

MARYLAND COASTAL RESILIENCY ASSESSMENT

March, 2016

With its extensive shoreline, Maryland's coasts experience flooding and erosion, caused by tides and storms and exacerbated by sea level rise. Natural habitats, such as marshes and coastal forests, can reduce the impacts of these hazards through the processes of wave attenuation, increased infiltration and sediment stabilization. While the Maryland Department of Natural Resources (DNR) utilizes various tools to target restoration and protection of habitats based on ecological, water quality and other criteria, these tools do not evaluate the risk-reduction benefits of natural features such as forests, marshes, dunes, oyster reefs, and underwater grasses. To support the DNR in their efforts to incorporate risk-reduction benefits into decision-making, The Nature Conservancy (TNC) partnered with the Chesapeake and Coastal Services (CCS) to conduct a Statewide Coastal Resiliency Assessment.

In order to spatially assess where natural habitats have the greatest potential to reduce risk for people, it is important to address three questions: where are the hazards, where are the people, and where are the habitats? The project team used spatially explicit computer modeling informed by scientific literature and local expert opinion to answer these questions and identify where natural habitats provide the greatest potential risk reduction for Maryland's coastal communities. The products of the Assessment include calculation of a Shoreline Hazard Index, which estimates the relative exposure to coastal hazards for the entire Maryland shoreline; delineation of Coastal Community Flood Risk Areas; selection of Priority Shoreline Areas for conservation and/or restoration; and the calculation of a Marsh Protection Potential Index. Habitats play a large potential role in risk reduction for MD coastal residents. The results of this Assessment provide tools to target coastal adaptation efforts so that protecting or restoring natural habitats also provides the greatest risk reduction benefit to coastal residential communities.



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Abbreviations and Acronyms

CBP	Chesapeake Bay Program
CCS	DNR Chesapeake and Coastal Service
CMECS	Coastal and Marine Ecological Classification Standard
DEM	Digital Elevation Model
DNR	Maryland Department of Natural Resources
ESI	NOAA Environmental Sensitivity Index
ESRGC	Eastern Shore Regional GIS Cooperative
FEMA	Federal Emergency Management Agency
MDP	Maryland Department of Planning
MEMA	Maryland Emergency Management Agency
MGS	Maryland Geological Survey
MHCD	Maryland Department of Housing and Community Development
MOM	Storm Surge Maximum of the Maximum
MPPI	Marsh Protection Potential Index
NACCS	USACE North Atlantic Coast Comprehensive Study
NatCap	The Natural Capital Project
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetlands Inventory
PDI	Population Density Index
SLAMM	Sea Level Affecting Marshes Model
SLOSH	NOAA Sea, Lake, and Overland Surges from Hurricanes Model
SLR	Sea Level Rise
STWAVE	USACE Steady-State Spectral Wave Model
SVI	Social Vulnerability Index
SWEL	Stillwater Flood Elevation
TNC	The Nature Conservancy
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
VIMS	Virginia Institute of Marine Science

Project Definitions

- **Community Resilience** – The ability of a community to prepare for, respond to, and recover from a coastal hazard event.
- **Coastal Hazard**¹ – Coastal storm and flood events that may increase the likelihood of danger or damage to life and property as a consequence of inundation and shoreline erosion. These hazards are caused by storms and exacerbated by sea level rise.
- **Coastal Communities** – People living within the coastal zone and exposed to coastal storm and flood hazards such as inundation and shoreline erosion. For the purposes of this assessment, we have represented coastal communities by mapping residential populations within the area predicted to be inundated by a Category 4 Hurricane storm surge.
- **Targeted Coastal Communities** – Coastal communities with demographic parameters or community characteristics that may limit the population’s ability to prepare for, respond to, and/or recover from coastal hazard events. For the purposes of this assessment, we examined population density and the social vulnerability metrics of age, poverty, and English proficiency.
- **Risk Areas** – Locations within the coastal zone where targeted coastal communities are exposed to periodic coastal storm and flood hazard events with possible impacts from sea level rise.
- **Natural Features** – Habitats within the subtidal, intertidal, and coastal environment that enhance coastal community resilience through wave attenuation, shoreline stabilization, infiltration and other storm and flood risk reduction benefits. Maryland’s natural features include tidal wetlands and marshes, vegetated buffers, oyster reefs, submerged aquatic vegetation, Bay islands, beaches, and dunes.

¹ The State Hazard mitigation Plan identifies coastal hazards as: Hurricanes, nor’easters, and other coastal storm events that result in storm surge inundation, heavy precipitation, flash flooding, and/or shoreline erosion. Coastal hazards also include longer-term hazards such as sea level rise. We have altered the definition to focus on events at the land/water interface while putting equal emphasis on inundation and erosion.

Executive Summary

With its extensive shoreline, Maryland's coasts experience flooding and erosion, caused by tides and storms and exacerbated by sea level rise. Natural habitats, such as marshes and coastal forests, can reduce the impacts of these hazards through the processes of wave attenuation, increased infiltration and sediment stabilization. While the Maryland Department of Natural Resources (DNR) utilizes various tools to target restoration and protection of habitats based on ecological, water quality and other criteria, these tools do not evaluate the risk-reduction benefits of natural features such as forests, marshes, dunes, oyster reefs, and underwater grasses. To support the DNR in their efforts to incorporate risk-reduction benefits into decision-making, The Nature Conservancy (TNC) partnered with the Chesapeake and Coastal Services (CCS) to conduct a Statewide Coastal Resiliency Assessment.

In order to spatially assess where natural habitats have the greatest potential to reduce risk for people, it is important to address three questions: where are the hazards, where are the people, and where are the habitats? The project team used spatially explicit computer modeling informed by scientific literature and local expert opinion to answer these questions and identify where natural habitats provide the greatest potential risk reduction for Maryland's coastal communities. The products of the Assessment include calculation of a Shoreline Hazard Index, which estimates the relative exposure to coastal hazards for the entire Maryland shoreline; delineation of Coastal Community Flood Risk Areas; selection of Priority Shoreline Areas for conservation and/or restoration; and the calculation of a Marsh Protection Potential Index. Habitats play a large potential role in risk reduction for MD coastal residents. The results of this Assessment provide tools to target coastal adaptation efforts so that protecting or restoring natural habitats also provides the greatest risk reduction benefit to coastal residential communities.

1. Introduction

Maryland's extensive coastline is an integral part of the state's economy and cultural identity. Hurricane Sandy was a stark reminder of the coastal hazards of storm-induced flooding and erosion. While other states were harder hit, damages from Hurricane Sandy throughout Maryland were estimated at more than \$41 million (MHCD, 2013). Between 1993 and 2010, coastal hazard events accounted for \$109 million in property damage, \$193,215 in crop damages, 1 death and 201 injuries (MEMA, 2011). In the future, sea-level rise caused by climate change will exacerbate the impacts from coastal storms as well as tidal flooding (Boesch et al., 2013). Maryland is a signatory to the 2014 Chesapeake Bay Watershed Agreement (CBP, 2014), which established a Climate Resiliency Goal and associated Adaptation Outcome to "continually pursue, design, and construct restoration and protection projects to enhance the resiliency of Bay and aquatic ecosystems from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms and sea-level rise." Among State agencies, DNR has the lead role in advancing the scientific understanding of Maryland's vulnerability to climate change, and in advocating for sound planning to avoid or minimize the anticipated impacts (DNR, 2016). Shoreline armoring, once the standard response to coastal flooding and erosion, is now known to negatively impact natural ecosystems, cause flooding and erosion to worsen elsewhere, and can be costly to build and maintain. Natural habitats can reduce the impacts of coastal hazards while providing many co-benefits, such as wildlife habitat, improved water quality, and recreational opportunities. While DNR utilizes various tools to target restoration and protection based on ecological, water quality and other criteria, these tools do not evaluate the risk-reduction benefits of natural features such as forests, marshes, dunes, oyster reefs, and underwater grasses. DNR developed the Statewide Coastal Resiliency Assessment to fill this information gap.

The Coastal Resiliency Assessment project team was composed of staff from CCS and TNC and was informed by a steering committee consisting of 25 staff from three state agencies, two federal agencies, and three non-profit organizations. The steering committee met quarterly to inform model development and ensure that products of the Assessment are applicable and relevant to current decision-making processes. An additional 29 advisors provided guidance on particular model components and feedback on draft results.

2. Inventory of Existing Data, Tools and Projects

The project team inventoried background information for the Assessment, including existing data resources (Appendix A) and coastal resiliency tools (Appendix B). The team also met with partners who had recently completed or were currently working on analyses related to coastal hazards and social vulnerability in Maryland including 1) MD Emergency Management Agency, MD Department of Information Technology, and MD Environmental Service staff regarding the upcoming MD Hazard Mitigation Plan 2016 Update; 2) Eastern Shore Regional GIS Cooperative staff regarding the MD State Highway Administration transportation infrastructure vulnerability analysis; 3) US Army Corps of Engineers (USACE) staff regarding the North Atlantic Coast Comprehensive Study (NACCS); 4) Natural Capital Project staff regarding the InVEST Coastal Vulnerability model; 5) Conservation Fund staff

regarding the Greater Baltimore Wilderness Coalition; and 6) DNR staff regarding the MD Park Equity Analysis Mapping Tool.

3. Natural Features Analysis: Coastal Hazards and Habitats

In order to spatially assess where natural habitats have the greatest potential to reduce risk for people, it is important to address three questions: where are the hazards, where are the people, and where are the habitats? In general, risk occurs where people are in close proximity to hazards, and nature-based risk-reduction solutions are possible where natural features lie between people and hazards.

With coastal resilience projects in twelve states, as well as Latin America and the Caribbean, TNC has a network of practitioners actively developing and promoting nature-based risk-reduction solutions. A suite of mapping tools has been deployed on the CoastalResilience.org website to facilitate a four-step approach to resilience: assess risk; identify solutions; take action; and measure effectiveness (TNC, 2016). The Risk Explorer Tool on CoastalResilience.org ranks shoreline segments according to relative coastal exposure, social vulnerability and overall risk, and also highlights segments where habitats contribute the most to risk reduction. Underlying the Risk Explorer is The Natural Capital Project (NatCap) InVEST Coastal Vulnerability model, which has been run at a one-kilometer resolution for the entire U.S. coastline (Arkema et al., 2013), and at higher resolution for selected geographies, including the Gulf of Mexico, Long Island Sound, and Southeast Florida. Building on these successful efforts in other coastal states, the project team worked with NatCap staff to refine the InVEST Coastal Vulnerability model for the State of Maryland using local data, a higher model resolution and adjustment of default model settings. The Maryland analysis estimates the relative exposure of each 250-meter segment of the Maryland coastline to storm-induced erosion and flooding, and the relative effectiveness of existing natural habitats to buffer the shoreline from these hazards. The Maryland Shoreline Hazard Index was calculated from six physical variables (geomorphology, elevation, relative sea level rise, wave power, storm surge height and erosion rates) and five natural feature types (forest, marsh, dune, oyster reef and underwater grasses). Each variable is ranked from very low hazard (rank=1) to very high hazard (rank=5), based on criteria shown in Table 1 and explained below. The Shoreline Hazard Index is calculated as the geometric mean of the input variable hazard ranks at each shoreline segment. Two scenarios of the model were run - one scenario incorporating the protective role of all existing coastal habitats and a second scenario simulating the complete loss of habitats. The difference in the Shoreline Hazard Index between the two scenarios indicates the potential magnitude of coastal hazard reduction by habitats at each location.

Geomorphology

The geomorphology variable represents the propensity of the shoreline to erode based on landform and substrate. NatCap assigned Geomorphology Hazard Ranks based on natural shoreline types and anthropogenic structures in the Maryland Environmental Sensitivity Index (ESI) Map (NOAA, 2007). CCS edited Geomorphology Hazard Ranks as necessary to reflect additional structures recorded in the Shoreline Structures component of Maryland Shoreline Situation Reports (VIMS, 2006) and living shoreline locations (MD DNR, unpublished). After consulting with CCS Habitat Restoration staff

Table 1. Variables and Ranking System for InVEST Coastal Vulnerability Model.

Variable	Very Low Hazard Rank (1)	Low Hazard Rank (2)	Moderate Hazard Rank (3)	High Hazard Rank (4)	Very High Hazard Rank (5)
Geomorphology	Bulkhead	Rip-rap	Groin, breakwater, jetty, unconventional structure, living shoreline	Coarse-grained sand to gravel beaches	Other natural shoreline, dilapidated bulkhead
Elevation (meters)	14.7 - 81.6	5.9 - 14.7	2.3 - 5.9	0.5 - 2.3	0 - 0.5
Natural Habitats	Forest	Marsh	Dune	Oyster reef, Underwater grass (dense = 4, less dense = 4.5)	No habitat
Sea Level Rise (meters)	None	1.32 – 1.42	1.46 – 1.48	1.49 – 1.67	2.05 – 2.35
Wave Power (kW/m)	0 - 0.02	0.02 - 0.05	0.05 - 0.16	0.16 - 0.78	Atlantic Shoreline
Storm Surge Height (feet)	0	0.1 - 2.2	2.3 - 3.5	3.6 - 4.6	4.7 - 8.9
Erosion Rate (feet/year)	Accretion or Protected	0 - 2, no change or unknown	2 - 4	4 - 8	>8

regarding appropriate ranks for structures, Geomorphology Hazard Ranks were assigned as follows: Very Low (1) = bulkhead; Low (2) = rip-rap; Moderate (3) = groin, breakwater, jetty, unconventional structure, living shoreline; High (4) = coarse-grained sand to gravel beaches; and Very High (5) = other natural shorelines, dilapidated bulkhead (Appendix C, Figure A1). These ranks differ from those used in the national analysis in two ways: rip rap was ranked as 2 rather than 3 as in the national study, and living shorelines were included as a shoreline type.

Elevation

The elevation variable reflects the probability of inundation by coastal flooding. Elevation Hazard Rank was assigned based on the average land elevation within a five kilometer radius of each shoreline segment. A five kilometer search radius was selected because this value is consistent with the default setting used in the national study (Arkema et al., 2013), and sensitivity testing found that changing the search radius to 3 km or 1 km did not change the geographic pattern of elevation categories along the shoreline. Source data for the elevation variable was a 30 meter digital elevation model (DEM) resampled from higher-resolution LiDAR based DEMs (ESRGC, 2015). Elevation Hazard Ranks were assigned as follows, based on a quantile classification of values along the entire Maryland coastline: Very Low Hazard (1) = 14.7 to 81.6 meters; Low (2) = 5.9 to 14.7 meters; Moderate (3) = 2.3 to 5.9 meters; High (4) = 0.5 to 2.3 meters; and Very High Hazard (5) = 0 to 0.5 meters (Appendix C, Figure A2).

Sea Level Rise

The sea level rise (SLR) variable represents the vulnerability of the coast to long-term sea level change. Maryland, particularly vulnerable to sea level rise because of a combination of rising seas and sinking land, is projected to face from 0.7 meters to 1.7 meters in relative sea level rise by the year 2100, with a best-estimate projection of 1.1 meters (Boesch et al., 2013). After discussion with the steering committee, the project team decided to base the Sea Level Rise Hazard Ranks on the High projection of

1.7 meters. In order to estimate a range of values across the shoreline, the project team used a methodology developed by NatCap to localize the statewide projection to the county scale using historic sea level trends measured at tide gauges. For each county, the projection of 1.7 meters was multiplied by the ratio of local sea level change to average statewide sea level change (3.96 mm/yr). Local sea level change values were available from the Sea Level Affecting Marshes Model (SLAMM) parameter table (MD DNR, 2011). Because the resulting range of values was relatively small (1.32 m – 2.35 m), the Sea Level Rise Hazard Ranks were distributed among only 4 categories from Low (2) to Very High (5) and the Very Low (1) category was not used (Table 2). Sea Level Rise Hazard Ranks were assigned as follows, based on a quantile classification of the values along the entire Maryland coastline: Low Hazard (2) = 1.32 – 1.42 meters; Moderate (3) = 1.46 - 1.48 meters; High (4) = 1.49 - 1.67 meters; and Very High Hazard (5) = 2.05 - 2.35 meters (Appendix C, Figure A3).

Table 2. Sea Level Rise Hazard Rank by County.

County	Historic SLR Trend (mm/yr)	Projected SLR 2100 (m)	SLR Hazard Rank
Anne Arundel	3.44	1.48	Moderate
Baltimore	3.08	1.32	Low
Calvert	3.41	1.46	Moderate
Caroline	3.48	1.49	High
Charles	4.78	2.05	Very High
Cecil	3.08	1.32	Low
Dorchester	3.9	1.67	High
Harford	3.08	1.32	Low
Kent	3.08	1.32	Low
Prince Georges	3.41	1.46	Moderate
Queen Annes	3.44	1.48	Moderate
Somerset	4.97	2.13	Very High
St. Marys	3.41	1.46	Moderate
Talbot	3.48	1.49	High
Wicomico	3.9	1.67	High
Worcester - bayside	3.3	1.42	Low
Worcester - seaside	5.48	2.35	Very High

Projected County SLR 2100 = 1.7 * (Historic County SLR Trend/3.96)
 1.7 m = Statewide 2100 High SLR Projection
 3.96 mm/yr = Statewide Average SLR Trend

Wave Power

The wave power variable indicates the potential for shoreline erosion. Wave Hazard Ranks along the Atlantic coast of MD were set to Very High (5) because of exposure to oceanic waves. Locally generated wind-wave power was calculated within the InVEST model using wind speed and direction compiled from existing WaveWatch III model results and provided with the InVEST model download, bathymetry

published by MD DNR, and fetch computed within the InVEST model. The project team also considered use of the USACE's Coastal Hazards System STWAVE data, but due to scale and time constraints, the default WaveWatch III model results were selected. After consulting with staff from the University of Maryland Center for Environmental Science, the Wave Hazard Ranks for Chesapeake and Coastal Bay shorelines were assigned as follows, based on a geometric classification of the wind-wave power values along those shorelines: Very Low (1) = 0 to 0.021238 kW/m; Low (2) = 0.021239 to 0.057832 kW/m; Moderate (3) = 0.057833 to 0.163745 kW/m; and High (4) = 0.163746 to 0.776808 kW/m (Appendix C, Figure A4).

Storm Surge Height

This variable reflects the probability of inundation by storm surge, which is an abnormal rise of water generated by a storm, over and above predicted astronomical tides (NOAA, 2016a). The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is used by NOAA's National Weather Service to estimate storm surge heights. Hurricanes are ranked from Category 1 (least damage predicted) to Category 5 (most damage predicted) on the Saffir-Simpson Hurricane Wind Scale (NOAA, 2016b). For the Assessment variable, surge height of a Category 2 hurricane was used, in order to be consistent with other state planning efforts that used this storm category as a benchmark. Surge Hazard Ranks were based on above-ground-level surge heights for a Category 2 hurricane at mean tide (c2_mean) from SLOSH MOM model results (NOAA, 2015). Where c2_mean = 0 or 99.9, land elevation is equal to or greater than surge height and Surge Hazard Rank was set to Very Low (1). The remaining Surge Hazard Ranks were assigned as follows, based on a quantile classification of the values: Low (2) = 0.1 to 2.2 feet; Moderate (3) = 2.3 to 3.5 feet; High (4) = 3.6 to 4.6 feet and Very High (5) = 4.7 to 8.9 feet (Appendix C, Figure A5). The resulting map was positively reviewed by staff from the Maryland Emergency Management Agency (MEMA).

Erosion Rate

The erosion rate variable indicates shoreline erosion as estimated by comparing recent (1988-1995) mapped shorelines to historical ones, generally about 40 years older (Hennessee et al., 2003). In the process of transposing cross-shore transects to shoreline segments, Hennessee et al. generalized erosion rates into relative categories applicable to fairly long stretches of shoreline (>=80 meters). Only 28% of the total shoreline length was assigned a quantitative rate of change (erosion, accretion, or no change); the balance of the shoreline was protected by erosion control structures, had no historic shoreline upon which to base a rate of change (No Data), or was assigned an "unknown" classification because of inconsistent or suspect transect data. Since the authors estimate that most of the Maryland shoreline assigned a quantitative rate of change is eroding at a rate of less than 2ft/year, and that nearly all of the "unknown" shoreline is changing at rates between -2 and +2 ft/yr, the No Data and Unknown categories were classified as Low Hazard (2). Erosion Rate Hazard Ranks were assigned as follows, based on categories used by the Maryland Geological Survey (MGS): Very Low (1) = Accretion or Protected; Low (2) = No change, 0 to 2 feet/year, No Data or Unknown; Moderate (3) = 2 to 4 feet/year; High (4) = 4 - 8 feet/year; and Very high (5) = > 8 feet/year (Appendix C, Figure A6).

MGS is currently working to update shoreline change information for the 16 tidewater counties in Maryland. As of May 2016, updates are complete for Anne Arundel, Baltimore (including Baltimore City), Calvert and Prince George’s Counties. Updates in Harford County will be complete by October 2016. MGS is working collaboratively with CCS to upload the results of this updated work to the Coastal Atlas. Shoreline change updates for the remaining tidewater counties will be completed as funding becomes available. These updates can be incorporated into local planning efforts and future iterations of the Assessment.

Habitats

Natural habitats reduce damage from coastal hazards through the processes of wave attenuation, increased infiltration, and sediment stabilization. For the national InVEST model run, relative hazard ranks were assigned to different habitat types based on literature review and expert opinion. These sources generally indicate that fixed and stiff habitats reduce hazards more effectively than flexible and seasonal habitats. Therefore, fixed and stiff habitats were assigned lower hazard ranks. In order to support the hazard reduction ranks used in the Maryland Assessment, the project team assembled a literature database of 39 papers (Appendix D) each of which examined some aspect of the ability of natural features to buffer shorelines from erosion and flooding through the processes of wave attenuation, sediment stabilization, or surge reduction. In addition, because many of the available studies are from geographies other than Maryland, the project team spoke with 12 local habitat experts (Table 3) before finalizing the relative habitat ranks.

Table 3. List of local habitat experts consulted.

Expert Consulted	Habitat Expertise
Jason Harrison (DNR)	Forest, wetlands
Matt Whitbeck (USFWS)	Marshes
Brian Needelman (UMS)	Marshes
Andy Baldwin (UMD)	Marshes
Bill Hulslander (NPS)	Dunes
Stephanie Westby (NOAA)	Oysters
Angie Sowers (USACE)	Oysters
Eric Weissberger (DNR)	Oysters
Lee Karrh (DNR)	Submerged Aquatic Vegetation
Brooke Landry (DNR)	Submerged Aquatic Vegetation
Rebecca Golden (DNR)	Submerged Aquatic Vegetation
Bhaskar Subramanian (DNR)	Living Shorelines

An overall Habitat Hazard Rank was calculated for each shoreline segment based on the presence or absence of each habitat type and their associated hazard ranks (Table 4). Habitat-specific search distances were used to determine the types of habitat providing protection benefits for each shoreline segment. Sensitivity testing was performed to determine if the default search distances used in the national InVEST model run were appropriate for Maryland’s study area. Consequently, the project team adjusted associated search distances to fall between 250 and 500 meters, which are more suitable for

the state-specific scale of the Maryland Assessment. Individual habitat types are described in more detail below.

Table 4. Habitat hazard ranks, search distances, and data sources.

Habitat	Hazard Rank	Search Distance	Data Source(s)
Forest	Very Low (1)	500 meters	Maryland Forested and Scrub-Shrub Wetlands (MD DNR, 2008) Maryland Forest (MD DNR, 2015)
Marsh	Low (2)	250 meters	Maryland Marshes as defined by the National Wetlands Inventory and DNR Green Infrastructure (MD DNR, 2008).
Dune	Moderate (3)	300 meters	Assateague Island National Seashore Dunes (TNC, 1995) Ocean City Dunes (USACE, 2015)
Oyster reef	High (4)	250 meters	Chesapeake Bay Benthic Habitat Characterization (CMECS) (NOAA, 2013) Restoration Data for Harris Creek, Little Choptank, Tred Avon (NOAA, 2015)
Underwater grass	High (4 – 4.5)	500 meters	Distribution of Submerged Aquatic Vegetation in the Chesapeake Bay and Tributaries and the Coastal Bays (VIMS, 2014)

Forest

Forests received a hazard rank of Very Low (1) in both the national and the Maryland models. This ranking indicates that coastal forests are considered one of the most beneficial habitats in protecting the shoreline from coastal hazard impacts. The search distance to determine forest presence was reduced from 2,000 meters in the national model to 500 meters in the Maryland model. Forests are widespread along the Maryland shoreline, occurring within 500 meters of 72% of the shoreline segments. Data sources included Maryland Forest (DNR, 2015) and Maryland Forested and Scrub-Shrub Wetlands (DNR, 2008). Both data sources were filtered by CCS to include only patches >1 acre in size and at least 120 feet wide within the study area. Filtering was conducted to ensure consistency with the US Forest definition of “forest” and to ensure that “non-forest tree cover” was eliminated from the analysis.

Marsh

Marshes received a hazard rank of Low (2) in both the national and the Maryland models. This ranking indicates that marshes are considered one of the most beneficial habitats in protecting the shoreline from coastal hazard impacts, only after coastal forests. The search distance to determine marsh presence was reduced from 1,000 meters in the national model to 250 meters in the Maryland model. Marshes are widespread along the Maryland shoreline, occurring within 250 meters of 76% of the shoreline segments. The data source was Maryland Marshes (MD DNR, 2008), which includes estuarine intertidal emergent (E2EM) and Palustrine emergent (PEM) wetlands compiled by DNR from National Wetlands Inventory (NWI) and DNR green infrastructure wetlands data.

Dunes

Maryland dunes received a hazard rank of Moderate (3), which is consistent with the rank given to low dunes in the national model. This ranking indicates that Maryland dunes have a moderate role in protecting the shoreline from coastal hazard impacts, relative to other coastal habitats present in the study area. While the national model included a separate ranking for “high dunes,” defined as dunes over 5 meters in height, Maryland does not have any dunes that meet this criteria. Therefore, the Maryland model was altered to be consistent with the “low dune” rank of moderate (3). The search

distance to determine dune presence was 300 meters, which is consistent with the national model. Dunes are restricted to Maryland's Atlantic shoreline, and so are found within 300 meters of only 2% of all shoreline segments. The data source for dunes along Assateague Island National Seashore was a dataset extracted from the comprehensive Vegetation Classification of Assateague Island National Seashore dataset (TNC, 1995). TNC filtered the vegetation classification data to include only features with Ecological Community Group = Maritime Dune Grassland, Maritime Dune Scrub or Maritime Dune Woodland. Dune presence north of the Ocean City inlet was manually recorded based on recent aerial photos and personal communication with USACE staff regarding the Atlantic Coast MD Shoreline Protection project.

Oyster reef

Oyster reefs received a hazard rank of Low (2) in the national model due to the wave attenuation benefits provided by intertidal reefs. In Maryland, however, all current oyster reefs are subtidal, with many locations having so little relief that they are classified as rubble rather than reef. The few reefs that do provide potential wave attenuation benefits have been human-built or restored. For example, in tributaries of the Choptank River, restored reefs have been built to 12-18 inches in height. Due to these differences, oyster reefs received a hazard rank of High (4) for the Maryland model run. This ranking indicates that Maryland oyster reefs have a low role in protecting the shoreline from coastal hazard impacts, relative to other coastal habitats present in the study area. The search distance to determine oyster presence was increased from 100 meters in the national model to 250 meters in the Maryland model due to the subtidal nature of Maryland reefs. In general, Maryland oyster reefs are very limited in distribution, with coverage found only in tributaries of the Choptank River, Little Choptank River and in Prospect Bay. In fact, oyster reefs were found to occur along less than 1% of all shoreline segments. Data sources included 1) the Chesapeake Bay Benthic Habitat Characterization (CMECS) (NOAA, 2013), which TNC filtered to include only features with 'Group' = 'Anthropogenic_Oyster_Reef' and 2) Oyster Restoration Data for Harris Creek, Little Choptank and Tred Avon (NOAA, 2015), which TNC filtered to include only features with 'Restoration_Status' beginning 'Constructed'. Both data sources were also filtered to exclude reefs less than one hectare in size (individual polygon area, or combined area of closely adjacent polygons) to ensure represented reefs were large enough to provide potential wave attenuation benefits.

Underwater grasses

Underwater grasses received hazard rank of High (4) in the national model, indicating that these grasses have a low role in protecting the shoreline from coastal hazard impacts, relative to other coastal habitats present in the study area. For the Maryland model, CCS divided the underwater grass occurrences into two categories based on density. Dense patches of underwater grasses were given the hazard rank of 4, and less dense patches were labeled as 4.5. This differentiation was incorporated into the Maryland model because underwater grasses vary in their coverage, and the project team wanted to integrate the role of density and year-to-year variation into the model results. The search distance to determine underwater grass presence was 500 meters, which is consistent with the national model. Underwater grasses are restricted to the Chesapeake and Coastal Bays, and are found within 500 meters of 26% of all shoreline segments. The data source for underwater grasses was Distribution of Submerged

Aquatic Vegetation in the Chesapeake Bay and Tributaries and the Coastal Bays (VIMS, 2014). CCS filtered this dataset to include only areas with consistent coverage for at least 7 years from 2004 – 2014. Areas with an average density ≥ 3 were assigned a hazard rank of 4 and all other areas that did not meet the density criteria were assigned a Hazard Rank of 4.5. While underwater grasses may have a low protective value by themselves, they can act as a buffer to nearby marshes, thereby enhancing their resiliency and protective value in the face of coastal hazards.

Habitat Hazard Rank

An overall Habitat Hazard Rank (Table 5) was calculated for each shoreline segment based on the presence/absence of each habitat type within habitat-specific search distances, as well as each habitat’s associated hazard rank. The InVEST model combines individual habitat ranks into an overall rank for each shoreline segment using the R_{Hab} equation (NatCap, 2011). Segments that have only one type of habitat (e.g., dune) are scored as more exposed to shoreline hazards than segments with more than one type of habitat present (e.g., dune and marsh). Shorelines with no habitats present are given a score of five. The equation also weights the habitat with the lowest hazard rank 1.5 times higher than other habitat types present. Shoreline segments with lower Habitat Hazard Ranks are considered relatively

Table 5. Overall habitat hazard ranks.

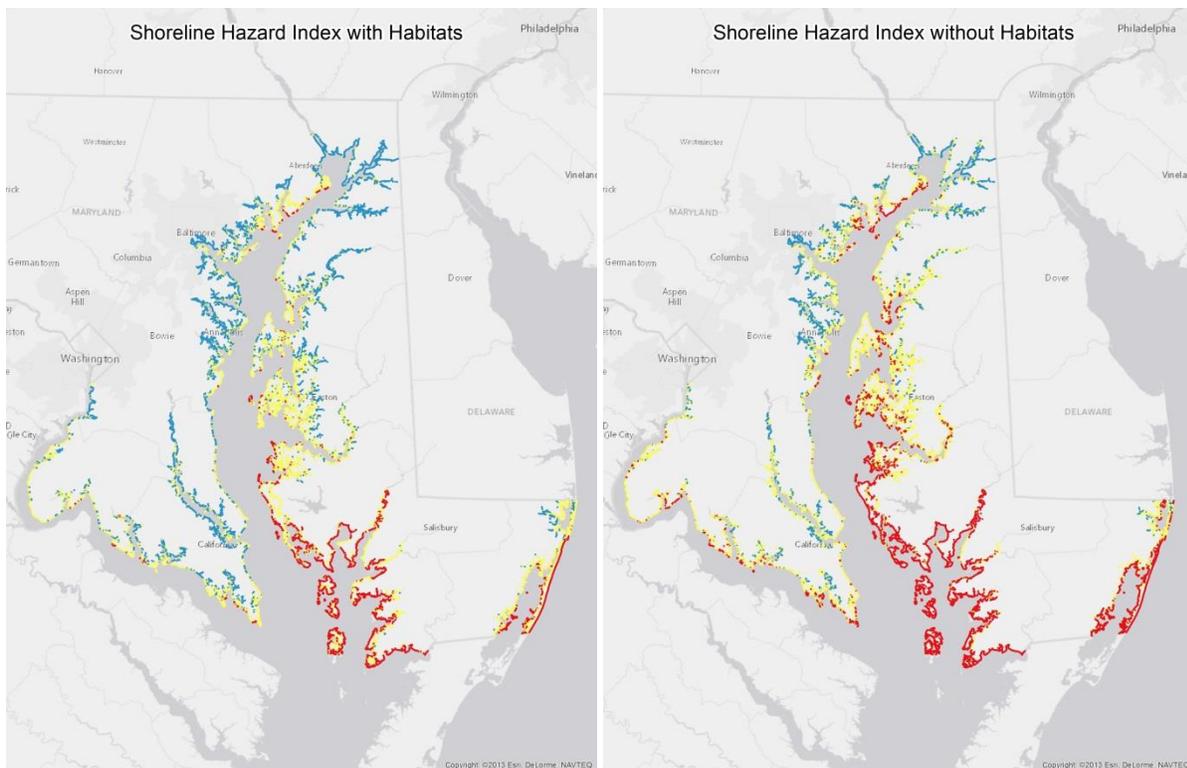
Habitat hazard rank	Habitats present
1.2645	forest, marsh, dune, underwater grass (dense)
1.2911	forest, marsh, dune, underwater grass (less dense)
1.3000	forest, marsh, dune
1.4088	forest, marsh, (oyster reef), underwater grass
1.4366	forest, marsh, underwater grass (less dense)
1.4459	forest, marsh
1.6279	forest, dune, underwater grass (less dense)
1.6377	forest, dune
1.7586	forest, (oyster reef), underwater grass
1.7896	forest, underwater grass (less dense)
1.8000	forest
2.2875	marsh, dune, underwater grass (dense)
2.3251	marsh, dune, underwater grass (less dense)
2.3378	marsh, dune
2.4951	marsh, (oyster reef), underwater grass
2.5361	marsh, underwater grass (less dense)
2.5500	marsh
3.2189	dune, underwater grass (dense)
3.2793	dune, underwater grass (less dense)
3.3000	dune
4.0500	(oyster reef), (underwater grass) (dense)
4.4250	underwater grass (less dense)
5.0000	no habitat

less exposed to coastal hazards because of the presence of habitats buffering the shoreline. See Appendix C, Figure A7 for a map of overall Habitat Hazard Rank, rounded to the nearest integer.

