vulnerability to coastal storms, flooding and sea level rise, thus building capacity for coastal community resilience. As noted previously the *Getting to Resilience Questionnaire* was envisioned to work in conjunction with the mapped information provided through the CVI and CCVAMP initiative. The questionnaire incorporates the key components of existing local government evaluation tools, developed by academics, international and federal agencies, and planning practitioners to improve community resilience to natural hazards, including, but not limited to, elements from the National Flood Insurance Program's *Community Rating System* and the MS/AL Sea Grant's *Community Resilience Index*. While this questionnaire incorporates many concepts and questions from existing tools, it is not intended to grade the resiliency of a community. It is however intended to start a dialogue among various decision-makers, spawning creative thinking and collaboration between plans and on ways for their community to become more resilient for existing and future generations.

The questionnaire highlights the importance of local plan integration and consistency with municipal building codes, ordinances and zoning to seamlessly support flood protection efforts.

The questionnaire is divided into five sections:

(1) Risk and Vulnerability Assessments,
(2) Public Engagement,
(3) Planning Integration,
(4) Disaster Preparedness and Recovery, and
(5) Hazard Mitigation Implementation.

In order to initiate information sharing and spawn collaborative decision-making, the facilitation of the questionnaire should include but not be limited to, elected and appointed officials, land use planners, hazard mitigation planners, floodplain managers, emergency managers, stormwater engineers, and natural resource planners. The *Getting to Resilience* questionnaire should be facilitated in a roundtable discussion and commence with a review of

Figure 3: Getting to Resilience Questionnaire

available vulnerability assessments and/or the results of CCVAMP. Participants will then be fully aware of the hazards their community faces when assessing its resilience.

While this document does not include the *Getting to Resilience* questionnaire, it can be obtained by contacting the New Jersey Office of Coastal Management.

Coastal Community Vulnerability Assessment and Mapping Protocol: *Cookbook Approach*

The NJOCM is presenting this document in a 'cookbook format' to help guide the assemblage of the data layers and development of maps and assessment tools. The following sections will outline the data required to perform the CCVAMP and give a few example maps. A detailed methodology (Cookbook) for creating your own Coastal Vulnerability Index, Assessment and Maps can be found in Appendix A: Building a Coastal Vulnerability Assessment: A Technical Guidance. Each section is hyperlinked to the appropriate 'mapping protocol' in Appendix A.

The *CCVAMP* is designed to help coastal communities navigate the process to generate a geospatial hazard and vulnerability assessment. The maps generated by a hazard assessment can increase awareness of vulnerable infrastructure, environmental resources, and populations that lie in high hazard areas, providing decision-makers with the information to adapt, mitigate, and plan for response and recovery to current risks and future hazard scenarios. *CCVAMP* is a two-part mapping process that requires the development of hazard maps and the identification of vulnerable community assets, natural resources, and people. This document attempts to define some of the mapping procedures that a community should pursue when developing a hazard and vulnerability assessment.

What Does It Take to Develop a Geospatial Coastal Vulnerability Assessment?
- Expertise: Geographic Information Systems Specialist with raster modeling capabilities
- Software: ArcGIS 9.2 or higher and Spatial Analyst Extension
- Computer: High performance computer, especially for large scale assessments
- GIS Data: Geospatial data representing community assets, natural resources, and social vulnerable populations, some of which sources are noted throughout this document

Prior to developing new hazard maps, a community should identify if there are existing maps and/or assessment available through the state or the county. In many cases, storm surge maps are available from the State Office of Emergency Management or a county emergency management office, and floodplain maps are available within each municipality. While these maps typically do not provide the necessary level of detail to perform a local vulnerability assessment, some communities may solely have to rely upon such maps due to a lack of GIS staff or consultants. For those communities that do have GIS mapping capabilities, they should consider pursuing the development of multiple inundation scenarios, including spring tide, storm surge, and sea level rise. They should also consider the development of a coastal vulnerability index or environmental constraint model to geospatially identify land areas that are susceptible to multiple hazard scenarios. A community can then assess the potential hazard exposure of infrastructure and development, natural resources and environmental concerns, and vulnerable sectors of the population. The following sections of this document will define suggested mapping methodologies to follow when developing a risk and vulnerability assessment.

Publically Available Data & Tools

The New Jersey shore has historically been heavily impacted by coastal storms, flooding, and erosion. It is important for coastal communities to build upon past experiences to help identify current and future hazard vulnerabilities. Inundation and hazard mapping play a large role in helping a community understand its risks and vulnerabilities, and should be one of the first steps taken to help a community become more resilient to coastal hazards. To obtain a full understanding of inundation threats of current and future climate conditions, the NJOCM suggests that communities develop multiple inundation scenarios. Through a collaborative process, municipal leaders and staff should identify which inundation scenarios to consider in an assessment, along with the appropriate scale of the analysis.

NOAA Coastal Services Center's *Coastal Inundation Mapping Guidebook* defines the methodologies to model shallow coastal flooding, storm surge, and sea level rise.[22] The NJOCM recommends using Light Detecting and Ranging (LiDAR) derived digital elevation models (DEMS) as the topographic baseline for the development of the inundation models and hazard indexes. To ensure that inundation models are meaningful and represent realistic worst case scenarios, the NJOCM recommends the use of NOAA's Vertical Datum Transformation Tool (VDatum)[23] to adjust elevation data from NAVD88 to an appropriate tidal datum. Because there are multiple steps involved in developing inundation scenarios, NOAA Coastal Service's Center provides training on mapping methodologies and inundation visualization to ensure that coastal managers and local decision-makers have the necessary tools and baseline knowledge to develop local hazard maps.[24] By leveraging these innovative resources, New Jersey coastal communities will be better equipped to identify storm and inundation threats, allowing them to plan and prepare for potential adverse impacts to infrastructure and development, cultural and historic places, natural resources, and other locally significant assets.

Topography and Shoreline

LiDAR

Elevation was identified as one of the most influential factors affecting vulnerability of the coastal landscape. Elevation defines flood patterns, the likelihood for coastal erosion, and potential development constraints. Because accurate elevation data can influence coastal management, long-range planning, and hazard mitigation, high resolution elevation data, otherwise known as Light Detecting and Ranging elevation (LiDAR), is recommended for a variety of purposes, including, but not limited to, vulnerability mapping, storm surge and sea level rise modeling, floodplain mapping, land suitability analysis, and shoreline mapping.

In 2007, the NJOCM began the process of identifying the necessary data to understand changes and vulnerability along the Delaware Bayshore. Using LiDAR technology, the NJDEP acquired 2-meter resolution elevation data with a vertical precision of ± 15 centimeters (6 inches). Data was contracted to be collected within ± 3 hours of mean low water to capture the topography of the intertidal zone, which will allow for the delineation of the Bay's shoreline. The LiDAR

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[22] NOAA: CSC. (2009). http://www.csc.noaa.gov/digitalcoast/inundation/_pdf/guidebook.pdf
[23] NOAA: NGS. (2010).
[24] NOAA: CSC. Inundation Toolkit. http://www.csc.noaa.gov/digitalcoast/inundation/

acquisition was funded through partnerships with NOAA (NJCZM Grant), NJDEP (OIT), Office of Homeland Security and Preparedness, US EPA Region 2, USDA NRCS, USACE Philadelphia District, and USGS.

Figure 3: 10-Meter v 2-Meter Resolution Elevation Data

10-Meter Resolution   LiDAR 2-Meter Resolution

10-meter resolution digital elevation models were formerly the best available elevation data (left). LiDAR provides higher quality elevation data (right) which generates more accurate digital elevation models (DEMs).
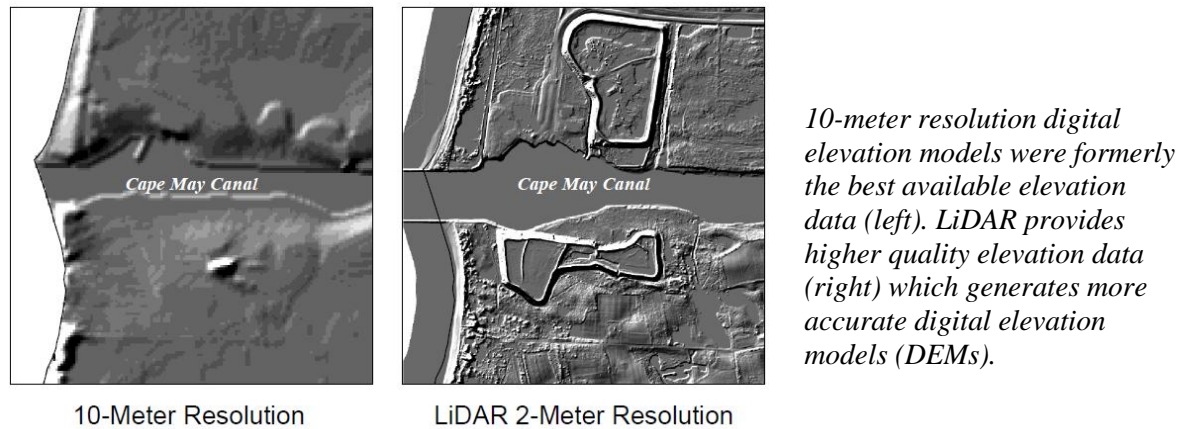
Today, bare-earth LiDAR digital elevation models (DEMs) are available for every coastal county in the state. While tides were not considered in the acquisition of elevation data in Atlantic coastal counties, a great deal of analysis and inundation modeling can be done using the available data. As technology and mapping standards continue to improve, New Jersey should continue to pursue the attainment of best available elevation data with consistent acquisition standards that allow for the development of a seamless coastal DEM and digitally represented shoreline. LiDAR data is available from multiple sources, including:

- NJDEP Bureau of Geographic Information Systems (available by request)
- USGS Seamless Server http://seamless.usgs.gov/
- USGS Center for LiDAR Information Coordination and Knowledge (CLICK) http://lidar.cr.usgs.gov
- NOAA's Digital Coast http://www.csc.noaa.gov/digitalcoast/data/coastallidar/download.html

VDatum

In order to adequately visualize the inundation impacts of shallow coastal flooding, storm surge, and sea level rise, elevation data should be referenced to a tidal datum. Doing so will allow inundation scenarios to be represented at a preferred tidal stage, such as mean high water or mean higher high water. NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS) developed the Vertical Datum Transformation Tool (VDatum) to vertically transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums. [25] Because New Jersey elevation data is typically referenced to North American Vertical Datum of 1988 (NAVD88), the NJOCM suggests converting digital elevation models into a tidal datum. By doing so, storm surge and sea level rise models can be represented at various tidal stages, preferably mean higher high water (mhhw) to represent worst case scenarios. VDatum can also be used to model scenarios at mean lower low water, which may be useful when mapping predicted water elevations, like future

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[25] NOAA. NGS. (2010).

spring tides. Visit the VDatum website (http://vdatum.noaa.gov/) to learn how to apply the transformation tool to elevation data in your area of interest.

Shallow Coastal Flooding and Past Storm Events

New Jersey coastal communities often experience coastal flooding in low-lying areas during spring tides, nor'easters, and hurricanes. In order to understand inundation patterns from past storm events or spring tides, visit NOAA's Tides and Currents website (http://tidesandcurrents.noaa.gov/) to locate the tide gauge closest to your area of interest. Explore the tabs and information that are available on this website. It not only provides future tide predictions, it has records of past tidal records. To identify the highest water elevations recorded near your community: (1) Pick a tide station closest to you, (2) chose "Extremes," (3) from the drop down menu, select "Station Extremes-Report," (4) choose a broad range of dates, and (5) Click "Apply Change." A list of extreme tide events, along with the dates will appear. Identify the date of the worst tide event. In most cases, the date will correspond with Hurricane Donna (1960), the December 1992 Nor'easter, or Hurricane Irene (2011). Identify the date of the worst event, and select the "Verified Data" option. On this webpage, input the date of the identified event, choose "Hourly" as the Interval, and select "mllw" as the Datum. To the right is an example of the results from the Sandy Hook tide station for Hurricane Irene, which identifies the maximum water elevation as 9.75 feet above mllw. To

Figure 4: Water Depths from Sandy Hook During Hurricane Irene

```
Historic Tide Data
Station Date        Time  Pred 6  Vrfy 6
DCP#:                         1       1
Units:                     Feet    Feet
Data%:  MLLW       GMT   100.00  100.00
Maximum:                   6.05    9.75
Minimum:                  -0.22    0.98
------- -------- ----- ------- -------
8531680 20110828 00:00    5.56    6.64
8531680 20110828 00:06    5.49    6.61
8531680 20110828 00:12    5.42    6.58
```

visualize this inundation pattern in a map of Sandy Hook, ensure that the elevation data is in feet and has been adjusted to mean low lower water, using VDatum. In ArcMap or Arc Catalog, use the raster calculator under the Spatial Analyst extension to identify all elevations in the DEM below 9.75 feet. (Example expression: [MLLW_DEM] <= 9.75) This will generate a data layer showing the likely inundation pattern that occurred during Hurricane Irene in Sandy Hook. By utilizing NOAA's Tides and Currents website, a coastal community can also identify the tidal depths of past spring tide events, which occur during new and full moons. Note that the highest tides of the year typically occur during the spring and fall equinoxes (March 20/21 and September 22/23). Following the same steps as before, a coastal community can then model the inundation patterns of past spring tides.

Figure 5: Water Elevations at Sandy Hook During Hurricane Irene
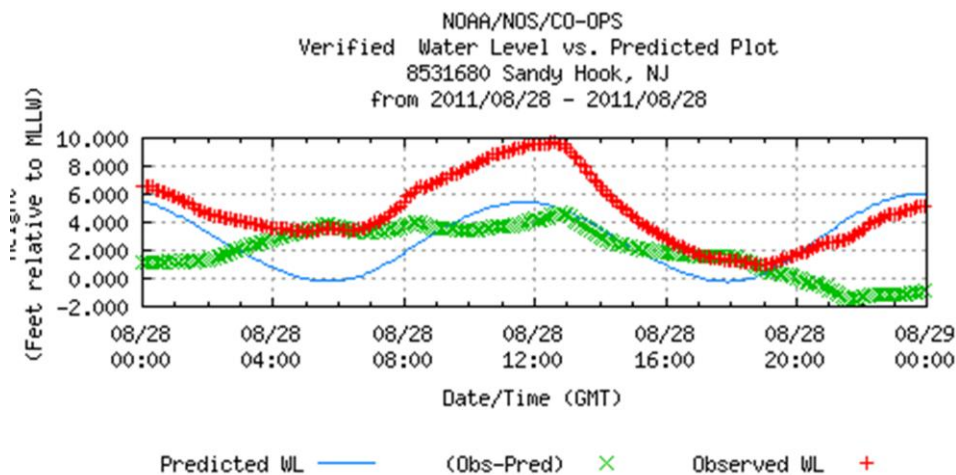
This graph represents the variation in the predicted water elevation and the observed water elevation 12
during Hurricane Irene, indicating a storm surge of approximately 5 feet near Sandy Hook, New Jersey.
Source: NOAA. (2011). Tides and Currents, Historic Tide Data

Storm Surge Inundation

The New Jersey coast has experienced multiple tropical storms and low-grade hurricanes since the 1850s.[26] While the Shore has been spared the catastrophic impacts of a major hurricane, changes in climate could produce more intense and frequent storm events. The Sea, Lake and Overland Surges from Hurricanes (SLOSH) Model and Advanced Circulation (ADCIRC) Model are two types of storm surge models that can be applied to elevation data to visualize inundation scenarios. The NJOCM recommends using the SLOSH model because it is readily available and updated by the National Hurricane Center (NHC). SLOSH estimates storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes by taking into account pressure, size, forward speed, storm track, and winds.[27] The SLOSH model is run for a large number of storm scenarios (directions, speed, etc.) to determine maximum storm surge for each hurricane category. The NJOCM recommends downloading MOM shapefiles (Maximum of the MEOW), which reflect the Maximum Envelope of Water (MEOW) for thousands of storm scenarios. The MOM Model is a composite of the maximum storm surge height for all hurricanes of a given category. This scenario-based approach is used in evacuation studies, and is ideal for planning and mitigation purposes.

Visit the NHC's SLOSH Display Package website (http://slosh.nws.noaa.gov/sloshPub/disclaim.php) to download training information and grid shapefiles of surge elevations. There are five basin models to choose from for a local analysis, including basins for Ocean City, MD, the Chesapeake Bay, the Delaware Bay, Atlantic City, and New York City. These grid basins should be transformed from NAVD29 to NAVD88 before applying them to LiDAR data. After adjusting the elevation data to the appropriate datum, follow the procedures defined in the *Coastal Inundation Mapping Guidebook* to map inundation scenarios and identify vulnerabilities within your community.

Waves Pound the beach at Asbury Park during Hurricane Irene
Photo Credit: Chip East, Reuters

Firefighters battle a fire at 484 Brielle road in Manasquan after Irene
Photo Credit: Andrew Mills/The Star-Ledger

Hurricanes have the capability to damage and destroy coastal properties and threaten the lives and livelihoods of coastal residents. New Jersey was fortunate to avoid major coastal losses during Hurricane Irene. Emergency management efforts ensured that the coastal zone was evacuated in adequate time and coastal residents and businesses heeded the warnings of the state and federal government. Taking precautionary actions and planning ahead were key to ensure the safety and resilience of New Jersey coastal residents and industries.

