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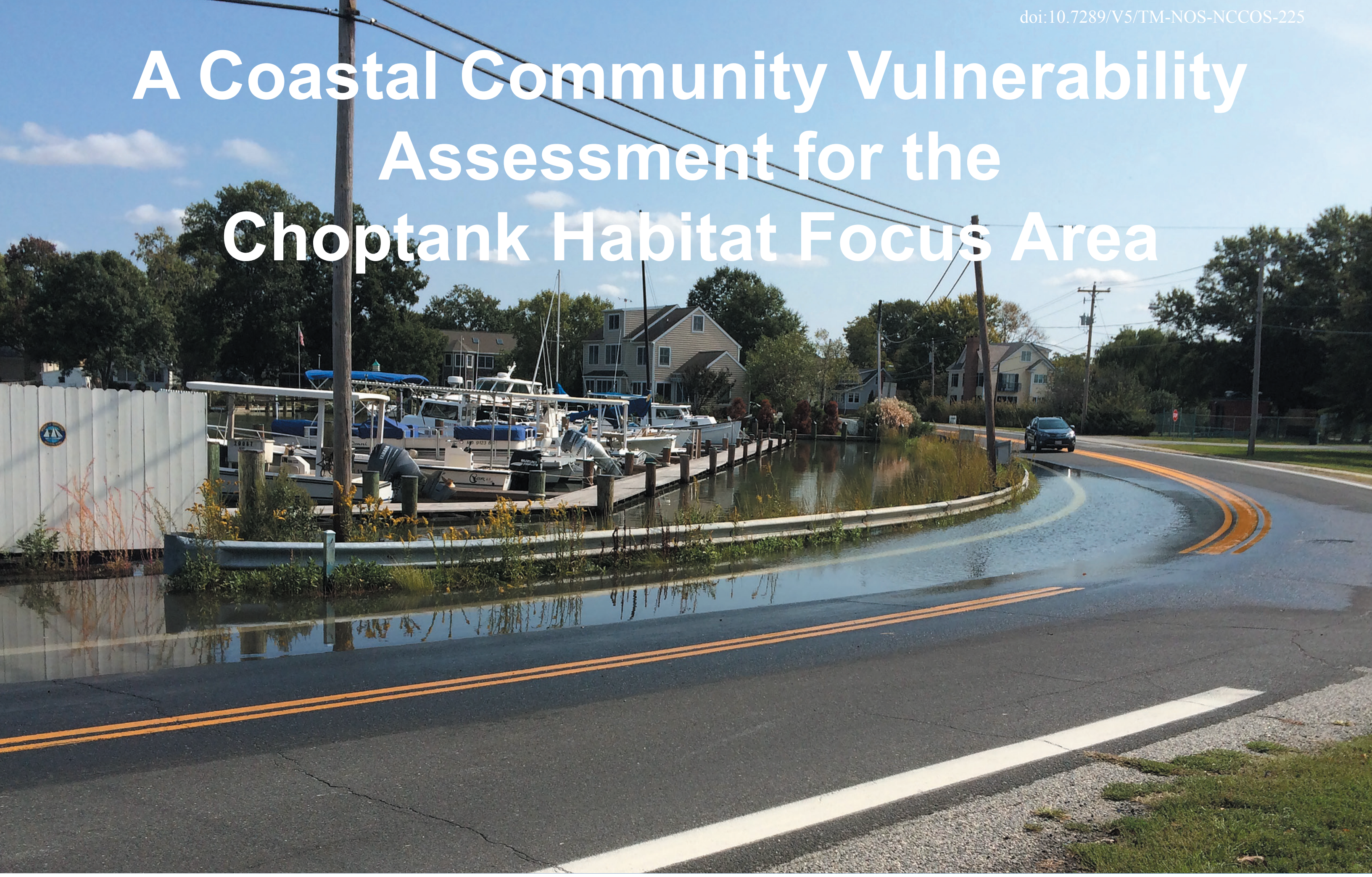
A Coastal Community Vulnerability Assessment for the Choptank Habitat Focus Area



NOAA National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment

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January 2017

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United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Penny Pritzker Secretary	Kathryn D. Sullivan Administrator	Russell Callender Assistant Administrator

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LIST OF ACRONYMS

ACS	American Community Survey
C-CAP	Coastal Change Analysis Program
DE	Delaware
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GED	General Education Degree
HFA	Habitat Focus Area
MD	Maryland
NCCOS	National Centers for Coastal Ocean Science
NERRS	National Estuarine Research Reserve System
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OCM	Office for Coastal Management
PCA	Principle Components Analysis
PRCP	Long-Term Averages of Monthly Precipitation Totals
SAV	Submerged Aquatic Vegetation
SD	Standard Deviation
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SNAP	Supplemental Nutrition Assistance Program
SoVI	Social Vulnerability Index
SWARM	Stormwater Runoff Modeling System
TAVE	Long-Term Averages of Monthly Average Temperatures
TMAX	Long-Term Averages of Monthly Maximum Temperatures
TMIN	Long-Term Averages of Monthly Minimum Temperatures
TNC	The Nature Conservancy
US	United States
USDA	United States Department of Agriculture

Executive Summary

Photo credit: University of Maryland IAN

This report presents a framework and provides findings from a community vulnerability assessment analysis conducted in the Choptank Habitat Focus Area (HFA) within the Chesapeake Bay.