Shoreline Hazard Index and Habitat Role

The Shoreline Hazard Index is calculated as the geometric mean of the input variable hazard rank at each shoreline segment. Two scenarios of the model were run - one scenario incorporating the protective role of all existing coastal habitats and a second scenario simulating the complete loss of habitats (Figure 1). For the *With Habitats* scenario, the Index calculation includes the Habitat Hazard Rank explained above. For the *Without Habitats* scenario, the Index calculation includes the Habitat Hazard Rank set to Very High (5) for all shoreline segments, simulating the complete loss of all habitats. The Habitat Role in reducing shoreline hazards was calculated as the difference between the Index calculated for the *Without Habitats* scenario and the Index calculated for the *With Habitats* scenario. Initial results were generated within the model (Appendix E: InVEST log) and as inputs were changed, result values were updated using Python scripts (Appendix F: Python scripts).

Figure 1. Shoreline Hazard Index calculated from the With Habitats scenario (left) and the Without Habitats Scenario (right).

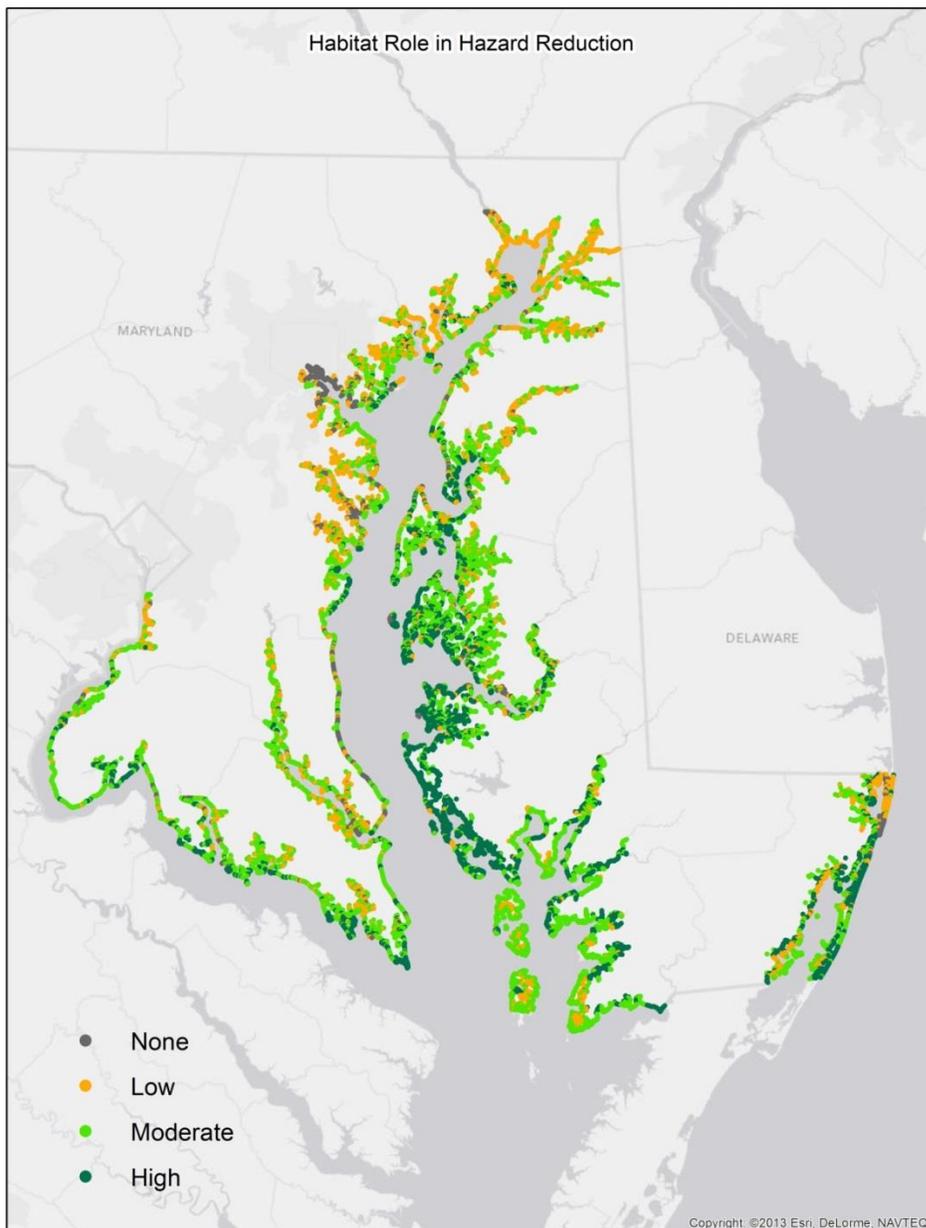


The calculated Hazard Index ranges from 1.16381 to 4.84313 in the With Habitats scenario and from 1.3895 to 4.84313 in the Without Habitats scenario. These values indicate the exposure of a shoreline segment to coastal hazards, relative to the rest of the shoreline segments in Maryland. The Index values were classified into Low, Moderate and High Hazard categories based on the 25th and 75th percentile

thresholds across the full distribution of values from both scenarios. There is a 50% increase in the number of shoreline segments in the High Hazard category when the protective value of habitats is lost.

The Habitat Role in reducing hazards ranges from 0.0, where no habitats are present, to 0.847815 where forest, marsh, and dunes are present along a High Hazard shoreline. Habitat Role values indicate the magnitude of potential hazard reduction by coastal habitats at a particular shoreline segment, relative to all of the other shoreline segments in Maryland. These values were classified into High Habitat Role, Moderate Habitat Role and Low Habitat Role based on the 25th and 75th percentile thresholds. In general, the results indicate a High Habitat Role where at least forest or marsh is present along a Moderate Hazard or High Hazard shoreline.

Figure 2. Habitat role in reducing shoreline hazard.



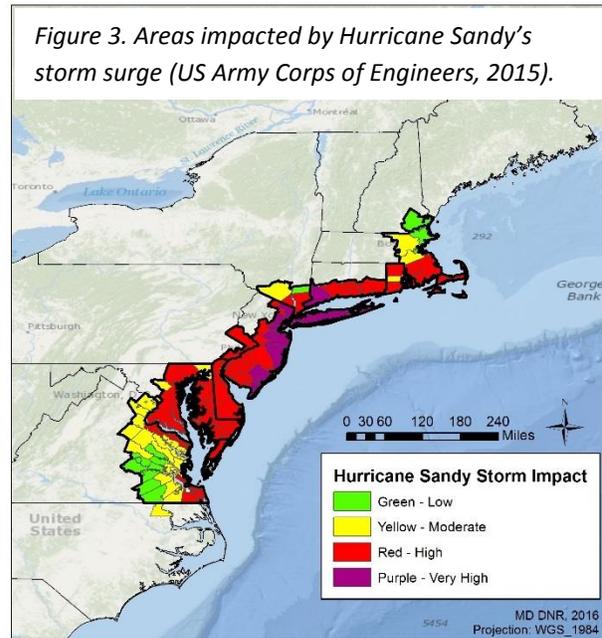
4. Community risk analysis: coastal community flood risk areas

Overview

To successfully integrate risk reduction into Maryland’s conservation and restoration targeting, the project team conducted a Community Risk Analysis. This analysis identified residential areas within Maryland’s Category 4 storm surge extent that are exposed to flooding and erosion from periodic storms and coastal hazard events. Community characteristics and demographics were used alongside flood exposure data to rank residential areas from low to high flood risk. Community Flood Risk Areas are considered alongside natural features data when targeting shorelines for conservation and restoration to ensure that the implementation of natural feature solutions directly benefits vulnerable coastal communities.

Background

In October 2012, Hurricane Sandy made landfall on the United States’ East Coast. The resulting storm surge devastated coastal populations, infrastructure, and cultural and environmental resources from North Carolina through Maine. Recognizing a need for pre-disaster preparation, the U.S. Army Corps of Engineers (USACE) issued a report in January 2015 to address flood risk in the North Atlantic region. The report, *North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk (NACCS)*, provided a regional risk management framework that can be applied at state and local levels to increase community preparedness through planning and implementation of natural and nature based solutions. The NACCS study area included jurisdictions impacted by Hurricane Sandy’s storm surge as indicated by FEMA’s Modeling Task Force Hurricane Sandy Impact Analysis. Impact Areas were identified in the District of Columbia and the States of New Hampshire, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Delaware, Maryland, and Virginia (Figure 3).



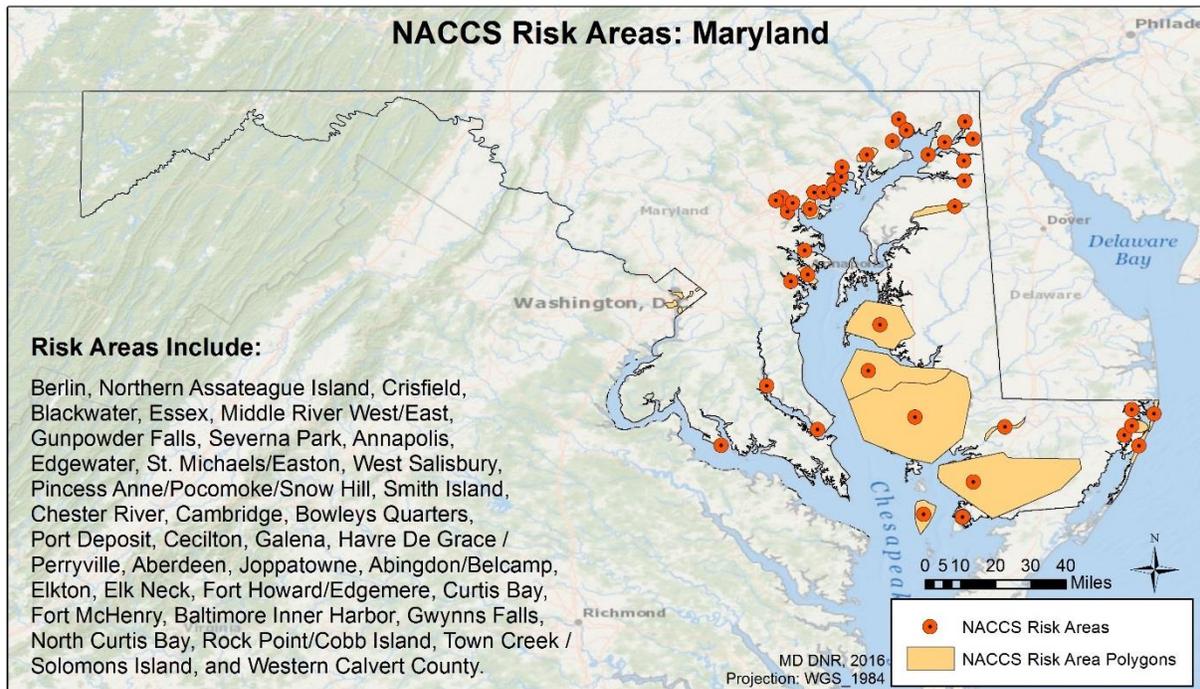
Over 4 million people reside in the 18 Maryland jurisdictions that were affected by Hurricane Sandy, and the NACCS analysis identified 37 risk areas along Maryland’s coastline (Figure 4). Risk areas were identified by evaluating population density, social vulnerability, critical infrastructure, cultural and environmental assets, and probability of exposure to flood events. The Category 4 storm surge area was used to represent the furthest extent of a flood hazard event.

Identifying Community Flood Risk Areas

The Maryland Department of Natural Resources reviewed, customized, and applied the NACCS at a state scale to identify coastal populations in need of flood risk reduction. The state analysis was significantly improved by narrowing focus to residential areas and applying a 30 meter analysis grid. Future iterations of the analysis will explore impacts to critical infrastructure and other vital economic assets. Population density, social vulnerability, and probability of exposure to flood events were evaluated at a 30 meter

scale to identify and relatively rank residential areas based on flood risk (Table 6). Maryland’s Category 4 storm surge area within the Coastal Zone was used to define the furthest extent of a flood hazard event and acted as the study area. Social and demographic parameters that may limit a population’s ability to prepare for, respond to, and/or recover from coastal hazard events were considered in the analysis, with relevant social metrics defined as age, poverty, and English proficiency. The Risk Analysis resulted in a map of residential areas divided into five tiers of risk (very low, low, moderate, high, and very high) that can be considered when targeting future conservation and restoration projects.

Figure 4. Risk Areas identified as points and polygons within the North Atlantic Coast Comprehensive Study. This regional risk analysis was conducted at an approximately 70 meter scale (US Army Corps of Engineers, 2015).



Methodology

The project team consulted with USACE to apply the regional NACCS risk methodology at a state scale. Additionally, a Steering Committee of state, federal, and non-profit partners was consulted to steer model development and sensitivity testing.

Community Flood Risk Areas were developed by applying the following equation within Maryland’s Category 4 storm surge extent. Individual components are explained below and more detailed methodology is available in Appendix G. See Appendix G, Figure A8 for the risk toolbox.

$$(\text{Population Density Index} + \text{Social Vulnerability Index}) \times \text{Probability of Exposure}$$

The Sea Level and Overland Surges from Hurricanes (SLOSH) model Category 4 storm surge extent was used as a proxy for tidal regions in Maryland’s coastal zone and to define the furthest extent of a flood hazard event (NOAA, 2015). Communities outside of this extent were not considered in the analysis. Inland flood and riverine modeling is required to address risk in non-tidal regions, but these areas were outside the scope of this study.

Table 6. Community Flood Risk Metrics.

Mapping Layer	Mapping Objective	Criteria / Metric	Source Data
Population Density Index (PDI)	Rank residential areas from low to high based on the number of residents per unit area	Population Density within residential land uses 5 Tier Quantile Reclassification	2013 American Community Survey 5-year estimate (Total Population); 2010 MDP Land Use Land Cover; 2015 Federal, State, and County Lands; USGS Dasymetric Mapping Toolbox for ArcMap 10.0
Social Vulnerability Index (SVI)	Rank residential areas from low to high based on the ability of populations to prepare for, respond to, and/or recover from coastal hazard events	AGE: % Population ≤ 17 years or ≥ 65 years POVERTY: % Population with income below poverty LANGUAGE: % Population of non-proficient English speakers Sum % Population with 5 Tier Quantile Reclassification	2013 American Community Survey 5-year estimate (Age, Poverty status in the last 12 months, Language spoken at home/Ability to speak English)
Probability of Exposure	Weight residential areas based on probability of exposure to a flood event in any one given year	Effective floodplain extents for 10-year, 50-year, 100-year, and 500-year floods; and Category 4 storm surge extent (used as proxy low frequency high impact event) Probability values associated with exposure extents: 10%, 2%, 1%, 0.2%, and 0.1% respectively	Statewide Effective 100-year and 500-year floodplains; FEMA Q3 Floodplains for Prince George’s County; 2003 – 2014 County Lidar; 2015 County 10-year and 50-year Surface Water Elevation
Composite	Rank residential areas from low to high risk to target risk reduction solutions near vulnerable coastal communities that are exposed to periodic coastal storm and flood hazard events	(PDI + SVI) X Probability of Exposure 5 Tier Quantile Reclassification (very low, low, moderate, high, very high)	Population Density Index Social Vulnerability Index Seamless floodplain probability layer

Population Density Index

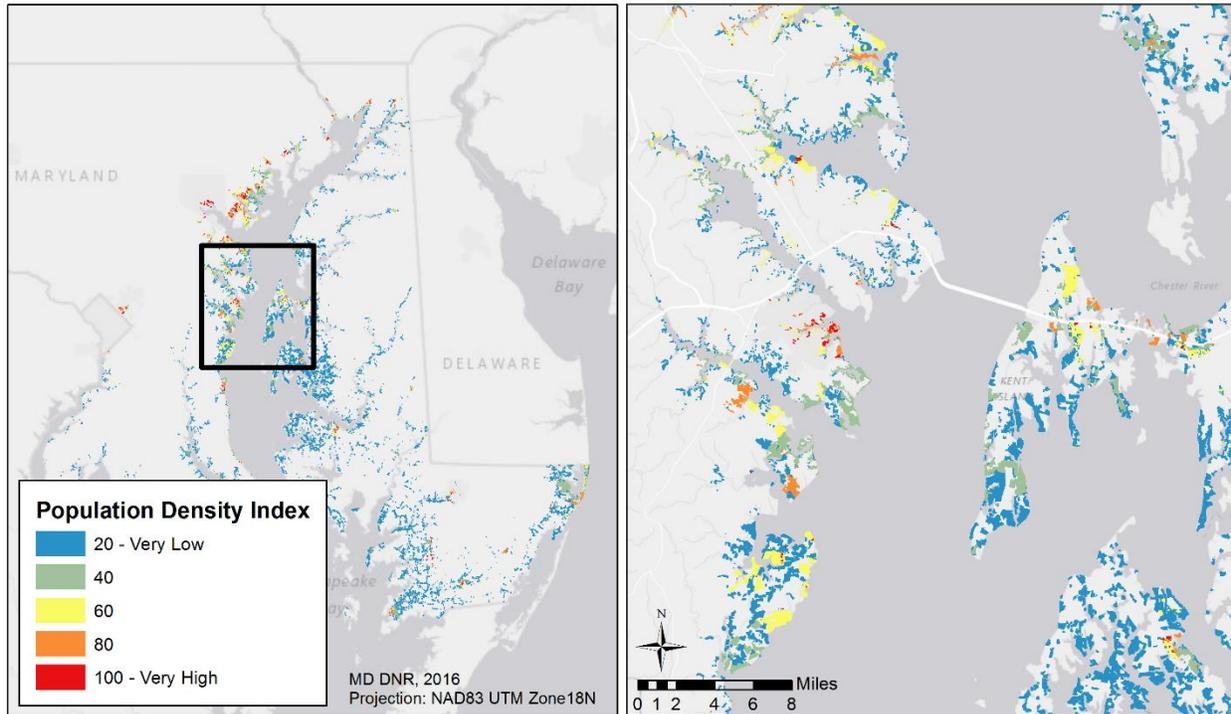
Population density was calculated for residential areas by applying U.S. Census Bureau 2013 American Community Survey total population, 2010 Maryland Department of Planning land use land cover, and open space datasets within a USGS Dasymetric Mapping Toolbox (USGS, 2014). Dasymetric mapping creates surface-based representations of demographic data, allowing for analysis at more refined scales (Mennis, 2003). The Toolbox requires 1) a shapefile of census block groups with total population information joined from American Community Survey spreadsheets; and 2) a land use raster that has been reclassified into 3 urbanization classes and an uninhabited land use class. The 2010 Maryland Department of Planning Land Use Land Cover layer was converted to a 30-meter raster and reclassified into 3 urbanization classes (Table 7). All other land use designations were identified as uninhabited and removed from the analysis. Uninhabited areas were removed from the analysis to narrow the scope of the study and because U.S. Census Bureau population data is based on residential surveys. Maryland Department of Natural Resource lands, county owned lands, and federal lands that were identified as open space were also labeled as uninhabited (Appendix G, Figure A9).

Table 7. Urbanization Classes.

Land Use / Urbanization Class	MDP/State Codes	Raster Value
Low Density Residential	11, 191 - 192	3
Medium Density Residential	12	2
High Density Residential	13	1
Commercial, Industrial, Institutional, Extractive, Agriculture, Forest, Water, Wetlands, Barren Land, Transportation	14-17, 21 - 80	0
Open Space	18, state/federal/county open space	0

The USGS toolbox was run at a 70% coverage threshold for empirical sampling (Appendix G, Figure A10). To establish population density values, the toolbox samples representative census block groups for each urbanization class and calculates the relative difference in population density among urbanization classes. All block groups with at least 70% coverage by each urbanization class were sampled to calculate and allocate density values. If the 70% criteria could not be met, then areal weighting was applied. The NEWDENSITY field in the resulting raster provided population density estimates (Appendix F, Figure A11). To create the Population Density Index (PDI), the new density raster was clipped to the Category 4 storm surge extent, reclassified into five quantiles, and scored from 20 to 100 in increments of 20 (Figure 5). See Appendix G, Figure A12 for more information on the population density model builder tool.

Figure 5. Population Density Index representing low to high population density relative to Maryland’s Category 4 storm surge extent (left) and Index variations near the Route 50 Bridge (right).



Social Vulnerability Index

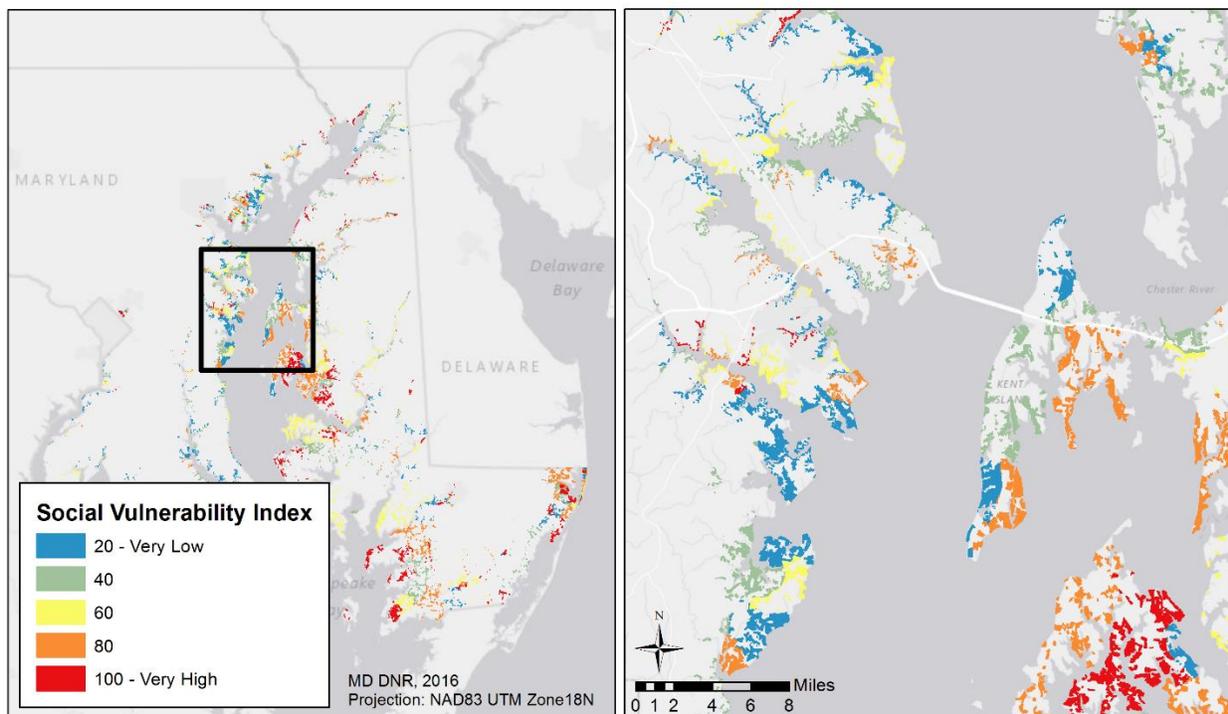
Alongside population density, social vulnerability metrics were used to target risk reduction practices in communities that may be less equipped to prepare for, respond to, and/or recover from coastal hazard events. Many metrics are available to indicate social vulnerability, including income, social isolation, race, age, sex, education level, vehicle ownership, language proficiency, occupation (i.e. single sector economic reliance), and disabled populations. Following expert interviews and literature consultation, the metrics of age, poverty, and language proficiency were selected to indicate social vulnerability (Messick and Dillard, 2016). These metrics were also applied in the regional NACCS and relate to mobility, preparedness, ability to respond to an emergency and emergency communication. The project team recognized that social vulnerability is far more complicated than what these three metrics represent, and that community strengths such as local support networks (neighborhood groups, churches, etc.) may balance out perceived weaknesses. Re-evaluation of these metrics will be required for smaller scale, local analyses.

U.S. Census Bureau 2013 American Community Survey 5 year block group data was downloaded for the following categories: sex by age, poverty status of individuals in the past 12 months by living arrangement, and age by language spoken at home by ability to speak English for the population 5 years and over. While there is a margin of error associated with the American Community Survey, these data were the most recent, are commonly used in state planning exercises, and provide information at a state block group scale. Further refinement can be accomplished once the next decadal Census is conducted.

Percent population less than or equal to 17 and greater than or equal to 65 years of age was calculated by block group within an excel spreadsheet and joined to census block groups (Appendix G, Figure A13).

These age ranges identify children and elderly individuals who may require assistance with travel. They are also consistent with other DNR targeting tools; namely, the Park Equity Tool, which identifies communities with little or no access to nature and open space. Percent population with income below poverty in the last 12 months was also calculated by block group (Appendix F, Figure A14), noting that the American Community Survey does not include income data for residents under the age of 15, or living in institutional group quarters, college dormitories, military barracks, or living situations without conventional housing. Lastly, percent population that speaks English less than “very well” was calculated by block group for populations greater than or equal to 5 years of age (Appendix F, Figure A15). All block group percentages were joined to the Maryland block group shapefile. Percent population was used to create the Social Vulnerability Index to control for the size of the population across a statewide scale. Because these variables were normalized as a percentage, they were summed to indicate overall vulnerability by block group. Block groups were converted to a 30 meter raster with percent population applied as the cell values. The resulting grid was masked to the study area, reclassified into five quantiles, and scored from 20 to 100 in increments of 20 (Figure 6). See Appendix G, Figure A16 for more information on the social parameter model builder tool.

Figure 6. Social Vulnerability Index representing low to high social vulnerability relative to Maryland’s Category 4 storm surge extent (left) and Index variations near the Route 50 Bridge (right).



Flood Exposure

Probability of exposure to a flood event in any one given year can be determined by applying floodplain data from the Federal Emergency Management Agency (FEMA). FEMA floodplain data identifies areas that will be inundated by a flood event having a 1% or 0.2% chance of being equaled or exceeded in any given year. These data layers are more commonly referred to as the 100 and 500-year floodplains, respectively. 2015 effective floodplain data was obtained from Dewberry and Maryland Environmental Service for the 100-year and 500-year floodplains in all counties except Prince George’s where FEMA Q3

floodplain data were applied. To strengthen the analysis, the project team processed August 2015 County Lidar from Salisbury University and surface water elevation (SWEL) data from Dewberry to create 10-year and 50-year floodplains with 10% and 2% probability of occurrence, respectively. The following equation was applied by county and floodplain type where “Floodplain” refers to the 25-foot grid SWEL and “Topo” refers to resampled 25-foot Lidar.

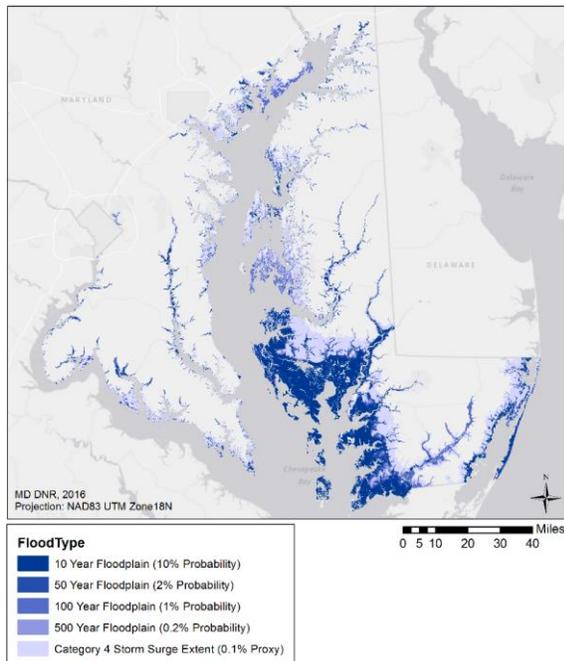
$$\text{Con}(\text{"\%Floodplain\%"} \geq \text{"\%Topo\%"}, 1)$$

The resulting floodplain rasters were converted to polygons, simplified, and processed so that all 10-year floodplains fell within 50-year floodplains, and 50-year floodplains fell within 100-year floodplains. The smoothed polygons were compared to original outputs, residential land use areas, and State Highway Administration island polygons to ensure as careful and accurate processing as possible near coastal communities. County floodplains were merged to create statewide polygons for all floodplain types. More detailed methodology can be found in Appendix G.

A seamless data layer that represents 10-year, 50-year, 100-year, and 500-year floodplains was developed to identify areas with relatively low or high probability of exposure in any one given year (Appendix G, Figure A17). Data gaps were found in the following regions due to unavailable Lidar or SWEL data: Aberdeen Proving Grounds, Pocomoke, and a portion of Prince George’s County. Areas between the 500-year floodplain and the Category 4 storm surge extent were treated as a 1,000-year storm with 0.1% probability of occurrence, although there is no specific probability associated with a Category 4 event. The 1,000-year statistic was applied to indicate a low frequency, high impact event.

The resulting polygon was converted to a 30-meter raster with each cell indicating probability of exposure. Following USACE methodology, probability values were re-scaled so that summed values equal 1 (Figure 7).

Figure 7. Coastal areas impacted by 10-year, 50-year, 100-year, and 500-year floods within a Category 4 storm surge extent (left) and probability of exposure rescaled from 0 to 1 (right).



Cat 4 Extent	500yr	100yr	50yr	10yr
0.1%	0.2%	1%	2%	10%
0.001	0.008	0.01	0.08	0.9
0.001	0.002	0.01	0.02	0.1
				1.0

Probability of inundation increases near the coast due to lower elevations. The bottom scale (in black) indicates probability of occurrence for each floodplain. The upper scale (in red) indicates the re-scaled value applied in the risk analysis.