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[26] NOAA: CSC. (2010a).
[27] NOAA: NHC. (2011)

Map 3: Storm Surge Map of the Delaware Bay

Hurricane Scenario
- Category One Hurricane
- Category Two Hurricane
- Category Three Hurricane
- Category Four Hurricane
- Existing Waterbodies
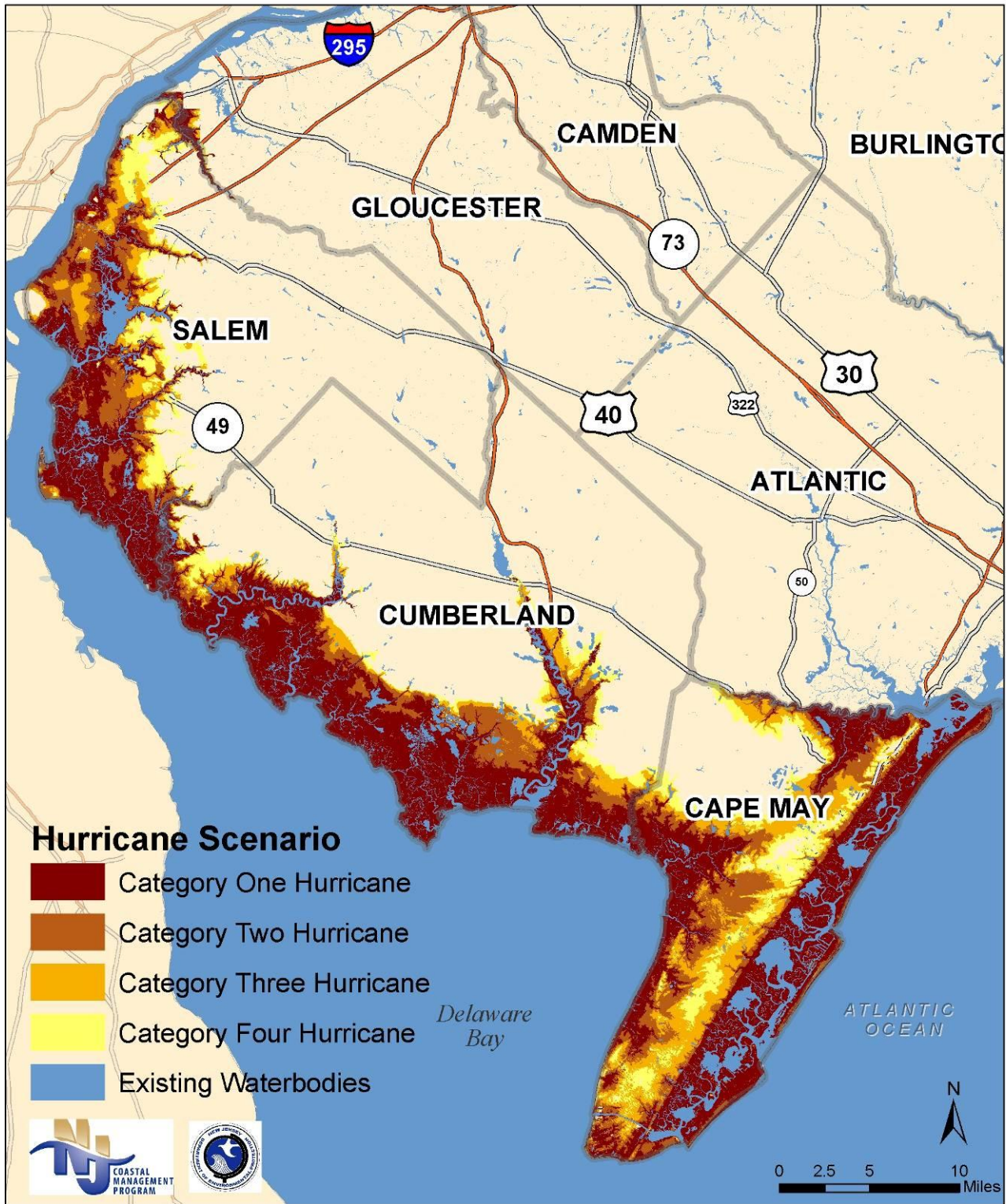
The map shows the potential extent of storm surge inundation. Surge was modeled using the National Hurricane Center's SLOSH Maximum of the Maximum Envelope of Water (MOM) with a 2-meter resolution LiDAR-derived DEM. Inundation is represented at mean high higher water (mhhw), which was determined through the use of NOAA's Vertical Datum Transformation Tool. The inundation models do not account for wave action, upland rainfall, or flood control structures.

Sea Level Rise Inundation

Over the next century, sea levels are predicted to rise between 0.5- 1.5 meters (~1.6 - 4.9 feet) along the New Jersey shore, threatening coastal development and natural resources. While local planning horizons are typically on a 10 to 20 year cycle and infrastructure budgeting spans a 50 year time scale, the impacts of natural processes, like shoreline change and sea level rise, typically occur over an extended period of time. Prior to making substantial budget decisions, coastal communities should consider the threat of sea level rise on existing and proposed infrastructure, development and land use, and open space conservation.

While there are numerous sea level rise projections available, the NJOCM suggests that communities utilize a 0.5, 1.0, and/or 1.5 meter scenario when modeling sea level rise. There are multiple ways that a community can visualize the potential inundation threats associated with sea level rise. A Bath Tub Model is a simple model that utilizes a digital elevation model to determine land areas that lie below a particular elevation contour. To create such a model, one can either convert a LiDAR DEM from NAVD88 to a MHHW tidal datum prior to performing the inundation analysis or create a 'generic' MHHW zero raster and convert this to NAVD88 using V-Datum. Sea level rise models can also be applied on top of spring tide scenarios to reflect the inundation extent of future spring tides

While a Bath Tub Model may be useful for planning or infrastructure purposes, there are other assessments that are typically used to analyze sea level rise impacts on habitat, including the Sea Level Affecting Marshes Model (SLAMM).[28] SLAMM is a wetland migration model that simulates the impact of sea level rise on coastal land classifications. It combines elevation data with wetland classifications, erosion rates, subsidence rates, tidal data, and dike and levee data with user defined sea level rise scenarios and timeframe intervals to simulate changes in the coastal landscape due to sea level rise. Utilizing SLAMM can improve the understanding of climatic changes on shorelines and habitat.

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[28] Clough, J. (2010).

Saltwater Intrusion
Photo Credit: Mary Judge

The impact of saltwater intrusion into the shallow water table can already be seen along portions of the New Jersey coastline, especially where dead trees mark the transition line between tidal wetlands and upland forests. As sea level rise accelerates, freshwater wetlands and fringing forests will become highly susceptible to the impacts of sea level rise. The Partnership for the Delaware Estuary has applied the SLAMM model along portions of the Delaware Bay. Visit the following website for more information: www.delawareestuary.org/

Sea level rise modeling can inform coastal decision-makers and wildlife managers about the conditions that are conducive to the landward migration of coastal wetlands, the development of pioneering coastal wetlands along open water areas, and the transformation of freshwater wetlands to tidal wetlands. Understanding how the natural environment may react to changes in sea level will inform adaptation measures like natural shoreline stabilization and acquisition of conservation land.

Map 4: Sea Level Rise Map of the Delaware Bay
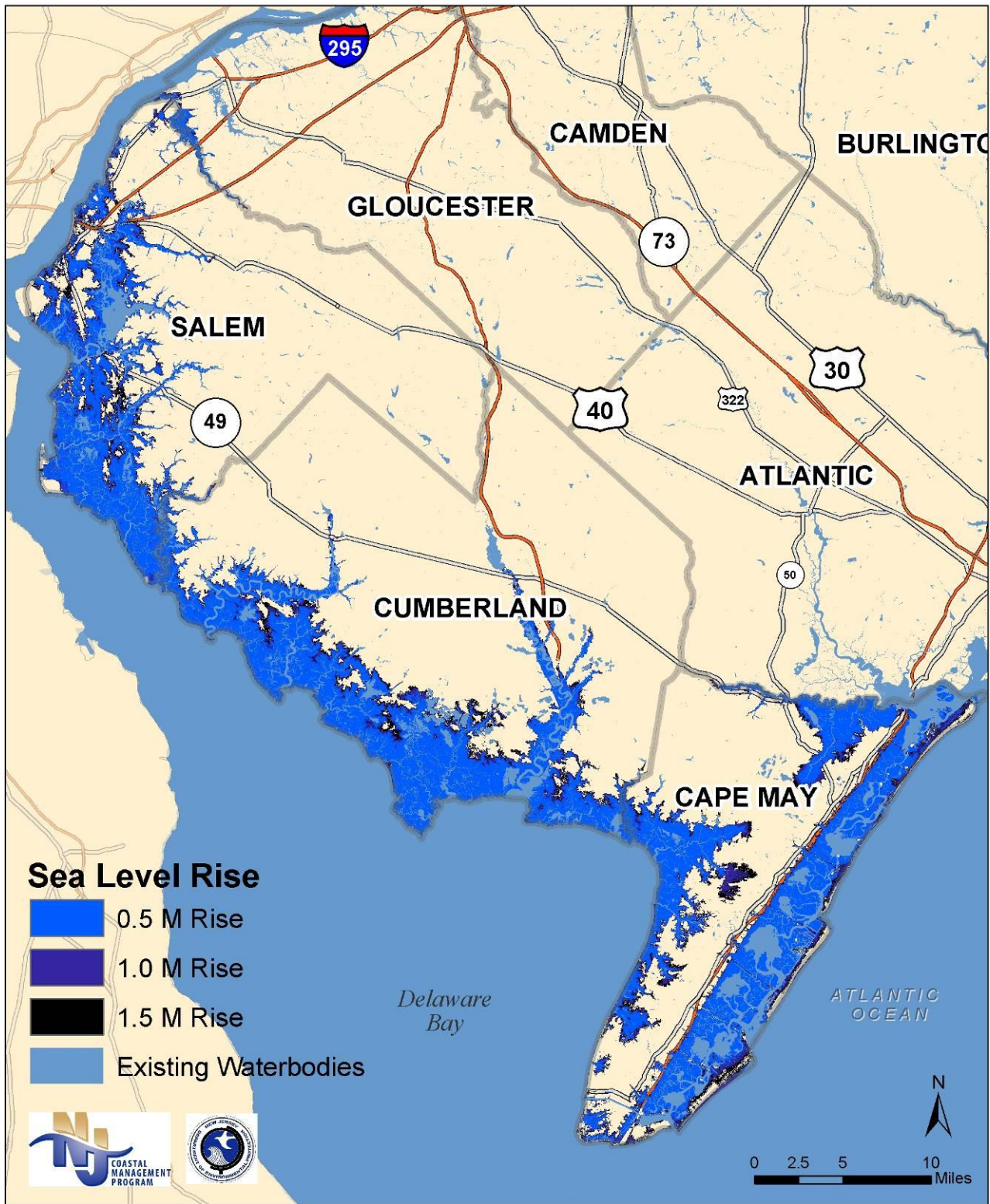
The map shows the potential extent of inundation with 0.5, 1.0, and 1.5 meter sea level rise . Sea level rise was modeled at mean high higher water (mhhw) using a 2-meter resolution LiDAR-derived DEM and NOAA's Vertical Datum Transformation Tool. The inundation models do not account for erosion, beach replenishment, excelerated subsidence, or flood control structures.

Coastal Vulnerability Index

Storm surge and sea level rise maps may help coastal communities visualize flooding threats, but inundation mapping alone does not clearly define most high risk areas in and around a community. Historic flooding and erosion, combined with potential inundation areas and natural features of the landscape help a community determine where property damages and environmental impacts are likely to occur the next time around. Creating an index whereby a "baseline of natural risk" is mapped, community decision makers can start to understand the potential risk to critical infrastructure, natural resources, and populations. In order to delineate high hazard areas, the New Jersey Office of Coastal Management developed a composite overlay model of six geospatial hazard indicators, including geomorphology, low slopes, flood prone areas, storm surge inundation scenarios, poorly drained soils, and erosion pr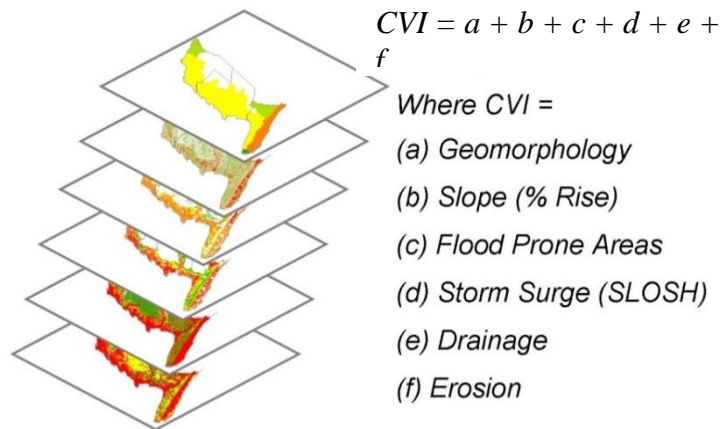one areas. This model is known as a Coastal Vulnerability Index (CVI) and is based on previous vulnerability modeling applications.[29] The CVI can help land use planners and hazard mitigation planners identify areas of highest development constraints due to natural conditions that are indicative of flooding and erosion. The CVI can be used as an environmental constraint model to determine land suitability for future development and zoning classifications. It can also be used to help identify mitigation opportunities in high hazard areas, in addition to areas where engineering and climate adaptation may prove to be extremely difficult or ineffective.

Figure 6: Coastal Vulnerability Index Model

$$CVI = a + b + c + d + e + f$$

Where CVI =

(a) Geomorphology

(b) Slope (% Rise)

(c) Flood Prone Areas

(d) Storm Surge (SLOSH)

(e) Drainage

(f) Erosion

Note: While highly recommended the CVI is not an essential part of a full hazards profile or vulnerability assessment. Therefore, if resources and/or expertise are such that a CVI cannot be performed effectively, it can be left out.

It is important to understand that the CVI created by the NJOCM represents one method of assessing natural risk, and therefore could be modified by adding additional layers and/or weighting attributes of those layers such that the sum of the parts more accurately depicts factors of regional importance. For instance, CVI is merely a static model that represents lands that are presently vulnerable to inundation and erosion, but it can be adapted to incorporate sea level rise scenarios into existing storm surge models to visualize how climate change may move high hazard areas further inland overtime. By understanding the vulnerabilities that presently exist in coastal New Jersey, along with potential changes in future conditions, communities will have the opportunity to mitigate existing development and guide future decision-making in a more holistic and sustainable manner.

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[29] Gornitz, V. M.; Daniels, C. R.; White, T. M., and K. R. Birdwell. (1994); Lennon et al. (1996); Thieler and Hammar-Klose (1999); Bush, D.M.; Neal, W. J.; Young, R.S.; and O.H. Pilkey (1999); PSDS. (2001).

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Map 5: Coastal Vulnerability Index Map of the Delaware Bay
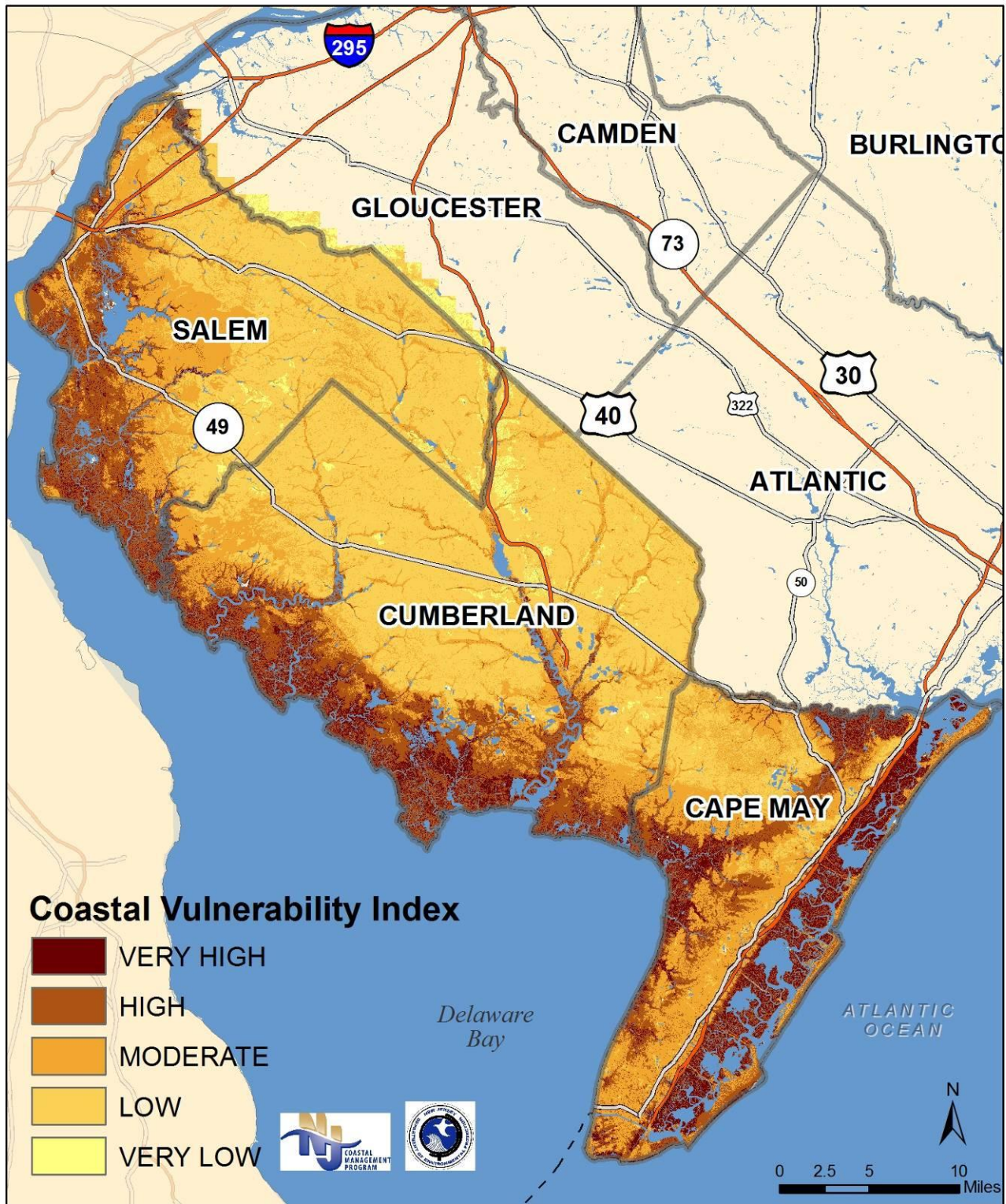
The coastal vulnerability index (CVI) is an environmental constraint model intended to highlight land areas that are most vulnerable to coastal hazards. The model was developed by combining the following geospatial data layers into a composite overlay model: geomorphology, low slopes, flood prone areas, storm surge, poorly drained soils, and erodible lands.