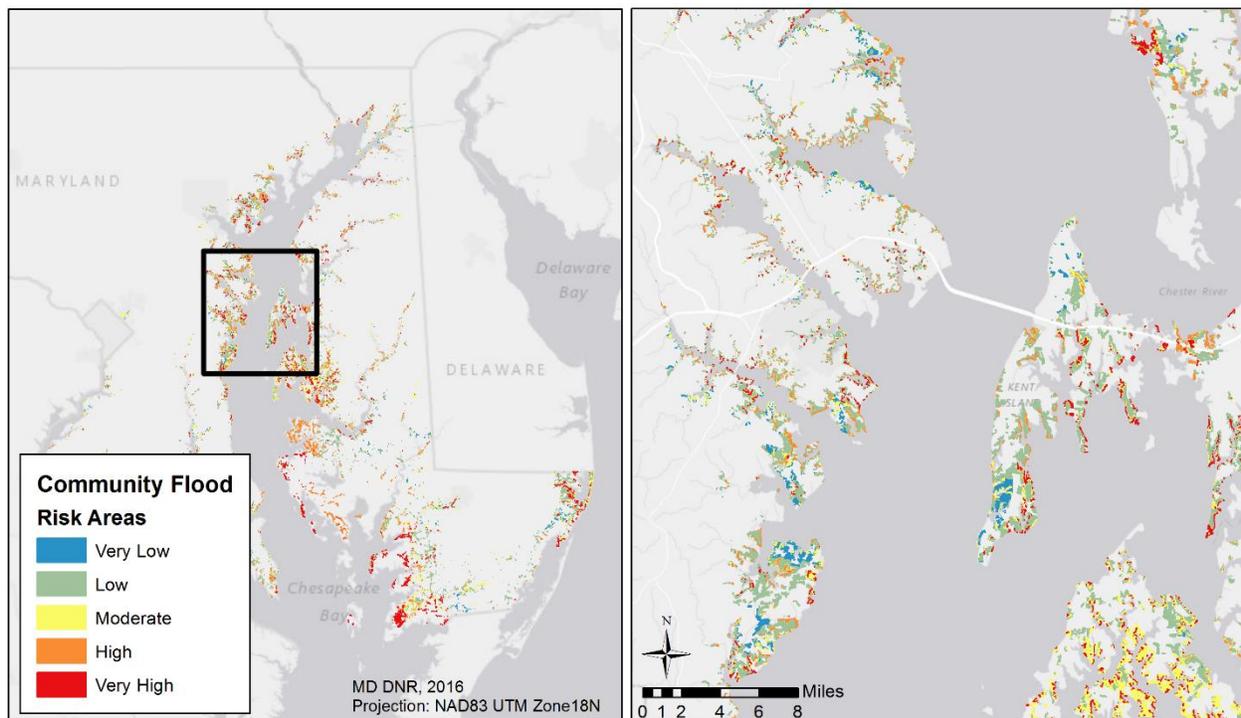
Composite Index

Community flood risk areas were ranked from low to high risk by combining the above datasets into a Composite Index. Raster inputs were snapped to the floodplain layer and the following formula was applied:

(Population Density Index + Social Vulnerability Index) X Probability of Exposure

Following application of the formula, the Composite Index was reclassified into 5 risk tiers using quantile classification (Figure 8). See Appendix G, Figure A18 for more information on the risk model builder tool. During model development, sensitivity analyses were conducted to determine the impacts of applying various classification methods, scores, and weights to the indices. A Steering Committee reviewed various model iterations to select the methodology most representative of actual conditions. The final risk raster was converted into a geodatabase feature class and applied to the priority shoreline and marsh protection analyses (See Sections 5 and 6). The associated feature attributes include model inputs along with the final risk rank so that data users may query the data (Table 8).

Figure 8. Community Flood Risk areas, ranked from very low to very high relative to Maryland's Category 4 storm surge extent (left) and risk area variations near the Route 50 Bridge (right).



Future Refinement

While the community flood risk areas are more refined than the USACE NACCS swaths, future improvements are still encouraged. The following recommendations are offered to build on current work.

1. Expand Residential Focus. This risk analysis was conducted at a state scale with a focus on residential land use. Future iterations should consider the importance of critical infrastructure or economic hubs, such as commercial or agricultural lands.

2. Refine Data. As the State Hazard Mitigation Plan is updated, associated infrastructure and economic data (i.e. HAZUS, critical infrastructure, etc.) should be considered within community rankings. Current risk rankings are a product of the best available data and should be refined when necessary. Additionally, as counties or communities refine and apply the statewide risk framework to identify their own priority areas, the statewide analysis should be reviewed to ensure local priorities and data are considered.
3. Conduct Inland Analyses. The current risk areas represent communities impacted by coastal storm and flood events. Further research and modeling is required to better understand inland flood risk from precipitation and stormwater impacts, especially as climate change leads to more high intensity rainfall events.
4. Analyze Future Flood Risk. The Community Flood Risk Areas defined by this analysis are based on current surface water elevation data and represent today’s risk to inundation. To identify communities at risk to future flooding, the impact of sea level rise on surface water elevation should be considered before floodplain processing. Until revised data become available, sea level rise overlays should be used in conjunction with the Coastal Resiliency Assessment data when making investment decisions. Sea level rise projections can be used during the planning and design phases of on-the-ground projects to ensure project resiliency over an appropriate timescale or project lifetime. Furthermore, the Community Flood Risk Areas were identified based on 2013 American Community Survey data. As decadal Census data becomes available, population and social data should be updated. To further refine the Assessment, population projections can also be considered.

Table 8. Community Risk Area Attributes.

Field	Description
PDI	Population Density Index Score (from 20 – 100 in increments of 20). Determined using quantile classification.
SVI	Social Vulnerability Index Score (from 20 – 100 in increments of 20). Determined using quantile classification.
Composite	Sum of Population Density Index and Social Vulnerability Index scores (from 40 – 200).
Probability	Re-scaled probability of exposure value (from highest risk at 0.9 to lowest risk at 0.001).
FloodType	Inundation type associated with probability values (10-yr, 50-yr, 100-yr, 500-yr, or Category 4 storm surge extent)
Gridcode	Risk Area ranked from very low (1) to very high (5). Classes determined using quantile classification of final risk values [(PDI + SVI) X Exposure].
Risk	Relative rank of Community Flood Risk Areas based on gridcode. Ranked in a 5 tier quantile (very low, low, moderate, high, and very high).

5. Priority shoreline areas

In order to evaluate the role of habitats in reducing exposure to coastal hazards (not just for the shoreline in general, but for coastal communities in particular), the results of the InVEST Coastal Vulnerability model were integrated with MD DNR Coastal Community Flood Risk Areas (See Section 4 above). The flood risk index incorporates population density, social vulnerability, and frequency of flooding for residential areas within the predicted extent of a Category 4 storm surge inundation. The ArcGIS Spatial Join geoprocessing tool was used to determine the maximum flood risk score of any flood risk area located within 2 kilometers of a given shoreline segment, as well as the risk score of the closest flood risk area located within 2 kilometers of a given shoreline segment. A 2 kilometer search distance was applied after analyzing the average distance from each shoreline segment to the closest risk area by county and across the entire state.

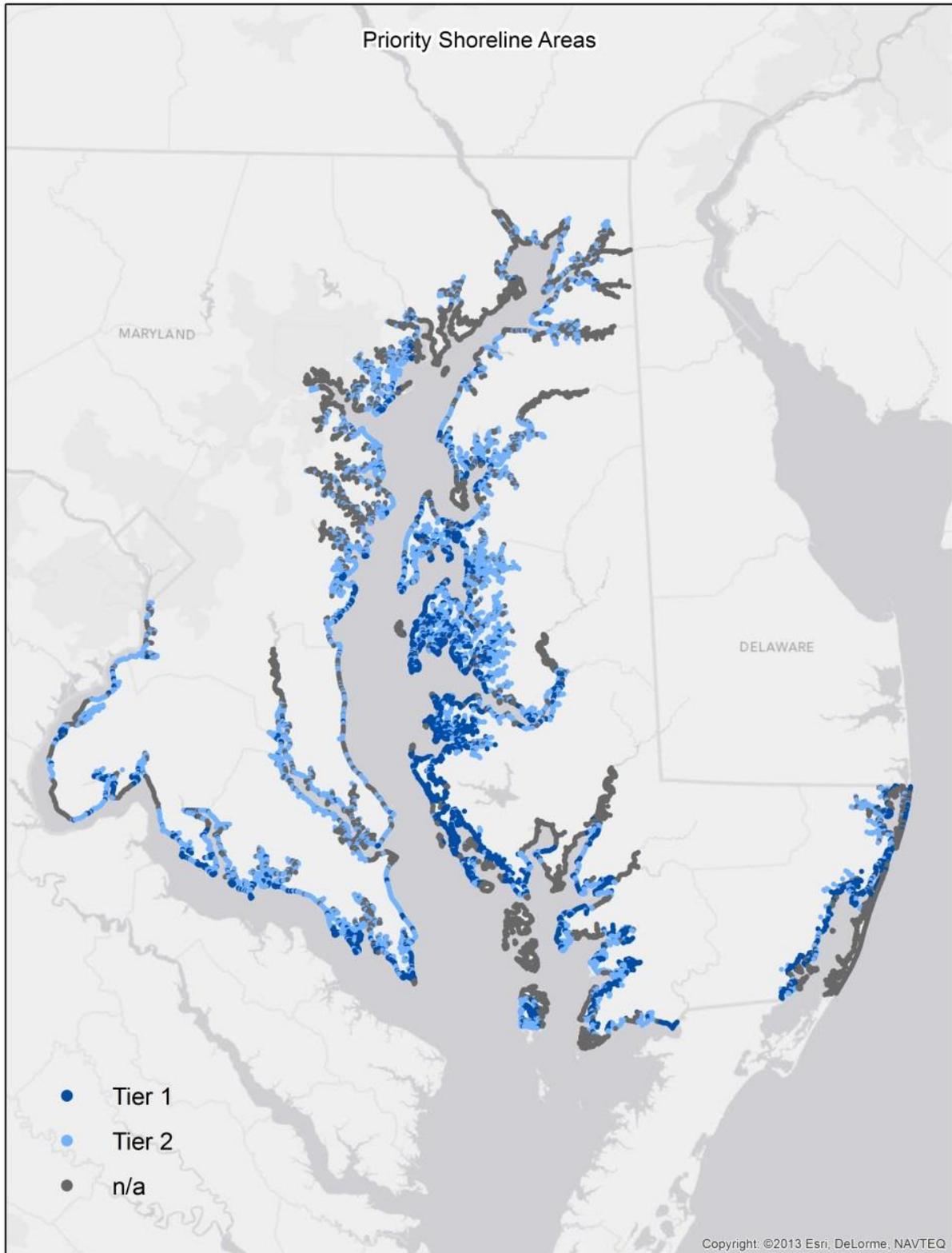
Priority Shoreline Areas are those areas where protection and restoration of natural habitats has the greatest potential to reduce the coastal hazard risk faced by residential communities (Figure 9). Two tiers of priority were determined. Tier 1 or High Priority areas are those shoreline segments where 1) the habitat role in reducing shoreline hazard is high and at least one Coastal Community Flood Risk Area is located within 2 kilometers or 2) The shoreline hazard transitions from moderate to high if habitats are lost and at least one Coastal Community Flood Risk Area is located within 2 kilometers. Tier 2 or Moderate Priority areas are those shoreline segments where 1) the habitat role in reducing shoreline hazard is moderate and at least one Coastal Community Flood Risk Area is located within 2 kilometers or 2) the shoreline hazard transitions from low to moderate if habitats are lost and at least one Coastal Community Flood Risk Area is located within 2 kilometers. Shoreline segments that meet none of these criteria are not considered priorities by this Assessment but may be priorities for other reasons, such as ecological value. Tier 1 areas comprise 22% of the MD coastline and Tier 2 areas comprise an additional 40% of the MD coastline.

Tier 1 priority shoreline areas where the habitat role in reducing shoreline hazard is currently high should be targeted for acquisition, easement, or other means of securing them from conversion to development. Once an area is protected, it should be managed in such a way to maintain its risk-reduction role. Tier 1 areas where the habitat role is only moderate, but enough to prevent the shoreline from transitioning to high hazard, may be candidates not only for protection but also restoration, in order to enhance risk-reduction by habitats.

Tier 2 priority shoreline areas, all of which have no more than a moderate habitat role, will likely offer the greatest number of opportunities for restoration. However, since the models used in the Assessment do not take habitat health or condition into account, site specific investigations may reveal the need for restoration or enhancement at any location, regardless of priority status.

Tier 1 areas represent a relatively small and focused (< 25% of total Maryland shoreline) set of statewide priority areas. In locations where few Tier 1 areas exist, or where landowner willingness limits action, Tier 2 areas provide a more expansive set of opportunities from which to choose.

Figure 9. Priority Shoreline Areas.



6. Marsh Protection Potential Index

The Marsh Protection Potential Index (MPPI) focuses on an iconic feature of Maryland's landscapes, the coastal wetlands of the Chesapeake Bay and Coastal Bays. Marshes provide a wide range of important ecosystem services, from water quality benefits to carbon storage (Barbier, 2014). However, the Marsh Protection Potential Index is chiefly concerned with the ability of marshes to provide protection from coastal hazards such as erosion, storm surges, and rising sea levels. By dampening wave energy, absorbing floodwaters, and accreting sediment, marshes are able to mitigate these hazards (Shepard et al., 2011). Marshes are valuable for conservation groups, disaster mitigation agencies, and local communities alike, and collaboration between these stakeholders offers an enormous opportunity to benefit Marylanders. The goal of the Marsh Protection Potential Index is to provide stakeholders with information about which marshes are doing the most to protect Maryland's people.

Marsh Protection Potential Index Objectives

The Marsh Protection Potential Index ranks Maryland's coastal marshes by their ability to protect vulnerable communities from coastal hazards. To do so, the project team identified five key questions to assess each marsh:

- How much is the marsh able to reduce the impact of coastal hazards?
- Is the marsh located where coastal hazards are a threat?
- Is the marsh located where there are people to protect?
- Is the marsh located nearby other protective habitats?
- Is the marsh likely to survive in the face of rising sea levels?

Applying data from the natural features and community flood risk analyses discussed above (see Sections 3 and 4) and other sources, metrics were developed to score each marsh polygon on these five questions. Then, the sub-scores were combined to create the Marsh Protection Potential Index overall rating, which ranks the protective power of over 14,000 marshes statewide.

By narrowing the scope of study to a single habitat type, the MPPI is able to expand on the findings of the natural features shoreline analysis discussed above and rank individual marshes by their ability to protect vulnerable communities from coastal hazards. This scoring will enable decision-makers to identify specific marshes which are a priority for protection, conservation, or restoration based on their protective services. Furthermore, marshes that have a relatively low score may be further examined to determine if enhancement to the marsh or surrounding area could increase the protection value.

The MPPI also expands the Coastal Resiliency Assessment by incorporating information about inland habitats. Natural habitats that are not located on the shoreline proper can still provide important protective services. This is particularly true in areas of low topological relief, such as Maryland's eastern shore. The InVEST model used in the natural features analysis does not reflect these inland habitats, and by addressing inland marshes the Marsh Protection Potential Index provides valuable additional information.

Finally, the Marsh Protection Potential Index serves as a demonstration project for the shoreline data generated as part of the Coastal Resiliency Assessment. The Assessment incorporates a huge variety of data on habitats, coastal hazards, and coastal communities, and it does so at a statewide scale. All of these data gathered in one place is a powerful tool, and the MPPI represents a single example of how this tool can be used. The project team hopes that the Marsh Protection Potential Index will inspire users of the Coastal Resiliency Assessment to develop innovative applications of the Assessment's data for the benefit of nature and people alike.

It is important to note that the MPPI ranks marshes relative to other marshes, rather than providing an absolute measure of protective services. The Marsh Protection Potential Index does not attempt to describe the dollar-value of protective services provided by each marsh, nor does it compare marshes to other types of habitat or to other protection infrastructure solutions.

The Marsh Protection Potential Index Criteria

The goal of the Marsh Protection Potential Index is to rank the potential of existing marshes to protect communities on a qualitative low-to-high scale. The project team identified five important aspects of a marsh's ability to protect people from coastal hazards. Marshes were given a score between zero and five on each of these categories. The category scores were summed to give each marsh an overall score between zero and twenty-five, which was then converted into the qualitative Very Low – Very High assessment given in the Overall Rating. This schema was developed in internal discussions by the Coastal Resiliency Assessment project team. These discussions were informed by the literature review, expert interviews, and steering committee consultation performed as part of the broader Coastal Resilience Assessment project. The sub score categories and data sources are described briefly in Table 9 below and in more detail on the following pages.

Protective Capacity: How much the marsh is able to reduce the impact of coastal hazards?

Marshes provide a wide variety of ecosystem services, many of which are directly relevant to mitigation of coastal hazards. Marshes attenuate wave energy, absorb flood waters, resist erosion, and can even raise the land surface by accretion, reducing the impact of rising sea levels (Shepard et al., 2011).

But some marshes provide more protection than others. They attenuate more wave energy, absorb more floodwater, or better resist erosion. We reviewed the scientific literature to identify the key determinants of a marsh's ability to provide protection. Determinants include the extent of the marsh (the overall area or the width with respect to directional hazards, such as storm surges) and the vegetation structure (stem density, stem thickness and stiffness, etc.). The relationship between the timing of coastal storms and seasonal variation in marsh vegetation is also an important factor.

Unfortunately, the statewide scope of the Marsh Protection Potential Index precluded detailed assessment of every relevant characteristic for each of the 14,000 marshes in the study area. Three metrics were initially identified – area, width, and aboveground biomass – on which to assess marshes' protective capacity. However, low confidence in the width and biomass assessments led to their exclusion in the final Marsh Protection Potential Index. Instead, each marsh was assigned a protective capacity score based solely on its area, which was calculated in ArcGIS (Figure 10).

Maryland's marshes come in a wide range of shapes and sizes. The Marsh Protection Potential Index includes marshes as small as 100 square meters (0.02 acres) and as large as 51,000,000 square meters (12,600 acres, approximately 1/4th the size of the entire District of Columbia). There are a great many small marshes, and only a few very large marshes. The average size of a marsh in the study area was 54,000 square meters, only about 13 acres. We used a geometric interval classification to convert marsh areas into 1-5 scores, with 5 indicating the largest marshes and 1 indicating the smallest marshes (Appendix H, Figure A19). A geometric interval is generally considered the most appropriate way to classify heavily skewed data. There was another benefit to using a geometric interval: For our data, each classification boundary represents approximately an order of magnitude increase in area.

The vast majority of Maryland's marshes are relatively small, and so they received low scores for area. Though there are relatively few large marshes, their size makes them easy to spot on a map.

The Marsh Protection Potential Index was limited to comparing marshes' protective capacity based on their size, because robust data on other important marsh characteristics (i.e. aboveground biomass, vegetation structure, etc.) was not available on a statewide scale. Decision makers wishing to compare marshes on a more local scale are encouraged to incorporate data on species composition, vegetation structure, seasonal variation, and directionality of coastal hazards. All of these data may be easier to obtain (or already available) for a smaller study area, and will provide valuable information about a marsh's protective capacity.

Proximity to Hazards: Is the marsh located where coastal hazards are a threat?

For a marsh to provide protection from coastal hazards there must be hazards nearby from which it can protect people. Marshes in areas that are highly vulnerable to coastal hazards are especially important providers of protection. By contrast, a marsh that is far away from potential floods, storm surges, or erosion may have little protective impact in the real world. While extreme exposure to hazards may threaten the marsh itself, these habitats can bounce back through sediment accretion or inland migration, if given the opportunity. These components of resilience are discussed later and have been incorporated into the Index (see Persistence section below).

To assess each marsh's proximity to hazards, one product of the Coastal Resiliency Assessment was applied. Marshes near the shores of major rivers, the Chesapeake Bay, or the coastal bays were scored using the Shoreline Hazard Index developed via the InVEST Coastal Vulnerability model (See Section 3). The Shoreline Hazard Index assigns each 250 meter segment of Maryland's shoreline a low, moderate, or high hazard rank based on physical parameters and shoreline characteristics that indicate erosion and inundation risk.

The Marsh Protection Potential Index scores each marsh's exposure to hazards based on the hazard rank of shoreline points within 250 meters of the marsh. Marshes within 250 meters of a shoreline point were scored from 3-5 to reflect their close proximity to coastal hazards, with 3 indicating marshes near a low hazard shoreline and 5 indicating marshes near a high hazard shoreline. In order to capture the protection value of more inland marshes during extreme flooding events, marshes not within 250 meters of a shoreline point were assigned low scores from 1-2 for falling within the 500-year and 100-

year floodplains, respectively (Figure 11). See Appendix H, Figure A20 for an example of the classification.

Proximity to People: Is the marsh located where there are people to protect?

The welfare of Maryland's people is at the heart of the Coastal Resiliency Assessment. Because the purpose of the Marsh Protection Potential Index is to rank the potential of existing marshes to protect communities, proximity to people is a vital component of the Index. Communities that are especially dense or socially vulnerable are often at a greater risk from coastal hazards because they may be less equipped to prepare for, respond to, or recover from coastal hazard impacts.

The Marsh Protection Potential Index uses the Coastal Resiliency Assessment's Population Density Index and the Social Vulnerability Index to score marshes based on the population density and social vulnerability of communities within two kilometers of each marsh (Figure 12). A two kilometer area of influence was selected based on the scientific literature discussing marsh protection services, and is consistent with the 2km influence distance used in the Coastal Resiliency Assessment community risk analysis. Marshes within two kilometers of both highly dense residential communities and highly vulnerable residential communities received high scores for proximity to people, while marshes near communities which were less dense or less vulnerable received lower scores. Marshes that were more than two kilometers from any residential community received a score of 0 (Appendix H, Figure A21). For more information about the Population Density Index and the Social Vulnerability Index, please see Section 4. The Community Risk Analysis classifies residential areas based on US Census Bureau population and demographic data. The factors of age, income, and English language proficiency were used to describe social vulnerability.

Proximity to Habitats: Is the marsh located adjacent to other protective habitats?

Marshes function best when there are other natural habitats nearby. Network effects from neighboring coastal forests, sand dunes, oyster reefs, or submerged aquatic vegetation contribute to the health and effectiveness of a marsh. Likewise, a marsh that neighbors other marshes will enjoy benefits such as reduced wave energy, increased sedimentation, improved water quality, and larger habitat for important species (Spalding et al., 2014).

To quantify the influence of neighboring natural habitats, each marsh was evaluated to determine the extent of nearby habitats (Figure 13). A 250 meter buffer zone was created for each marsh to calculate the percent coverage by other habitats, such as forests, dunes, underwater grasses, oysters, and other marshes. 250 meters was selected as the buffer distance to remain consistent with the "protective influence" distance for marshes used in the Maryland run of the InVEST Coastal Vulnerability model. For the MD-specific version of the InVEST model, the "protective influence" distance of marshes was reduced from 1km to 250m in response to sensitivity testing. Very few shoreline segments in Maryland are more than 1km from a marsh, and so a more selective 250m distance was chosen. This more selective buffer zone emphasizes the influence of habitats which are adjacent (or nearly so) to a marsh, rather than merely nearby.

A defined interval of 20% was applied to classify the percentage of buffer occupied by habitats (Appendix H, Figure A22). The greater percentage of a marsh's buffer zone occupied by natural habitat, the higher the marsh's proximity to habitats score.

Persistence: Is the marsh likely to survive in the face of rising sea levels?

Many low-lying coastal areas are likely to be submerged in the next century as sea levels rise and land subsides. Though marshes have demonstrated the ability to mitigate rising sea levels by accreting sediment, in many cases waters will rise too quickly for marshes to keep pace. Still, many marshes are expected to continue providing valuable protective services, either by remaining above the rising waters or by migrating inland. For many stakeholders, knowing whether a marsh is likely to disappear, migrate, or remain in place will be an important factor in their decision-making.

To assess the likely status of marshes in 2100, existing marshes were compared to MD DNR's Wetland Adaptation Areas (Figure 14). MD DNR used the Sea Level Affecting Marshes Model (SLAMM) to identify areas which are likely to be suitable for marshes in the year 2100. These Wetland Adaptation Areas include both existing marshes (where they are likely to remain) and areas with a high potential for marsh migration. The Marsh Protection Potential Index incorporates the Wetland Adaptation Areas by scoring existing marshes based on how much they are likely to persist, and how much space nearby (within 250 meters) is likely to be available for migration in the future (Appendix H, Figure A23).

Table 9. Marsh Protection Potential Index Criteria.

Mapping Layer	Mapping Objective	Criteria / Metric	Source Data
Protective Capacity	Rank marshes by the amount of protective services they can provide	Marsh size	MD DNR-specific version of 2008 National Wetlands Inventory (DNR-NWI 2008)
Proximity to Hazards	Rank marshes by their proximity to coastal hazards	Exposure index of nearby shoreline Location with respect to 100-year and 500-year floodplains	DNR-NWI 2008 Maryland Coastal Resiliency Assessment Shoreline Points
Proximity to People	Rank marshes by their proximity to coastal communities	Population density of communities within 2 kilometers Social vulnerability of communities within 2 kilometers	DNR-NWI 2008 Maryland Coastal Resiliency Assessment Community Risk Areas
Proximity to Habitats	Rank marshes by their proximity to other natural habitats	% of a 250m buffer zone occupied by forest, oyster reefs, SAV, sand dunes, or other marshes	DNR-NWI 2008 Maryland Coastal Resiliency Assessment Model Inputs
Persistence	Rank marshes by their ability to persist into the year 2100	% of current marsh area expected to persist through the year 2100 % of a 250m buffer zone expected to be available for marsh migration through the year 2100	DNR-NWI 2008 MD DNR Wetland Adaptation Areas
Total Score	Rank marshes by their ability to provide lasting protection from coastal hazards to Maryland’s communities	Sum of 5 sub scores	Sub score Layers
Overall Rating	Final Product of the Marsh Protection Potential Index	Jenks Natural Breaks Intervals on Total Score	Total Scores

Figure 10. Marsh Protective Capacity (Area).

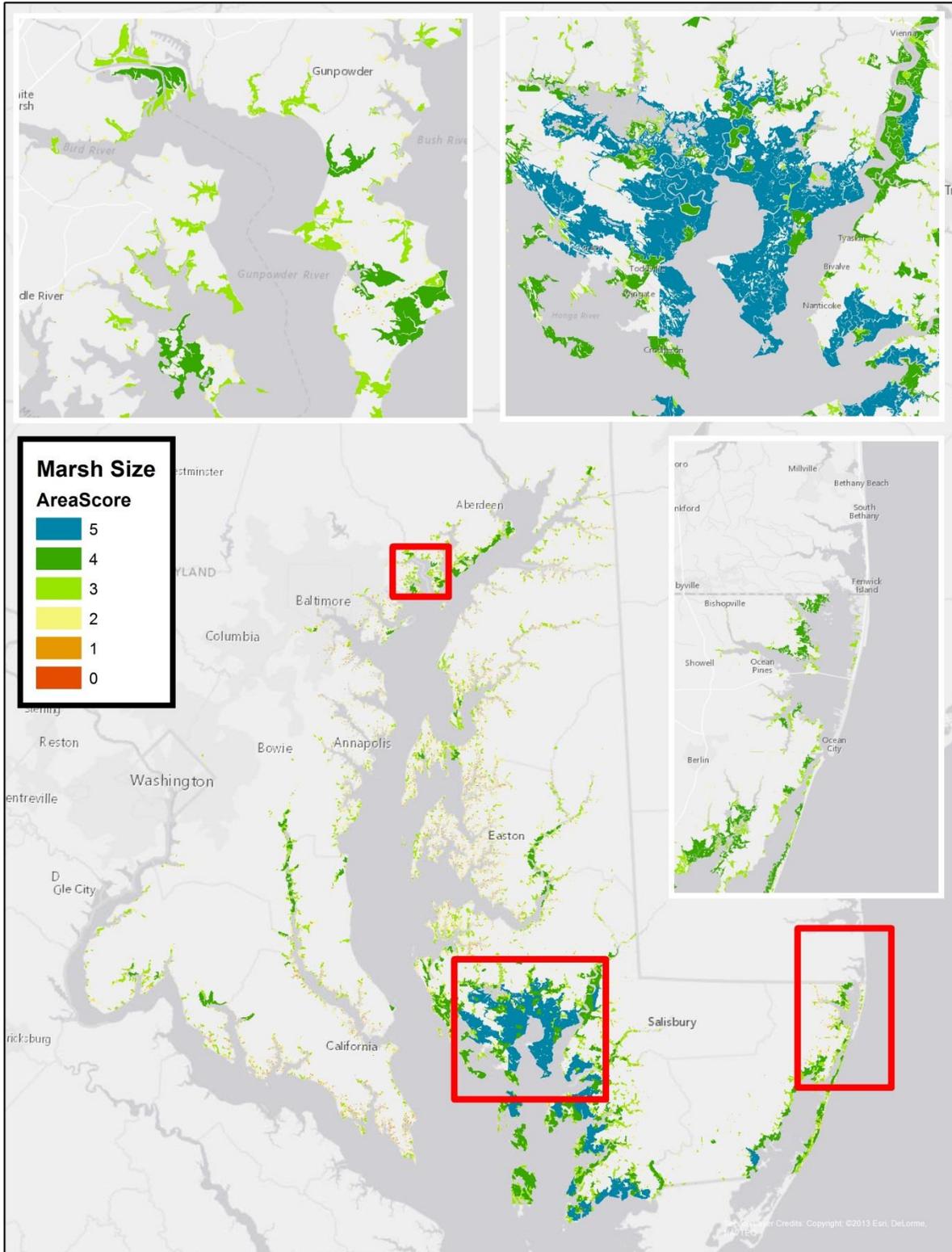


Figure 11. Marsh Proximity to Hazards.

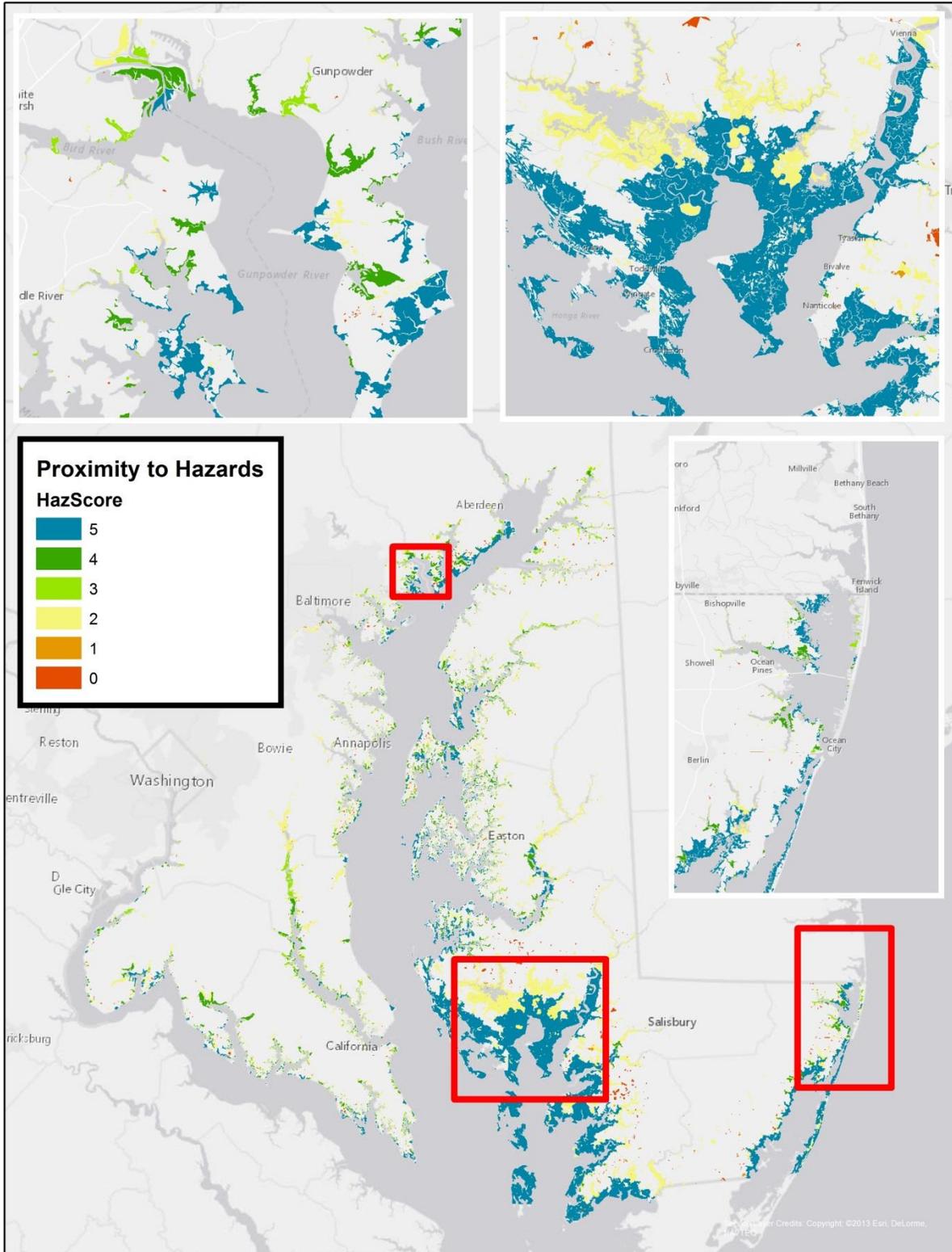


Figure 12. Marsh Proximity to People.