Slope

The terrain of a coastal region can greatly impact its vulnerability to periodic flooding and sea level rise. Utilizing available LiDAR, land areas below 2 percent slope were identified as vulnerable. As slope decreases, more land areas become prone to pooling of water, allowing for prolonged coastal flooding. Theoretically, the Brunn Rule indicates that every foot rise in water will result in a 100 foot loss of sandy beach, whether it is an episodic storm event or permanent inundation due to sea level rise. In other words, a 1 percent slope or less is likely to be inundated with a 1 foot rise in water. While the Brunn Rule does not apply to all land types, it provides insight that low-lying coastal areas are most vulnerable to inundation and changing coastal conditions. Looking at the map below, it is evident that coastal wetlands and beaches coincide with the very high classification.
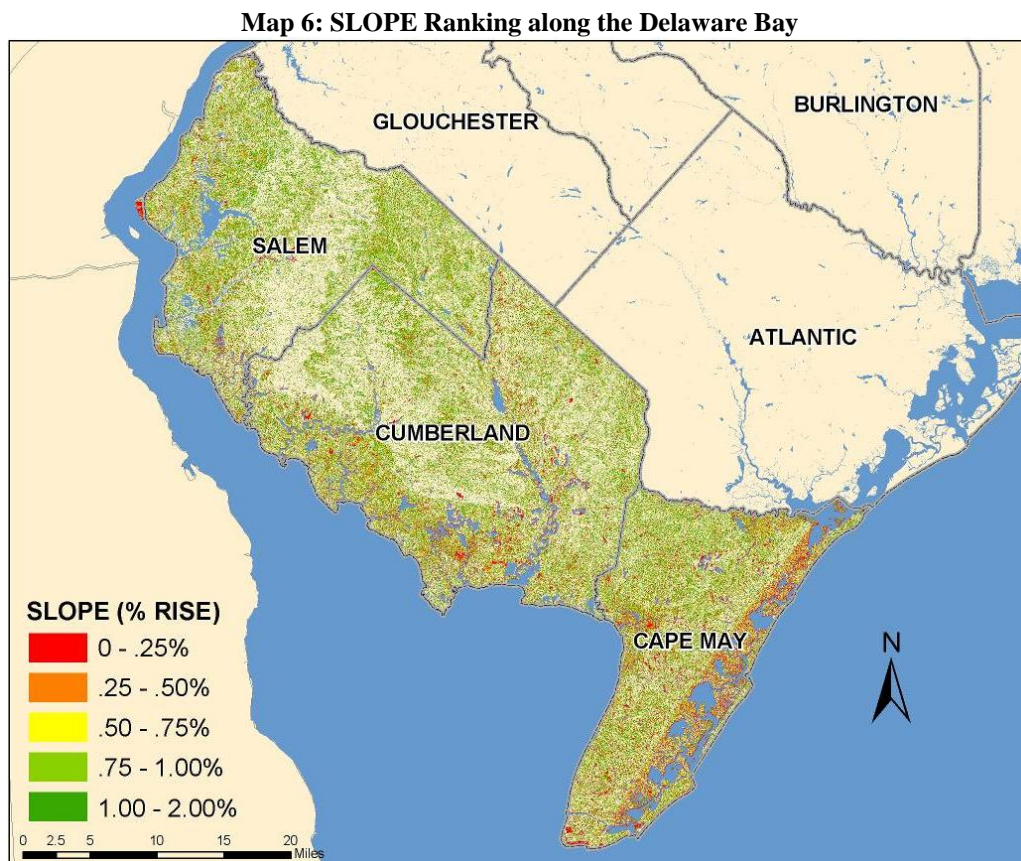
Map 6: SLOPE Ranking along the Delaware Bay

Flood Prone Areas

FEMA's Flood Insurance Rate Maps (FIRM) are the most accessible digital flood information available to municipal officials. While FEMA is in the process of generating updated flood maps for coastal New Jersey, communities can supplement their knowledge by using existing soils data to identify flood prone lands. The DFIRM Q3 Maps were used as the basis for the analysis and rank of the attributes according to level of risk. The V-Zone should be ranked as the most risk prone, while the 100-Year Floodplain and the 500-Year Floodplain should be identified as high to moderately risk prone. Where shorelines have shifted and lands have accreted since the Q3 maps were developed, utilize the ranking of the floodzone adjacent to it, typically a V-Zone or A-Zone. For the land areas that are outside of designated floodzones, utilize soils data (SSURGO, flodfreqmax) to identify soils that have a high to occasional likelihood of flooding in a given year.

Map 7: Flood Prone Areas along the Delaware Bay

Drainage

Soil drainage influences the period of time coastal lands are inundated after a storm event. While highly drained soils typically consist of sands and porous sediments, poorly drained soils are typically wetland soils or clays. Using soil data from USDA NCRS (SSURGO, drclassdcd), rank soils from well drained to very poorly drained. '*Somewhat excessively drained*' and '*excessively drained*' soils should not be considered in this analysis because they are not vulnerable to extended inundation. While well drained soils can decrease vulnerability, be aware that there may be an inverse relationship with erodible soils because well drained soils are typically associated with sand.

Map 8: Soil Drainage along the Delaware Bay
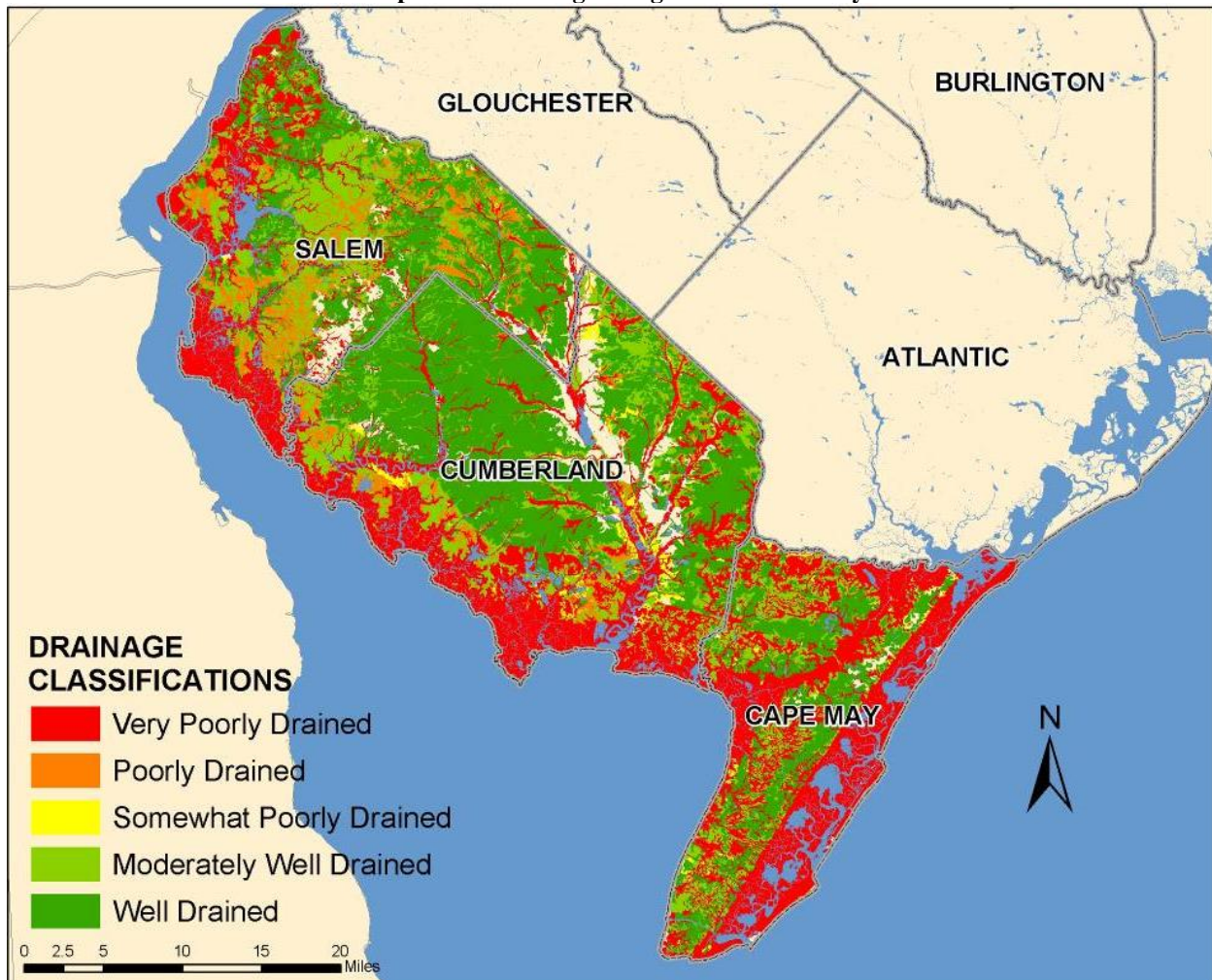
Erosion

There are multiple ways to assess erosion risk. Communities should use erosion data that are available to them, which many require erosion rates of coastlines to be projected into the future to fully assess erosion risk. Because erosion analysis has not been done for all shorelines and shoreline types in New Jersey, communities can utilize existing datasets available to them, including erodible soils data (SSURGO, kffact) and historical shoreline data. The soils data should serve as the basis of the erosion model. Rank the kffact scores, which represent the susceptibility of soil particles to detachment by water. Most of the Delaware Bay is 28 to 43 percent susceptible to erosion due to water. Note that there are gaps in the data. Where there is an obvious correlation between adjacent soils, utilize the adjacent classification. Where there is not an obvious correlation, rank the area as 0. To supplement the soils data, utilize historic shoreline data to identify beachfront areas that have a history of erosion or accretion. Areas of historic erosion should be classified as very high. Areas of historic accretion should be classified as 5 because those land areas are susceptible to change.

Map 9: Erosion Classifications
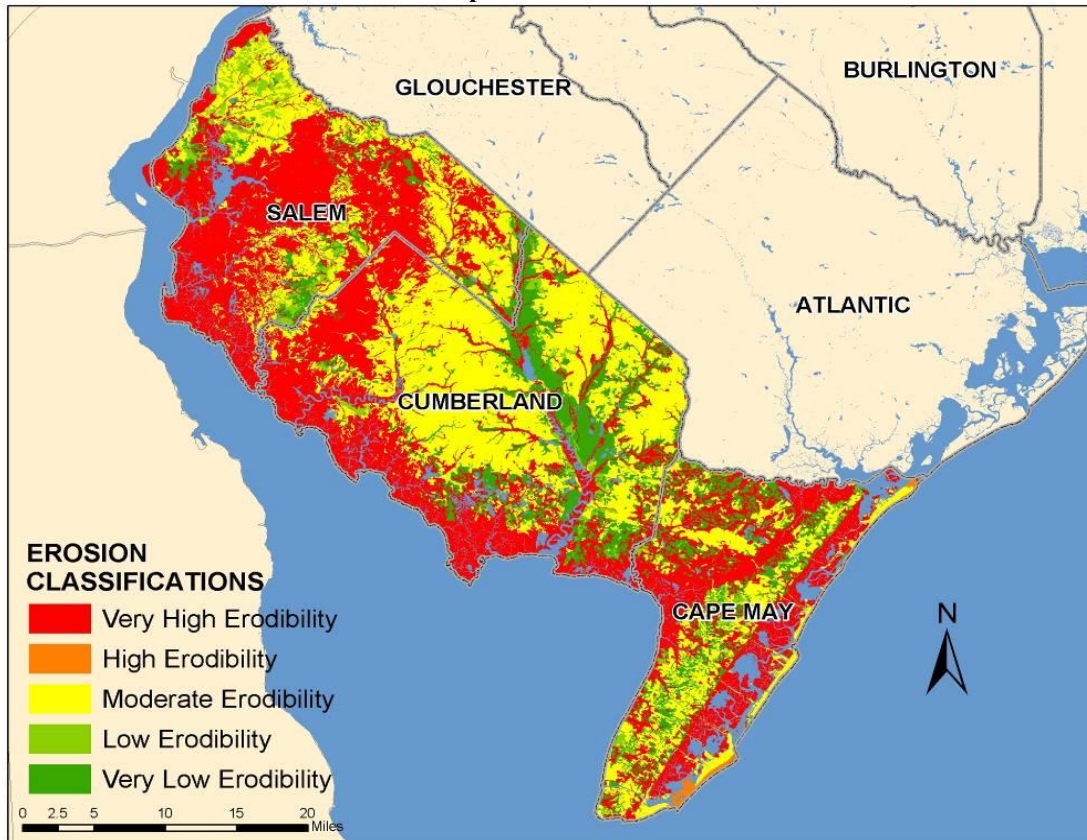
Geomorphology

The New Jersey shore is comprised of multiple geomorphic settings because of varying wave, current, and wind energy that exists along the coast. There are seven distinctive shoreline types along the Jersey shore, including spits, high and mixed-energy barrier island systems, headlands, bays and open bay systems, tidally influenced, freshwater rivers and estuaries. These shoreline types are indicative of the natural hazards and geologic processes that have shaped them over time. Geomorphology should be included in large-scale assessments, but may not be necessary in coastal communities because they typically represent one geomorphic region. The NJOCM delineated multiple geomorphic classifications along the New Jersey shore by identifying the watersheds that are tidally influenced and labeling them with the geomorphic description shown in the New Jersey Shore Protection Master Plan. Based on anecdotal information, each geomorphic region was ranked for its vulnerability to coastal hazards and sea level rise.

Map 10: Geomorphic Regions along the Delaware Bay

Storm Surge

Storm surge inundation patterns are not usually well represented in flood plain maps. To understand the potential for inundation, communities should apply the National Hurricane Center's SLOSH Model, coupled with a MHHW scenario, to understand the worst case scenario of any storm event. MHHW represents the daily extent of tidal inundation and is obviously the most vulnerable area. The inundation of a category one storm would be classified as the high, followed by the inundation extent of a category two hurricane, etc. These storm scenarios are ranked this way because a category one storm is most likely to occur. Additionally, if a category four storm impacted the Shore, the inundation will be worst in low-lying areas.

Map 11: Storm Surge (SLOSH) along the Delaware Bay
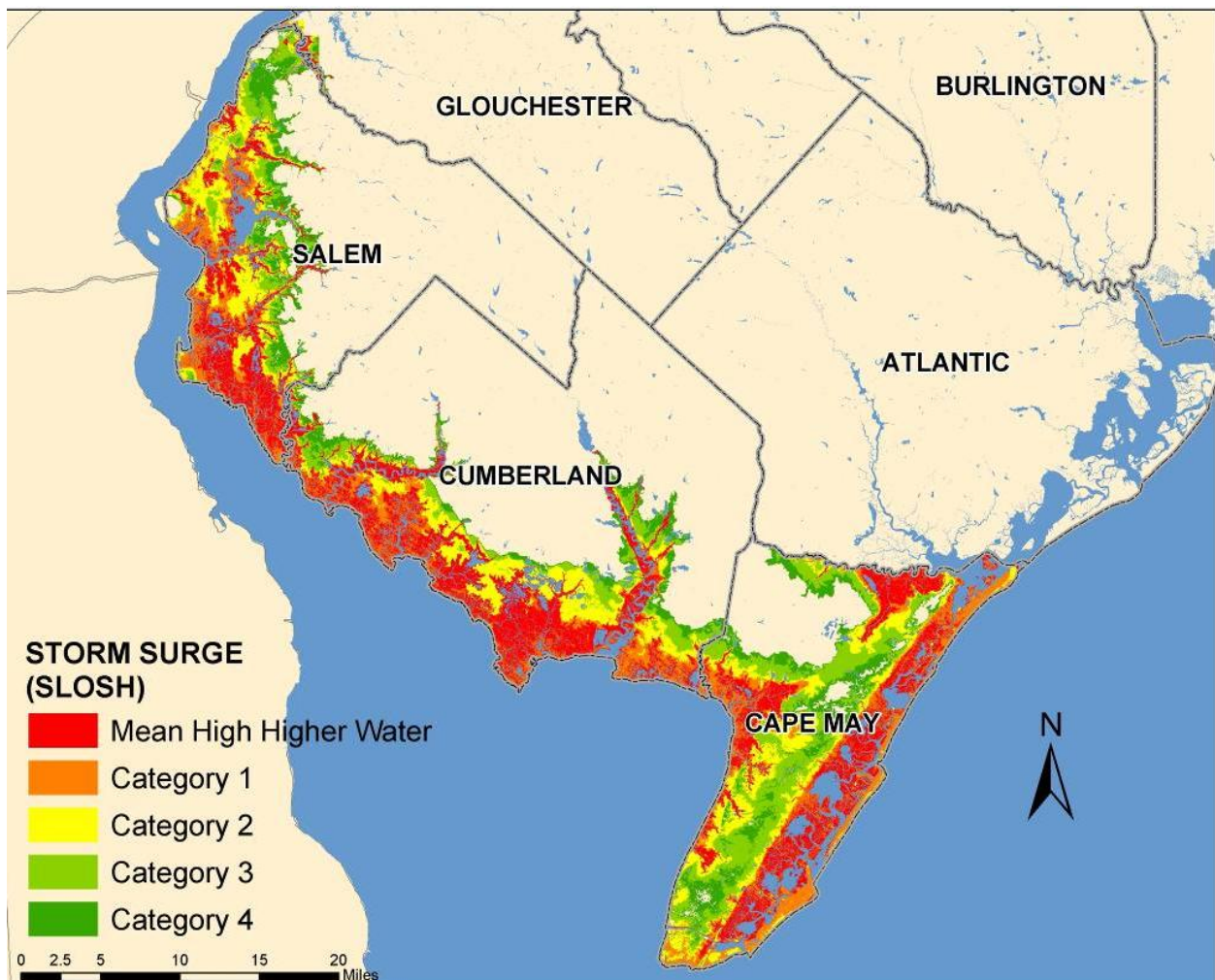
Vulnerability Analysis

Maps of hazard prone areas are informative in themselves, but local decision-makers should be aware of the community assets that lie within these areas to guide policy and planning. The vulnerability analysis within each community will not be the same, as each community will likely be concerned with assessing different assets that are vital to its functioning and character. The input of community leaders and the public on the types of assets to assess vulnerability not only engages stakeholders in the assessment, it can build community consensus around the mapping results. Participatory mapping is one way to engage stakeholders in the vulnerability assessment. NOAA Coastal Services Center's "Stakeholder Engagement Strategies for Participatory Mapping" provides guidance on how to conduct this form of community outreach and information gathering.[30] Information gathering may occur in the form of public workshops or meetings. During these public programs, members of the assessment team may wish to utilize checklists of known community assets to consider for a geospatial vulnerability assessment. The assessment team can then accurately identify and map significant features of the built and natural environment, in addition to social characteristics, that intersect various inundation and hazard scenarios. Municipal leaders can use this information to inform mitigation and adaptation strategies and guide dialogue during the facilitation of the *Getting to Resilience* questionnaire. The following pages provide some examples of the types of community assets, natural resources, and social characteristics that a community may want to consider in a vulnerability assessment, along with available GIS resources to utilize during the mapping process.

Figure 7: Example of a Vulnerability Mapping Considerations Checklist

✓ Built Environment Vulnerability	✓ Natural Environment Vulnerability	✓ Social Vulnerability (Census Data by Block or Block Group)
Evacuation Routes	Wetlands	Population Density per sq. mile
Roads and Bridges	Forestlands	Housing Units per sq. mile
Railroads	Farmland	% Elderly, Age 65+
Emergency Shelters	Environmentally Sensitive Lands	% Youth, Age 5 and under
Police & Fire	Conservation Easements*	% Youth, Age 17 and under
Nursing Homes*	Blue Acres Land*	% Minorities
Municipal Buildings*	Green Acres Land*	% Individuals Below the Poverty Level
Public Works*	Brownfield Sites	% Households without English Fluency
Schools	Manufacturing Sites	% Individuals Without a High School Education
Houses of Worship*	Landfills	% Disabled Individuals
Community Center(s) or Meeting Halls*	Drycleaners	% Single Parent, Head of Household
Shopping Centers*	Gas Stations	% Single Mothers, Head of Household
Libraries, Museums*	Point Source Pollution Surface Water Discharge	% Properties Built Prior to the NFIP
Business District*	Known Contamination Sites	% of Housing that are Mobile Homes
Historic Homes*	Other:	Other:
Parks*		
Landmarks*		
Dams and Levees		
Stormwater Discharge		
Other:		

*Note: Please provide the names and address of any facilities that are marked with an asterisk. If your community is reliant upon any critical facilities that are located outside of your municipal boundaries, please provide their names and addresses as well.

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[30] NOAA. (2009).

Built Environment Vulnerability

Coastal communities should assess the vulnerability of multiple types of infrastructure and community assets to coastal storms and sea level rise, including lifelines and critical infrastructure, community facilities, economic centers, historic and cultural facilities, and recreational destinations. Critical infrastructure and lifelines are the facilities or networks that are inherent to the functioning of a community. Examples of lifelines include roads and evacuation routes, emergency shelters, and hospitals. The failure or interrupted service of these lifelines can endanger the health, safety, and welfare of a community's citizens, interrupt disaster response, and result in property damage and the loss of lives. In addition to assessing the vulnerability of critical infrastructure, communities are urged to assess how its community facilities will be impacted by coastal storms and changes in sea level. Community facilities include, but are not limited to, municipal offices, schools, houses of worship, and community centers. Other forms of infrastructure that affect the character, economy, or quality of life of coastal communities include historical and cultural facilities, business centers, and recreational facilities.

Municipal officials should have a clear understanding of the vulnerable infrastructure and assets that exist within their community. It is not feasible to assess the structural vulnerability of all facilities, so a community should begin a vulnerability assessment by identifying facilities and networks that are likely to be exposed within areas of high coastal vulnerability. After identifying infrastructure and assets that may be exposed to coastal hazards, a local government can then conduct further investigations, including engineering and code inspections, to determine if there are structural or operational vulnerabilities that may need mitigation. While many forms of infrastructure may not be vulnerable under present conditions, coastal storms coupled with an increase in sea level rise have the potential to inundate land areas that are not presently identified within flood hazard areas. By identifying vulnerable infrastructure, municipal officials can then determine mitigation options for existing facilities and ensure that new infrastructure is built away from high hazard areas, using higher construction standards.

Hurricane Floyd Recovery, 1999
Location: Bridgewater
Photo Credit: Andrea Booher, FEMA

Contaminated water purification systems and well water can have an immense impact on a community's ability to rebound quickly from a disaster.

Nor'Ida, Fall 2009
Location: Seaside Heights
www.theweatherchannel.com

The economic centers of shore communities are often situated in close proximity to the water, making them vulnerable to the impacts of erosion, coastal storms and sea level rise.

Built Environment Considerations
There are multiple types of infrastructure that a community may wish to assess the vulnerability of in regards to coastal storms and sea level rise. A community may wish to first assess the vulnerability of its lifelines, but it should also consider assessing the vulnerability of additional community facilities that impact the ability to respond and recover from a disaster, such as schools, houses of worship, nursing homes, mental care facilities, and prisons. In addition, a community should consider assessing economic sectors, business districts and cultural resources. Below are some examples of the built environment that may be considered when conducting a vulnerability assessment. By assessing and mitigating the vulnerabilities of these facilities, a community can improve their overall resilience to coastal storms and climate change. Infrastructure data can be obtained from numerous sources, including TigerLine, FEMA's HAZUS-MH (v.1.4, DVD 6), and local GIS and planning offices.

Lifelines and Critical Infrastructure
- Evacuation Routes
- Interstates and Roads
- Bridges and Tunnels
- Emergency Shelters, Human and Pet
- Military Facilities
- Police and Fire Stations
- Public Works
- Hospitals
- Mental Care Facilities
- Nursing Homes
- Homeless Shelters
- Prisons
- Airports
- Dams and Levees
- Radio Towers
- Power Supply
- Water and Sewer Treatment Facilities
- Railroads and Rail Bridges
- Ports
- Ferries

Community Facilities
- Municipal Offices/Town Hall
- Schools
- Houses of Worship
- Community Centers
- Libraries
- Business Districts
- Shopping Centers

Historic and Cultural Facilities
- Landmarks
- Historic Homes and Sites
- National Register Sites
- Historic Districts
- Museums

Recreational Facilities
- Parks
- Public Access Sites
- Boardwalks
- Piers
- Marinas

Natural Environment Vulnerability

Coastal hazards and sea level rise threaten the natural resources of the New Jersey coast, not only the habitat and species within the coastal zone, but the scenic and recreational resources that draw people to the shore as well. Coastal storms have the ability to impair or destroy habitat, cause saltwater intrusion into freshwater ecosystems and resources, and allow pollutants to degrade water quality and affect public health. Fortunately, many of these impacts subside with time, habitats restore, and most species eventually recover from the impact of coastal storms. However, over time, climate change will heighten the threat of coastal hazards by increasing the intensity and frequency of coastal storms, erosion, and inundation, while decreasing recovery intervals between events. Rising seas are expected to continue to encroach upon beaches and tidal wetlands, but at a much faster rate than has been experienced during the twentieth century. Beaches and wetlands will be incapable of 'keeping pace' with sea level rise, especially where coastal development and shoreline stabilization structures inhibit shoreline migration. While this poses some obvious threats to habitat and native species, some less obvious impacts may include saltwater intrusion, loss of sediment and increases in non-point source pollution.

Coastal hazards, sea level rise, and other climate change impacts not only threaten coastal landscapes, they threaten the long-term resiliency of many coastal communities by negatively impacting public health, various economic sectors, and quality of life. To help the coastal environment keep pace with coastal hazards and sea level rise, decision-makers will need to advocate for and implement adaptation and mitigation measures. In some cases, open space and easements may be acquired to allow habitats to naturally migrate inland with rising seas. In other cases, mitigation may be necessary to reduce the threat of man-made hazards on the environment by remediating hazardous waste sites, replacing septic tanks with sewer services, and relocating waste disposal sites. Identifying vulnerable natural resources is the initial step to understand the threat of coastal hazards and sea level rise.

Horseshoe Crabs
Photo credit: Lawrence Niles, PhD

The New Jersey coastal zone is home to more than 24 state designated endangered and threatened species. Among them is the Red Knot, a migratory bird species that relies upon horseshoe crab eggs to sustain itself during its journey from South America to the Arctic. The Delaware Bay serves as the largest spawning ground in the world for horseshoe crabs, making it an essential stopover for over 1.5 million shorebirds. Loss of sandy beaches due to erosion, coastal storms, and sea level rise threaten the spawning grounds for horseshoe crabs and a valuable food source for migratory birds.

Red Knot
Photo Credit: Lawrence Niles, PhD
http://www.state.nj.us/dep/fgw/ensp/pdf/shrbrdfuture.pdf

Natural Environment Vulnerability Considerations

There are numerous environmental features and vulnerabilities that a community or special interest group may want to consider when performing a vulnerability assessment. The features listed below encompass just a few types of geospatial features that could be assessed when determining coastal hazard and sea level rise vulnerability. While a community may want to first assess the vulnerability of natural resources that impact public health or those that influence economic sectors, research scientists and wildlife biologists may be more inclined to assess the impacts of coastal hazards and sea level rise on particular habitat types and species. Such an analysis may require the application of a more in depth vulnerability assessment, like Nature Serve's Climate Change Vulnerability Index[31] or SLAMM.[32] And a combination of habitat and sea level rise mapping can help identify the potential impacts of climate change on ecosystem services. Understanding the capabilities of various assessments will prove to be useful when determining the type of vulnerability mapping to perform; which will then provide insight on mitigation and adaptation opportunities. The following are examples of natural resources, habitat, and man-made hazardous contaminants that could be considered during a vulnerability assessment. Natural resource GIS data can be obtained from multiple sources, including NJDEP-GIS (http://www.state.nj.us/dep/gis/) and many federal agencies.

Hazardous Contaminants
- Superfund and Brownfield Sties
- Hazardous Waste Sites
- Manufacturing Sites
- Petrochemical Sites
- Landfills
- Drycleaners
- Wastewater Treatment Plants
- Sewage Treatment Facilities
- Habitat of Species of Special Concern

Water Resources
- Aquifer Recharge Areas

Agriculture
- Aquaculture Sites
- Farmland of Statewide Importance
- Timberlands

Conservation Lands
- National and State Parks
- Coastal and Estuarine Land Conservation
- Wildlife Management Areas
- Fish and Wildlife Refuges
- Green Acres Land

- Blue Acres Land
- Conservation Easements

Habitat
- Saltwater Wetlands/Marshes
- Freshwater Wetlands
- Brackish Rivers, Streams, and Creeks
- Freshwater Rivers, Streams and Creeks
- Beach and Dune Systems
- Forestlands
- Environmentally Sensitive Areas
- Wildlife Corridors
- Migratory Bird Nesting Areas
- Federally Threatened and Endangered Species
- State Threatened and Endangered Species

Natural Capital
- Ecosystem Services Values

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[31] Climate Change Vulnerability Index: http://www.natureserve.org/prodServices/climatechange/ccvi.jsp
[32] SLAMM: http://warrenpinnacle.com/prof/SLAMM /

Social Vulnerability

The socio-economic composition of coastal communities varies throughout the State of New Jersey from densely populated, seasonal communities along the Atlantic coast to the rural, agricultural communities of the Delaware Bay. Because Shore communities vary in size and development patterns, the socio-economic factors that influence their resilience and adaptability to coastal storms and sea level rise vary as well. Some communities may consist of a large number of retirees or disabled residents, while others may be comprised of a large number of immigrant households or poverty stricken families. Identifying where vulnerable populations live in relationship to high hazard coastal areas can inform community leaders and emergency management officials where to target flood and storm preparedness, public outreach, and evacuation, recovery and mitigation assistance. By providing public outreach and reducing the exposure of vulnerable populations to natural hazards, communities can improve their overall resilience to coastal storms and inundation.

There are multiple ways that a community can identify where vulnerable populations live in relationship to high hazard areas. For the purposes of a hazard vulnerability assessment, the NJOCM defines socially vulnerable populations as individuals who may be unaware of the threat of coastal storms, lack access to resources to prepare for, evacuate, or cope in the event of a disaster. Census data is the most readily available information to utilize in a vulnerability assessment. Coastal counties and large communities should consider developing a social vulnerability index (SoVI)[33] to determine where vulnerable populations live in relationship to high hazard areas. Because there are many socio-economic factors that contribute to social vulnerability, this methodology allows the user to choose the socio-economic parameters to include in the analysis. The NJOCM piloted this methodology by identifying, classifying and combining nine Census datasets into one geospatial data layer, revealing the stratification of socially vulnerable areas relative within a three county area along the Delaware Bay.

Hurricane Floyd, 1999
Location: Bound Brook, NJ
Photo credit: Andrea Booher, FEMA

**Hurricane Lili, 2002**
Location: New Iberia, LA
Photo credit: Joe Raedle, LIFE

Disabled and elderly people are sectors of the population may require evacuation assistance, safe shelter, medical care, and/or recovery assistance in the event of a coastal storm.

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[33] Cutter, S. L.; Mitchell, J. T.; and M. S. Scott. (2000; 1997).

While the pilot was successful on the regional scale, it revealed limitations of existing Census data on the regional and municipal scale. One such limitation is the varying size of Census block and block groups. Jurisdictions that are small in geographic size and those that are rural in nature will likely have limited use for Census data; thus, local facilities and zoning information may be more useful in identifying the location of vulnerable populations. At this scale, municipal leaders and emergency managers should consider using a local registry to capture the location of special needs populations or utilize the existing New Jersey Register Ready Program to identify the individuals who may need preparedness, evacuation, or recovery assistance. In more densely developed areas, Census data is limited because it does not account for the large and fluctuating vacation populations that visit the shore each year. Considering that tropical storms and hurricanes occur during peak tourist season, these populations are often left out of vulnerability analyses. Tourist may not be aware of preparedness and evacuation procedures or heed the warning in time. On the other hand, if the shore experiences a nor'easter during the winter, fewer people are likely to be impacted. Additionally, Census data may not be appropriate to use for climate change analyses unless population projections are utilized. But, sea level rise and storm surge mapping can direct local governments where to avoid future development of affordable and low income housing, in addition to schools, soup kitchens, and homeless shelters. By doing so, communities can proactively reduce the susceptibility of vulnerable populations.
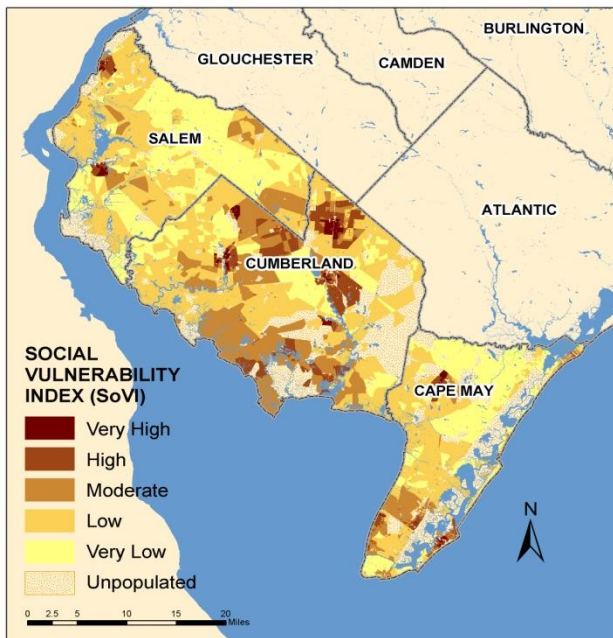
Map 12: Social Vulnerability along the Delaware Bay

Social Vulnerability Considerations

While there are limitations to Census data, it remains one of the only sources of demographic information to include in such an assessment. Tabular Census data from *American Factfinder* can be joined with Census block and block group shapefiles from *Tigerline* to geospatially represent the distribution of socially vulnerable populations. Additionally, the location of local facilities and zoning can be obtained from a local planning and zoning department.

Census Data Considerations
- Population Density
- Housing Density
- Poverty
- Linguistically Isolated
- Single Parent, Head of Household
- Disabled
- Undereducated
- Children (17 and Under)
- Elderly (65 and Up)

Local Facilities and Zoning
- Mental Care Facilities
- Nursing Homes
- Homeless Shelters
- Low-Income Neighborhoods
- Retirement Communities
- High Density Zoning

Findings and Recommendations

Coastal communities may not be fully aware of all of the potential impacts of coastal hazards and accelerated sea level rise on their infrastructure, natural resources, and vulnerable populations. Local vulnerability assessments can go beyond the capabilities of a county or regional all-hazard mitigation plan by incorporating locally significant assets, landmarks, and character defining features of a community. Understanding local vulnerabilities is a critical first step in a community becoming more resistant to coastal hazards.
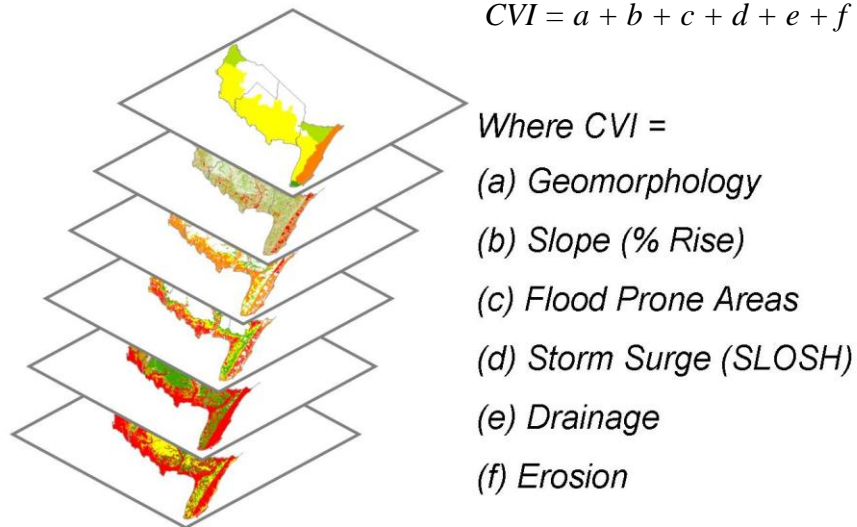
During the piloting of the *Coastal Community Vulnerability Assessment and Mapping Protocol* and the *Getting to Resilience* questionnaire, it was evident that local and county emergency responders are typically the most informed about community vulnerabilities to coastal hazards. Yet, typically, there is a disconnect between emergency management and the long-range planning efforts that could minimize adverse impacts to people, development, and natural resources. The development of local hazard and vulnerability assessments serves as an opportunity to bridge this disconnect and inform coastal decision-makers from multiple community sectors of threats to their community's resilience. It also serves as an opportunity to engage the community in understanding hazard vulnerabilities and building the public support to pursue mitigation and adaptation measures.