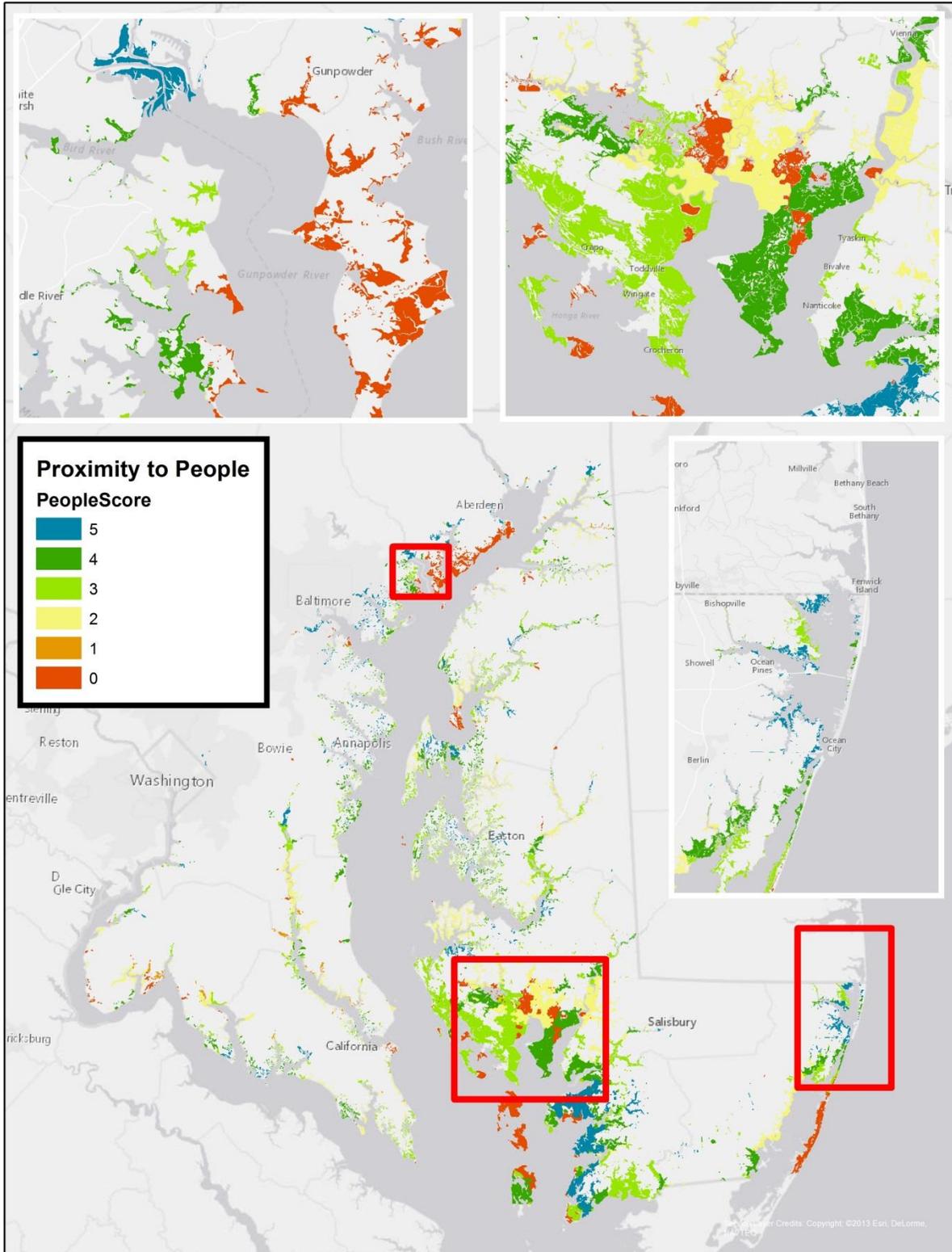


Figure 13. Marsh Proximity to Habitats.

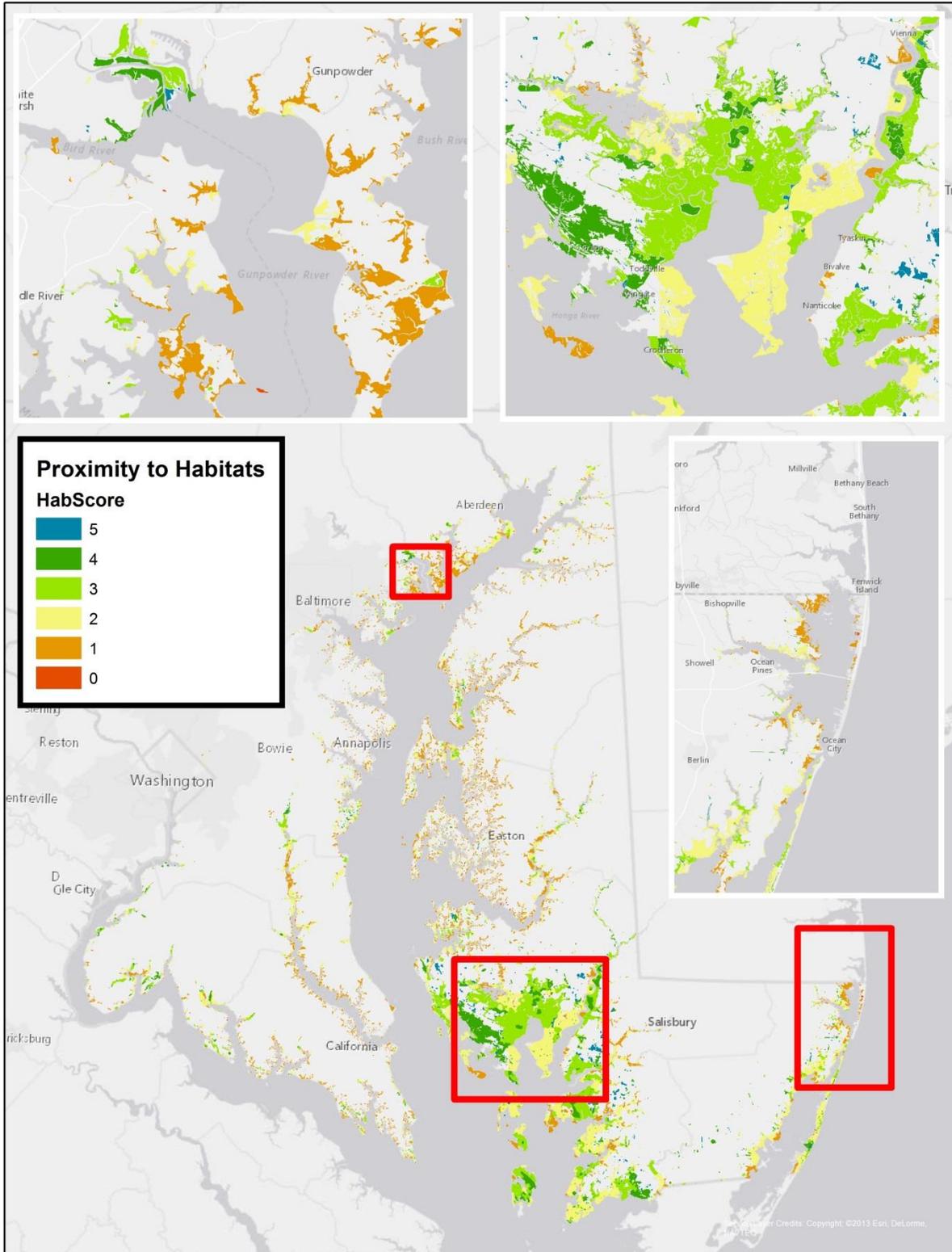
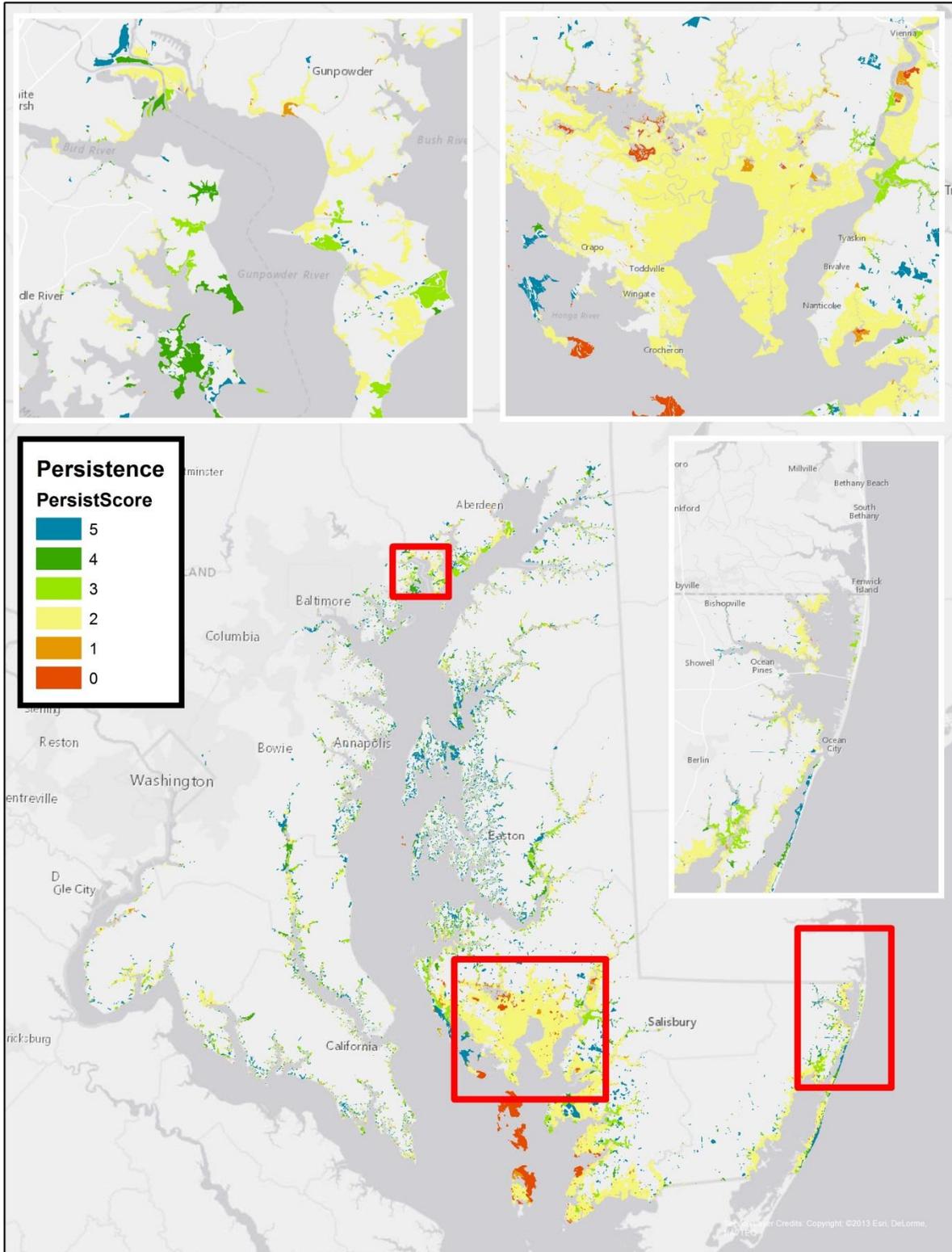


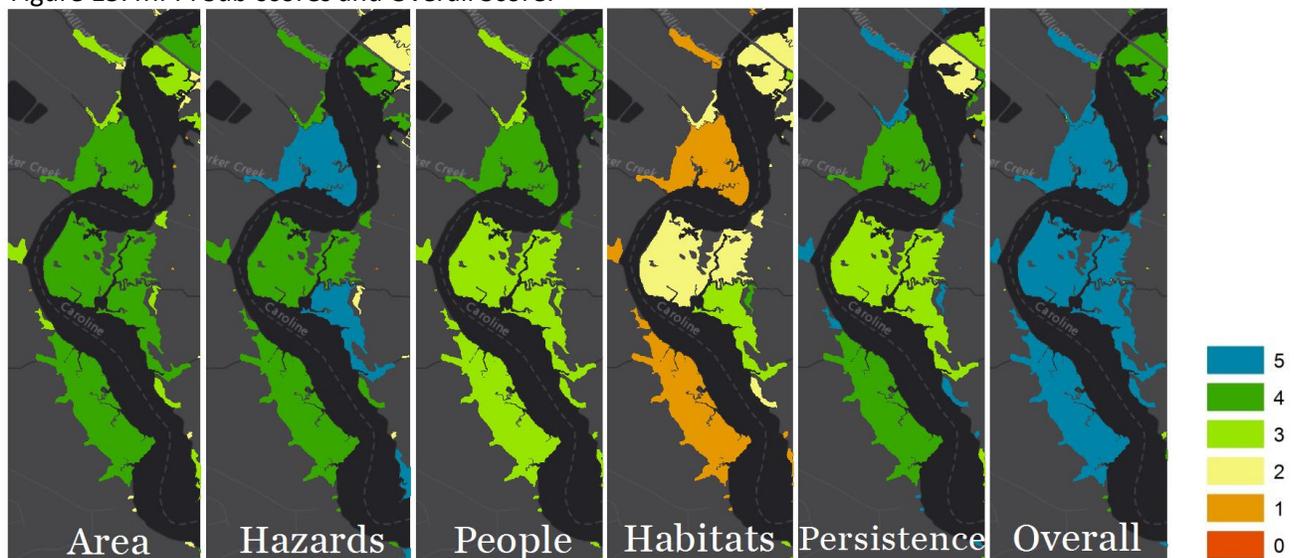
Figure 14. Marsh Persistence.



Total Score and Overall Rating: What is the potential for the marsh to protect communities from coastal hazards?

The overall Marsh Protection Potential Index rating represents a general assessment of marshes' ability to protect people from coastal hazards, which may be useful for stakeholders in a variety of ways. Funding agencies concerned with coastal hazards are increasingly targeting green infrastructure solutions, such as marshes. Likewise, conservation groups (federal, state, and private) are increasingly seeking to prioritize protective services when targeting conservation or restoration. Finally, local communities are interested in whether nearby marshes can play a prominent role in their plans to protect their people from coastal hazards. For all of these stakeholders, knowing which marshes are (or are not) protecting local communities will help them make more informed decisions about the best use of their time and money.

Figure 15. MPPI Sub-scores and Overall Score.



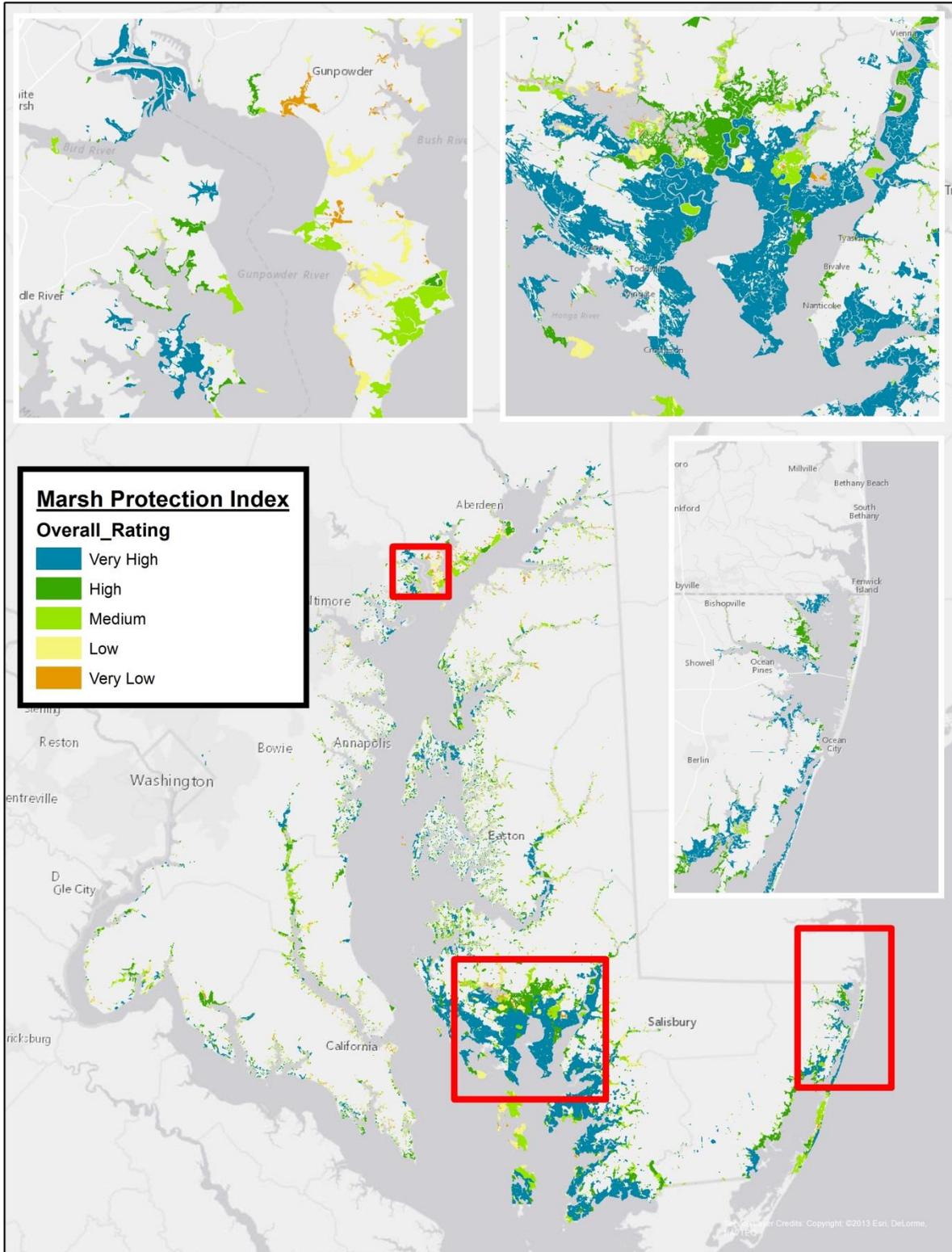
By summing the five sub scores, each marsh was assigned a total score with a theoretical range from 1-25. The different sub scores are weighted equally; for example, a 5/5 on protective capacity is worth the same as a 5/5 on proximity to people. The minimum actual score was 2/25, and the highest actual score was 23/25. The total scores have a bell curve distribution with a mean value of 12.72 and a median score of 13. See Appendix H, Figure A24 for an example of marsh total scores.

To assist with interpretation of the results, the numerical total scores were converted into qualitative protection categories ranging from Very Low to Very High. A Jenks Natural Breaks classification with five intervals was applied to the Total_Scores field. The ranges are (1-9), (10-11), (12-13), (14-15), and (16-23) for the categories Very Low, Low, Medium, High, and Very High, respectively. The overall protection ratings incorporate assessments of each marsh's protective capacity, proximity to hazards, proximity to people, proximity to habitats, and future persistence (Figure 15). Because some users may prefer to focus on one or more of the five sub scores associated with these assessments, the sub scores and

associated metrics are available alongside the final protection categories within the Index's attribute table.

It is important to note that the overall rating describes a marsh's protective potential *relative to other marshes* (Figure 16). Users should not infer some absolute dollar-value of protection services based on a marsh's qualitative ranking. Likewise, the ratings only compare marshes to other marshes. The Marsh Protection Potential Index does not compare marshes to other natural habitats or other types of protection infrastructure, such as bulkheads.

Figure 16. MPPI Overall Rating.



7. Discussion

Habitats play a large potential role in risk reduction for MD coastal residents, particularly where more than one habitat type occurs along shorelines that are exposed to moderate or high levels of coastal hazards and that are in close proximity to at-risk communities. The results of this Assessment provide tools to target coastal adaptation efforts so that protecting or restoring natural habitats also provides the greatest risk reduction benefit to coastal residential communities.

In order to be selected as a Priority Shoreline Area, a location must be no more than two kilometers from a residential area. Similarly, the Proximity to People variable in the Marsh Protection Potential Index measures the population density and social vulnerability of communities with two kilometers. These criteria emphasize the fact that the Assessment is exclusively concerned with the ability of habitats to reduce risk for people. Factors such as biodiversity, ecosystem health, rare species, recreation value, and water quality services are often important to stakeholders, but are not captured by the Assessment. The Assessment results are intended to supplement, not replace, the current approaches that decision-makers use to prioritize natural habitats for protection and restoration. For instance, in order to incorporate the ecological value of habitats, users should consult DNR's GreenPrint map, particularly Blue Infrastructure Priority Shoreline Areas and the Biodiversity Conservation Network (BioNet).

The Assessment is a screening-level tool; specific actions appropriate in any given area will depend on the local conditions, including the specific hazards present, the current condition of existing habitats and the suitability of the site for expansion or creation of habitats. By themselves, natural features may be best suited for risk-reduction in lower energy areas and in response to nuisance or tidal flooding and erosion, rather than preventing impacts from high impact storms. Large scale natural feature approaches to risk reduction may not be feasible in highly urbanized landscapes, especially if communities are at high risk to flooding and other coastal storm impacts. In locations where a nature-only solution is not possible, planners can consider a green-gray hybrid approach to shoreline stabilization and flood reduction. A hybrid approach combines nature-based with more traditional solutions, in order to achieve the hazard reduction sought while also realizing many co-benefits from the natural features, such as wildlife habitat, improved water quality, and recreational opportunities. Ground-truthing and site level analysis will be required to identify appropriate risk reduction solutions for any vulnerable community.

Management or restoration actions taken to enhance risk-reduction benefits of habitats must be weighed against any potential trade-offs with ecological value, which is not accounted for in the Assessment results. Ecological resilience – the ability of the habitats to remain viable in the face of long-term climate change – is also not considered in the shoreline model, although it is represented by the Persistence variable in the Marsh Protection Potential Index. The planning horizon for a given action will influence the degree to which current conditions versus future projections are emphasized, especially when considering factors such as sea level rise.

A number of opportunities exist to incorporate the results of the Assessment into State and Local planning and decision making. The project team has begun discussions with appropriate staff about

integrating Assessment data into the GreenPrint scorecard used to evaluate potential DNR acquisitions and coastal resilience conservation easements. DNR staff have also indicated that the data may be useful for evaluating potential forest legacy easements, conducting natural area inventories, conducting environmental review of state projects, and identifying locations where water quality best management practices may also address coastal resiliency. While conservation decisions are often made at the parcel level, restoration decisions take a project or site-level approach. Due to these differences, staff are working separately with state restoration experts and funding programs to determine data applications and funding opportunities, as well as develop guidance on general restoration options available to practitioners.

Local governments may also find the Assessment data valuable additions to their County Hazard Mitigation Plans and Comprehensive Plans, in order to consider the use of natural feature solutions when preparing and planning for future hazards. Acknowledging that the Assessment was conducted at a statewide scale, similar analyses can be replicated at a local scale to identify natural feature priorities informed by local concerns. While the state analysis specifically evaluates communities based on residential land use and demographics (i.e. age, income, and language proficiency), these factors are not set in stone. Local communities may choose to weight certain demographics, select other indicators of social vulnerability, or include economic hubs and critical infrastructure within the analysis.

At the regional level, the Assessment results contribute to the 2014 Chesapeake Bay Watershed Agreement Climate Resiliency Goal, which aims to increase the resiliency of the Chesapeake Bay watershed, including its living resources, habitats, public infrastructure and communities, to withstand adverse impacts from changing environmental and climate conditions. As a signatory to the Agreement, Maryland has pledged to contribute to monitoring, assessment and adaptation efforts within the Bay Watershed. The Coastal Resiliency Assessment specifically supports adaptation efforts by identifying priority locations for restoration and protection actions, which will enhance the resiliency of the Bay's ecological and human communities from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms, and sea level rise. The Assessment results are also available to inform the Chesapeake Bay Comprehensive Plan currently in development by the U.S. Army Corps of Engineers and the National Fish and Wildlife Foundation. Funding opportunities for implementation include the Federal Emergency Management Agency Pre-Disaster Mitigation Grant Program and NOAA Regional Coastal Resilience Grants, as available.

Future iterations of the Assessment would benefit from information on the condition of Maryland's habitats, particularly marshes and coastal forests, and efforts to quantify the risk-reduction benefits of Maryland habitats, such as the work currently being conducted by George Mason University on wave-attenuation by marshes (Haddad et al., 2015). Other important considerations, beyond the scope of work for the Assessment, include: the ability of different types of habitats to address different types of hazards; the seasonality of hazards and habitats; the location and vulnerability of critical infrastructure; economic implications of coastal hazards and risk-reduction by habitats; cost-benefit analyses; population and development trends and projections; and the development of ground-truthing checklists or procedures to determine model effectiveness as selected sites are evaluated for resiliency projects.

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Marsh

MD DNR (Maryland Department of Natural Resources). 2008. Maryland Marshes. Estuarine intertidal emergent (E2EM) and Palustrine emergent (PEM) wetlands compiled from NWI and DNR wetlands data.

Dunes

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USACE (U.S. Army Corps of Engineers). 2015. Ocean City Dunes. Dune presence north of the Ocean City inlet was manually recorded based on recent aerial photos and personal communication with USACE staff regarding the Atlantic Coast MD Shoreline Protection project.

Underwater Grass

VIMS (Virginia Institute of Marine Science). 2014. Distribution of Submerged Aquatic Vegetation in the Chesapeake Bay and Tributaries and the Coastal Bays. CCS filtered data to include only areas with consistent coverage for at least 7 years from 2004 – 2014. Areas with average density ≥ 3 were assigned a Hazard Rank of 4; less dense areas were assigned a Hazard Rank of 4.5.

<http://web.vims.edu/bio/sav/>

Oyster Reefs

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beginning 'Constructed' and size \geq 1ha (individual polygon area, or combined area of closely adjacent polygons). <http://chesapeakebay.noaa.gov/oysters/oyster-restoration>.

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Coastal Vulnerability Model

NatCap (Natural Capital Program). InVEST Coastal Vulnerability Model version 3.0.1.

http://data.naturalcapitalproject.org/invest-releases/documentation/3_0_1/

Dasymetric Mapping Tool

USGS (U.S. Geological Survey). 2012. <http://geography.wr.usgs.gov/science/dasymetric/data.htm>

Appendix A

Available Data & Resources

** Indicates that this data was used in the State Hazard Mitigation Plan.*

Coastal Hazards

Data layers indicating exposure to coastal hazards/climate impacts.

***Sea Level Rise Vulnerability/Elevation Data.** The Maryland Department of Natural Resources has elevation data collected over the last 10 years using aerial-based laser surveying instruments (LiDAR). These data have been used to identify areas at risk of inundation and flooding in coastal counties. This vulnerability mapping depicts land at risk to inundation under the following sea level rise scenarios: 0 -2 feet, 2 – 5 feet, and 5 – 10 feet. As new data are collected and added to the database, updated sea level rise inundation zones can be developed for 50 and 100-year planning windows. For more information, visit esrgc.org/mapservices

Erosion Vulnerability Assessment. The Erosion Vulnerability Assessment Tool (EVA) is a shoreline planning tool developed by the Baltimore District Army Corps of Engineers and Maryland Department of Natural Resources to identify shorelines with historic patterns of instability, as well as shorelines that support valued natural, social, or economic resources.² EVA uses a 50-year planning window to estimate and project the shoreline position in 50 years. These projections inform local planners about potential risks to current infrastructure and valued resources. EVA can be used to flag at-risk areas and prioritize erosion control measure sites.

***Shoreline Rates of Change.** In 2003, the Maryland Geological Survey, Towson University’s Center for Geographic Information, and the US Geological Survey developed shoreline rates of change data with the Digital Shoreline Analysis System (DSAS) software for Maryland shores. DSAS outputs rates of change based on a baseline condition.

***Maryland Storm Surge Areas.** The US Army Corps of Engineers completed two hurricane evacuation studies for the eastern (2007) and western (2010) shores of Maryland. Storm surge areas were developed using NOAA’s Sea, Level, and Overland Surges from Hurricanes (SLOSH) model. SLOSH estimates storm surge heights from historical, hypothetical, or predicted hurricanes. These areas are used in local planning, as they predict flooding likelihood during major storm events.

***Q3 Floodplains.** Both 100-year and 500-year floodplain maps are available from the Federal Emergency Management Agency (FEMA). These maps display 1% and 0.2% annual chance floods.

***Wind Speed.** ASCE wind speeds based on 3 second gust wind speeds in miles per hour at 33 feet above ground for the 50-year recurrence interval.

² http://ccrm.vims.edu/gis_data_maps/interactive_maps/erosion_vulnerability/index.html

***NCDL Storm Events.** The NOAA National Weather Service NCDL storm database provides information on coastal hazard events, including frequency and property damage.

Fetch. At any given shoreline reach, the distance over which wind can blow to generate waves.

Coastal Hazards System. The CHS is a coastal storm hazard data storage and mining system. It stores comprehensive, high-fidelity, storm response computer modeling results including climatology, surge, total water levels, waves, and currents and corresponding measurements. Extremal statistics and epistemic uncertainties of the processes are also stored, and the data are easily accessed, mined, plotted, and downloaded through a user-friendly web interface. CHS regional data are comprehensive, uniformly spanning the coastal region and practical probability space. The types of data that are available for access along broad reaches of coastline include the following: ADCIRC model output, including storm surge, total water level, and tides; STWAVE, SWAN, and WAM wave model output; storm tracks and storm climatologic characteristics; and storm probabilities and response annual recurrence rates and confidence limits.

Social Vulnerability

Data layers identifying populations and infrastructure sensitive to coastal hazards.

***Population.** The US Census Bureau provides population estimates for 2010.

Demographics. The Maryland Department of Planning maintains databases containing information on population, housing, employment, income, businesses, school enrollment, natural resources, and land use.

***Parcel Data.** The Maryland Property View Database is updated and maintained by the Maryland Department of Planning. MD Property View is an electronic information system which contains data on every land parcel within the State. For more information, visit

<http://planning.maryland.gov/OurProducts/PropertyMapProducts/PropertyMapProducts.shtml>

***Roads.** The State Highway Administration has information on state-owned bridge, overpass, and road locations. Local road data that is created and maintained by the counties is available to supplement state data.

Building Polygons. Building outlines are maintained generally by counties in Maryland via planimetric mapping techniques. Several State agencies (MDP, MDE, DOITT) have collected building polygons to support specific applications. Data distribution agreements limit the sharing of this data for some counties.

***Critical Facilities.** Facilities that are critical to the health and welfare of the population and that are especially important following hazard events. Critical facilities include, but are not limited to, shelters, police and fire stations, and hospitals.

***State Facilities.** The Maryland State Treasurers Office has information on state facilities, including the location of administrative, airport, correctional, natural resource, educational, environment, fire/police, health, historic, judicial/legal, military, social service, transportation, and utility facilities.

***Repetitive Loss/Severe Repetitive Loss Properties.** Repetitive Loss Properties are properties with a National Flood Insurance Program (NFIP) flood insurance policy with two or more claims within a ten-year period that exceed \$1,000. Severe Repetitive Loss Properties have at least 4 NFIP claims over \$5,000 each with the cumulative amount exceeding \$20,000, or at least two separate claim payments with the cumulative amount exceeding the market value of the building.

***Hazards US, Multi Hazard (HAZUS-MH).** HAZUS is a risk assessment model developed by FEMA that analyzes potential losses from floods, hurricane winds, coastal surge, and earthquakes. Damage and loss estimates are developed for pre and post disaster events. The model considers social and economic impacts from the event. MEMA has conducted a Level 2 analysis to 1) estimate flood loss and risk to critical facilities throughout the state; and 2) determine potential losses due to tropical storm and hurricane winds.

Riparian Structures. The Virginia Institute of Marine Science (VIMS) conducted a shoreline inventory for the tidal portions of Maryland and Virginia counties.³ The Maryland Department of Natural Resources partnered with VIMS to complete the Maryland inventory, which provides information on shoreline condition, resources, and structures in GIS format. GIS layers include access and stabilization structures.

Working Waterfronts Infrastructure. An inventory of waterfront dependent industries is available via the Coastal Atlas, including the location of waterfront-dependent businesses and landing sites.

Environmental Justice Screening Tool. This EPA tool will be used to meet the 2014 Chesapeake Bay Agreement goals for diversity.

³ http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/index.html

Appendix B

Existing Tools

The Nature Conservancy's Coastal Resilience Tools

<http://coastalresilience.org/>

Coastal Resilience is a global network of practitioners who are applying an approach and web-based mapping tools designed to help communities understand their vulnerability from coastal hazards, reduce their risk and determine the value of nature-based solutions. The approach includes four steps: assess risk, identify solutions, take action, and measure effectiveness.

Tools available to help assess risk and identify solutions:

* Indicates that the model underlying this tool was modified for use in the MD Statewide Coastal Resiliency Assessment.

***Risk Explorer** is an interactive application based on the Natural Capital Program's InVEST Coastal Vulnerability Model, in which a Risk Score is calculated for each shoreline segment based on exposure to coastal hazards and vulnerability of adjacent human communities. The coastal hazard exposure is based on seven physical and biological variables: geomorphology, relief, sea level rise, wind exposure, wave exposure, surge potential, and the presence of habitats with potential risk reduction capabilities (e.g. oyster reefs, coastal forests, dunes, marshes, seagrass beds). Removing existing habitats from the model increases the calculated exposure and identifies places where habitats are currently providing risk reduction for vulnerable coastal communities. Risk Explorer is available on a national scale for the East Coast and Gulf of Mexico.

***Habitat Explorer** is an interactive application based on the calculation of a Marsh Protection Potential Index, which estimates the risk reduction potential of tidal marshes based on marsh size and proximity to people, property, and critical infrastructure. Each marsh's "protection zone" is estimated as its upland drainage basin, up to five meters of elevation. Habitat Explorer is available for New York and Connecticut.

Coastal Defense is an interactive application based on the Natural Capital Program's InVEST Coastal Protection Model, which quantifies how natural habitats protect coastal areas by reducing wave-induced erosion and inundation. Coastal Defense is available for Southeast Florida and Puget Sound, and is under development for the eastern shore of Virginia.

Restoration Explorer examines ecological and socio-economic factors for restoration suitability, and is available for oyster restoration suitability in Gulf of Mexico.

Future Habitat maps the extent of forested wetlands, marshes and beaches/flats under different sea level rise scenarios. Future Habitat is for Gulf of Mexico, Connecticut, New York, California, and Southeast Florida.

Community Planning is where communities can host locally specific data to inform decisions and track successes. It has been used to perform Resilience Analyses incorporating coastal hazard risk and marsh viability for several communities in Florida and Texas.

Flood and Sea Level Rise maps are available for the East Coast, Gulf of Mexico, Ventura County, CA, and Puget Sound.

North Atlantic Coast Comprehensive Study

<http://www.nad.usace.army.mil/compstudy>

The U.S. Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS) addresses coastal storm and flood risk to vulnerable populations, property, ecosystems, and infrastructure affected by Hurricane Sandy in the United States' North Atlantic region. Products of the study include a nine-step Coastal Storm Risk Management Framework, State-specific risk analyses and coastal storm risk management strategies, a report examining the use of natural and nature-based features (NNBF) to improve coastal resilience, and geospatial data. The data includes raster layers of the NACCS exposure analysis, risk analysis, future mean sea level inundation mapping, and housing density projections, and a vector geodatabase containing base map layers, coastal features (classified shoreline, coastal vulnerability index, 100 floodplain, and SLOSH categories 1-4), federal & state shore protection projects, high risk areas, natural and nature-based (NNBF) feature suitability classifications, and Sandy impacts.

NOAA's Oyster Decision Support Tool

<http://chesapeakebay.noaa.gov/products/oyster-decision-support-tool>

The Oyster Decision Support Tool is a web-map with data layers of oysters, oyster habitat, and oyster restoration projects in the Chesapeake Bay.

NOAA's Chesapeake Bay Habitat Tool

<http://maps.tnc.org/chesapeakehabitat/>

The Chesapeake Bay Habitat Tool provides spatial context for multi-habitat conservation opportunities in the Bay. Features of the tool include a web map with Bay-wide data for important nearshore habitats (fish passage, tidal wetlands, oysters, submerged aquatic vegetation), new benthic data layers to better describe the habitat on the Bay floor, and an interactive tool to prioritize wetland protection and restoration.

NOAA's Sea Level Rise and Coastal Flooding Impacts Viewer

<http://coast.noaa.gov/slr/>

The Viewer simulates various sea level rise scenarios (from one to six feet above the average highest tides) and the corresponding areas that would be impacted by flooding. The Viewer also provides information about marsh impacts and marsh migration, nuisance flood frequency, and social and economic data.

NOAA Economic Framework

<http://coast.noaa.gov/digitalcoast/publications/adaptation>

NOAA developed a cost-benefit framework to help community planners determine the cost of various sea level rise adaptation approaches.

MD GreenPrint

<http://greenprint.maryland.gov/>

Maryland's GreenPrint displays the State's Targeted Ecological Areas (TEAs), or areas prioritized from an ecological perspective for land acquisition. The following data layers were used to identify ecologically significant lands that promote habitat function and connectivity: green infrastructure and forests important for protecting water quality, wildlife and rare species habitat, non-tidal streams and fisheries (i.e. watersheds important for protecting Maryland's freshwater aquatic biodiversity), tidal fisheries/bay/coastal ecosystems (i.e. areas with high quality habitat that support productive anadromous fisheries), and wetland adaptation areas (i.e. important future wetland habitats).

Blue Infrastructure Near-shore Assessment (BI)

<http://www.dnr.state.md.us/ccs/bi.asp>

Maryland's BI identifies high priority shoreline segments and watersheds for conservation and management to maintain and improve coastal habitats. These areas support productive and diverse coastal ecosystems, fisheries, and human uses. Data components of the BI include sensitive species, shoreline-dependent species, spawning and nursery areas, protected lands, impervious surface, hardened shores, fish blockages, water quality, and natural infrastructure such as coastal marshes, submerged aquatic vegetation, oyster bars and beaches. Maryland's high priority BI areas have been incorporated into the GreenPrint TEAs and all BI areas are considered during environmental review and land conservation decisions.

Sea Level Rise Wetland Adaptation and Vulnerability Model (Marsh Migration Corridors)

http://dnr.maryland.gov/ccs/pdfs/coastalland_conserv_md.pdf

The Maryland Department of Natural Resources ran the Sea Level Affecting Marshes Model (SLAMM) to predict wetland cover in 2050 and 2100. SLAMM simulates wetland conversion and shoreline modification during long-term sea level rise. The model was run under accelerated sea level rise conditions (1.3 feet by 2050 and 3.4 feet by 2100). These data display future and at-risk wetland areas and were used to identify State Marsh Migration Corridors.

Natural Filter Restoration Targeting

http://www.dnr.state.md.us/ccs/coastal_fellowship.asp

Wetland and riparian buffer restoration opportunities are identified by coastal county. Land use, soil, and hydrology characteristics were used to identify potential restoration sites. A methodology was also developed to prioritize locations with potential for enhanced water quality improvement (i.e. N, P, and sediment removal). This methodology can be paired with the Coastal Resiliency Assessment outputs to help identify restoration options for vulnerable coastal communities.

Appendix C: Intermediate InVEST Results

Figure A1: Geomorphology Hazard Rank.

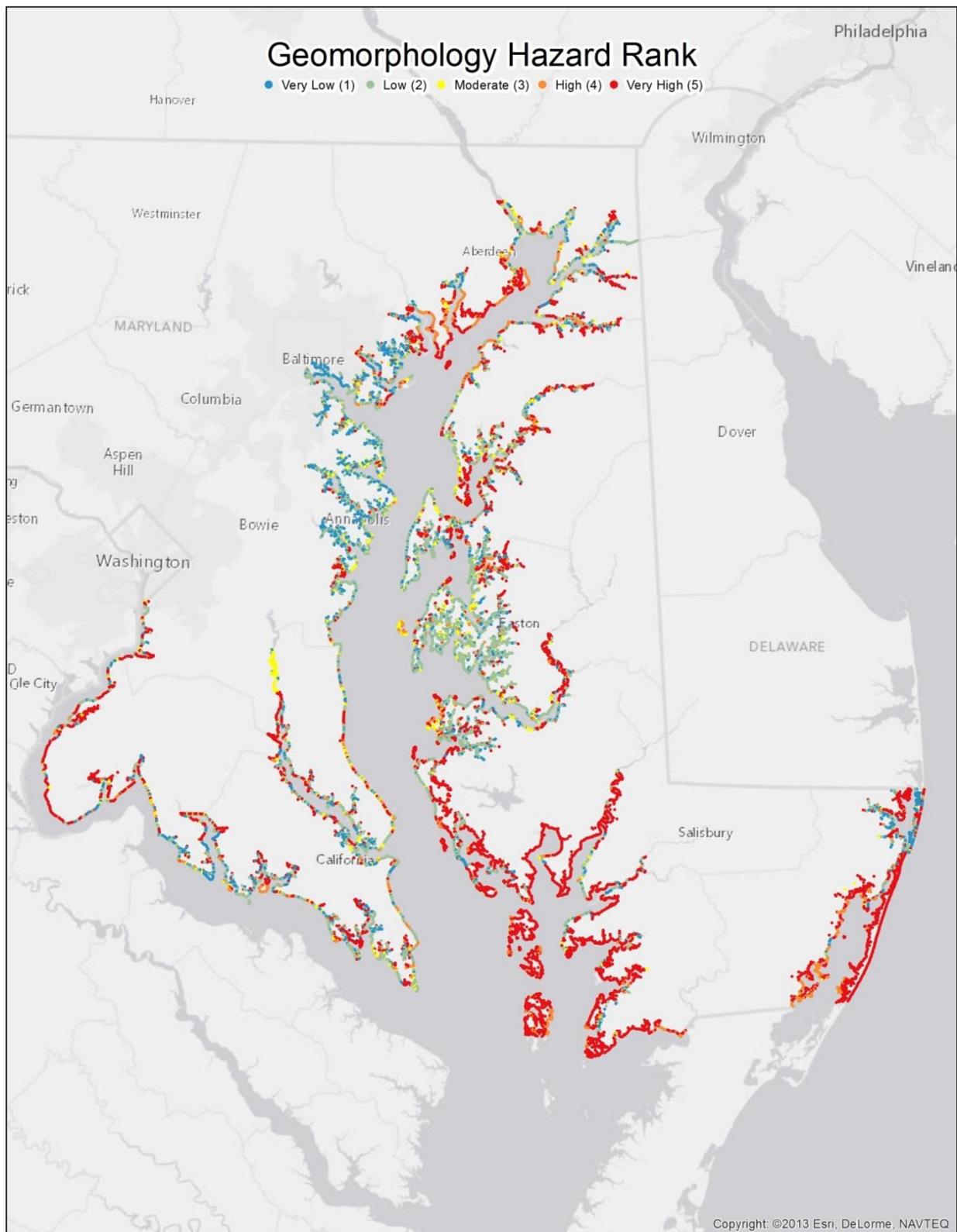


Figure A2: Elevation Hazard Rank.

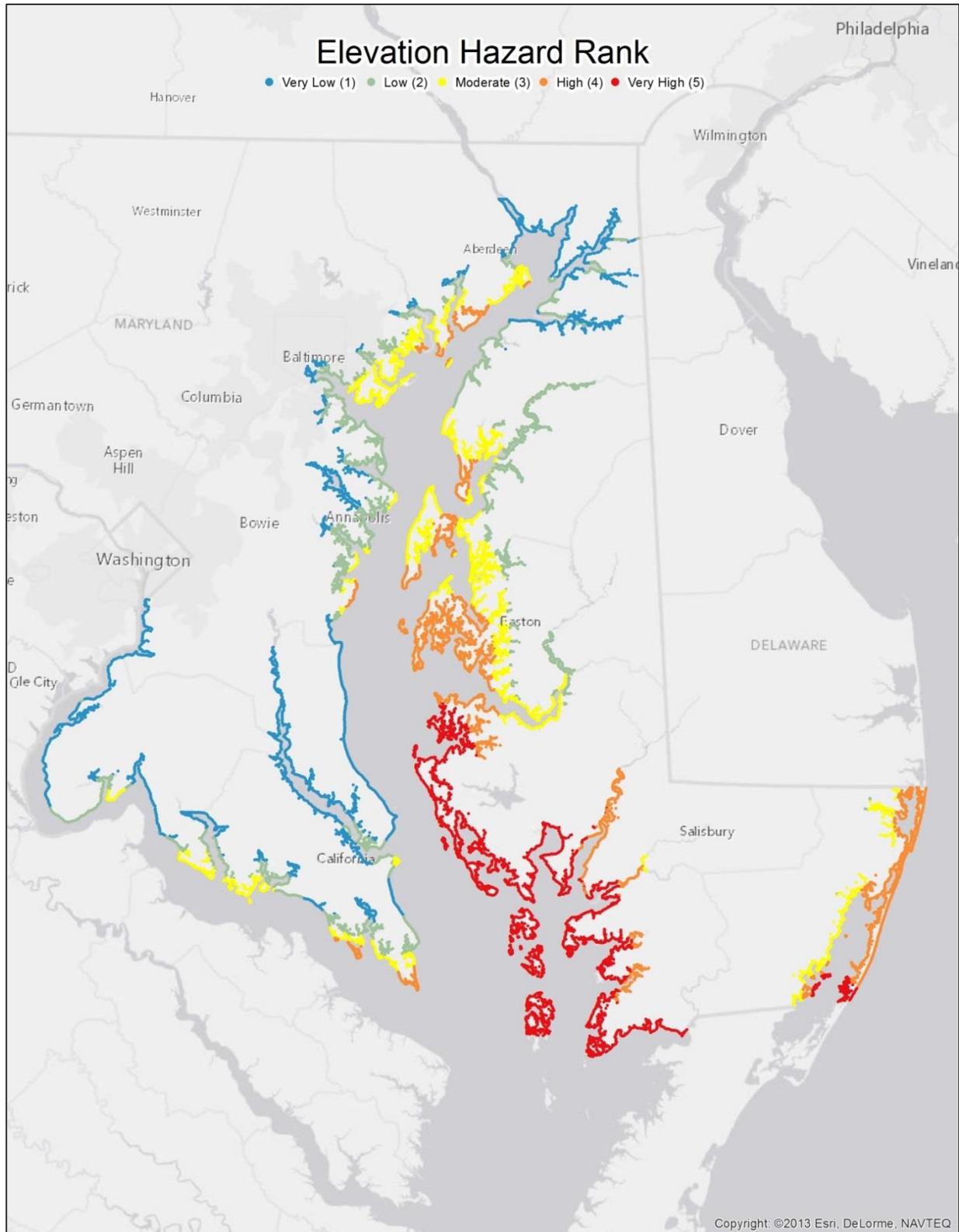


Figure A3: Sea Level Rise Hazard Rank.

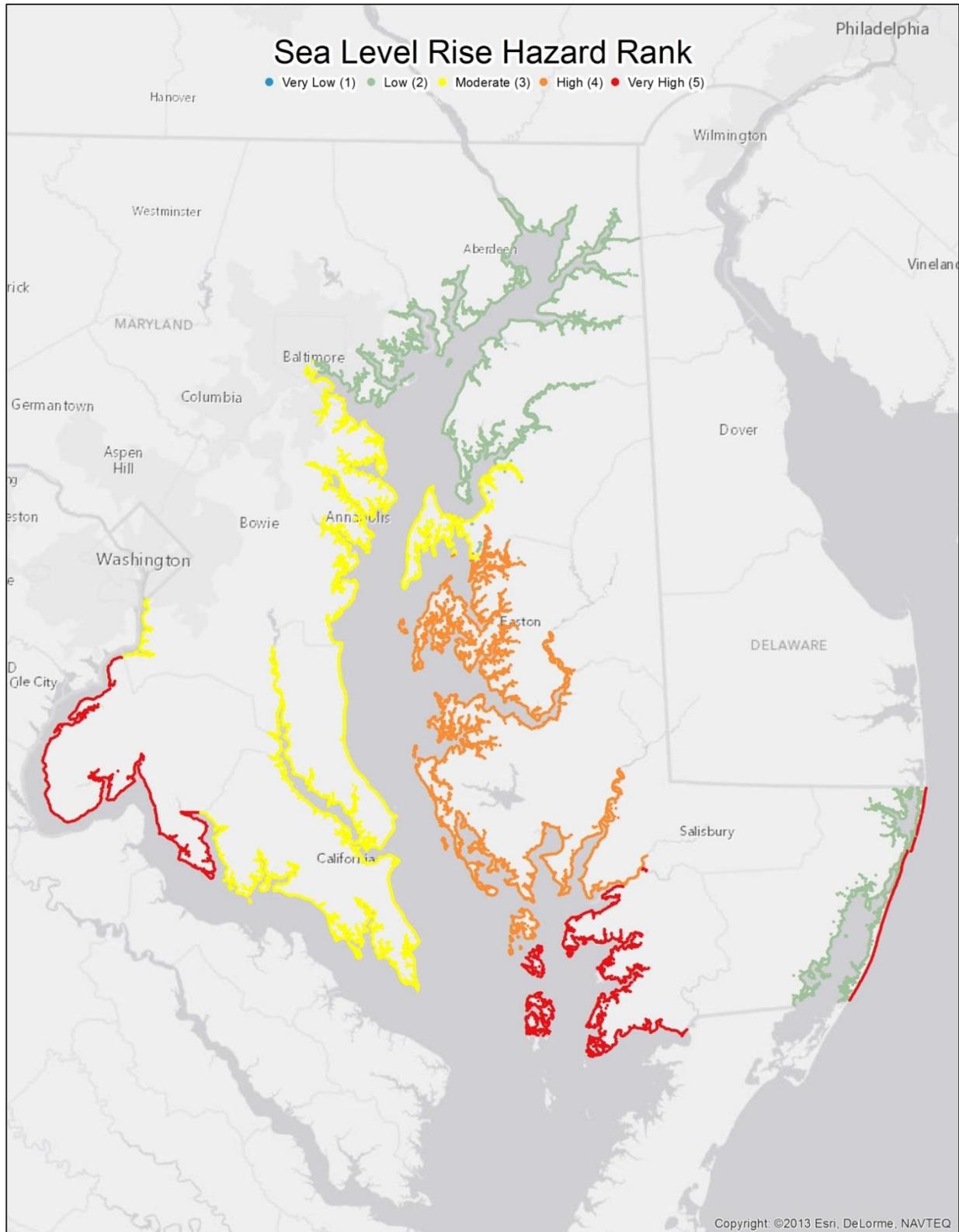


Figure A4: Wave Power Hazard Rank.

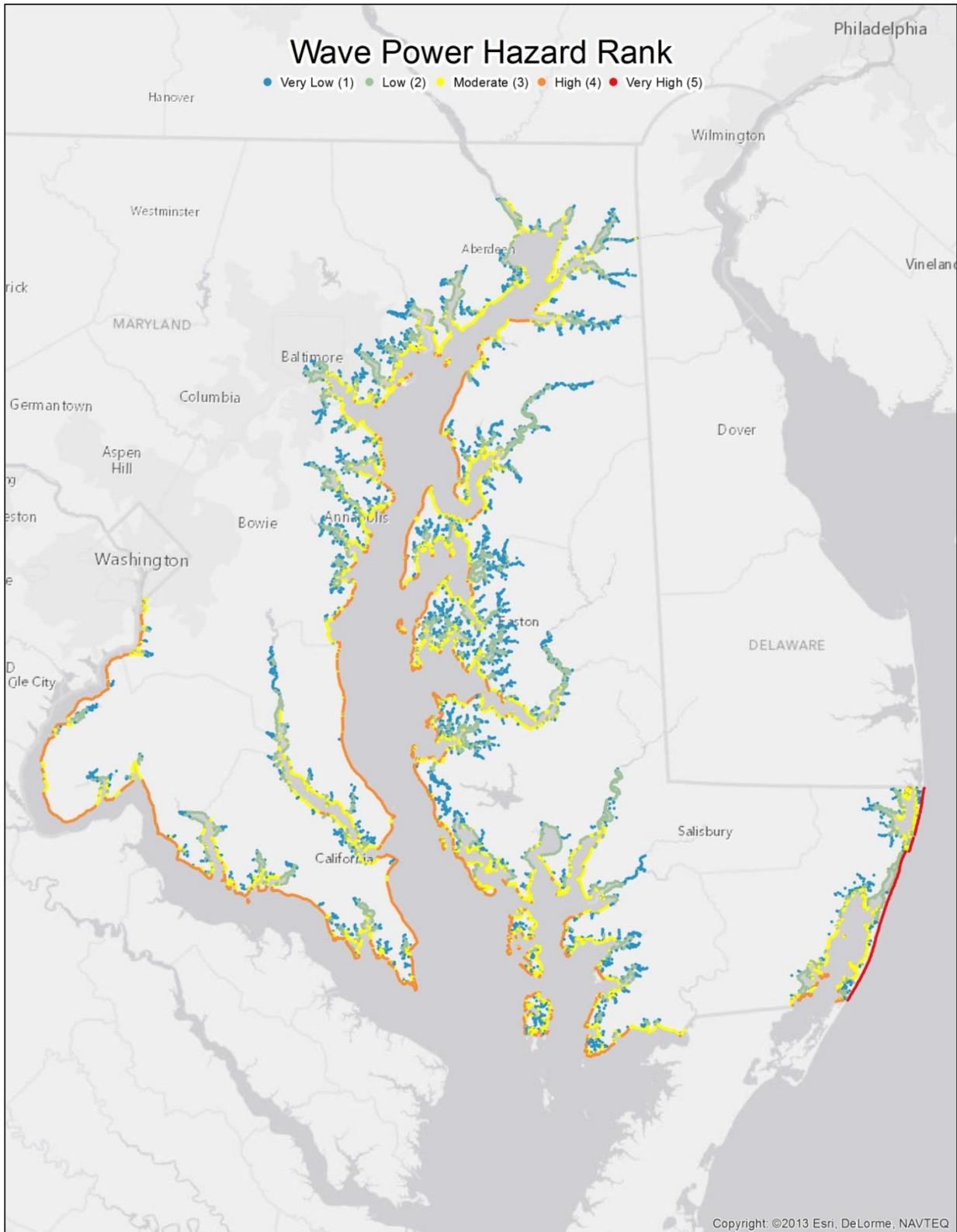


Figure A5: Storm Surge Hazard Rank.

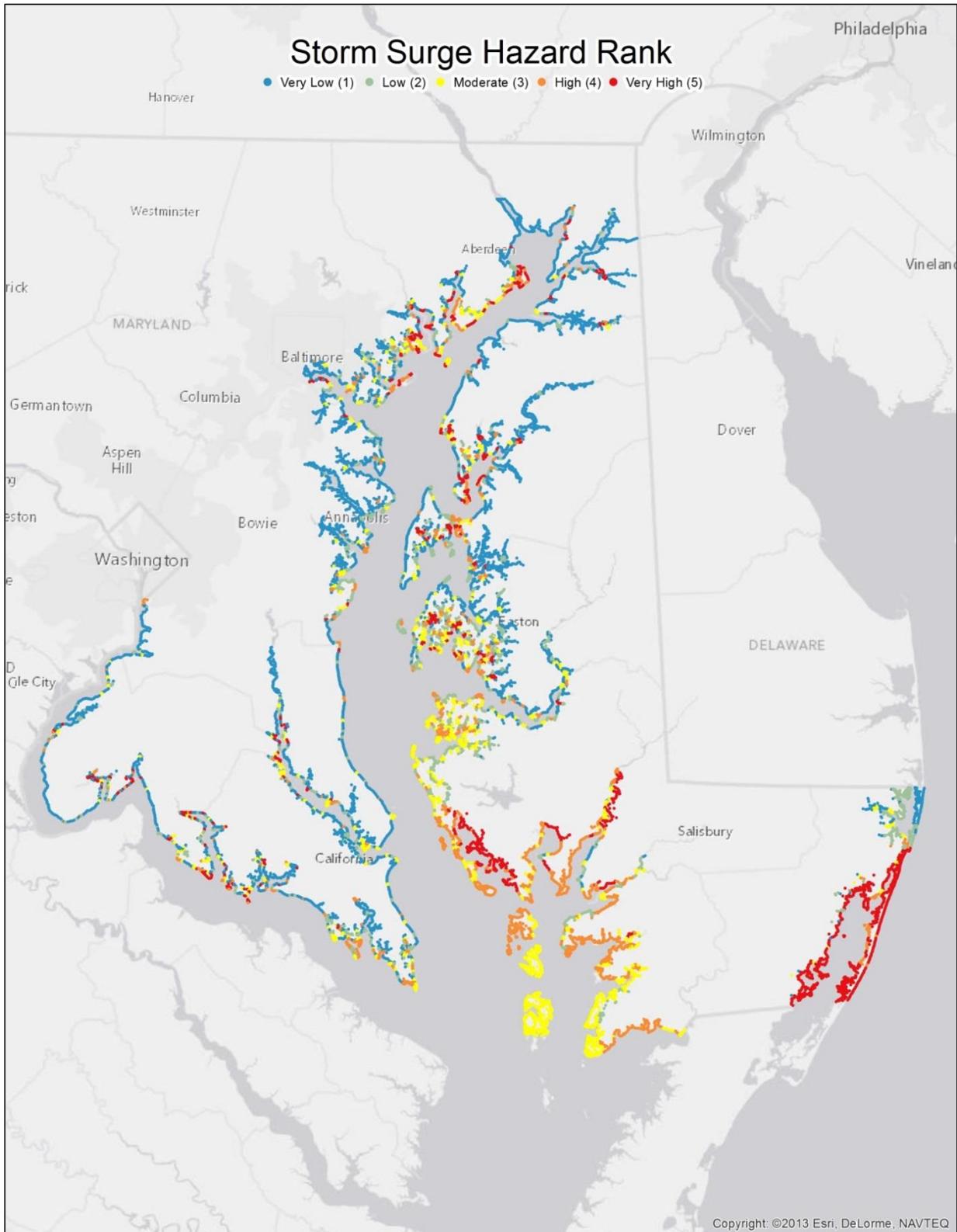


Figure A6: Erosion Rate Hazard Rank.

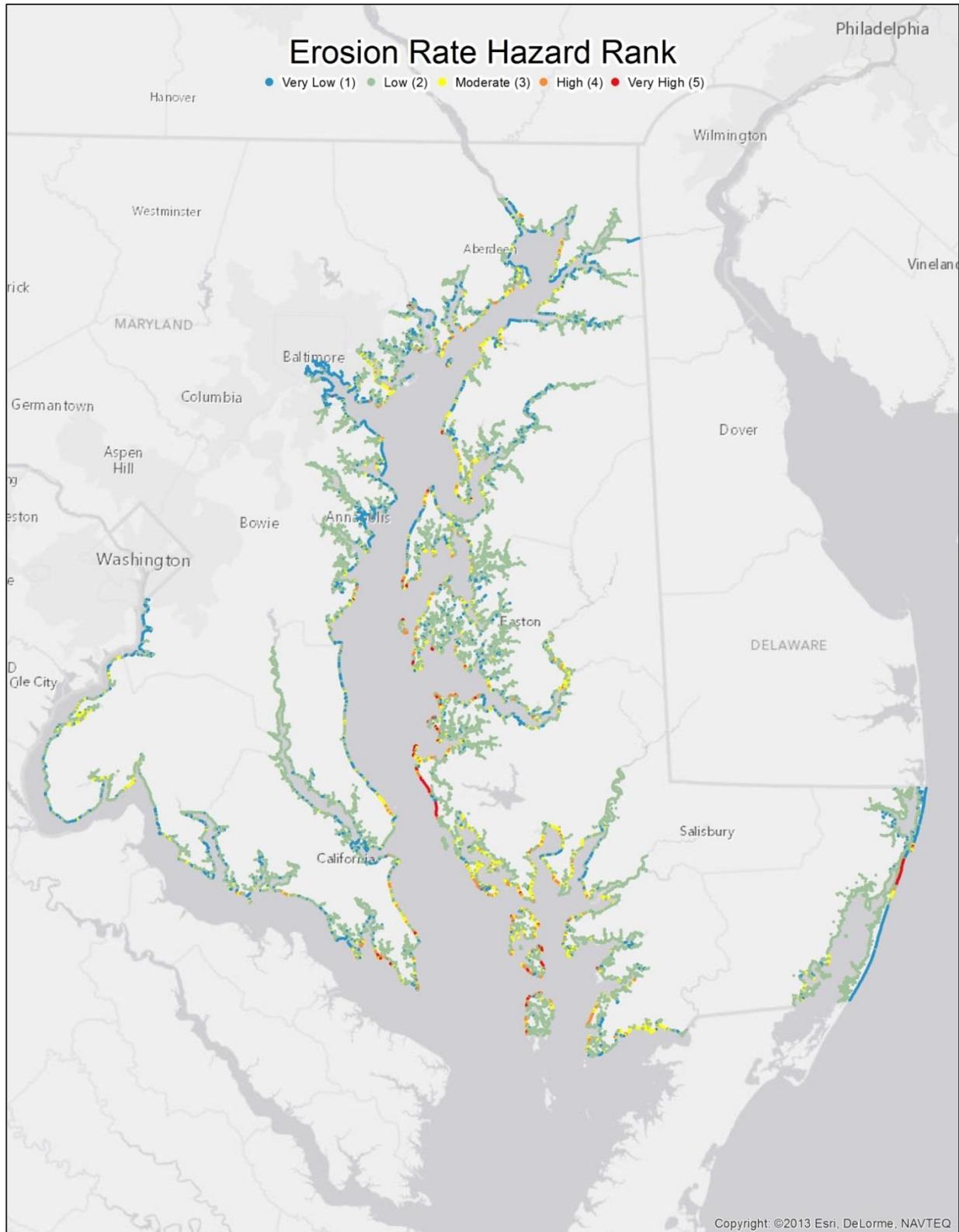
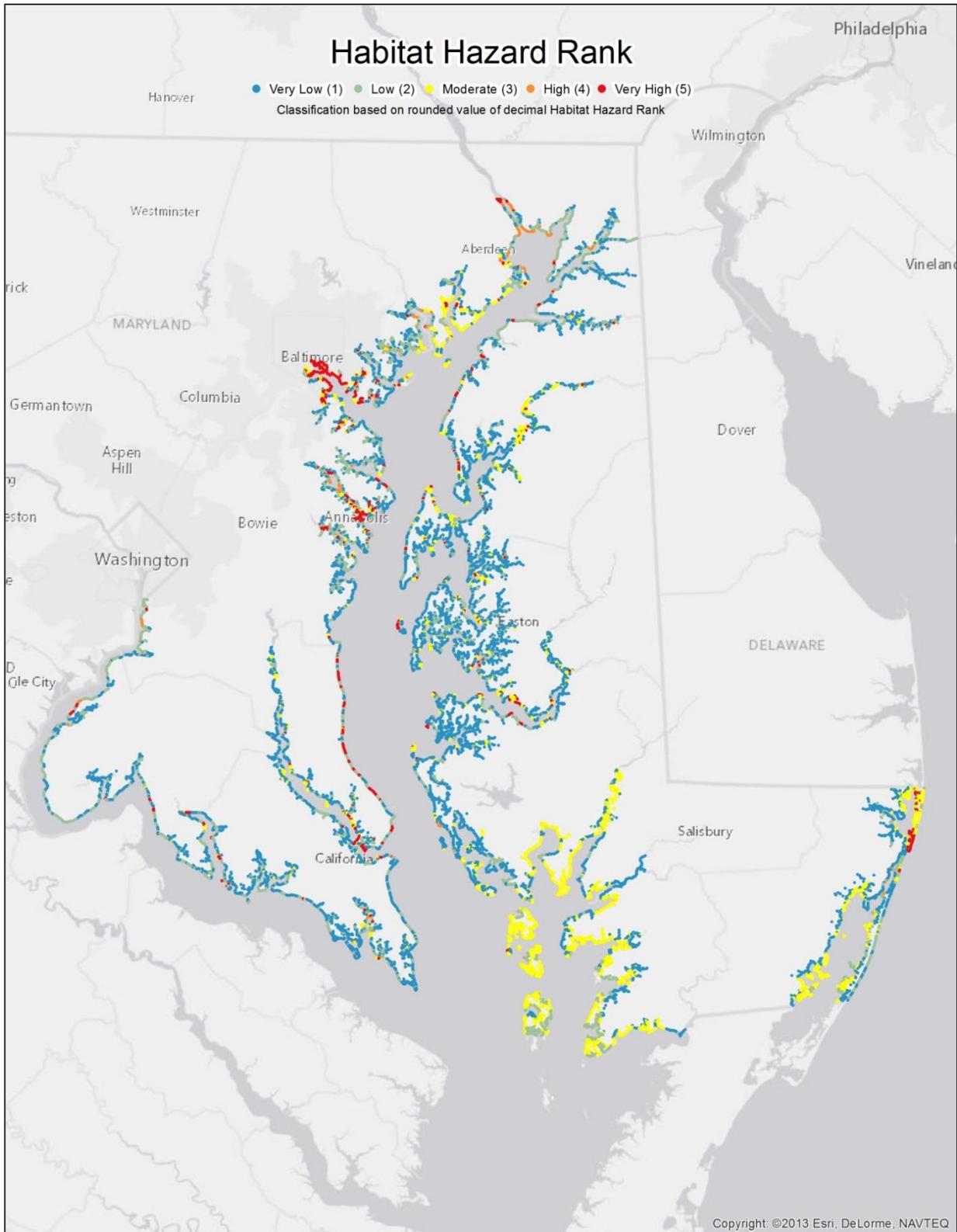


Figure A7: Habitat Hazard Rank.