Unfortunately, many communities lack the appropriate staff to assist in the development of inundation and vulnerability maps. In these cases, a community should consider hiring a consultant or teaming up with a neighboring community to perform a shared assessment. In those communities that do have GIS and planning staff, inundation mapping and vulnerability assessment trainings may be necessary. Inquire with the New Jersey Office of Coastal Management and/or the Jacques Cousteau National Estuarine Research Reserve about professional training courses that address coastal hazard and climate change. In order to accommodate the mapping needs of coastal communities, NOAA Coastal Services Center, the Jacques Cousteau National Estuarine Research Reserve and Rutgers Center for Remote Sensing and Spatial Analysis are developing a web resource to help communities visualize their vulnerabilities to sea level rise and flooding. Many of the methods that are defined in this document will be represented in this online tool and support local mapping efforts. Upon completing a hazard and vulnerability assessment and evaluating existing local policies and decision-making, coastal communities will have the necessary information to begin embarking on hazard mitigation and climate adaptation opportunities; thus, building a resilient New Jersey shore.

Appendix A: Building a Coastal Vulnerability Index

Technical Guidance – Mapping Protocol

The New Jersey Office of Coastal Management identified the need to go beyond inundation mapping to define the location of high hazard areas in coastal communities. For the purpose of long-range planning and the development of municipal master plans, coastal communities should consider developing land suitability models, which typically identify hazard areas. To delineate high hazard areas, the New Jersey Office of Coastal Management developed a composite overlay model of six geospatial vulnerability indicators, including geomorphology, low slopes, flood prone areas, storm surge inundation scenarios, poorly drained soils, and erosion prone areas. This type of model is a qualitative analysis that will assist in classifying a range of hazard prone areas, including those susceptible to chronic or episodic hazards.

$$CVI = a + b + c + d + e + f$$

Where CVI =

(a) Geomorphology

(b) Slope (% Rise)

(c) Flood Prone Areas

(d) Storm Surge (SLOSH)

(e) Drainage

(f) Erosion

This analysis requires the use of ArcGIS Spatial Analyst, along with experience using raster data layers and ModelBuilder. The Coastal Vulnerability Index (CVI) can be developed using a Composite Rating Procedure,[34] which involves the ranking of multiple datasets into one representative dataset. The suggested model inputs include geomorphology, low-lying slopes, flood prone areas, storm surge inundation, soil drainage, and soil erosion.

Once each input raster dataset is created and the risk ranked, the sum will be calculated using the Raster Calculator tool. Therefore, care must be taken to ensure that these input data sets are in the correct format. The following pages will provide technical guidance on building these input raster datasets for a region.

---

[34] Anderson, L. T. (1987)

Getting Started

1. **Obtain the most-recent, highest resolution elevation data.** Elevation data sources are listed in the [Publically Available Data & Tools](#) section. Take some time to examine the file in GIS as well as the associated metadata. The most important aspects of your data to keep in mind for the remainder of the analyses are:

   - Resolution (cell size)
   - Reference datums (horizontal and vertical)
   - Units (horizontal and vertical)

   It will be important to write these down because every new layer of the analysis should share these same parameters.

2. **Clip DEM to study area**. DEM data files are very large. Since larger files increase the processing time, it is helpful to define your study area and then clip the DEM to this area. It will save time in the future.

   ```
   Spatial analyst tools > Extraction Tools > Extract by mask
   ```

3. **Hydroflatten DEM**. LiDAR data is wonderful for land elevation; however, the devices are not capable of penetrating water. Therefore, data over water are unreliable and often meaningless. It is best to deal with this by creating a "hyroflattened" DEM file by changing all values that occur over water to zero within cells of your DEM. To accomplish this, you will need a GIS polygon of the water in your region.

   a. Obtain water shapefile. Examine it to make sure it represents actual coastal boundaries (i.e. wetlands or other low-lying areas are not cut off).

   b. Add field within attribute table. Name it WL and give all rows a value of "0"

   c. Convert water feature to raster
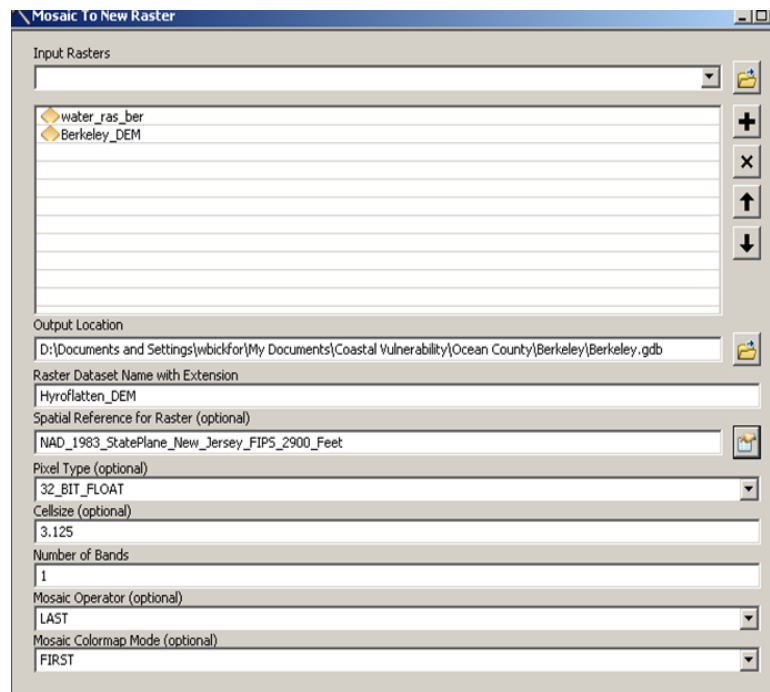
   ```
   Conversion Tools > To Raster > Feature to Raster
   ```

   Make sure FIELD is set as "WL" – The result will be a raster file representing water areas with a value of zero at all cells.

d. Create mosaic raster combining DEM and water rasters.

```
Data Management Tools > Raster > Raster dataset > Mosaic to New Raster
```

Be sure that the output raster has the same cell size as the DEM

4. **Use this hydroflattened DEM for all future analyses.**

5. **Create a MHHW raster.** In this step you will give V-Datum a data set that you create for MHHW and have it convert it to NAVD88 (the vertical datum of your DEM). If the input dataset is intentionally set to zero, V-Datum will output the distance above or below NAVD88 that the real MHHW reference lays. To do this, create a new raster over your study area with a constant value of Zero. Set the cell size to at least 250 (this is probably enough to get capture the MHHW variability in the region; the raster will later be scaled to the same cell size as the DEM).

```
Spatial analyst tools > Raster Creation > Create Constant Raster
                           Value = 0
                Output extent = same as study area
```

6. **Convert Raster to points**. Since V-Datum only uses point data, we need to convert to points.

```
Conversion Tools > From Raster > Raster to Point
```

7. **Assign coordinates to the points.** V-datum needs to be able to match the coordinates of your study area with those of the basins loaded into its databases. It can be difficult to be sure of the coordinate system of your raster is recognized similarly by V-Datum (this is especially true if your DEM uses one of the State Plane coordinate systems). Luckily with just a couple extra steps, you can save some confusion and be sure that V-Datum is calculating correctly.
    a. Be sure that your projection is the same as is assigned to your DEM
    b. Open Attribute Table and add 2 new fields
    c. Populate each with X or Y coordinates

```
Calculate Geometry > Add X coordinates > Units: decimal degree
```

    d. Close Attribute Table
    e. Add XY coordinates (using the same coordinate system as your map)

```
Data Management Tools > Features > Add XY Coordinates
```

8. **Open Attribute Table.** Now your dataset has coordinates assigned to each point that both V-Datum and ArcMap will understand

9. **Export Table as dbase file (.dbf).** The exported table will need to be "cleaned up" for V-Datum to recognize the data. This can be easily done in Excel.

10. **Clean up using Excel**
    a. Open the dbase file in Excel. V-Datum only reads numbers in a particular order. The finished table should be in the following format:

```
FID | LONG | LAT | OBJECT_ID
```

35

Once the columns are arranged in this way, delete the extras and the top row (labels)

    b. Save file as .csv and Close Excel.

11. Convert to NAVD88 using V-Datum

    a. Open V-Datum. Make sure your study area is listed in the dropdown menu. If not, you may need to download it.

note V-datum basins are updated periodically; therefore it's a good idea to make sure your basin data is current. When in doubt, download a new version.

    b. Horizontal datum should match your study area (probably NAD83)

    c. Vertical input is MHHW

    d. Vertical Output is NAVD88

    e. Make sure the height units match your DEM

    f. Coordinate System is Lat, Long

    g. Under "file conversion" make sure "long, lat" is selected (this is the order that columns are in your data file).

    h. Find your .csv file as your input

    i. Convert. You now need to "clean up" the output for GIS
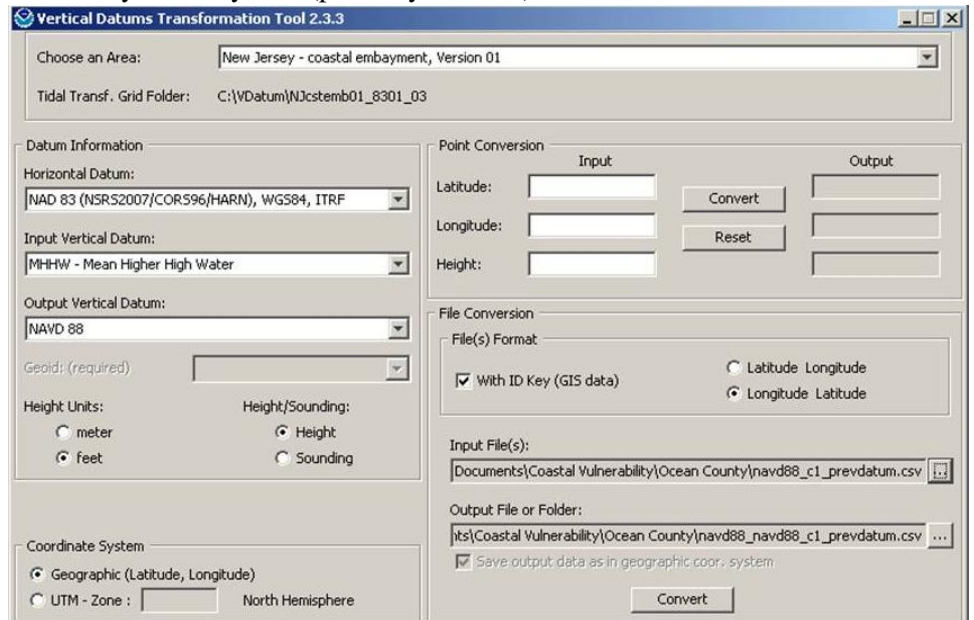
12. Clean up in Excel

    a. Open a new blank document in Excel

    b. Import from text and find new .csv file

    c. Add top row and labels (as below).

<div align="center">

`ID | LONG | LAT | MHHWinNAVD88`

</div>

    d. Also open your pre-VDatum dbase file

    e. Copy the entire columns named `POINT_X` and `POINT_Y`

    f. Paste them in the new .xlsx file. Your new data now reference the coordinate system of your map.

    g. Examine your data. The MHHWinNAVD88 column should have many cells with -99999 as the value. This represents points where there was no V-Datum conversion. Make sure all values do not appear as -99999. If so, the coordinates were likely wrong.

    h. Save as new .xlsx file and close Excel

13. Import new table into ArcMap

14. **Plot data on map.** In the table of contents, right click on new file and select Display XY Data

```
X field = X_POINT
Y field = Y_POINT
Z Field = <none> (assigned later)
```

The new plotted points will appear as "Sheet1events." Export this to new file to make it permanent.

15. **Examine your file.** Zoom to layer. Your points should be displayed in the same place as the pre-VDatum points. If, not the coordinates are probably wrong.

16. **Convert points to raster**

```
Conversion Tools > To Raster > Point to Raster
Value = MHHWinNAVD88
Cell Assignment = Maximum
Priority Field = NONE
Cell Size = [whatever was used before]
```

17. **Extrapolate Upstream.** V-Datum does not give values up into tidal creeks and small rivers. As these are still areas of flood concern, we need a way to extrapolate our values up into the creeks. There are several steps involved in this transformation because the particular tool used uses only integer values and the V-Datum outputs have decimals. To allow for the use of this tool, but also preserve the accuracy of our water heights, we need to incorporate several steps. It may be best to use ModelBuilder for this step. **The model below is taken from the NOAA Coastal Services Center's Coastal Inundation Mapping Guidebook (2012).** Tools for each step can be found in the Spatial Analyst Tools.

a. Multiply the Raster by 1000. This preserves the accuracy of the points in integer form.

b. Convert this value to an integer. ArcMap has to view this number as an integer, which requires a small conversion.

c. Convert unknown values to "NoData." Remember that V-Datum uses a value of -99999 for all unknown values. This tool will not read that as such, so it should be converted to "NoData."

d. Run the Euclidian Allocation tool.

e. Spatial Analyst Tools > Distance > Euclidian Allocation

f. Convert Output back to Floating Point. This step is to get back to a decimal form

g. Divide by 1000. This puts the accuracy back to its original form.
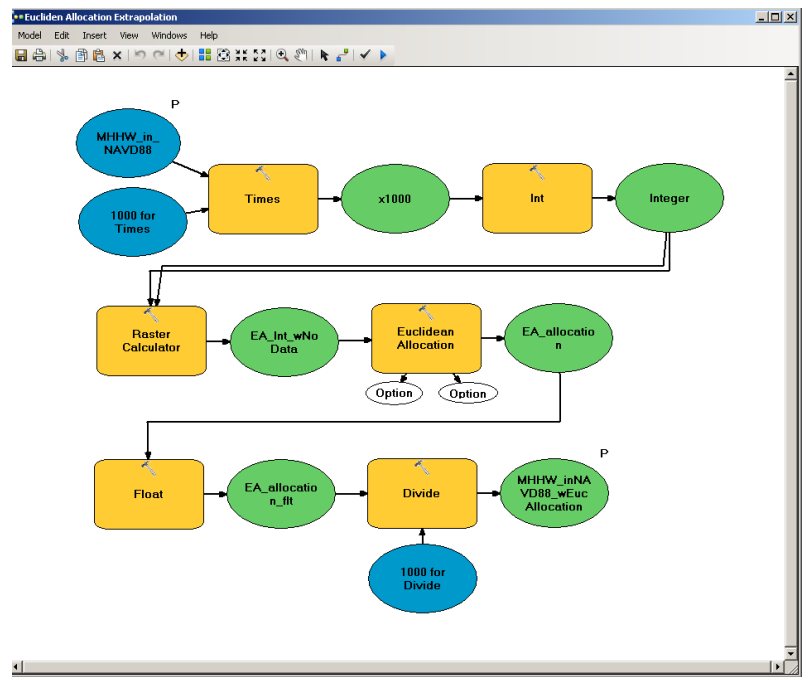
    h. Save this file. Many of the outputs from Spatial Analyst are temporary, so it is important to make them permanent. Name this file EA_MHHW.

18. **Subtract the DEM from this Raster.** The raster just created represents the distance to MHHW from NAVD88. To get inundation at MHHW, the DEM needs to be subtracted. Use the following conditional statement in Raster Calculator:

$$\text{Con(MHHW>=DEM, MHHW-DEM)}$$

    Scale back to cell size of the DEM. While in Raster Calculator, click on the `Environments` button. Under `Spatial Extent`, select "`Same as DEM`."

19. **Display this Raster as MHHW inundation. Save this raster.**

Slope

The terrain of a coastal region can greatly impact its vulnerability to periodic flooding and sea level rise. Utilizing available LiDAR, land areas below 2 percent slope were identified as vulnerable. As slope decreases, more land areas become prone to pooling of water, allowing for prolonged coastal flooding. Theoretically, the Brunn Rule indicates that every foot rise in water will result in a 100 foot loss of sandy beach, whether it is an episodic storm event or permanent inundation due to sea level rise. In other words, a 1 percent slope or less is likely to be inundated with a 1 foot rise in water. While the Brunn Rule does not apply to all land types, it provides insight that low-lying coastal areas are most vulnerable to inundation and changing coastal conditions.