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Appendix E: InVEST Coastal Vulnerability Model log

```
Arguments:
additional_layer_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/ErosionRates_Maryland.shp
aoi_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/AOI_Maryland.shp
area_computed          both
bathymetry_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/DEM/dem_bathy_30m.tif
cell_size              250
climatic_forcing_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/WW3_Maryland_FilterDeep10m.shp
depth_threshold        0
elevation_averaging_radius 5000
exposure_proportion    0.7
geomorphology_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/Geomorph_ESI_Maryland.shp
habitats_csv_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/Natural_Habitats/Habitats_Maryl
and.csv
habitats_directory_uri
C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\Natural_Habitats
landmass_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/LandMassPoly_MedRes.shp
max_fetch              12000
mean_sea_level_datum   0
population_radius      1000
population_uri
C:/InVEST_3_0_1_x86/Base_Data/Marine/Population/global_pop/hdr.adf
rays_per_sector        1
relief_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/DEM/dem_topo_30m.tif
sea_level_rise_uri
C:/InVEST_3_0_1_x86/coastal_vulnerability/Maryland/SeaLevelRise_County2100_High.sh
p
spread_radius          250
urban_center_threshold 5000
workspace_dir
C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\_250m
```

```
09/05/2015 09:39:42 root
INFO      Logging will be saved to coastal_vulnerability-log-2015-09-05--
09_39_42.txt
09/05/2015 09:39:42 root
DEBUG     Loaded the model from
invest_natcap.coastal_vulnerability.coastal_vulnerability
09/05/2015 09:39:42 root
INFO      Executing the loaded model
09/05/2015 09:39:42 root
INFO      Running InVEST version "3.0.1"
09/05/2015 09:39:42 root
INFO      Python architecture: ('32bit', 'WindowsPE')
09/05/2015 09:39:42 root
INFO      Disk space remaining for workspace: 231.8 GB
09/05/2015 09:39:42 root
INFO      Pointing temporary directory at the workspace at
C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\_250m
09/05/2015 09:39:42 root
```

```

INFO      Updating os.environ["TMP"]=C:\Users\gverutes\AppData\Local\Temp to
C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\_250m
09/05/2015 09:39:42  root
INFO      Updating os.environ["TEMP"]=C:\Users\gverutes\AppData\Local\Temp to
C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\_250m
09/05/2015 09:39:42  root
INFO      Setting
os.environ["TMPDIR"]=C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\_250m
09/05/2015 09:39:42  root
INFO      Starting coastal_vulnerability
preprocessing inputs...
Pre-processing landmass...
detecting shore...
C:\InVEST_3_0_1_x86\invest-3-x86\.\scipy\signal\signaltools.py:422:
ComplexWarning: Casting complex values to real discards the imaginary part
Pre-processing bathymetry...
09/05/2015 09:40:09  raster_utils
INFO      clip_dataset nodata value is -3.40282346639e+38
09/05/2015 09:41:31  raster_utils
INFO      building aoi mask
09/05/2015 09:41:36  raster_utils
INFO      masking out each output dataset
09/05/2015 09:42:35  raster_utils
DEBUG     ulx 297548.774491, uly 4384987.15503, lrx 525608.774493, lry
4063927.15503
Pre-processing population...
09/05/2015 09:42:47  raster_utils
INFO      clip_dataset nodata value is -2147483647.0
09/05/2015 09:42:47  raster_utils
INFO      building aoi mask
09/05/2015 09:42:47  raster_utils
INFO      masking out each output dataset
09/05/2015 09:42:47  raster_utils
DEBUG     ulx 292782.894976, uly 4397746.99422, lrx 662382.486557, lry
4063423.71941
computing fetch...
done.
Pre-processing geomorphology...
Pre-processing relief...
09/05/2015 09:56:01  raster_utils
INFO      clip_dataset nodata value is -3.402823e+38
09/05/2015 09:57:28  raster_utils
INFO      building aoi mask
09/05/2015 09:57:34  raster_utils
INFO      masking out each output dataset
09/05/2015 09:58:28  raster_utils
DEBUG     ulx 297548.774491, uly 4396447.23155, lrx 515198.774493, lry
4062637.23155
Pre-processing climatic forcing...
Pre-processing sea level rise...
pre-processing additional layer
generated_uris
passing arguments to execute_core
09/05/2015 10:33:05  coastal_vulnerability_core
DEBUG     structures not loaded. Missing key:['structures_uri']
Skipping structures.
Processing segment exposure...
Processing geomorphology...
Processing relief...
09/05/2015 10:33:19  raster_utils

```

```

INFO      building aoi mask
09/05/2015 10:33:20 raster_utils
INFO      masking out each output dataset
09/05/2015 10:36:16 raster_utils
INFO      building aoi mask
09/05/2015 10:36:16 raster_utils
INFO      masking out each output dataset
Processing natural habitats...
Processing wind exposure...
09/05/2015 10:37:59 raster_utils
INFO      building aoi mask
09/05/2015 10:37:59 raster_utils
INFO      masking out each output dataset
Processing wave exposure...
09/05/2015 10:39:18 raster_utils
INFO      building aoi mask
09/05/2015 10:39:18 raster_utils
INFO      masking out each output dataset
09/05/2015 10:42:42 raster_utils
INFO      building aoi mask
09/05/2015 10:42:42 raster_utils
INFO      masking out each output dataset
09/05/2015 10:42:54 raster_utils
INFO      building aoi mask
09/05/2015 10:42:54 raster_utils
INFO      masking out each output dataset
09/05/2015 10:42:57 coastal_vulnerability_core
DEBUG     surge potential not loaded. Missing key:['depth_contour',
'continental_shelf_raster_uri']
Skipping surge potential.
Processing sea level rise...
Processing coastal exposure...
09/05/2015 10:43:04 coastal_vulnerability_core
INFO      adding layer geomorphology
09/05/2015 10:43:04 coastal_vulnerability_core
INFO      adding layer relief
09/05/2015 10:43:04 coastal_vulnerability_core
INFO      adding layer sea_level_rise
09/05/2015 10:43:04 coastal_vulnerability_core
INFO      adding layer natural_habitats
09/05/2015 10:43:04 coastal_vulnerability_core
INFO      adding layer wave_exposure
Processing coastal exposure no habitats...
Processing habitat role...
Processing erosion exposure...
Processing population map...
09/05/2015 10:46:16 raster_utils
INFO      building aoi mask
09/05/2015 10:46:16 raster_utils
INFO      masking out each output dataset
Processing additional layer...
Processing fetch...
09/05/2015 10:46:21 coastal_vulnerability_core
DEBUG     structure edges not loaded. Missing key:['structure_edges']
Skipping structure edges.
Processing erodible shoreline...
09/05/2015 10:46:22 raster_utils
INFO      building aoi mask
09/05/2015 10:46:22 raster_utils
INFO      masking out each output dataset

```

```
09/05/2015 10:46:23 coastal_vulnerability_core
DEBUG    continental shelf distance not loaded. Missing
key:['shore_shelf_distance']
Skipping continental shelf distance.
Processing wind generated waves...
Processing oceanic wave exposure...
Processing local wave exposure...
Processing HTML page...
creating groups...
group coastal_exposure size 11
group population size 5
('No tifs found in',
'C:\\InVEST_3_0_1_x86\\coastal_vulnerability\\Maryland\\_250m\\intermediate\\1_g_s
urge_potential')
('No tifs found in',
'C:\\InVEST_3_0_1_x86\\coastal_vulnerability\\Maryland\\_250m\\intermediate\\3_1_s
tructure_edges')
('No tifs found in',
'C:\\InVEST_3_0_1_x86\\coastal_vulnerability\\Maryland\\_250m\\intermediate\\3_3_c
ontinental_shelf_distance')
09/05/2015 10:49:43 root
INFO     Opening file explorer to workspace directory
09/05/2015 10:49:43 root
INFO     Using windows explorer to view files
09/05/2015 10:49:46 root
INFO     Disk space free: 230.92 GB
09/05/2015 10:49:46 root
INFO     Elapsed time: 1h 10m 3.4s
09/05/2015 10:49:46 root
INFO     Finished.
09/05/2015 10:49:46 root
INFO     Elapsed time: 1h 10m 3.65s
09/05/2015 10:49:46 root
INFO     Operations completed successfully
```

Appendix F: Python Scripts

Python Script to Recalculate Habitat Rank

Author: Gregg Verutes

Purpose: Recalculate natural habitat rank

Last updated: September 6, 2015

```
import sys, string, os, array, time, datetime, csv
from math import *
import numpy
import arcgisscripting
import fpformat, operator
```

```
# create the geoprocessor object
gp = arcgisscripting.create()
```

```
# set output handling
gp.OverwriteOutput = 1
# check out extensions
gp.CheckOutExtension("spatial")
gp.CheckOutExtension("management")
gp.CheckOutExtension("analysis")
gp.CheckOutExtension("conversion")
```

```
## path name to CV point shapefile
exp_index =
r'C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\Output_R1_coastal_exposure_090815\Output_
R1_coastal_exposure_090815.shp'
HabRCList = ["OYSTER", "DUNE", "SEAGRASS", "MARSH", "FOREST"] ## column headinds for all natural
habitats
```

```
cur = gp.UpdateCursor(exp_index)
row = cur.Next()
while row:
    # rank habitat
    RankList = []
    for i in range(0,len(HabRCList)):
        if row.GetValue(HabRCList[i]) > 0:
            RankList.append(row.GetValue(HabRCList[i]))
```

```
# calculate natural habitat rank based on presence of multiple habitat layers
if len(RankList) > 0:
```

```

RankListMinus5 = [(5.0 - i) for i in RankList]
SqRankList = [(i*i) for i in RankListMinus5]
HabEq = (1.5*max(RankListMinus5))**2+numpy.sum(SqRankList)-(max(RankListMinus5))**2
rankValue = 4.8-0.5*((HabEq)**0.5)
row.SetValue("nat_habit", rankValue)
else:
    row.SetValue("nat_habit", 5)

cur.UpdateRow(row)
row = cur.next()
del row, cur

print "DONE!"

```

Python Script to Recalculate Exposure Index Scores

Author: Gregg Verutes

Purpose: Recalculate exposure index scores

Last updated: September 6, 2015

```

import sys, string, os, array, time, datetime, csv
from math import *
import numpy
import arcgisscripting
import fpformat, operator

```

create the geoprocessor object

```
gp = arcgisscripting.create()
```

set output handling

```
gp.OverwriteOutput = 1
```

check out extensions

```
gp.CheckOutExtension("spatial")
```

```
gp.CheckOutExtension("management")
```

```
gp.CheckOutExtension("analysis")
```

```
gp.CheckOutExtension("conversion")
```

path name to CV point shapefile

```
exp_index =
```

```
r'C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\Output_R1_coastal_exposure_090815\Output_
R1_coastal_exposure_090815.shp'
```

```

cur = gp.UpdateCursor(exp_index)
row = cur.Next()
while row:

    # calculate vulnerability index
    ## formula for exposure index with habitats
    VIExpr_wHab = row.GetValue("wave_expos")*row.GetValue("relief")*row.GetValue("nat_habit")*\
        row.GetValue("geomorphol")*row.GetValue("O_addition")*row.GetValue("sea_level_")

    ## formula for exposure index w/o habitats
    VIExpr_woHab = row.GetValue("wave_expos")*row.GetValue("relief")*5.0*\
        row.GetValue("geomorphol")*row.GetValue("O_addition")*row.GetValue("sea_level_")

    # calculate various indices
    row.SetValue("EI_wHAB", ((VIExpr_wHab)**(1.0/6.0))) ## make sure denominator is number of
variables in exposure index
    row.SetValue("EI_woHAB", ((VIExpr_woHab)**(1.0/6.0))) ## make sure denominator is number of
variables in exposure index
    row.SetValue("hab_role", (row.GetValue("EI_woHAB"))-(row.GetValue("EI_wHAB"))) ## exposure
index column name (w/o minus w/ habitats)

    cur.UpdateRow(row)
    row = cur.next()
del row, cur

print "DONE!"

```

Python Script to Find Quantile Breaks

```

# Author: Gregg Verutes
# Purpose: Find 25th and 75th percentiles of a distribution of values for 2 scenarios
# Last updated: September 6, 2015

import sys, string, os, array, numpy
from math import *
from scipy import stats ## requires SciPy extension
import arcgisscripting
import fpformat, operator

# create the geoprocessor object
gp = arcgisscripting.create()

```

```

# set output handling
gp.OverwriteOutput = 1
# check out extensions
gp.CheckOutExtension("spatial")
gp.CheckOutExtension("management")
gp.CheckOutExtension("analysis")
gp.CheckOutExtension("conversion")

# percentiles list (25, 75)
def getPercentiles(list):
    PctList = []
    PctList.append(stats.scoreatpercentile(list, 25))
    PctList.append(stats.scoreatpercentile(list, 75))
    return PctList

VList = []

## path name to CV point shapefile
cur =
gp.UpdateCursor(r'C:\InVEST_3_0_1_x86\coastal_vulnerability\Maryland\_250m\outputs\coastal_expo
sure_Snap.shp')
row = cur.Next()
while row:
    VList.append(row.GetValue("EI_wHAB")) ## exposure index column name (with habitats)
    VList.append(row.GetValue("EI_woHAB")) ## exposure index column name (w/o habitats)
    cur.UpdateRow(row)
    row = cur.next()
del row, cur

# get percentile breaks
VIPctList = getPercentiles(VList)
print str(VIPctList)

```

Appendix G: Community Flood Risk Toolboxes, Intermediate Data & Methodology

Risk Areas were developed via various toolboxes (Figure A8). The following methodology was used to create intermediate and final data layers referenced in Section 4 of the Report.

Figure A8. Dasymetric Mapping and Risk Toolboxes applied and/or developed for the Coastal Resiliency Assessment.



Population Density Index: Identify population density in residential areas.

Dasymetric Mapping will distribute population density relative to Land Use Land Cover. A USGS Dasymetric Mapping Toolbox for ArcMap 10.0 was used in conjunction with Maryland Department of Planning 2010 Land Use Land Cover data, as well as state, federal, and county lands, which were used to identify open lands. For more information on this methodology, see http://astro.temple.edu/~jmennis/pubs/mennis_pg03.pdf. For more information on the Dasymetric Mapping Toolbox, see <http://geography.wr.usgs.gov/science/dasymetric/>.

1. Download Census 2010 American Community Survey 5 year Block Group data:
 - a. Total Population per Block Group = Table B01003.
 - b. Download Block Group shapefile and join Total Population to the shapefile.
 - c. Use Total Population Value in Population Density Calculation (See Step 4).
2. Process Open Space Data Layer (Figure A9).
 - a. Merge DNR, Federal, and County Lands to create an open space file. Convert to raster and reclassify so all open space = 10.
 - i. Merge all DNR lands except easements (may have residents).
 - ii. Merge all county owned lands except lands ≤ 0.22 acres to eliminate some of these features. Remove non-open space polygons from the shapefile before merging.
 - iii. Some federal lands were removed to only keep lands open to the public with open space. The following were removed: Ammendale Normal Institute, Beltsville Agricultural Research Center, Federal Aviation Administration, General Services, Marina Piscataway, NASA, Office, Research Institution, Suitland Federal Center, and US Dept of Agriculture.

3. Download and Process Maryland Department of Planning 2010 Land Use Land Cover data, and run Dasymetric Mapping Toolbox to identify residential areas (Figure A10).
 - a. Project LULC to NAD83 UTM 18N
 - b. Convert polygon to Raster
 - c. Reclassify LULC:
 - i. Class 13 = 1 for High Density Residential
 - ii. Class 12 = 2 for Medium Density Residential
 - iii. Classes 11, 191, and 192 = 3 for Low Density Residential
 - iv. Classes 14 – 80 = 0 for elimination class (no population). People do not live in industrial, extractive, agricultural, forested, wetland, barren, transportation, water, or urban open lands, so these classes were removed from the analysis (value = 0). Census Data for population density is based on home surveys.
 - d. Use Raster Calculator to add Open Lands data.
 - e. Reclassify Open Lands = 0 and convert raster to FLOAT.
4. Run the Dasymetric Toolbox with 1) block groups shapefile with total population; 2) LULC raster; and 3) 70% coverage. Cell size will equal cell size of input rasters. See image below.
5. Use NEWDENSITY field to obtain correct population density information and Clip to study area (Figure A11).
6. Reclassify Index into 5 classes using quantile classification and score from low to high using intervals of 20 (Figure A12).

Figure A9. Open Lands Model Builder Work Flow (top) and Model Interface (bottom). Model creates an “Uninhabited” raster for input into the USGS Dasymetric Mapping Toolbox.

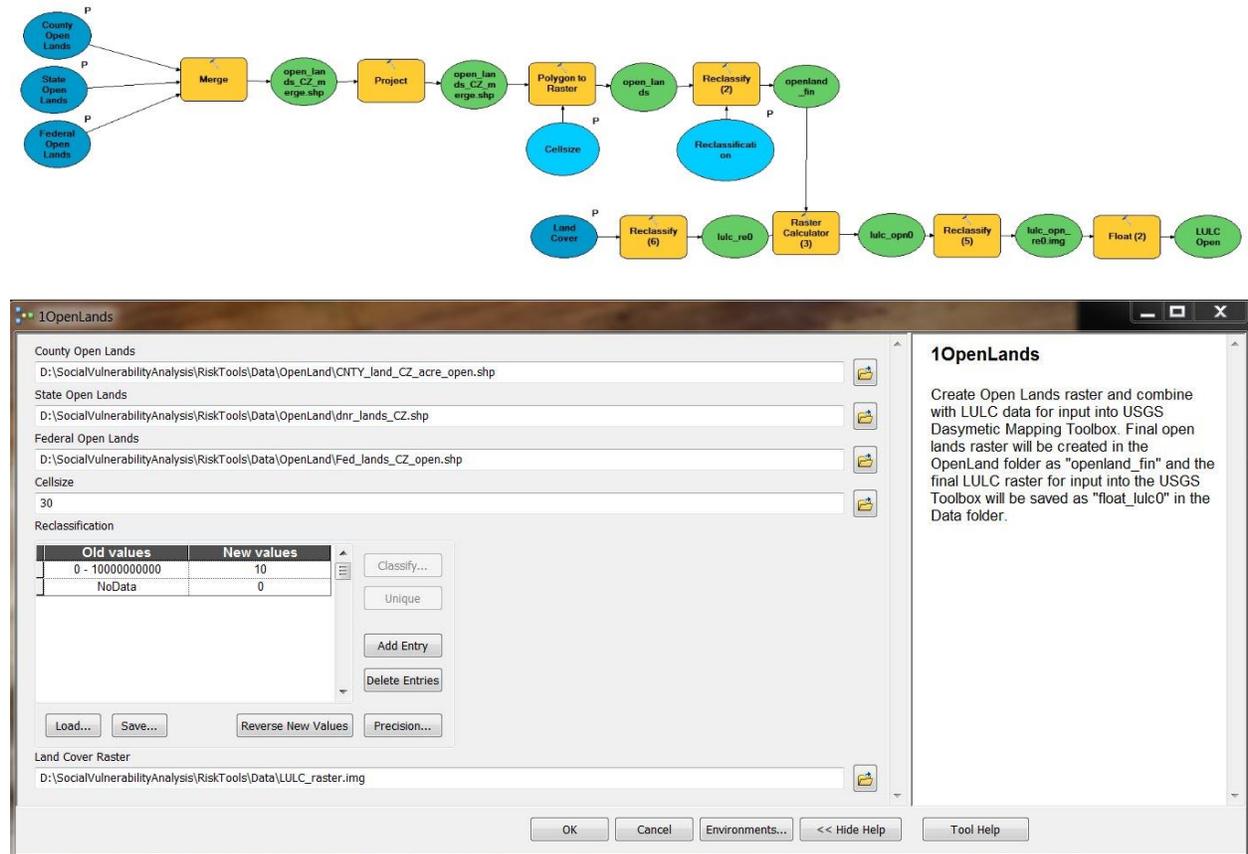


Figure A10. Dasymetric Mapping Model Interface. USGS Toolbox was applied to estimate population density within residential areas at a 30-meter scale.

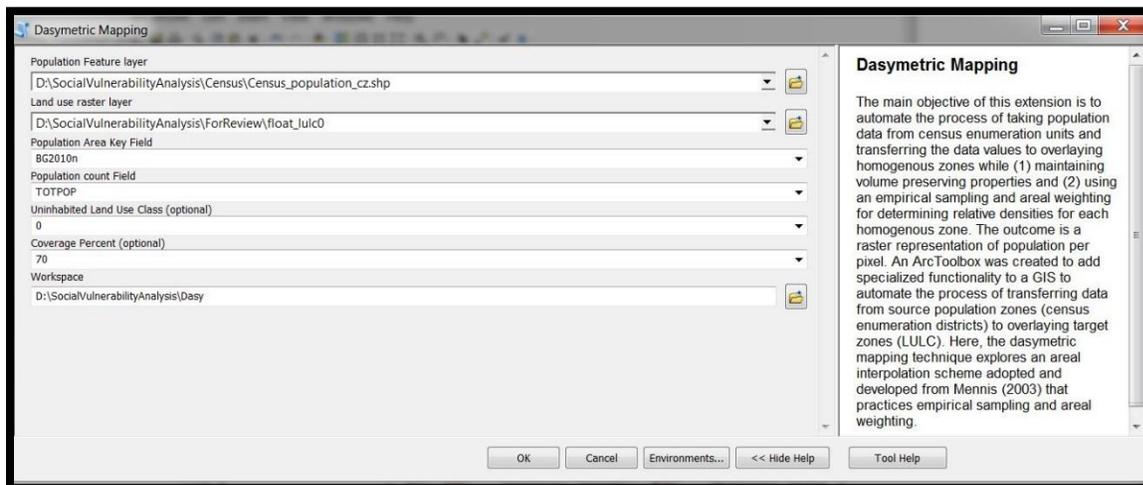


Figure A11. Population Density Output from Dasymetric Mapping Toolbox.

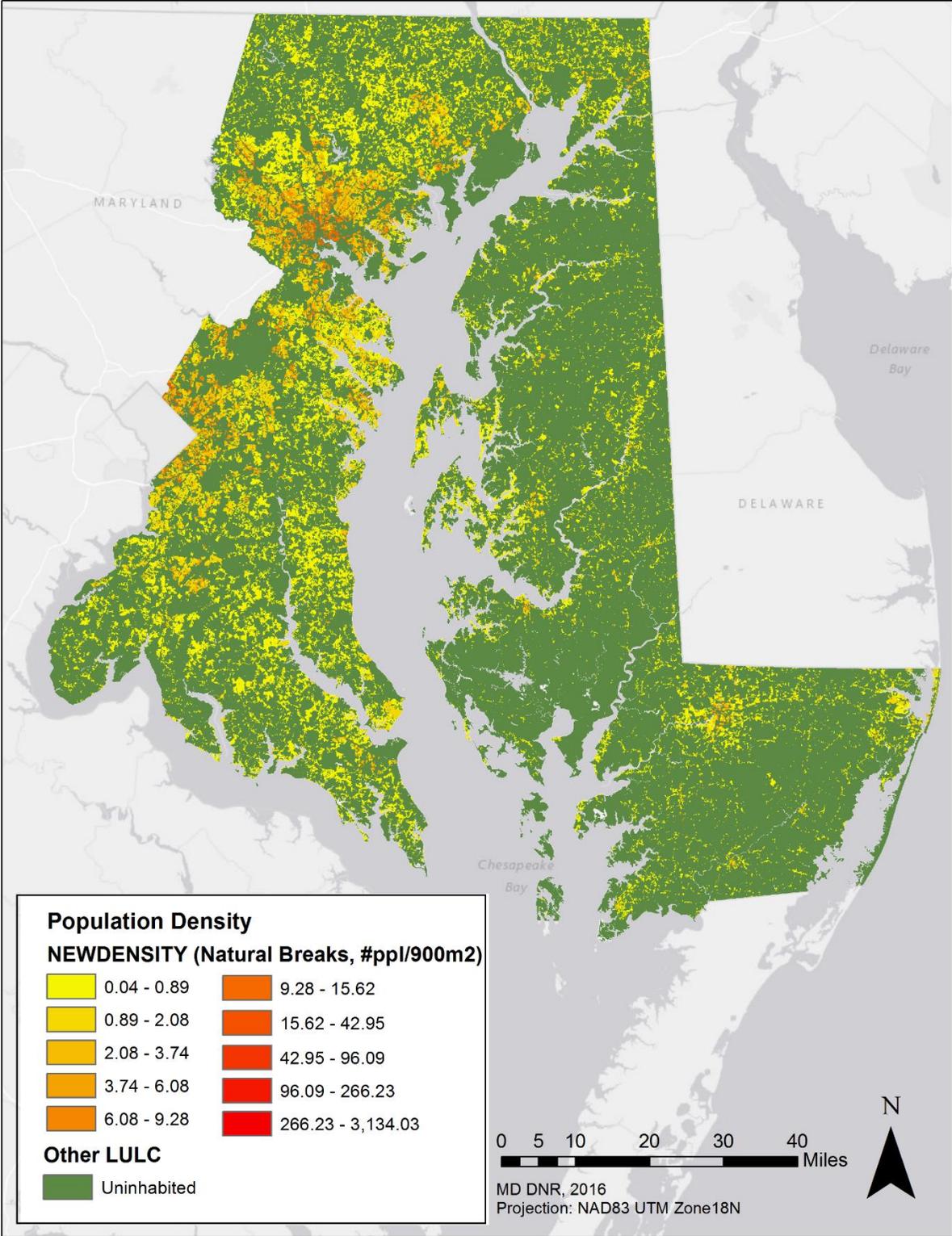
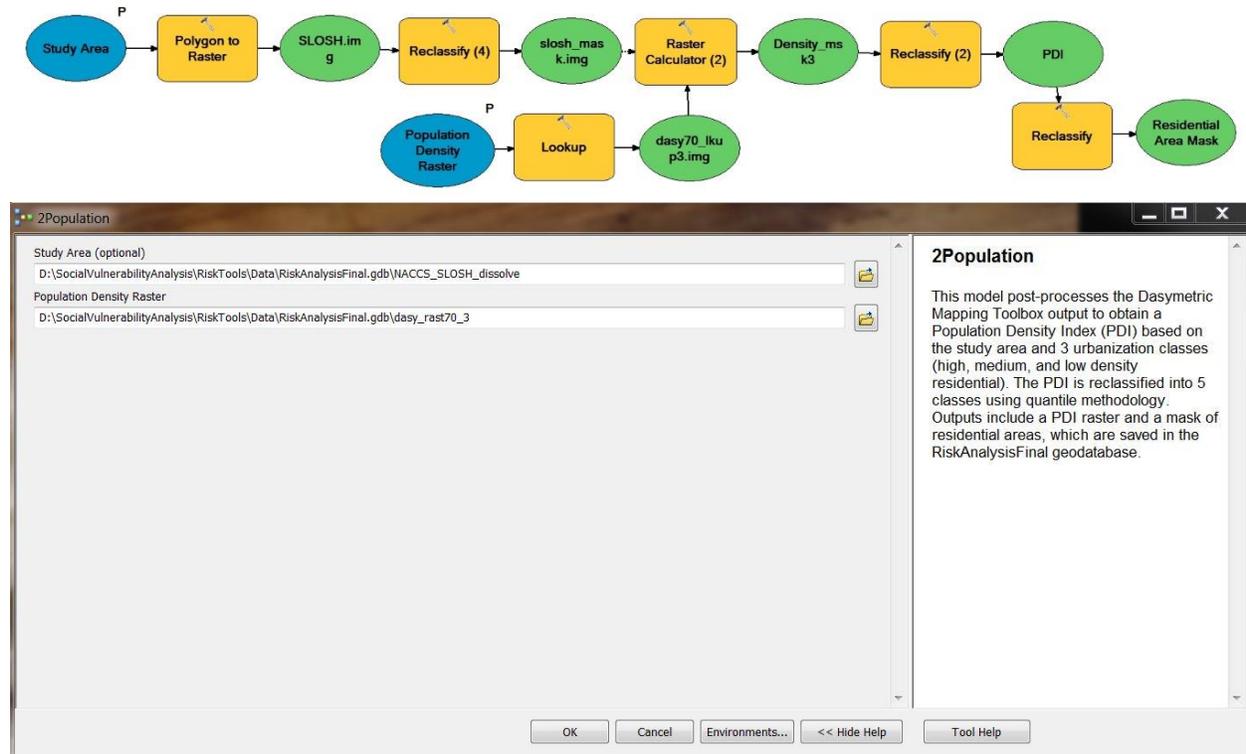


Figure A12. Population Model Builder Work Flow (top) and Model Interface (bottom). Model creates the Population Density Index.



Social Vulnerability Index: Identify socially vulnerable populations within residential areas.

1. Download Census 2010 American Community Survey 5 year Block Group data and Process:
 - a. Within Excel, Calculate % Population <= 17 and >= 65 years of age: Table B01001 SEX BY AGE.
 1. FORMULA: % Pop <=17 =

$$\frac{[SUM(HD01_VD03,HD01_VD04,HD01_VD05,HD01_VD06,HD01_VD27,HD01_VD28,HD01_VD29,HD01_VD30)]}{HD01_VD01} \times 100$$
 2. FORMULA: % Pop >=65 =

$$\frac{[SUM(HD01_VD20,HD01_VD21,HD01_VD22,HD01_VD23,HD01_VD24,HD01_VD25,HD01_VD44,HD01_VD45,HD01_VD46,HD01_VD47,HD01_VD48,HD01_VD49)]}{HD01_VD01} \times 100$$
 3. Join to Block Group Shapefile.
 - b. Within Excel, Calculate % Population with income below poverty: Table B17021 POVERTY STATUS OF INDIVIDUALS IN THE PAST 12 MONTHS BY LIVING ARRANGEMENT.
 1. NOTE: The population assessed does not include data for age <15, institutional group quarters, college dormitories, military barracks, and living situations without conventional housing.

2. FORMULA: $(HD01_VD02/HD01_VD01) \times 100$
 3. Join to Block Group Shapefile.
- c. Within Excel, Calculate % Population of non-proficient English speakers: Table B16004 AGE BY LANGUAGE SPOKEN AT HOME BY ABILITY TO SPEAK ENGLISH FOR THE POPULATION 5 YEARS AND OVER.
1. NOTE: Percent calculated from total population ≥ 5 years of age in each Block Group within Maryland's Coastal Counties.
 2. FORMULA: % Pop that speak English less than very well = $[\text{SUM}(HD01_VD06, HD01_VD07, HD01_VD08, HD01_VD11, HD01_VD12, HD01_VD13, HD01_VD16, HD01_VD17, HD01_VD18, HD01_VD21, HD01_VD22, HD01_VD23, HD01_VD28, HD01_VD29, HD01_VD30, HD01_VD33, HD01_VD34, HD01_VD35, HD01_VD38, HD01_VD39, HD01_VD40, HD01_VD43, HD01_VD44, HD01_VD45, HD01_VD50, HD01_VD51, HD01_VD52, HD01_VD55, HD01_VD56, HD01_VD57, HD01_VD60, HD01_VD61, HD01_VD62, HD01_VD65, HD01_VD66, HD01_VD67)/HD01_VD01] \times 100$
 3. Join to Block Group Shapefile.
- d. Convert block group polygons to a 30-meter raster for each social metric.
- i. % Population Vulnerable by Population (Figure A13)
 - ii. % Population Vulnerable by Income (Figure A14)
 - iii. % Population Vulnerable by Language Proficiency (Figure A15).
- e. Apply Raster Calculator to add % vulnerable populations. Variables were normalized (as a percentage) and thus can be added together even if a person represents one or more social vulnerability characteristic. By using % population, one can also control for the size of the population.
- f. Mask to Study Area and Reclassify Index into 5 classes using quantile classification and score from low to high using intervals of 20 (Figure A16).

Figure A13. Percent Population Vulnerable by Age from 2013 American Community Survey (ACS) 5-year estimate.

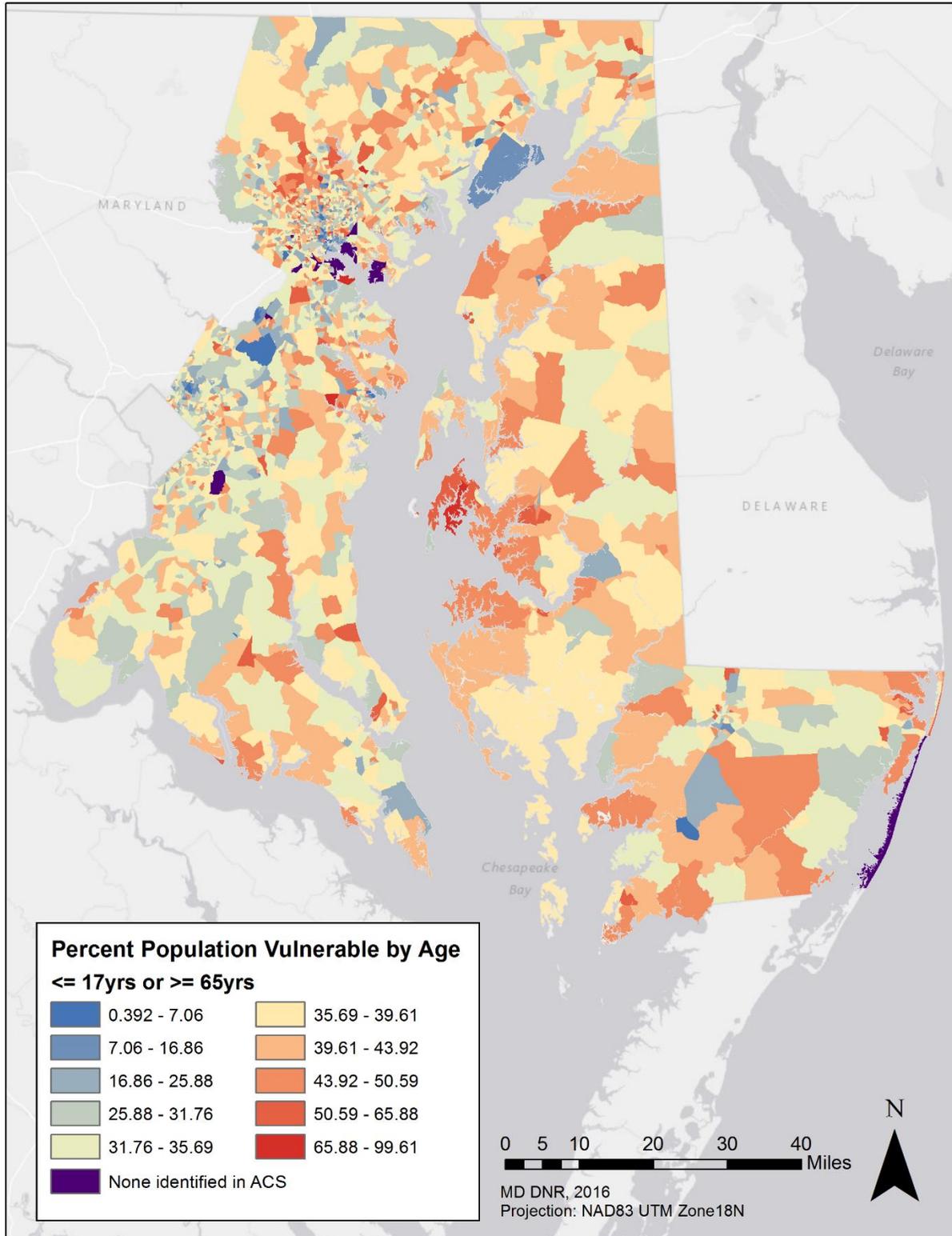


Figure A14. Percent Population Vulnerable by Income from 2013 American Community Survey (ACS) 5-year estimate.

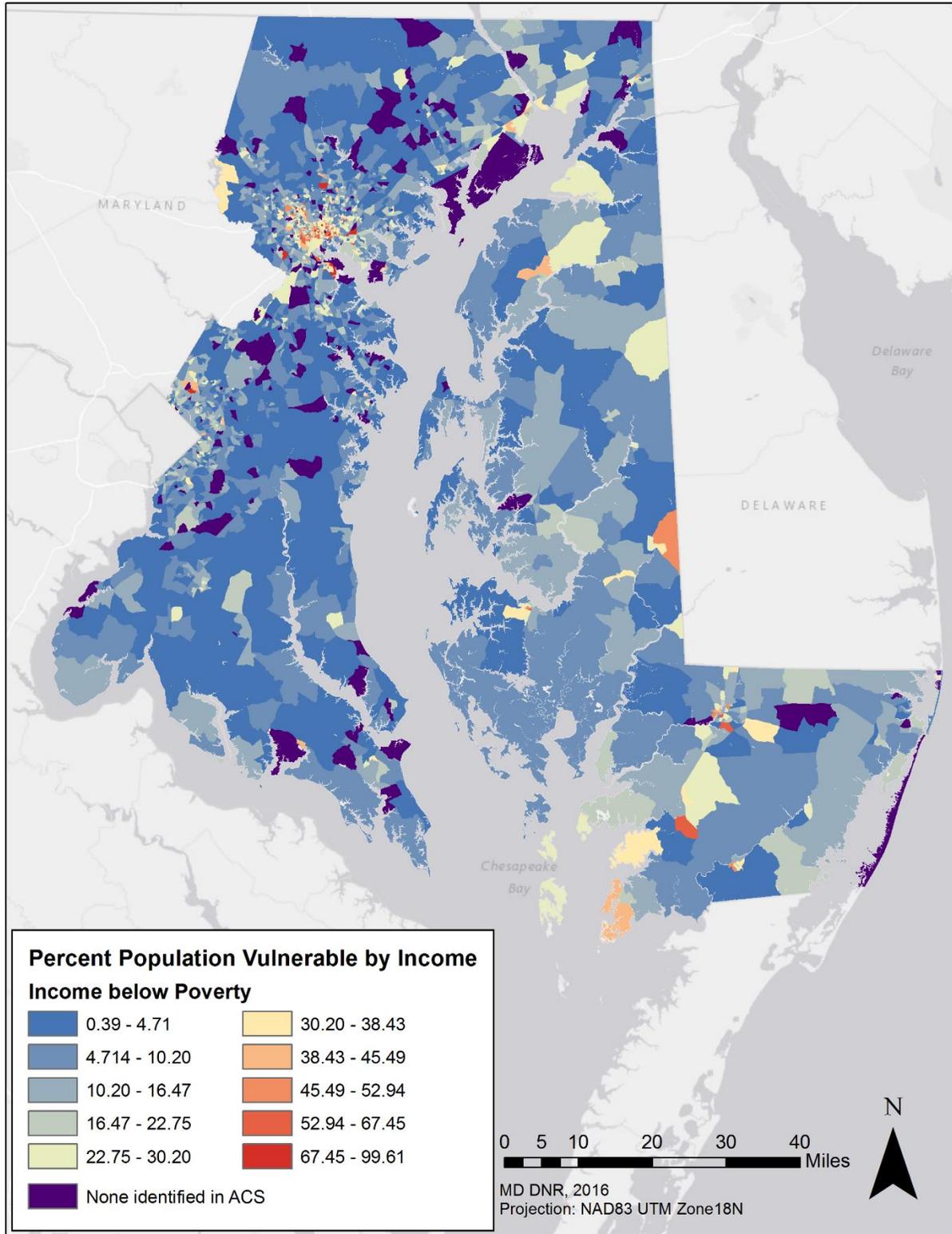


Figure A15. Percent Population Vulnerable by Language Proficiency from 2013 American Community Survey (ACS) 5-year estimate.

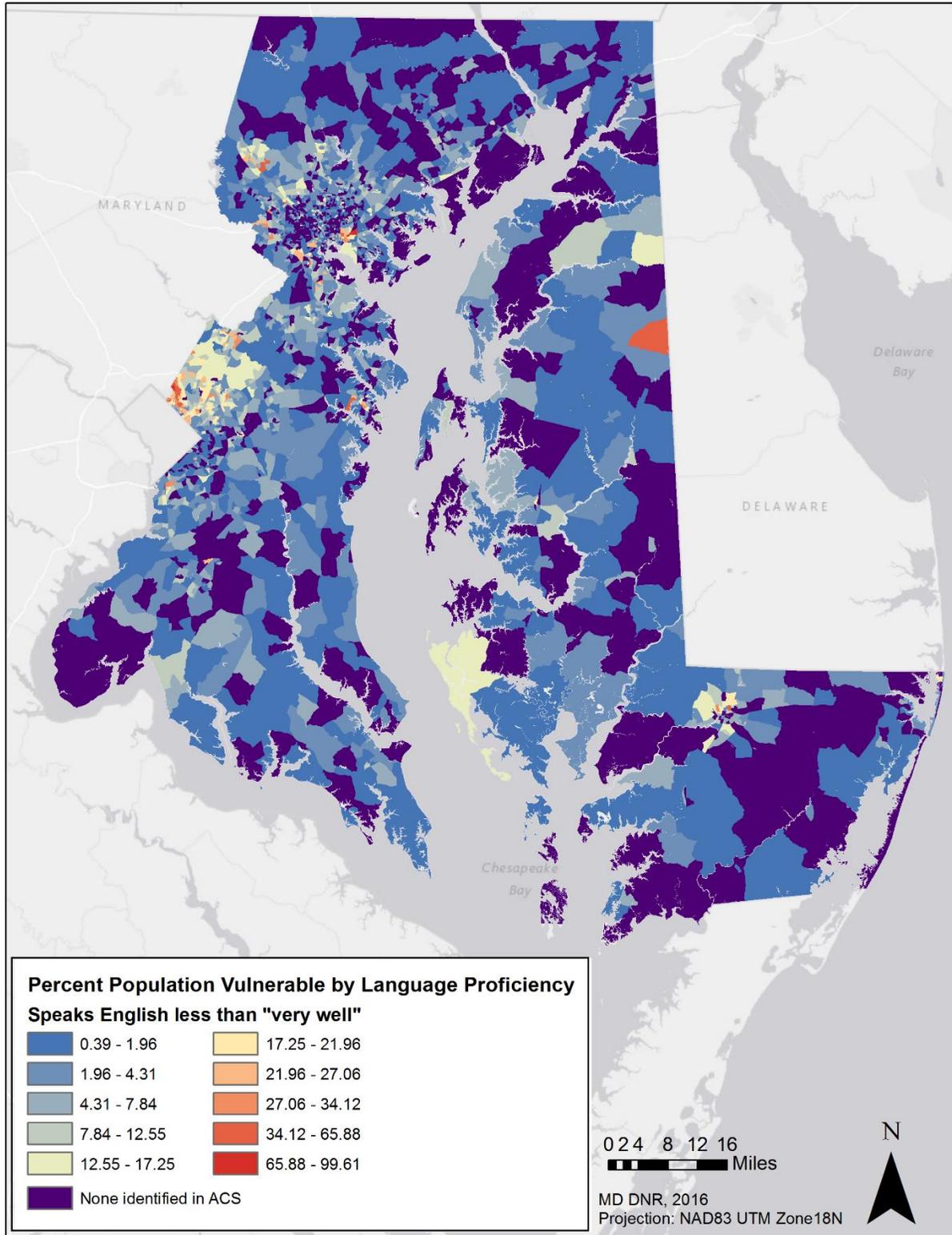
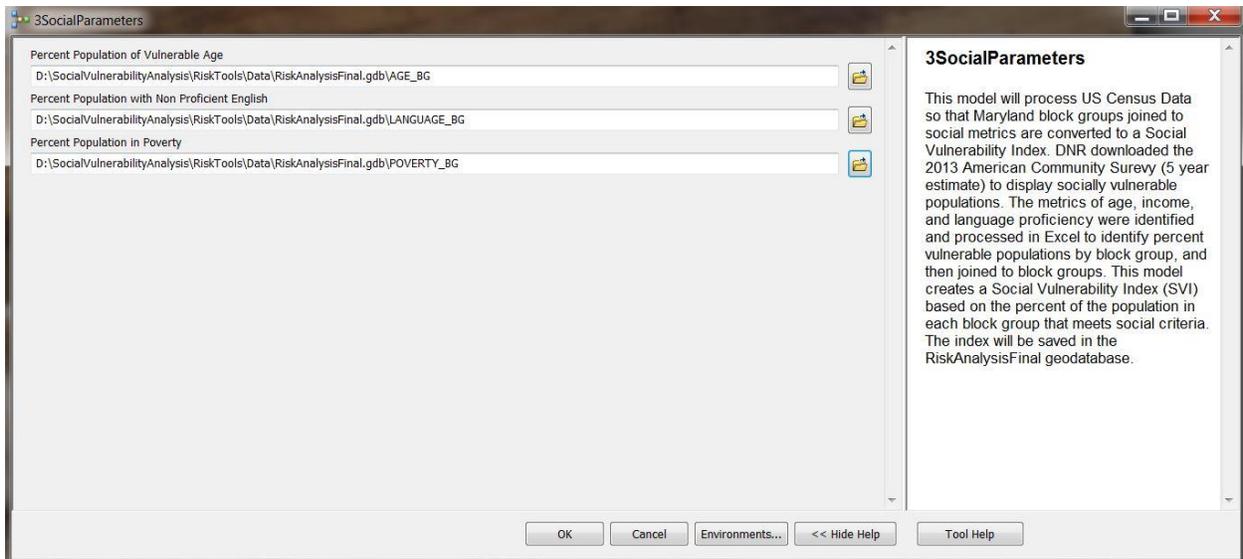
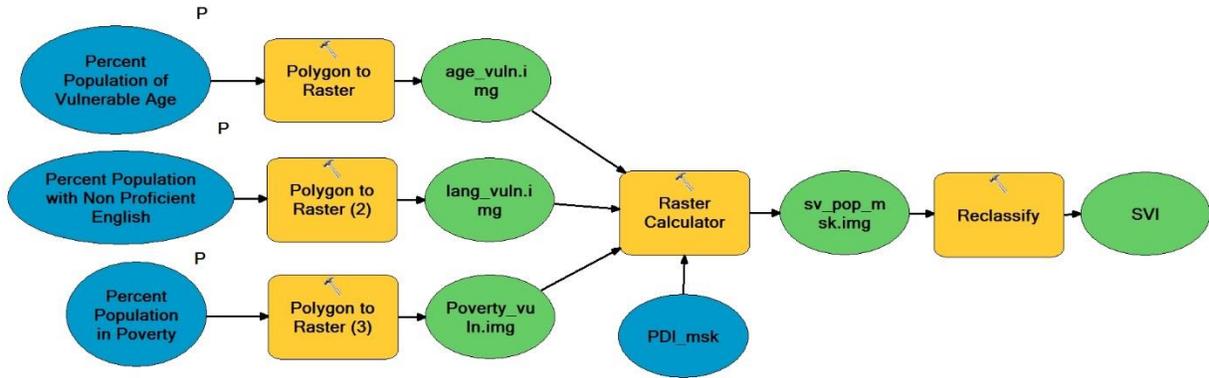


Figure A16. Social Model Builder Work Flow (top) and Model Interface (bottom). Model creates the Social Vulnerability Index.



Floodplain Processing: Identify probability of exposure.

Using the following methodology, process surface water elevation data (SWEL) by county, fill in gaps that should be part of floodplain, and remove areas that are not connected to the floodplain. Apply the MES/Dewberry 2015 100-year Effective Floodplain as a source layer for 50-year floodplain processing [Updated 100-year Effective Floodplain data for Prince George's County was not available at the time of this study, so 100-year Q3 Floodplain data was applied]. Apply the resulting 50-year floodplain as a source layer for the 10-year floodplain processing. All 50-year floodplain polygons should be within the 100-year floodplain, and all 10-year floodplain polygons should be within the 50-year floodplain. Specific methodology is described below.

1. **Collect Data:** Obtain Effective 100 and 500-year floodplain data from Maryland Environmental Service/Dewberry. Obtain 10 and 50-year SWEL rasters from Dewberry. Combine 2016 Effective floodplain data with 2015 data for Prince George's County.

2. **Process Lidar by County:** Resample Lidar to 25 X 25 foot grid for consistency with SWEL data.

3. **Process 50-year SWEL Data:**

`Con("%Floodplain%" >= "%Topo%",1)` where %Floodplain% refers to the 25-foot SWEL grid and %Topo% refers to resampled 25-foot Lidar grid.

Perform Raster to Polygon conversion and add to geodatabase to calculate area.

4. **Simplify Floodplain for Processing:** Select for all areas that intersect with the 100-year floodplain and are larger than 625 ft² (one cell).
5. **Identify Floodplain Gaps:** Union with no gaps allowed. Select for FID = -1 and extract data. The resulting feature represents floodplain gaps.
6. **Fill Gaps:** Select gaps by location. Select gap features that have their centroid in the 100-year floodplain/source layer feature. Calculate Area and extract features less than a threshold area (see below for County thresholds). Union gaps with 50-year floodplain.

This step "fills in" the gaps. However, due to county topography differences, some areas will be filled in that should not be part of the floodplain. A size threshold was used to ensure non-floodplain areas were not included. Size thresholds were tested for each county.

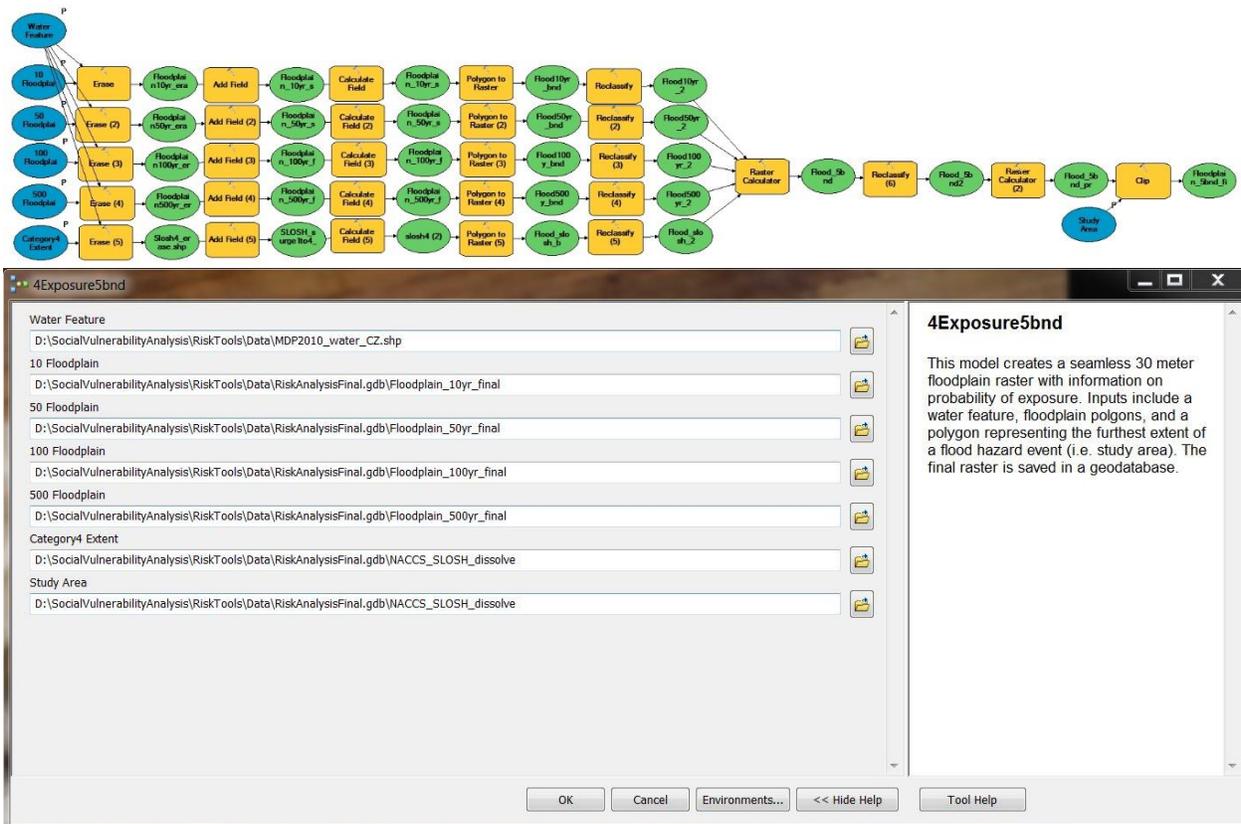
No Threshold Required: Baltimore City 10/50yr, Cecil 10/50yr, Kent 10yr, St. Mary's 50yr
50,000 ft² Threshold: Baltimore 10/50yr, Caroline 10/50yr, Kent 50yr, Prince George's 10/50yr, Somerset 10/50yr, St. Mary's 10yr, Talbot 10/50yr
100,000 ft² Threshold: Anne Arundel 10/50yr, Calvert 10/50yr, Harford 10/50yr
200,000 ft² Threshold: Charles 10/50yr, Dorchester 10/50yr, Queen Anne's 10/50yr, Wicomico 10/50yr, Worcester 10/50yr

7. **Create Floodplain Polygon:** Dissolve 50-year floodplain and Clip 50-year Floodplain to 100-year floodplain. Check and Repair Geometry. Smooth Polygon using 75-ft threshold and PAEK smoothing algorithm.
8. **Final Check:** Compare smoothed floodplain to original dissolved version. If unhappy, test other smooth thresholds. Explode polygon to multipart. Check for floodplain areas that should be connected or removed. Edit feature using the editor toolbar. Connect adjacent polygons and delete those that are not connected based on original 50yr floodplain raster (from step 2) and 100-year floodplain. Risk Analysis residential land use areas may be used to ensure careful processing near residential areas. SHA Island data may also be used for counties with islands.
9. **Final Processing:** Clip 50-year floodplain polygon to 100-year floodplain polygon. Dissolve 50-year floodplain. Check and repair geometry. Project to NAD_1983_UTM_18N meter for use in final risk analysis.
10. Repeat the above methodology for the 10-year floodplain, using the 50-year floodplain as a guide instead of the 100-year floodplain. Repeat for all coastal counties and merge results to create a statewide 10-year floodplain polygon and a statewide 50-year floodplain polygon.

To create the “probability of exposure” feature (Figure A17):

11. Dissolve the SLOSH Category 1 – 4 storm surge layers to obtain full study area polygon.
12. Erase water features from floodplain polygons and Category 4 extent.
13. Add grid column and calculate columns as 1, 10, 100, 1,000, and 10,000. Convert to Raster and Reclassify so NoData = 0.
14. Sum Rasters and reclassify so 10-year = 900; 50-year = 80; 100-year = 10; 500-year = 8; and Category 4 = 1. Use Raster Calculator to divide by 1,000.0 and perform float function.

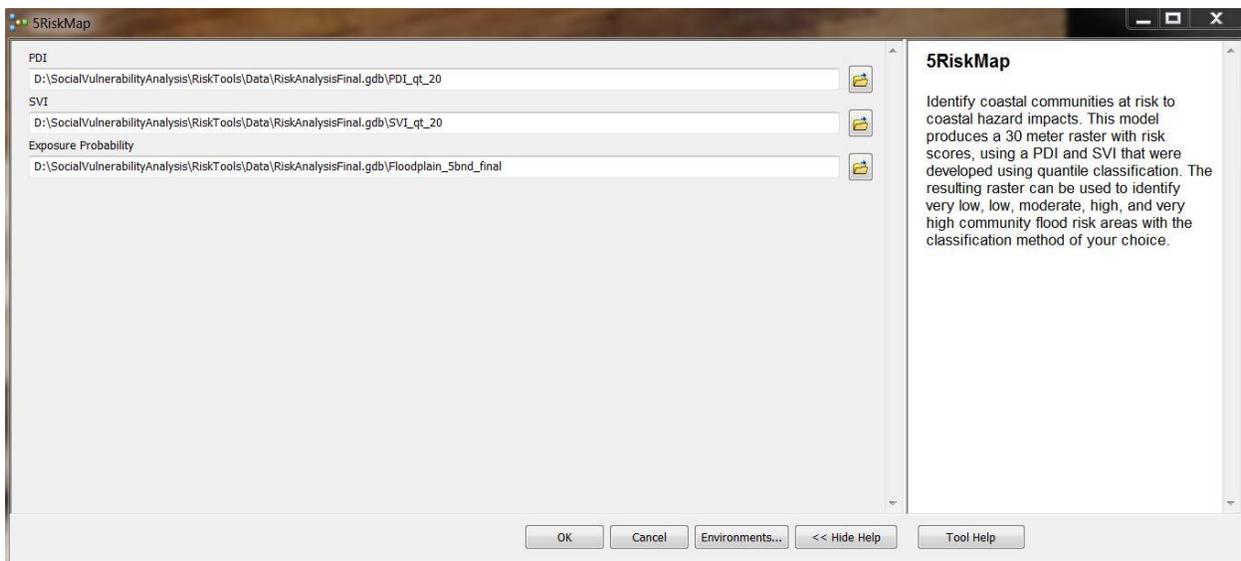
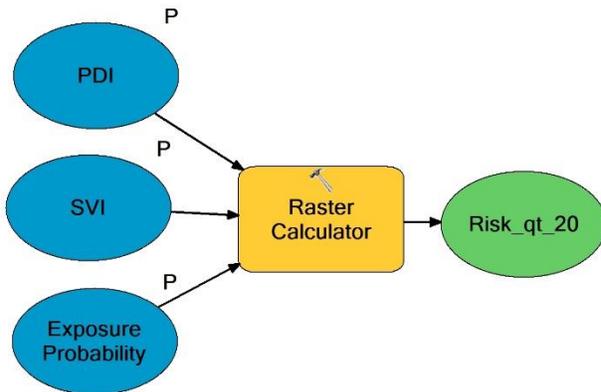
Figure A17. Exposure Model Builder Work Flow (top) and Model Interface (bottom). Model creates a seamless floodplain layer that represents probability of exposure.



Composite Index: Create Community Flood Risk Map.

1. Use Raster Calculator with the following equation: $((\%PDI\%) + (\%SVI\%)) * \%Exposure\ Probability\%$.
2. Reclassify into 5 classes using quantile classification to identify communities at risk to flood exposure, ranked from low risk (1) to high risk (5) (Figure A18).

Figure A18. Risk Model Builder Work Flow (top) and Model Interface (bottom). Model identified residential areas at risk to flood exposure, ranked from low risk (1) to high risk (5). Numeric values can be replaced with qualitative rankings (very low to very high).



Appendix H: Intermediate Marsh Protection Potential Index Results

Figure A19: Example of marsh area classification with histogram.

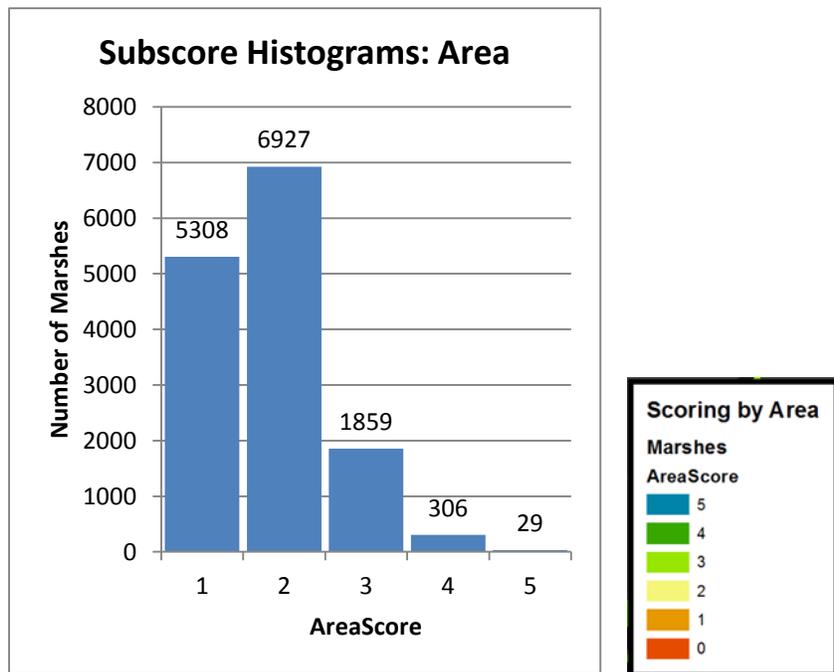
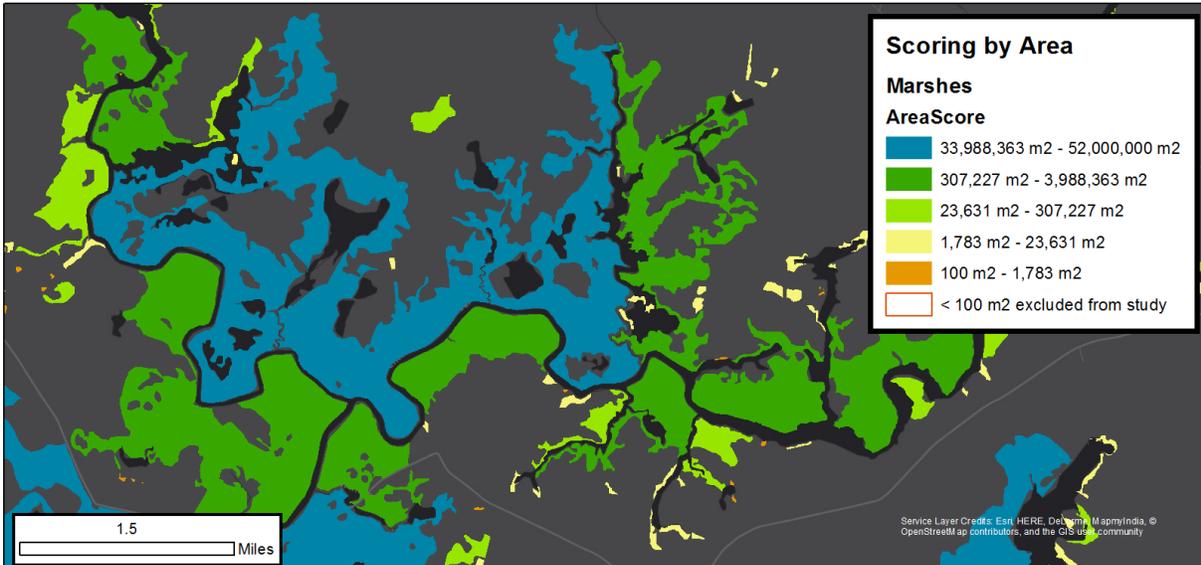


Figure A20: Example of marsh hazard classification with histogram.

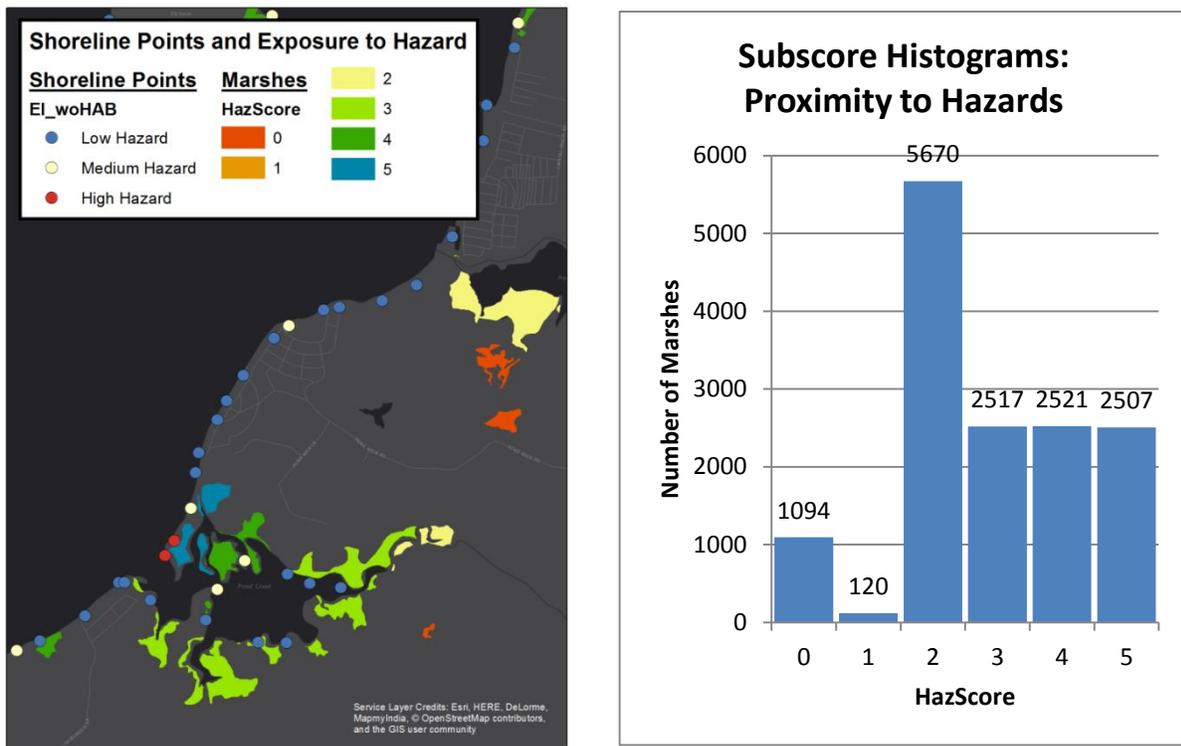


Figure A21: Example of marsh proximity to people classification with histogram.