1. **Get Slope Values from DEM**.

```
Spatial Analyst Tools > Surface > Slope
        Add layer: DEM (hydroflattened)
```

Note: Slope should be assessed as "percent rise." z-correction option should be used if the DEM used different units for x & y than it does for z (e.g. meters for x & y, but elevations in ft)

2. **Rank and reclassify as below**.

```
Spatial Analyst Tools > Reclass > Reclassify
```

Note: The upper limit of the ranking should be the upper limit of your slope raster.
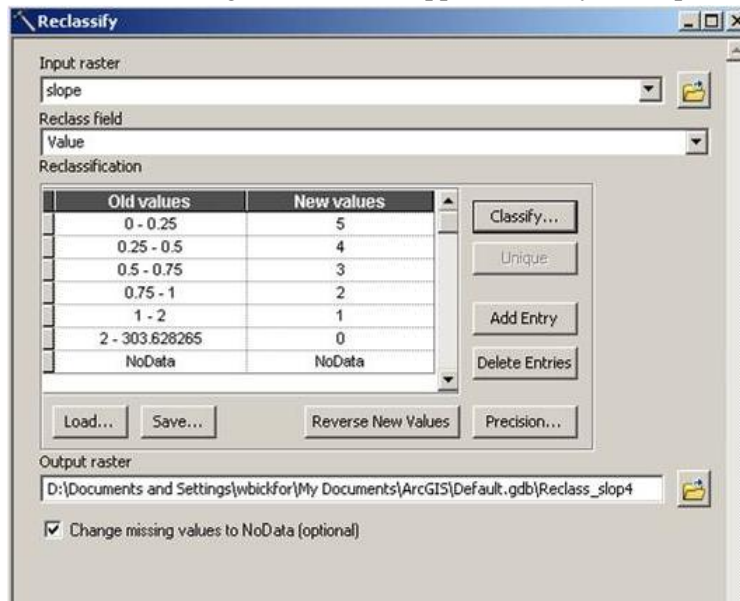
Slope (%)	Rank	GIS Rank
> 2.00	None	0
1.00 - 2.00	Very Low	1
.75 – 1.00	Low	2
.50 - .75	Moderate	3
.25 - .50	High	4
< .25	Very High	5

Brick Township, NJ
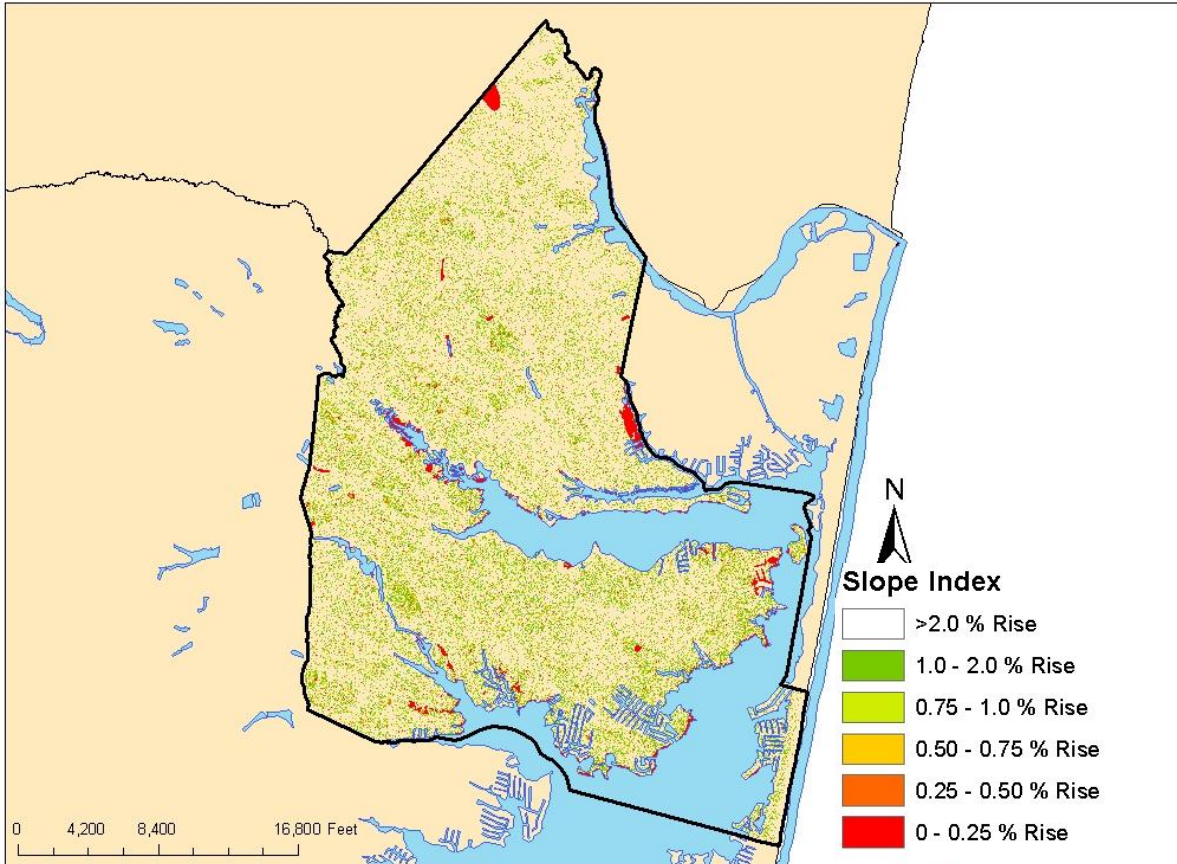
Slope Index

- >2.0 % Rise
- 1.0 - 2.0 % Rise
- 0.75 - 1.0 % Rise
- 0.50 - 0.75 % Rise
- 0.25 - 0.50 % Rise
- 0 - 0.25 % Rise

N

0   4,200   8,400   16,800 Feet

Flood Prone Areas

FEMA's Flood Insurance Rate Maps (FIRM) are the most accessible digital flood information available to municipal officials. While FEMA is in the process of generating updated flood maps for coastal New Jersey, communities can supplement their knowledge by using existing soils data to identify flood prone lands. Utilize DFIRM Q3 Maps were used as the basis for the analysis and rank the attributes according to level of risk. The V-Zone should be ranked as the most risk prone, while the 100-Year Floodplain and the 500-Year Floodplain should be identified as high to moderately risk prone. Where shorelines have shifted and lands have accreted since the Q3 maps were developed, utilize the ranking of the floodzone adjacent to it, typically a V-Zone or A-Zone. For the land areas that are outside of designated floodzones, utilize soils data (SSURGO, flodfreqmax) to identify soils that have a high to occasional likelihood of flooding in a given year.:

Necessary Data and Sources:

Data	Source
Flood Hazard Areas	FEMA DFIRMS
Flood Prone Soils	USDA: Soils Data Mart; New Jersey SSURGO (with tabular files: mapunit and muggatt; found at: http://soildatamart.nrcs.usda.gov/templates.aspx)

1. **Import FEMA Flood Hazard Areas (DFIRM)**. Clip map to study area.
2. **Examine Feature.** Open Attribute Table and examine fields FLD_ZONE & LEGEND
   Notice
   0.2 PCT ANNUAL CHANCE FLOOD HAZARD = 500 Year Flood Zone
   A & AE = 100 Year Flood Zone
   V & VE = 100 Year Flood Zone*
   *V & VE represent velocity zones, higher vulnerability
3. **Import SSURGO layer**
4. **Add Tabular Soil Data.** Tabular soils data is available for download at the link above. The download contains an MS Access Database. Individual tables can be added to ArcCatalog by exporting from Access to .xls files.
   a. From ArcCatalog, add "mapunit" & "muggatt"
   b. Right click on SSURGO layer and join mapunit. They share the field "mukey" in common.
   c. Then join muggatt
5. **Create Feature of Flood Prone Soils**
   a. Open joined attribute table
   b. Examine field: flodfreqmax
   c. Select by attributes (flodfreqmax = frequent, very frequent, and occasional)
   d. Export Selected areas to new layer
6. **Delete area outside already covered by FEMA maps**
   ```
   Analysis Tools > Overlay > Erase
   ```
7. **Merge Frequently Flooded Soils to FEMA Zones**
   ```
   Data Management Tools > General > Merge
   ```

8. **Expand new feature to cover entire study area. Because all indices will be added together** eventually, it is important to have cells present in areas where data does not exist.
   a. Erase Flood areas from study area feature.
      ```
      Analysis Tools > Overlay > Erase
      ```
   b. Add field to non-flood prone areas feature
   c. Name the new Field "Index" and value at "0"

9. **Create Flood Prone Index**
   a. Merge non-flood with flood zones
   b. Turn Edit On
   c. Rank in Index Field (as below)

Flood Prone Areas	Rank	GIS Rank
Outside of Floodplain and non-flood prone soils	None	0
Occasionally Flooded Soils Outside of the Floodzone	Very Low	1
Frequently Flooded Soils Outside of the Floodzone	Low	2
500-Year Floodplain (X500)	Moderate	3
100-Year Floodplain (A, AE)	High	4
Velocity Zones (V & VE)	Very High	5

10. **Convert to Raster**
    ```
    Conversion Tools > To Raster > Feature to Raster
                    Field = Index
           Output cell size = [same as DEM]
    ```

Brick Township, NJ

Flood Zone index

- ☐ Not Frequently Flooded
- ☐ Very Frequently Flooded
- ☐ 500 - Year Flood Zone
- ☐ 100-Year Flood Zone
- ☐ Velocity Zones

N

0   5,500   11,000   22,000 Feet

Drainage

Soil drainage influences the period of time coastal lands are inundated after a storm event. While highly drained soils typically consist of sands and porous sediments, poorly drained soils are typically wetland soils or clays. Using soil data from USDA NCRS (SSURGO, drclassdcd), rank soils from well drained to very poorly drained. '*Somewhat excessively drained*' and '*excessively drained*' soils should not be considered in this analysis because they are not vulnerable to extended inundation. While well drained soils can decrease vulnerability, be aware that there may be an inverse relationship with erodible soils because well drained soils are typically associated with sand.

Necessary Data and Sources:

Data	Source
Soil Drainage Class	USDA: Soils Data Mart; New Jersey SSURGO (with tabular files: mapunit and muaggatt; found at: http://soildatamart.nrcs.usda.gov/templates.aspx)

1. **Import SSURGO layer**
2. **Add Tabular Soil Data**
   a. From ArcCatalog, add "mapunit" & "muaggatt"
   b. Right click on SSURGO layer and join mapunit. They share the field "mukey" in common.
   c. Then join muaggatt (sharing "mukey").
3. **Create Drainage Index**
   a. Add Index Field to Attribute Table and sort by drainage class ("drclassdcd")
   b. Turn Editor On and rank drainage classes as below
4. **Convert to Raster**
   ```
   Conversion Tools > To Raster > Feature to Raster
                    Value: index
   ```

Soil Drainage	Rank	GIS Rank
Excessively Well Drained	None	0
Well Drained	Very Low	1
Moderately Well Drained	Low	2
Somewhat Poorly Drained	Moderate	3
Poorly Drained	High	4
Very Poorly Drained	Very High	5

Brick Township, NJ

Value

☐ Excessively Well Drained
🟩 Well Drained
🟨 Moderately Well Drained
🟧 Somewhat Poorly Drained
🟧 Poorly Drained
🟥 Very Poorly Drained

Erosion

There are multiple ways to assess erosion risk. Communities should use erosion data that are available to them, which many require erosion rates of coastlines to be projected into the future to fully assess erosion risk. Because erosion analysis has not been done for all shorelines and shoreline types in New Jersey, communities can utilize existing datasets available to them, including erodible soils data (SSURGO, kffact) and historical shoreline data. The soils data should serve as the basis of the erosion model. Rank the kffact scores, which represent the susceptibility of soil particles to detachment by water. Note that there are gaps in the data. Where there is an obvious correlation between adjacent soils, utilize the adjacent classification. Where there is not an obvious correlation, rank the area as 0. To supplement the soils data, utilize historic shoreline data to identify beachfront areas that have a history of erosion or accretion. Areas of historic erosion should be classified as very high. Areas of historic accretion should be classified as 5 because those land areas are susceptible to change.

Necessary Data and Sources:

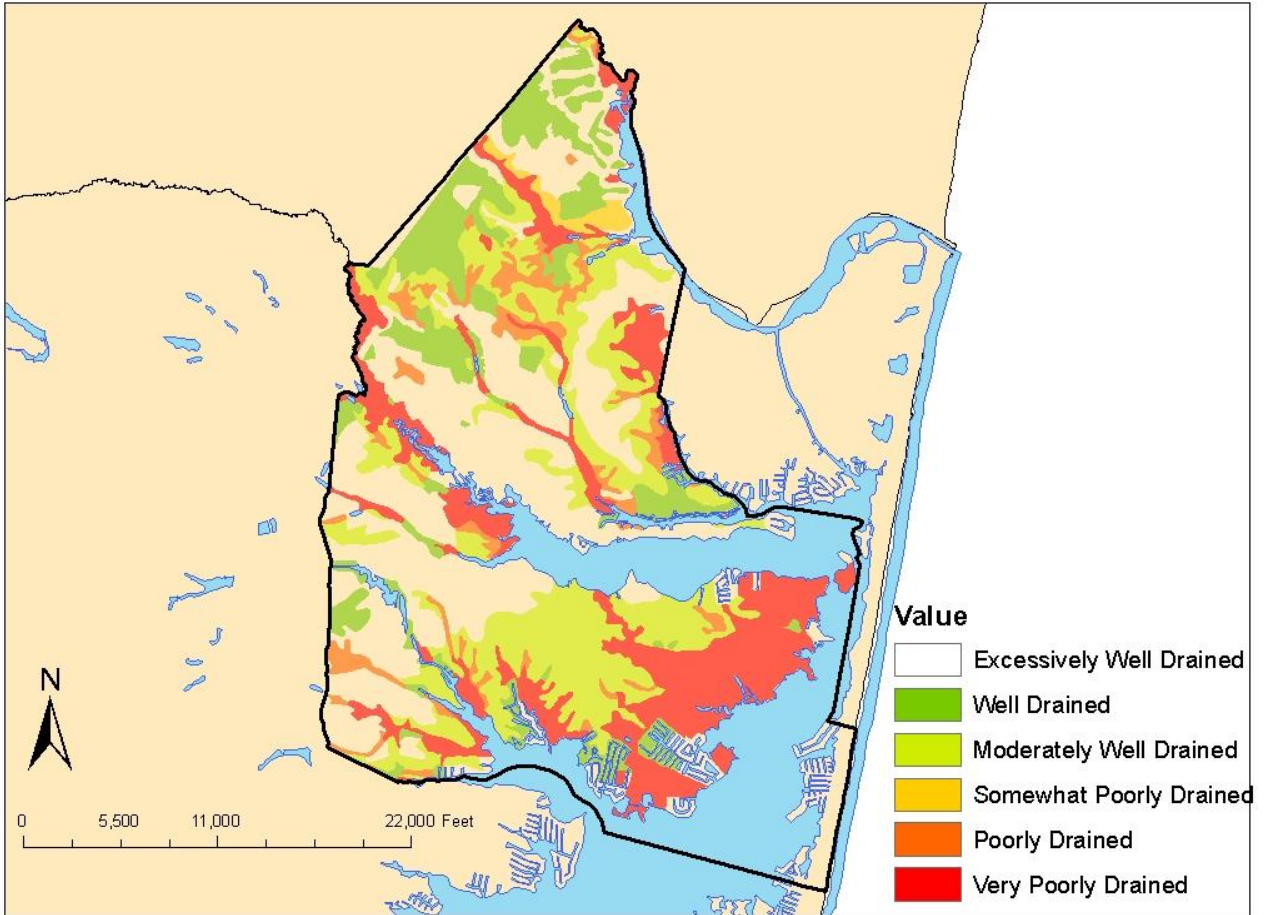| Data	Source
Soil Erodability	USDA: Soils Data Mart; New Jersey SSURGO (with tabular files: mapunit, component, and chorizon; found at: http://soildatamart.nrcs.usda.gov/templates.aspx)
Historical Erosion	Any existing data sets that display areas of historic erosion

1. **Import SSURGO layer**
2. **Add Tabular Soil Data**
   a. From ArcCatalog, add "mapunit," "component," and "chorizon"
   b. Right click on SSURGO layer and join mapunit. They share the field "mukey" in common.
   c. Right click on component and join chorizon. They share the field "cokey" in common.
   d. Join component:chorizon to the SSURGO layer using common field, "mukey."
3. **Add historic erosion/accretion data**
   a. If the data exists for your study area, add data layers
   b. Merge to SSURGO data as explained in Flood-Prone Section
4. **Create Erosion Index**
   a. Add Index Field to Attribute Table and sort by "Kffact"
   b. Turn Editor On and rank as below
5. **Convert to Raster**

```
Conversion Tools > To Raster > Feature to Raster
                  Value: index
```

Erosion Prone Areas	Rank	GIS Rank
No Kffact Attribute	None	0
.10 Kffact	Very Low	1
.17 and .15 Kffact	Low	2
.28 and .20 Kffact	Moderate	3
.37 and .32 Kffact, Historic Accretion	High	4
.43 Kffact, Historic Erosion	Very High	5

Brick Township, NJ

Erosion Index

	Very Low
	Low
	Moderate
	High
	Very High
	Extremely High

0   5,500   11,000   22,000 Feet

Geomorphology

The New Jersey shore is comprised of multiple geomorphic settings because of varying wave, current, and wind energy that exists along the coast. There are seven distinctive shoreline types along the Jersey shore, including spits, high and mixed-energy barrier island systems, headlands, bays and open bay systems, tidally influenced, freshwater rivers and estuaries. These shoreline types are indicative of the natural hazards and geologic processes that have shaped them over time. Geomorphology should be included in large-scale assessments, but may not be necessary in coastal communities because they typically represent one geomorphic region. The NJCMO delineated multiple geomorphic classifications along the New Jersey shore by identifying the watersheds that are tidally influenced and labeling them with the geomorphic description identified in the New Jersey Shore Protection Master Plan. Based on anecdotal information, each geomorphic region was ranked for its vulnerability to coastal hazards and sea level rise.