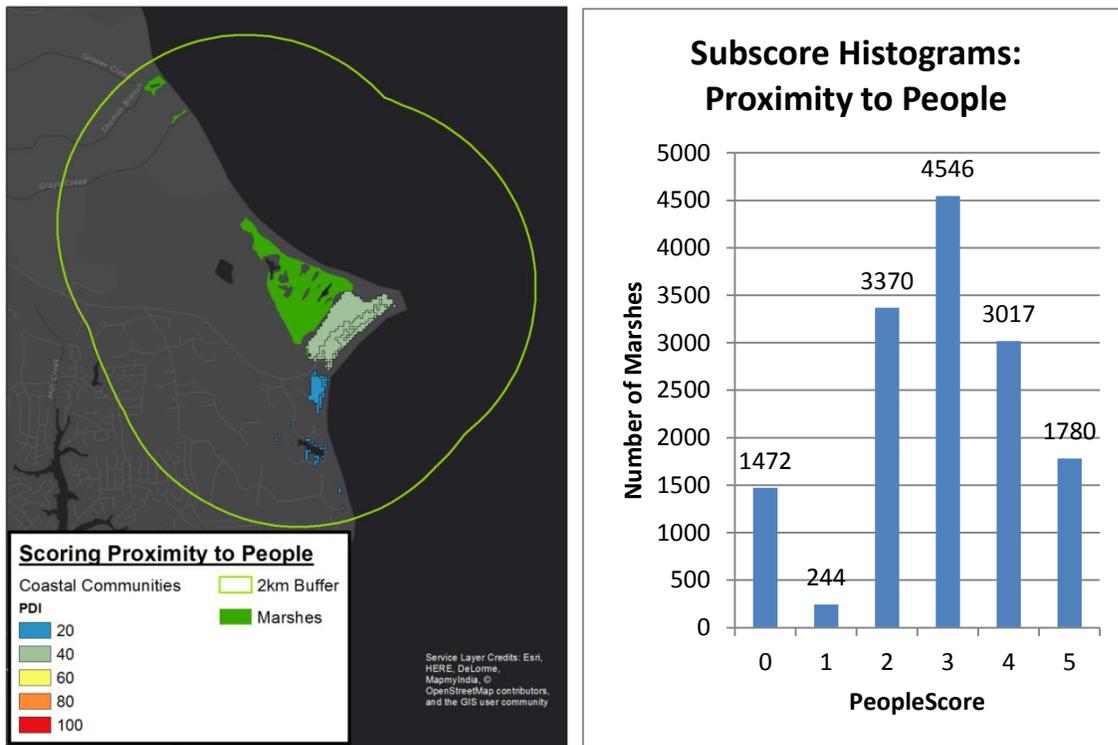


Figure A22: Example of marsh proximity to habitats classification with histogram.

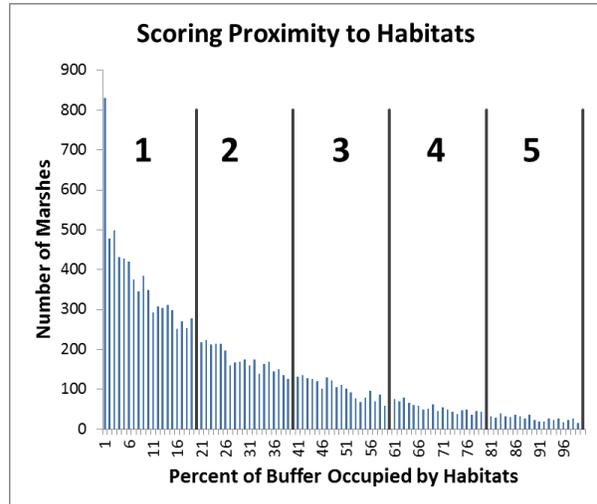
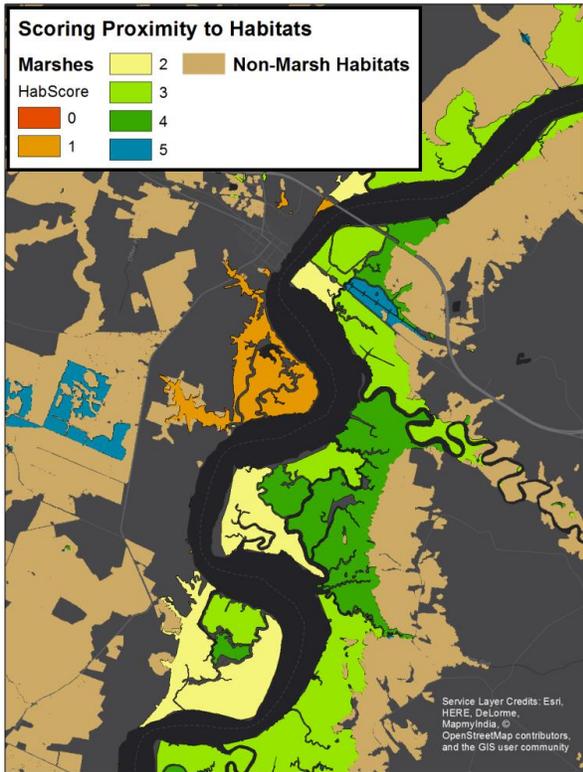


Figure A23: Example of marsh persistence classification with histogram.

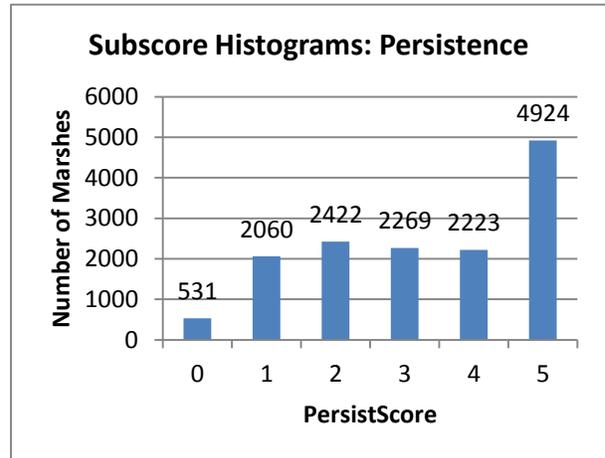
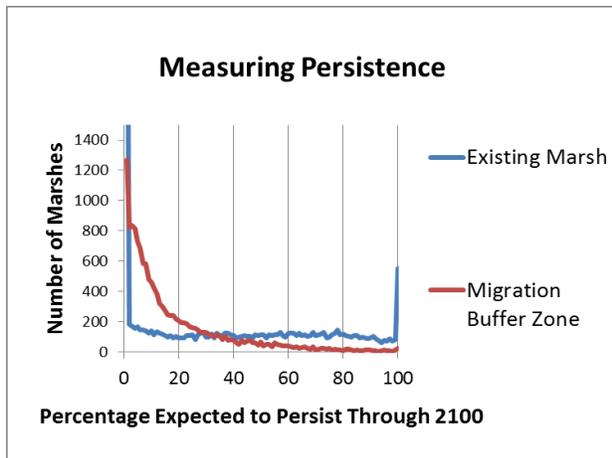
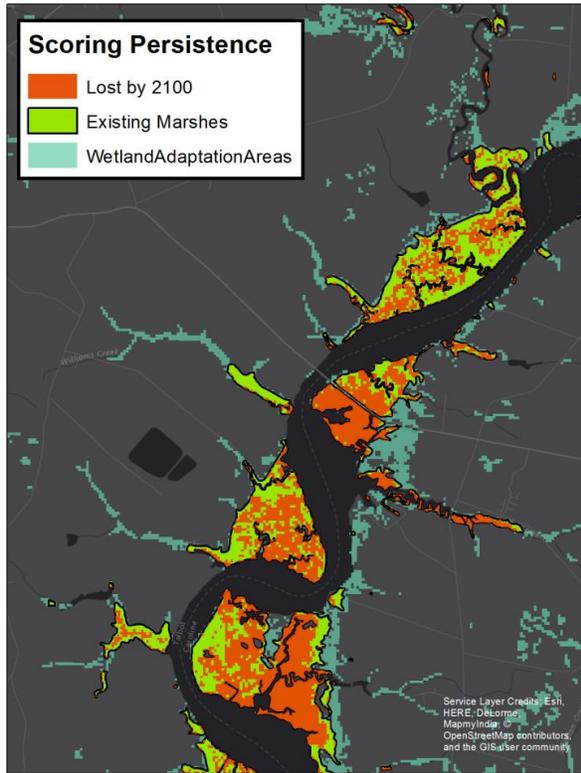
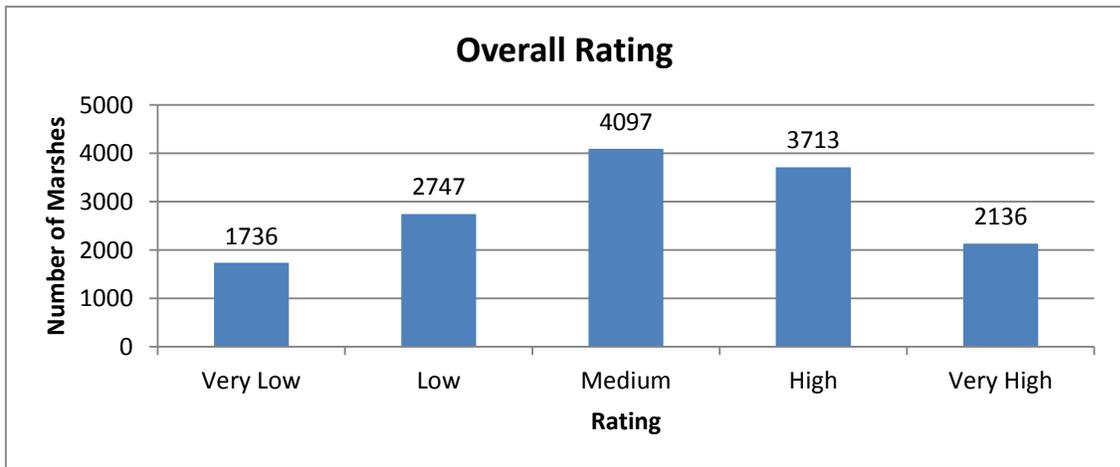
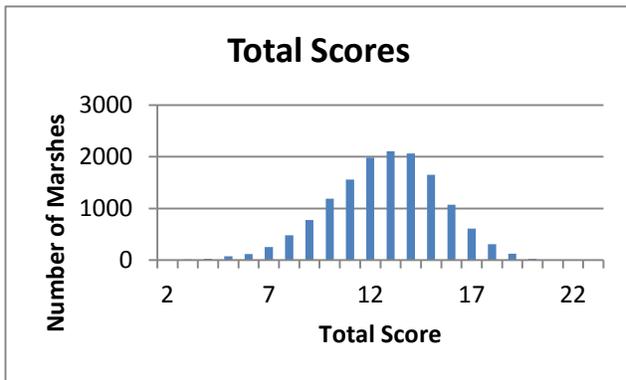
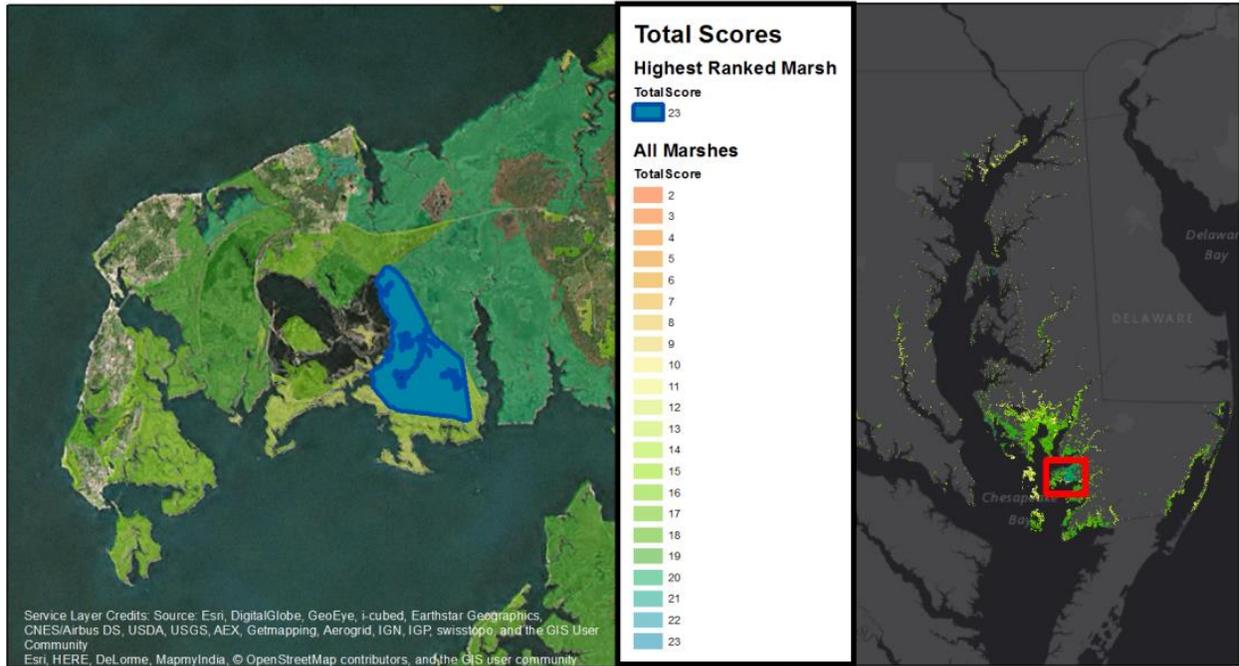


Figure A24: Example of marsh total scores with overall rating histogram. The highest rated marsh in the study, receiving a total score of 23 / 25, is part of Deal Island State Wildlife Management Area in Somerset County.



Appendix I: Marsh Protection Potential Index Model Protocol

What follows is a step-by-step guide to generating the Marsh Protection Potential Index from the given sources, included here to ensure the MPPI analysis is exactly reproducible. Except where otherwise specified, when creating a new attribute field the type is Double.

- I. Assemble Base Marsh Layer for analysis
 1. Import the marshes_2.shp shapefile from the coastal resilience model inputs (Coastal Resilience\Inputs\Natural_Habitats\marshes_2.shp) to the MPPI_Final_Run geodatabase.
 - a. Repair geometry
 2. Import the study area, the SLOSH category 4 storm surge line (Maximum of Minimum) SLOSH_1to4_dis.shp
 - a. Repair geometry
 3. Clip the marshes to the study area
 - a. Using toolbox/Analysis Tools/Extract/Clip, input features = marshes_2.shp, clip features = SLOSH_1to4_dis.shp, XY tolerance = blank, Output feature class = Marshes_StudyArea
 4. Aggregate adjacent marshes
 - a. Toolbox/Cartography/Generalization/Aggregate Polygons
 - i. Input features = Marshes_StudyArea, Output = Marshes_Agg, Aggregation Distance = 5m, Minimum Area = 0 m², Minimum Hole Size = blank (0), do not preserve orthogonal shapes, no barrier features
 5. Delete all marshes smaller than 100m² in area
 - a. From Marshes_Agg, Select by attributes all shapes where shape area < 100
 - b. Toolbox/Data Management/Features/Delete Features on Marshes_Agg
 6. Export result as MPPI_base_marshes into MPPI_Final_Run.gdb.
- II. Generate Proximity to Habitats Rating
 1. Export MPPI_Base_Marshes to ProxHab_base
 2. Gather/Create layers for other habitats using the CR model inputs
 - a. Forest patches used for the Coastal Resiliency Assessment InVEST run. (CoastalForestArea_fin.shp). Output feature class = Forests.
 - i. Repair geometry
 - b. oysterReefs_5 from CR first run. Output feature class = Oysters.
 - i. Repair geometry
 - c. SAVupdate101315 from CR intermediate run (the shapefile is SAV_cov_dissolve.shp). Output feature class = SAV
 - i. Repair geometry

- d. sandDunes_3 from CR intermediate run, modified to include dunes near Ocean City.
 - i. import shoreline_points from CR model outputs. Display based on the DUNE attribute (0 or 3), and zoom into Assawoman and Isle of Wight Bays. Using imagery (I used the ESRI basemap), add features to the sandDunes_3 layer corresponding to the dunes you can see on the imagery. Use the shoreline points as a guide to interpreting the imagery.
 - ii. Repair geometry
3. Combine the various habitat layers into a single layer of non-marsh habitats
 - a. Take the union of the four non marsh habitats, creating “NonMarshHabs”, gaps allowed, all fields.
 - b. Erase MPPI_base_marshes from NonMarshHabs to create “NonMarshHabs_erase_marshes” (NonMarshHabs intersects with our MPPI_base_Marshes, which would cause error in our area totals later without this erase.)
4. Create buffer layers of marsh polygons, and then get the area of the buffer without the marsh. (We do this instead of buffering outside only to improve processing speed on slower systems.)
 - a. Add a new field “MarshArea” to ProxHab_base, and use the field calculator to set it equal to Shape_Area.
 - b. Buffer ProxHab_Base to 250m, no dissolve, all sides, planar method, to create “ProxHab_b250”
 - c. Create a new attribute field in ProxHab_b250, “BufferOnlyArea”, and set it equal to Shape_Area – MarshArea.
 - d. Create a new attribute field in ProxHab_b250, “BufferWMarsh,” and set it equal to Shape_Area
5. Find the area of neighboring marshes within the 250m buffer zone of each marsh
 - a. Erase ProxHab_base from ProxHab_b250 to create ProxHab_b250_erasemarshes
 - b. Add a new field in ProxHab_b250_erasemarshes, “OtherMarshesWithin250” populate the field using the field calculator, and the expression OtherMarshesWithin250 = !bufferWMarsh! - !Shape_Area! - !MarshArea!
 - i. Other marshes within 250m = (total area of the 250m buffer including the marsh itself) – (area remaining after erasing all marshes) – (area of the marsh under examination). In other words, subtract the post-erase area to get the area of all marshes within 250m, and then subtract the area of the marsh itself to get the area of other marshes within 250m.
6. Find the area of neighboring non-marsh habitat intersecting each buffer

- a. Erase NonMarshHabs_erasemarshes from ProxHab_b250 to create ProxHab_b250_eraseNonMarshes
 - b. Create a new field "NonMarshWithin250", set it equal to BufferWMarsh – ShapeArea (the area of the non-marsh habitat within 250m is equal to difference between the original buffer area (which includes the marsh itself) and the area after erasing non-marsh features)
7. Join Fields back to ProxHab_base
- a. Join Field with input table = ProxHab_base, input join field = OBJECTID, Join table = ProxHab_b250_eraseNonMarshes, Output Join Field = ORIG_FID, Join Fields = NonMarshWithin250 and BufferOnlyArea
 - b. Join Field with input table = ProxHab_base, input join field = OBJECTID, Join Table = ProxHab_b250_erasemarshes, Output Join Field = ORIG_FID, Join Fields = OtherMarshesWithin250
8. Calculate the percentage of a marsh's 250m buffer occupied by natural habitats
- a. In ProxHab_base, add a new field "NeighborsWithin250", which is the sum of NonMarshWithin250 and OtherMarshesWithin250
 - b. In ProxHab_base, create a new field "PercentBufferOccupied", which is equal to $(\text{NeighborsWithin250} / \text{BufferOnlyArea}) * 100$.
9. Convert the percentage metric into a 0-5 score for proximity to habitats
- a. Create a new integer field, titled "HabScore"
 - b. Using the field calculator and the classify python function, populate the HabScore field


```
def Classify(percentage,breaks):
    score = 0
    for value in breaks:
        if percentage < value:
            return score
        else:
            score = score + 1
    return 5
```

 - i. HabScore = Classify(!PercentBufferOccupied!,[breaks])
 - The values for breaks are the lower bound of each classification interval. For the habitats layer, we chose a defined interval of 20% of buffer occupied by natural habitats. The breaks are: [.000001, 20.000001, 40.000001, 60.000001, 80.000001]

III. Generate Proximity to Hazards Rating

1. Export MPPI_Base_Marshes to ProxHaz_base
2. Use the CR model shoreline points to assign a hazard exposure index to each marsh, based on the maximum hazard exposure point within 250m of the marsh.

- a. Import ShorelinePoints from CR model results. Buffer Shoreline points to 250m, no join, to get ShorelinePoints_b250
 - b. Spatial join ShorelinePoints_b250 (join features) to ProxHaz_base (target features) to create ProxHaz_JoinPts. Join 1 to 1, keep all target features, delete all join feature attributes from the field mapping except EI_woHab. Set the merge rule for EI_woHab as maximum.
3. Assign scoring benefits based on whether marshes fall in the 10-year, 100-year, or 500-year floodplains
- a. Spatial join the floodplain data from CR model outputs (dataforreview.gdb) to ProxHaz_JoinPts to create ProxHaz_JoinPts_flood
 - i. Join 1 to 1, keep all target features, remove Id, grid_ccode, FloodType and Shape_length_1 and Shape_area_1 from the field map. (We are only keeping the “probability” field)Set the merge rule for probability to max.
 - ii. This join results in some null values. Though our study area is based on the Category 4 storm surge extent, the processing of the floodplain layer for the Risk Assessment has made some small changes at the margins of the floodplain (for example, by excluding areas that are normally open water). There are marshes on the seaward or landward edge of the floodplains that have a null rating. Marshes on the seaward edge of the floodplains will be scored based on nearby shoreline points, and we are comfortable assigning an exposure score of 0 to marshes on the inland edge of the category 4 storm surge extent.

4. Assign a proximity to hazards rating

- a. Convert null values to 0 for Probability and EI_woHab

```
def NtZ(value):
    if value is None:
        return 0
    else:
        return value
```

- b. Create a new field (short integer) in ProxHaz_JoinPtsg_flood. New field is called HazScore

- c. Use the following python script to populate HazScore in the field calculator:

```
def Rate(shorepoints, flood):
    if shorepoints >= 2.874101:
        return 5
    elif shorepoints >= 2.331951:
        return 4
    elif shorepoints >= 1.472360:
        return 3
    elif flood >= .01:
        return 2
    elif flood >= .008:
        return 1
```

```
else:  
    return 0
```

- i. Explanation: First, we check the associated Exposure Index associated with a particular marsh. If the marsh has an exposure index > 0 (ie, it is within 250m of a shoreline point) it is assigned a value from 3 to 5 based on what tercile (3-class quantile) the exposure index falls into. If a marsh has an exposure index of 0 (1.47 is the lowest non-zero value for EI_woHab), then the marsh gets assigned a score of 0-3 for falling in the category 4 storm surge, 500-year, 100-year, or 10-year floodplains, respectively.

IV. Generate Proximity to People Rating

1. Gather source data

- a. Export MPPI_Base_Marshes to ProxPeople_base
 - b. Import population density index and social vulnerability indices from the Coastal Resiliency Assessment data. These are included as attribute fields in the Risk Areas data, RiskAreaIndex.shp.
 - c. Buffer ProxPeople_base to 2km, no join, and save the result as ProxPeople_2km
 - d. Do a spatial join with ProxPeople_2km as the target features, RiskAreasIndex as the join features, joining 1 to 1, keeping only the ORIG_FID, Shape_Length, Shape_Area, PDI, and SVI codes. Set PDI and SVI to MAX merge rule. Save the result as ProxPeople_2km_PDI_SVI, match option intersect
 - e. Now we have a layer of marshes (buffered to 2km) associated with the maximum values of PDI and SVI that fall within the 2km buffer distance of the marsh.
 - i. To clean this up, use the Null-to-0 python script described above on the PDI_gridcode and SVI_gridcode attribute fields in ProxPeople_2km_PDI_SVI
- ```
def NtZ(value):
 if value is None:
 return 0
 else:
 return value
```
- f. Use toolbox/Data management tools/Joins/Join Field to join the PDI and SVI fields from ProxPeople\_2km\_PDI\_SVI to ProxPeople\_base, based on OBJECTID from ProxPeople\_Base and ORIG\_FID from ProxPeople\_2km\_PDI\_SVI
  - g. Create new field (short integer) in ProxPeople\_base, "Sum\_PDImax\_SVImax", which is equal to PDI + SVI
  - h. Create new field (short integer) in ProxPeople\_base, "PeopleScore". To convert the x/200 score in PDImax\_sum\_SVImax to an x/5 score, set PeopleScore to (in python):
    - i.  $\text{ProxPeople\_rating} = \text{int}(\text{round}(\text{!PDImax\_sum\_SVImax!} / 40.0))$

- ii. Note that we're rounding half points up here (so 120/200 -> 3/5 and 140/200 -> 4/5). The "40.0" is important – if you use "40", python will round the resulting division down, and all your scores will round down.

V. Generate Persistence Rating

1. Export MPPI\_Base\_Marshes to Persist\_base
2. Import DNR's Wetland adaptation areas  
(WEAT\_SeaLevelRiseWetlandAdaptationAreas\_DNR)
  - a. [http://geodata.md.gov/imap/rest/services/Weather/MD\\_SeaLevelRiseWetlandAdaptationAreas/MapServer](http://geodata.md.gov/imap/rest/services/Weather/MD_SeaLevelRiseWetlandAdaptationAreas/MapServer)
3. Store the current area of the marshes for comparison.
  - a. Add a new field to Persistence\_base, "Current\_area". Use the field calculator to set it equal to shape area. Add another new field, "ORIG\_OID" (long integer) and set it equal to the OBJECTID
4. Calculate the amount of marsh area which is predicted to be lost.
  - a. Erase, with input features = Persist\_base, Erase Features = WEAT\_SeaLevelRiseWetlandAdaptationAreas\_DNR, and output = "Persist\_erase\_WAA"
  - b. Create a new (double) field in Persist\_erase\_WAA, titled "Area\_Lost" and set it equal to Shape\_Area
  - c. Join field, with input table = Persist\_base, input join field= OBJECTID, Join table = Persist\_erase\_WAA, output join field = ORIG\_OID, and join fields = Area\_Lost
  - d. Null to zero function on Area\_Lost attribute in Persist\_base (marshes which were completely erased by the adaptation areas have 0 expected loss)
5. Calculate the % of each marsh's current area which is predicted to persist
  - a. New field in Persist\_base (double), "Area\_remaining\_2100", equal to Current\_Area – Area\_Lost
  - b. New Field in Persist\_base (double), "PercentRemaining2100", equal to  $100 * (\text{Area\_remaining\_2100} / \text{Current\_Area})$
6. Assess potential for migration
  - a. Create 250m buffer of Persist\_base, named "Persist\_b250"; no dissolve type
  - b. Erase the persist\_base from Persist\_b250 to create Persist\_b250\_erase\_marshes (we don't want to count areas that are currently marsh)
  - c. Store the current buffer area
    - i. Create a new attribute field, named "Current\_buffer\_area" and set it equal to the Shape\_Area
    - ii. Repair geometry on Persist\_b250\_erase\_Marshes

- d. Calculate the amount of buffer area not expected to be viable marsh habitat
    - i. Erase the adaptation areas. Erase with input features = Persist\_b250\_erase\_marshes erase features = WEAT\_SeaLevelRiseWetlandAdaptationAreas\_DNR, and output = Persist\_b250\_erase\_marshes\_WAA
  - e. Store the lost buffer area (area remaining after erase).
    - i. In Persist\_b250\_erase\_marshes\_WAA, create an attribute field named "Buffer\_lost\_2100" and set it equal to the Shape\_Area
  - f. Join current buffer and lost buffer to persist\_base
    - i. Join Field with input table = Persist\_base, input join field = OBJECTID, join table = Persist\_b250\_erase\_marshes\_WAA, Join Table = ORIG\_OID, Join Field(s) = Current\_buffer\_area and Buffer\_lost\_2100
  - g. Join Field with input tables = Persist\_Base, input join field = OBJECTID, Join Table = Persist\_b250\_erase\_marshes\_WAA, output join field = ORIG\_OID, join fields = PercentBufferRemain
  - h. Subtract and divide to get the % of buffer expected to remain
    - i. In Persist\_Base, create a new attribute field, "PercentBufferRemain" and set it equal to:
    - ii.  $\text{PercentBufferRemain} = 100 * ((\text{!Current\_buffer\_area!} - \text{!Buffer\_lost\_2100!}) / \text{!Current\_buffer\_area!})$
7. Convert null values in PercentBufferRemain and PercentRemaining2100 to 100.
- a. (If the entire marsh or buffer is expected to persist, it will be completely erased by the wetland adaptation areas, and the OBJECTID for that marsh will not be included in the post-erase tables. When we join back to Persist\_Base, that OBJECTID will not have a match in the post-erase table, and will get a null value for PercentBufferRemain or PercentRemaining2100.)
 

```
def NullToHundred(value):
 if value is None:
 return 100
 else:
 return value
```
8. Assign point values for percent remaining and percent of buffer remaining. Create a new attribute field (short integer), called "PersistScore"
- a. Use the python classify formulae and defined intervals. Intervals of 20 for area Remaining and intervals of 33 for percent buffer remaining.
    - i. Score based on the percentage of the marsh expected to persist, with 'extra credit' for percentage of the buffer available for migration.

```

def RemainScore(percent_remain, r_breaks):
 score = 0
 for value in r_breaks:
 if percent_remain < value:
 return score
 else:
 score = score + 1
 return 5

def MigrateScore(buffer_remain, m_breaks):
 score = 0
 for value in m_breaks:
 if buffer_remain < value:
 return score
 else:
 score = score + 1
 return 3

def PersistScore(percent_remain, r_breaks, buffer_remain, m_breaks):
 remainrank = RemainScore(percent_remain, r_breaks)
 migraterank = MigrateScore(buffer_remain, m_breaks)
 total = remainrank + migraterank
 if total > 5:
 return 5
 else:
 return total

```

ii. PersistScore = PersistScore(!PercentRemaining2100!, [0.000001, 20.000001, 40.000001, 60.000001, 80.000001], !PercentBufferRemain!, [0.000001, 33.333333, 66.666667])

## VI. Generate Area Score

1. Export MPPI\_Base\_Marshes to AreaBase
2. Classify marshes according to area
  - a. Using geometric classification on Shape\_Area with 5 classes.
3. Use area classification to assign Area Score to each marsh
  - a. Create a new field in the attribute table of MPPI\_base\_marshes. Field type is Short Integer and field name is AreaScore.
  - b. Calculate field using the following python script and expression

```

def Classify(area, breaks):
 score = 0

```

```

for value in breaks:
 if area < value:
 return score
 else:
 score = score + 1
return 5

```

i. AreaScore = Classify(!Shape\_Area!,[breaks])

- The values for breaks are the lower bound of each classification interval. These are: [100.062808, 1783.271893, 23631.655702, 307227.959607, 3988363.566384]

VII. Aggregate five sub scores into the final data layer

1. Using the Join Field tool, with MPPI\_base\_marshes as the input table, OBJECTID as the input join field, do these joins:
  - a. Join Table = ProxHab\_base, output join field = OBJECTID, Join Fields = PercentBufferOccupied and HabScore
  - b. Join Table = ProxHaz\_JoinPts\_flood, output join field = OBJECTID, Join Fields = EI\_woHab, Probability, and HazScore
  - c. Join Table = ProxPeople\_base, output join field = OBJECTID, Join Fields = SVI, PDI, and PeopleScore
  - d. Join Table = Persist\_base, output join field = OBJECTID, Join Fields = PercentRemain2100, PercentBufferRemain, and PersistScore
  - e. Join Table = AreaBase, output join field = OBJECTID, Join Fields = AreaScore
2. Create a new field (short integer) named "TotalScore", and set it to:
  - a. OverallScore = !AreaScore! + !HabScore! + !HazScore! + !PeopleScore! + !PersistScore!
3. Create a new field (text), named "OverallRating" and set it to:

```

def Classify(total,breaks):
 score = 1
 for value in breaks:
 if total <= value:
 return score
 else:
 score = score + 1

```

```

def Translate(score):
 if score == 1:
 return "Very Low"
 elif score == 2:
 return "Low"
 elif score == 3:

```

```
 return "Medium"
elif score == 4:
 return "High"
elif score == 5:
 return "Very High"
else:
 return "N/A"
```

- a. OverallRating = Translate(Classify( !TotalScore!, [9,11,13,15,23]))
  - i. These are Jenks Natural Breaks intervals on the TotalScore attribute.

4. Export MPPI\_base\_marshes as MPPI\_Final\_Results