Necessary Data and Sources:

Data	Source
Geomorphic Region	NJDEP-GIS: Tide Gauges and Watershed; NJCMP- Shore Protection Master Plan

1. **Import Geomorphology Layer.** There is no "standard" geomorphology layer. Keep in mind that your study area may not have all geomorphic regions below represented. If you do not have a geomorphic region layer, you can classify a watersheds layer by geomorphic region using editor as below.
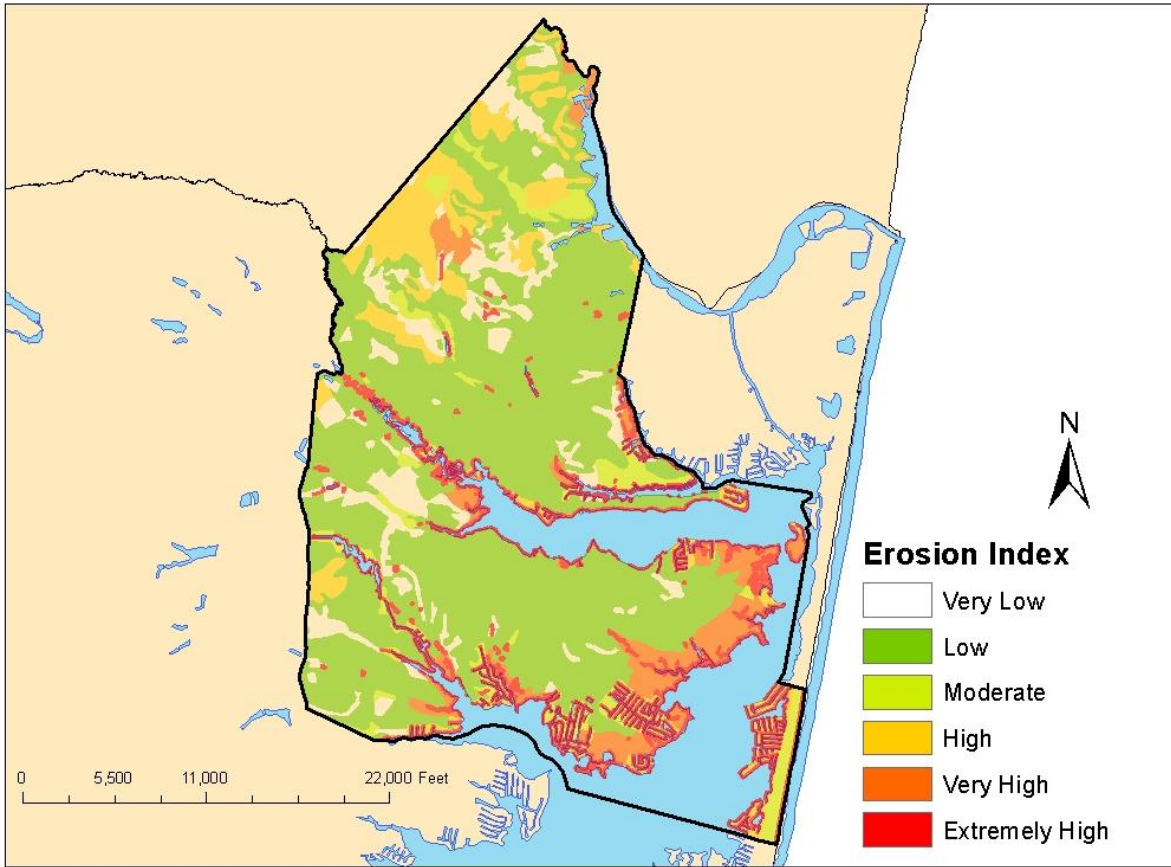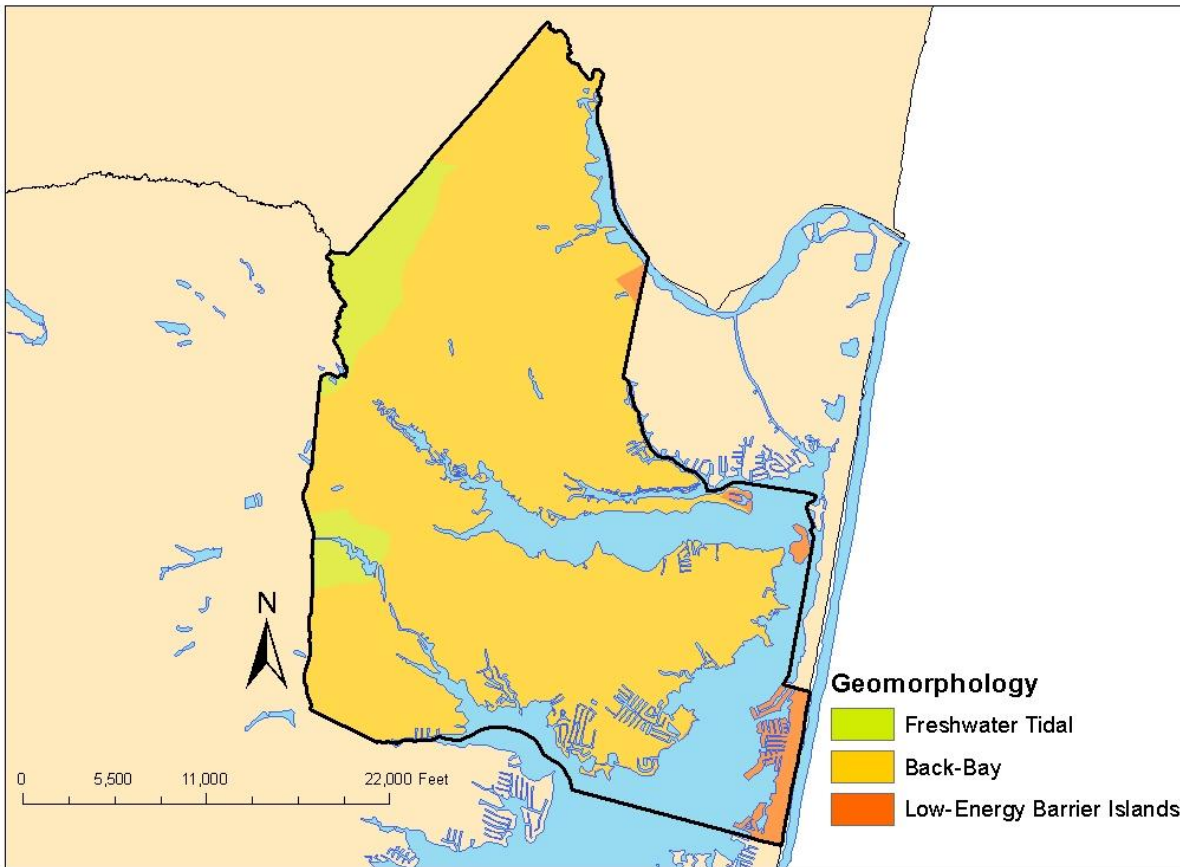
2. **Create Geomorphology Index**
   a. Add Index Field to Attribute Table and sort by region
   b. Turn Editor On and rank as below.

3. **Convert to Raster**

```
Conversion Tools > To Raster > Feature to Raster
                Value: index
```

Geomorphic Region	Rank	GIS Data
Non-Tidally Influenced Watersheds	None	0
Headland Systems	Very Low	1
Freshwater Tidal Systems	Low	2
Back Bays and Open Bay Systems	Moderate	3
Mixed-Energy Barrier Systems	High	4
Spits & High-Energy Barrier Systems	Very High	5

Brick Township, NJ

Geomorphology

- Freshwater Tidal
- Back-Bay
- Low-Energy Barrier Islands

0   5,500   11,000   22,000 Feet

Storm Surge

Storm surge inundation patterns are not usually well represented in flood plain maps. To understand the potential for inundation, communities should apply the National Hurricane Center's SLOSH Model, coupled with a MHHW scenario, to understand the worst case scenario of any storm event. MHHW represents the daily extent of tidal inundation and is obviously the most vulnerable area. The inundation of a category one storm would be classified as the high, followed by the inundation extent of a category two hurricane, etc. These storm scenarios are ranked this way because a category one storm is most likely to occur. Additionally, if a category four storm impacted the Shore, the inundation will be worst in low-lying areas.

To create the Storm surge index, we must create inundation maps for each category storm and then combine them. Below are instructions for doing this using the SLOSH viewer and ArcGIS.

Necessary Data and Sources:

Data	Source
Historic Storm Tracks	NOAA National Hurricane Center
Modeled Storms (MOM's)	SLOSH Model, VDatum
Elevation Data (LiDAR)	USGS Click

21. **Export SLOSH Outputs**. As mentioned in section (X), The MOM projections should be used in this analysis. SLOSH display basin are currently being updated to display surge with respect to NAVD88, however, some are still in NGVD29, so check the datum of reference listed on the legend when the storm is loaded.
    a. Open SLOSH Display
    b. Choose your basin of interest
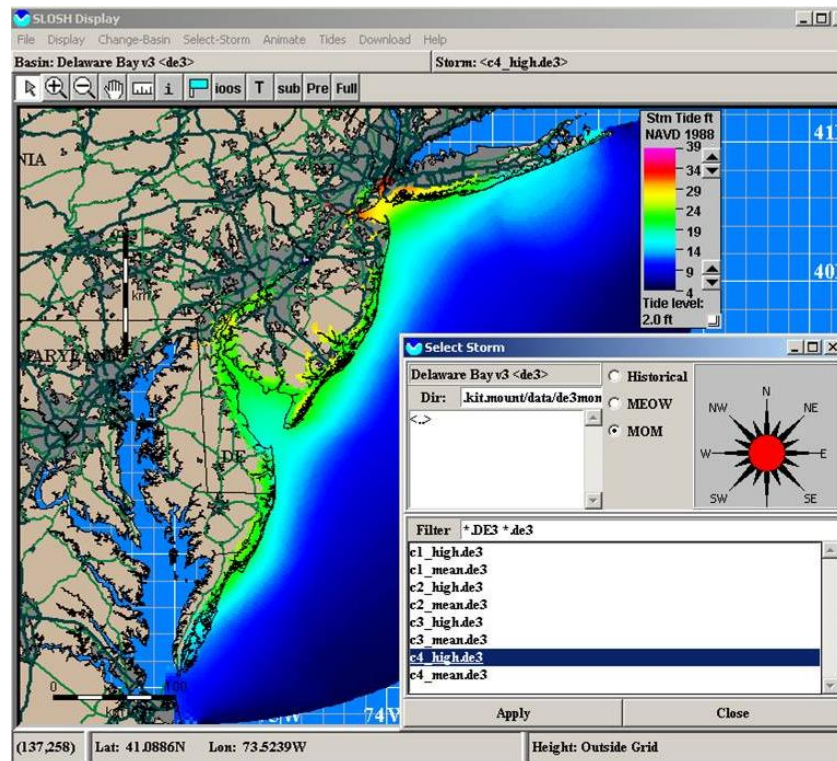
    c.   Select Storm. Choose MOM; use "HI" for each category to display worst case

    d.   Save data

```
File > save data to .shp
```

    e.   Repeat for each category storm

22. **Import SLOSH Outputs**. Examine this file. Make sure the projection of the SLOSH data matches the DEM. The surge values represent inundation relative to NAVD88. If they are not, V-Datum can transpose them not NAVD88 (This will be addressed in step 4 below). Some steps need to be taken to display as inundation over land for your region.

23. **Delete areas without surge values**. Open attribute table. Notice the value of "99.9" in many of the surge height rows. This represents areas where surge would not reach. This should be deleted.

    a.   Select (by attributes) and delete from feature.

24. **Plot the centroids of surge data.** The SLOSH outputs features give surge values across a wide swath of surge zone. As a result, the resolution can be quite coarse in some areas. Therefore, we need to interpolate this data on a smaller scale. To start this process, we must plot the centroids of the surge data.

    a.   Add fields for x and y in attribute table

    b.   Populate them accordingly using "Calculate Geometry."

    c.   Check the vertical units of your DEM. The SLOSH outputs are in feet. If your DEM uses metric units, you will need to add a new field to convert the output to meters.

    d.   Export Table as dbase file (.dbf). Add table to current map.

    e.   Right click on SLOSH table layer and go to "Display X Y Data" using new fields as X &Y. The Z field should be your surge height (with correct units).

    f.   Export new "Events" layer as new feature to make permanent

25. **Interpolate SLOSH centroids.** There are numerous interpolation methods available on ArcGIS, but we'll use Spline Tool. Chose surge heights (with correct units) for the value field. Be sure that your output cell size is the same as your DEM

```
Spatial Analyst Tools > Interpolation > Spline
```

26. **Subtract your DEM from the interpolated surge raster.** Because the surge heights are referenced to NAVD88, they do not represent inundation over land until the actual heights of the land surface (with respect to NAVD88) are subtracted. To accomplish this, we create a conditional statement in Raster Calculator.

```
Spatial Analyst Toots > Map Algebra > Raster Calculator
       Equation: Con(SURGEHGT>=DEM, SURGEHGT-DEM)
```
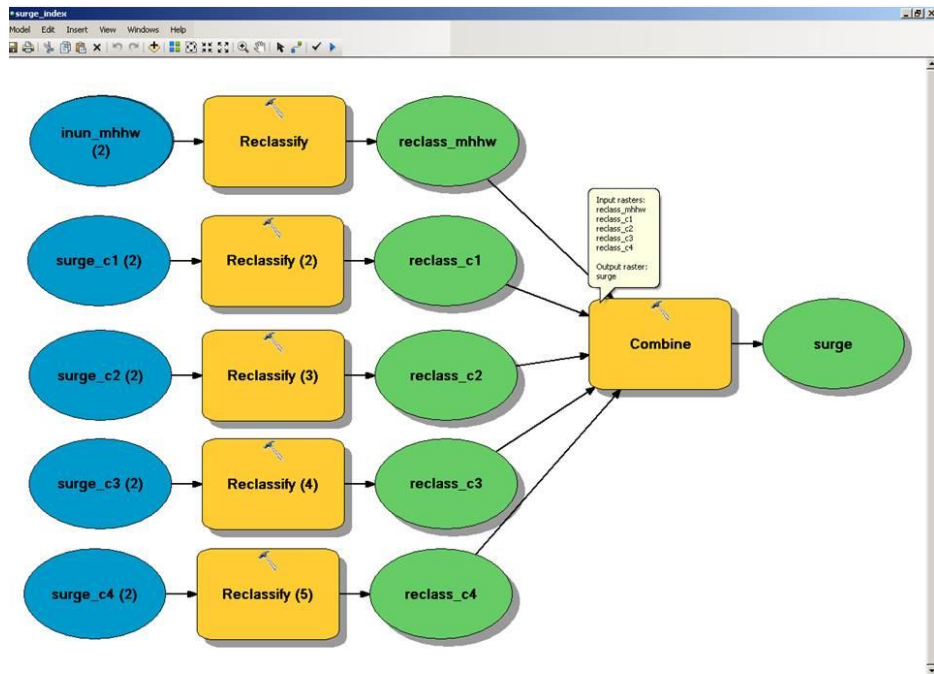
This states, "In all conditions in which the surge height is greater than the DEM (i.e. where inundation occurs); subtract the DEM from the surge height."

27. **Repeat steps 2 – 6 for all categories of storm.**

28. **Add MHHW raster created in Section 1**

29. **Create Storm Surge Index**

    a.   Reclassify rasters. Change "NoData" to "0." Change all other values to "1."

    b.   Use the Combine Tool to add all Storm Surge rasters and the MHHW raster.

c. Examine output raster. Add Index Field to attribute table. Add all raster columns in combined raster

d. Assign ranking based on index values.

Hurricane Storm Surge	Rank	GIS Rank
Areas Outside of Surge	None	0
Category 4	Very Low	1
Category 3	Low	2
Category 2	Moderate	3
Category 1	High	4
Mean Higher High Water	Very High	5

Brick Township, NJ
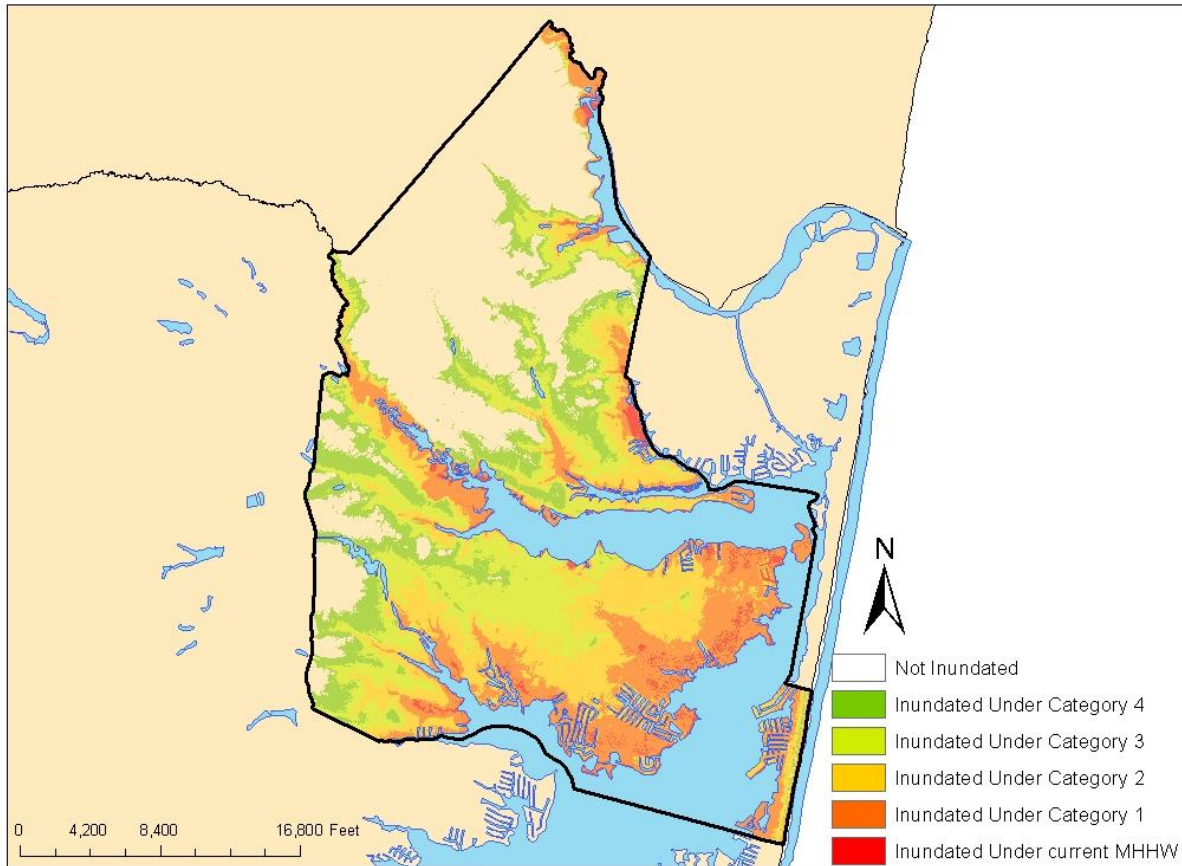
Putting It All Together – Coastal Vulnerability Index

$$CVI = a + b + c + d + e + f$$

Where
a = Geomorphology
b = Slope
c = Flood Prone Areas
d = Storm Surge Inundation (SLOSH)
e = Soil Drainage
f = Soil Erosion
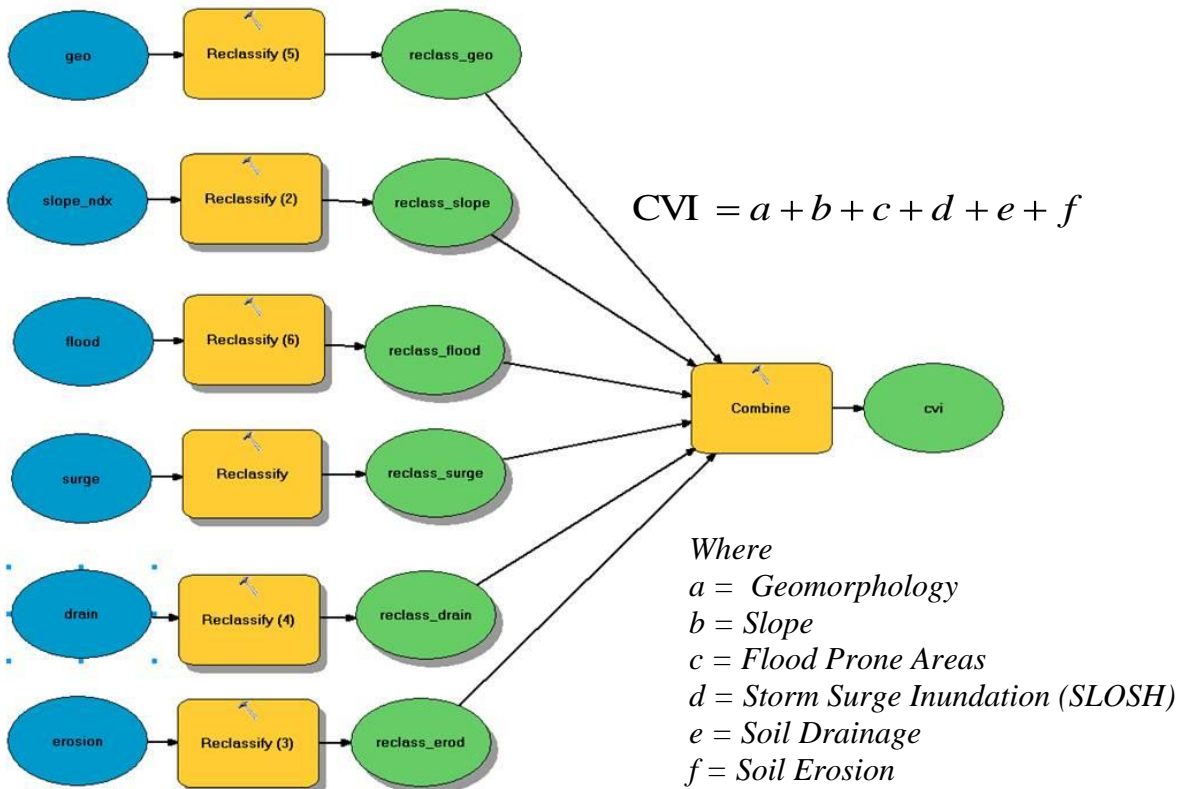
To classify each input, add a column to each feature or raster layer and add the corresponding rankings associated with the degree of vulnerability, as seen in the table on the following page and in the model input descriptions seen later in this appendix. Once all original inputs are ranked, ensure that it is in or is converted to a raster data layer, based off of the column of the vulnerability ranking. The cell size of each raster should correspond to the resolution of the LiDAR DEM being used in the analysis. Ensure that the rankings in the attribute table of each raster data layer still corresponds with the correct vulnerability rankings. If they do not, reclassify each input into the correct vulnerability ranking scheme. Next, combine each of the raster layers into one raster data set, using the Combine Tool or Weighted Sum Tool. Once the inputs are combined into one output model, the separate rankings from each input should be visible. Add a column. Within that column, sum the rankings from each input.

| 1	4	3		4	2	No Data		5	6	3
4	6	2	+	3	5	2	=	7	11	4
No Data	3	5		1	4	5		1	7	10

Note that spatial data does not always align with one another; therefore, unranked data and NO DATA values should equal 0. This will avoid deleting land areas where the datasets do not

perfectly align, especially along shorelines. After totaling the rankings, any areas that have a value of 0 can be deleted from the analysis. This will include coastal waters and may include upland areas that are not vulnerable to hazards.

1. **Create Coastal Vulnerability Index**
   a. Reclassify rasters. Change "NoData" to "0." All other values (1-5) should remain the same.
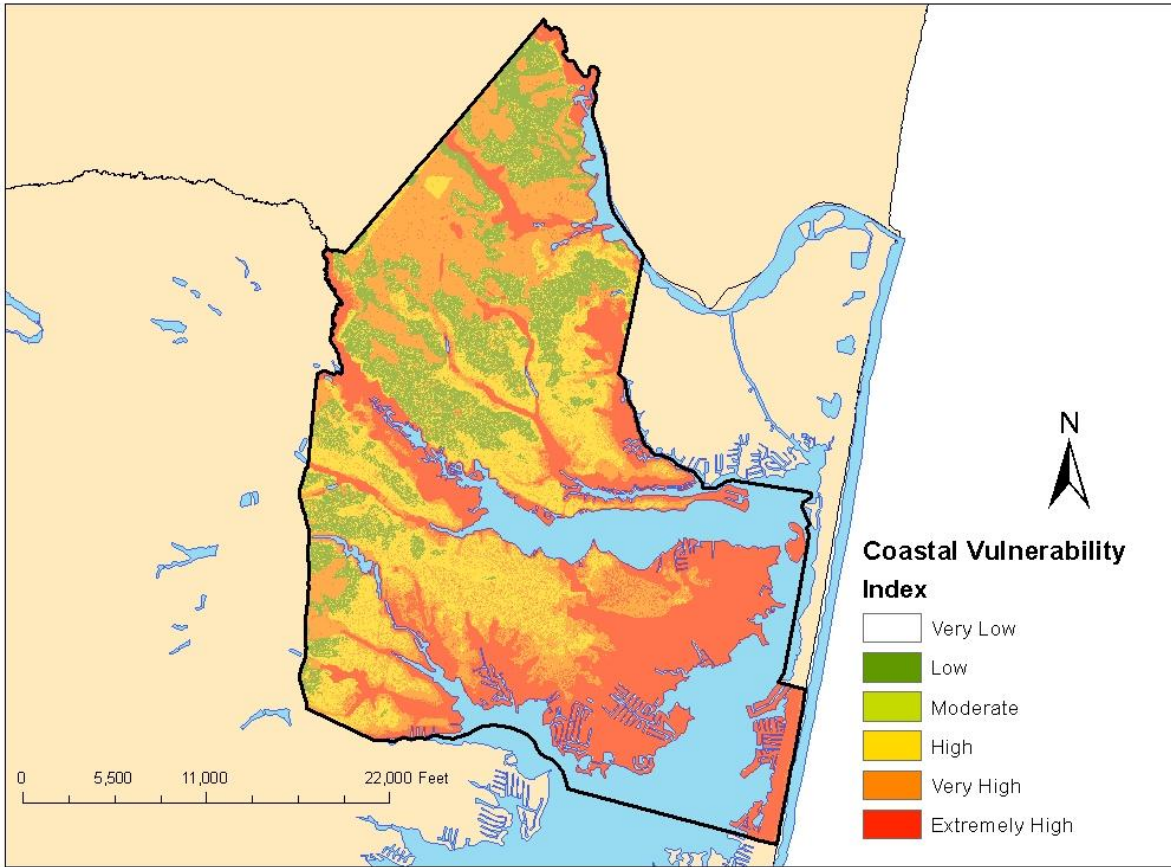   b. Use the Combine Tool to add all rasters.
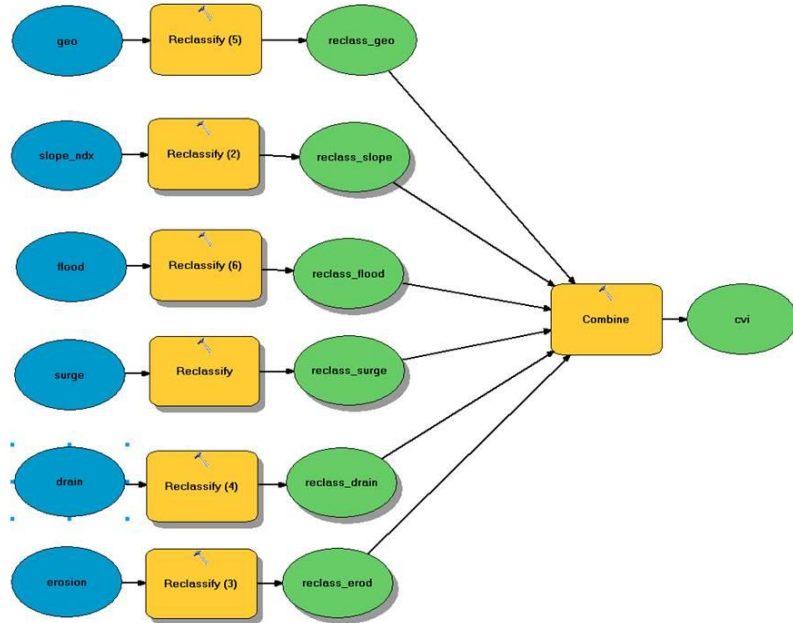
   c. Examine output raster. Add Index Field to attribute table. Add all raster columns in combined raster
   d. Assign ranking based on index values.

Table 1: Coastal Vulnerability Index: Ranking by Variable

	Variable	Very Low	Low	Moderate	High	Very High
(a)	Geomorphology	Headland Systems	Freshwater Tidal Systems	Back Bay and Open Bay Systems	Mixed-Energy Barrier Systems	Spits and High Energy Barrier Systems
(b)	Slope (%)	1.00 – 2.00	.75 – 1.00	.50 - .75	.25 - .50	<.25
(c)	Flood Prone	Moderately Flood Prone Soils Outside of the Floodplain	Highly Flood Prone Soils Outside of Floodplain	500-Year Floodplain	100-Year Floodplain	Velocity Zone
(d)	Storm Surge (SLOSH)	Category 4 Hurricane	Category 3 Hurricane	Category 2 Hurricane	Category 1 Hurricane	Mean High Higher Water
(e)	Drainage	Well Drained	Moderately Well Drained	Somewhat Poorly Drained	Poorly Drained	Very Poorly Drained
(f)	Erosion	.10 Kffact	.17 & .15 Kffact	.28 & .20 Kffact	Historical Accretion and .37 & .32 Kffact	Historical Erosion and .43 Kffact
	Ranking	**2**	**3**	**4**	**5**	**6**

Brick Township, NJ

Coastal Vulnerability Index

- ☐ Very Low
- ☐ Low
- ☐ Moderate
- ☐ High
- ☐ Very High
- ☐ Extremely High

0   5,500   11,000   22,000 Feet

Sea-Level Rise

Because there are numerous sea level rise projections, the NJOCM suggests that communities utilize a 0.5, 1.0, and/or 1.5 meter scenario when modeling sea level rise. There are multiple ways that a community can visualize the potential inundation threats associated with sea level rise. A Bath Tub Model is a simple model that utilizes a digital elevation model to determine land areas that lie below a particular elevation contour. To create such a model, one can either convert a LiDAR DEM from NAVD88 to a MHHW tidal datum prior to performing the inundation analysis or create a 'generic' MHHW zero raster and convert this to NAVD88 using V-Datum. If you have already run the CVI, you can use the MHHW raster you created in the Getting Started section. Sea level rise models can also be applied on top of spring tide scenarios to reflect the inundation extent of future spring tides.

1. **Add Sea-level rise projections**. Since we have a raster for MHHW, we can add levels of see-level rise to this file using the Math tools. Be sure that the SLR value is added to the EA_MHHW file. Also be sure that the additions are in the correct units (i.e. 1ft or 1m, depending on the vertical units of your DEM)

```
                      Spatial Analyst > Math > Plus
        Input raster or constant value 1: EA_MHHW (not the inundation file)
               Input raster or constant value 2: [value of SLR]
```

2. **Subtract the DEM from this Raster.** Follow the equation shown in step 14 above.
3. **Repeat for additional SLR values.** We recommend either 0.5 m intervals or 1 ft intervals.

Interaction between Sea-Level Rise and Storm Surge

So far, this cookbook has explained how to express inundation due to Sea-level Rise and due to Storm Surge separately. It can be useful to visualize impacted areas from each of these hazards on their own. However, these hazards are inherently linked. For example, if a region experiences 3 ft of SLR, a Category 1 hurricane will inundate much more area than it would have at current MHHW. Therefore, a simple "overlay" of the two layers does not account for the interaction between the two.

To account for sea level rise, storm surges can be geographically reflected with 0.5, 1.0, or 1.5 meters of additional rise and ranked with the same classification scheme as existing surge models. Since the SLOSH outputs are referenced to NAVD88, simply adding the projected rise in SLR to the output before subtracting the DEM will provide a rough idea of how SLR will affect storm surge in the future. This step should occur after the surge points are interpolated.

1. **Interpolate SLOSH centroids.** (Step 5 above). Be sure that your output cell size is the same as your DEM

   ```
   Spatial Analyst Tools > Interpolation > Spline
   ```

2. **Add Sea-level rise projections**. Since we have a raster for MHHW, we can add levels of see-level rise to this file using the Math tools. Be sure that the SLR value is added to the EA_MHHW file. Also be sure that the additions are in the correct units (i.e. 1ft or 1m, depending on the vertical units of your DEM

   ```
                    Spatial Analyst > Math > Plus
       Input raster or constant value 1: [interpolated surge raster]
            Input raster or constant value 2: [value of SLR]
   ```

3. **Subtract the DEM from this Raster.** Use the following formula in Raster Calculator
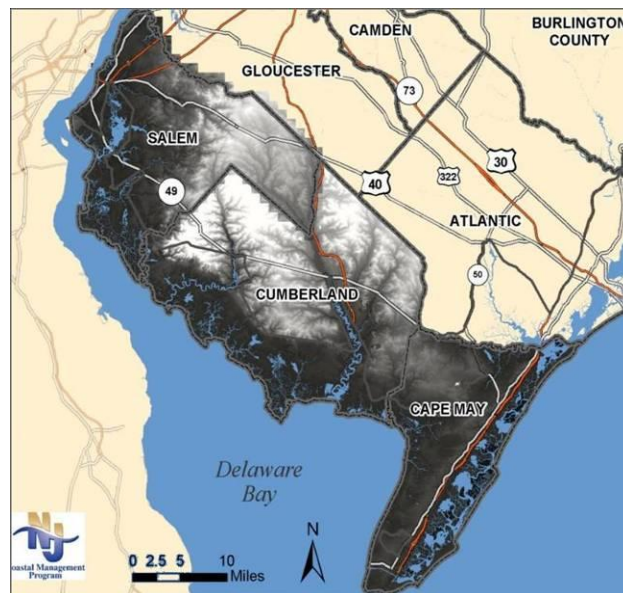
   ```
           Con(SURGEwSLR>=DEM, SURGEwSLR-DEM)
   ```

   Be sure to Scale back to the cell size of the DEM if the surge layer was coarser than the DEM
4. **Repeat for additional Surge values.** There are up to 20 combinations of SLR and Storm Surge that can be mapped. It will be up to the mapper to decide which projections to include.

Appendix B: Delaware Bay Focus Area

The Delaware Bay is designated as a region of particular importance by the New Jersey Office of Coastal Management because it remains relatively undeveloped compared to the Atlantic coast. The Bay serves as the terminating point of the vast Delaware River Basin drainage and is part of the nationally designated Delaware Bay Estuary which encompasses nearly 650 square miles of wetlands. Its rural landscape is comprised mainly of tidal wetlands, farmland and a handful of narrow, developed beaches. Historically, the Bay was once home to multiple ports and fishing villages, but large scale operations altered this scenario. The maritime industry is now located further up the Delaware River near Camden and Philadelphia. While the Delaware Bay

Map 13: Delaware Bay Coastal Counties – LiDAR

remains relatively undeveloped, it has been altered by human use. Despite the fact that the Bay as a whole has lost fifty percent of its tidal wetlands, it still supports the majority of the New Jersey's tidal wetlands and is rich in its biodiversity. The Bay serves as the largest spawning ground for horseshoe crabs in the world, and is the second largest avian staging area for migratory shorebirds in the Western Hemisphere. In addition, Salem, Cumberland, and Cape May counties alone provide an estimated $2.25 - $3.17 billion annually in ecosystem services, mainly due to filtration and habitat that the immense acreage of tidal wetlands provide within this region.[35] Unfortunately, high rates of erosion have resulted in a loss of tidal marshes and beachfront, threatening habitat, ecosystem services and historic resources alike. As sea level rise accelerates, it is anticipated that erosion rates, saltwater intrusion and inundation from storms will increase as well, exacerbating the loss of critical habitat and natural storm buffers.

Recognizing the Delaware Bayshore's abundant natural resources and that bay communities are threatened by the impacts of coastal hazards, the New Jersey Office of Coastal Management identified it as a pilot study location to develop and test the *Coastal Community Vulnerability Assessment and Mapping Protocol*. In 2007 and 2008, high resolution elevation data (LiDAR) was collected for this area.[36] Data was collected within ± 3 hours of Mean Low Water, capturing the intertidal zone, which will allow for more precise delineation of vulnerable areas along the Bay. High quality elevation is the single most important dataset in a vulnerability assessment. It allowed the NJOCM to assess the vulnerability of the Delaware Bay to the impacts of coastal hazards and sea level rise, as seen throughout this document.

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[35] NJDEP. (2007).
[36] See page 12 for more information on LiDAR.

Appendix C: Pilot Assessments

The New Jersey shore is geographically diverse, varying in geologic and demographic composition. New Jersey's northern shores are located within the New York-New Jersey Metropolitan area, one of the most highly urbanized and industrialized regions in the nation, while the shores of the Delaware Bay are sparsely populated and largely consist of tidal wetlands and agricultural lands. Because the character of coastal communities varies throughout the state, the NJOCM recognized the need to pilot the *Coastal Community Vulnerability Assessment and Mapping Protocol* and the *Getting to Resilience* questionnaire in coastal communities with varying geographic and demographic characteristics.

The Coastal Community Vulnerability Assessment and Mapping Protocol and resilience assessment tools were piloted in Cape May Point, Little Silver, and Oceanport.[37] The NJOCM was also able to pilot its assessment tools in Greenwich Township, which is located in Cumberland County along the Delaware Bay.[38] The pilot communities represented small to medium sized communities located along back-bays, beachfronts, and tidal creeks, but did not include Atlantic beachfront communities or large, intensely developed municipalities. Prior to these research efforts, none of the participating communities had locally generated vulnerability assessments. The communities had relied upon consultants to generate their existing municipal master plans and were dependent upon their county governments to incorporate them into countywide or regional all-hazard mitigation plans. In piloting the

Map 14: Pilot Communities

vulnerability mapping and resilience questionnaire, the NJOCM and coastal partners convened meetings with a diverse group of local decision-makers. While participation varied by municipality, the participating community leaders were eager to learn about their community's existing and future coastal hazard vulnerabilities and resilience capacity. Through the commitment of these community leaders, the NJOCM was able to validate and improve upon its assessment tools for their future application along the New Jersey shore.

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[37] New Jersey Sea Grant Consortium. (2010).
[38] NJDEP. NJOCM. (2011a).

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