Due to the strong connectivity between Chesapeake Bay communities and their environment, the risks associated with flooding, coastal storms, and sea level rise are heightened, thus requiring integrated science techniques and methods to determine community vulnerability to climate and coastal hazard impacts. This project supplies Choptank HFA partners, as well as coastal communities, local governments, and coastal and watershed organizations, with information that can be used to identify and prioritize areas that have the potential to be negatively impacted by climate-related hazards through the implementation of a framework for an integrated social-environmental vulnerability assessment.

The Integrated Vulnerability Assessment Framework is as follows:

1. Identify base condition social vulnerability, structural vulnerability, and natural resource vulnerability within the study area.
2. Identify flood risks and their inundation impacts within the study area.
3. Spatially intersect base condition vulnerabilities with individual flood risks.
4. Establish a system that can be used to help target or prioritize areas for adaptation action to mitigate coastal flooding through the identification of high vulnerability/high risk areas.

The overarching goal of this project was to expand upon the vulnerability assessment for the Town of Oxford and Talbot County, Maryland (Messick and Dillard 2016), which integrated measures of vulnerability with measures of risk in a spatial assessment. In both implementations of the Framework, the scientific assessment incorporated community and stakeholder engagement to ensure that vulnerability was appropriately identified and translated in a way that would serve as a foundation for the selected study area to address risk and identify adaptation strategies for future planning.

Identified vulnerabilities were as follows:

- Social vulnerability;
- Structural vulnerability; and
- Natural resource vulnerability (measured via potential loss of highly valued resources).

Social vulnerability component factors included 1) social class, 2) age, 3) wealth, 4) social isolation, 5) rurality, and 6) service industry employment and gender. Structural vulnerability components included 1) structure grade, 2) structure material, and 3) proportion of structures with basements. Natural resources included in the valuation were 1) submerged aquatic vegetation, 2) beaches, 3) wetlands, 4) marsh buffer, 5) oyster sanctuaries, 6) forested areas, 7) forest conservation easements, and 8) green infrastructure.

Identified flood risks were as follows:

- Sea level rise of 1 foot;
- Sea level rise of 2 feet;
- Category 1 hurricane storm surge;
- Category 2 hurricane storm surge; and
- Stormwater flooding.

Synthesis of data collection, indicator development, and methods of analysis are described in detail within the body of this report. Key findings of this analysis are listed below.

Key results from the spatial analysis of social, structural, and natural resource vulnerabilities (Figures B-1, B-8, and B-13) include:

- The northern portion of the Choptank HFA study area shares high social vulnerability, high structural vulnerability, and medium-high natural resource vulnerability.

- High social vulnerability is also present in the southernmost block group, and although this area is low in structural vulnerability, it is high in natural resource vulnerability.
- High structural vulnerability and high natural resource vulnerability share similar block groups in the central region of the study area, but are inverted in the coastal block groups, in which structural vulnerability is low, but natural resource vulnerability is high.
- Social vulnerability varies between low and high in these coastal block groups.
- While social vulnerability is generally high in and around the communities of Cambridge, Easton, Denton, and Viola, natural resource vulnerability is low within these municipalities, with the exception of Viola.
- Structural vulnerability within these areas varies, with high vulnerability in and around Easton, Denton, and Viola, but low vulnerability in and around Cambridge.

Key results from the intersection of vulnerabilities with flood risks (Figures B-18:B-34) include:

- When intersected with flood inundation risk, the southernmost block groups are highly vulnerable in terms of social vulnerability, natural resource vulnerability, and each of the five flood risks.
- This is not the case for structural vulnerability.
- Block groups located centrally have similarly varying levels of combined flood risk and social vulnerability, structural vulnerability, and natural resource vulnerability.
- The municipalities of Cambridge, Easton, and Denton generally have high combined social vulnerability and flood risk, as well as high combined structural vulnerability and flood risk across the five flood hazard scenarios.
- Conversely, these municipalities generally have low combined natural resource vulnerability.
- Tilghman Island and the surrounding region commonly have higher combined vulnerability and risk when compared to many of the other coastal block groups.

Key results from the identification of coastal flooding adaptation areas (Figures B-35 and B-36) include:

- Short term coastal flooding adaptation scores were determined through a combination of category 2 storm surge, stormwater flooding, and social, structural, and natural resource vulnerabilities.
- Scores for long term flood hazards included the addition of sea level rise of 2 feet.
- Tier 1 areas (high overall vulnerability and risk) for short and long term risks are generally located closest to the coast, and are concentrated along the southwestern parts of the Choptank HFA study area.
- Tier 3 areas (medium overall vulnerability and risk) for short and long term risks are scattered throughout the central and northeastern regions of the study area; some of these areas increase in potential priority to Tier 2 for long term risks.
- Tier 5 areas (low overall vulnerability and risk) for short and long term risks are scattered throughout the central region of the study area, and also just south of the northernmost block groups; these remain fairly consistent for long term risks, but some of the central block groups increase in potential priority to Tier 4.

Ultimately, the results of the vulnerability assessment for the Choptank HFA study area provide valuable information, which can be used to inform adaptation planning for coastal flooding within the Choptank HFA. Additionally, this Framework can be applied to a range of geographies, as well as social and environmental contexts, throughout the United States and beyond.

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Chapter 1
Introduction

Photo credit: Jane Hawkey, University of Maryland IAN

The Chesapeake Bay is the largest estuary in the United States with a total of 11,684 miles of shoreline along the main stem and its tributaries (Chesapeake Bay Program, 2012). The Chesapeake Bay includes two National Estuarine Research Reserve System (NERRS) sites, is one of the National Oceanic and Atmospheric Administration's (NOAA) Sentinel Sites, and contains the NOAA Choptank Habitat Focus Area (HFA). The ecology of the Chesapeake Bay and its watershed are deeply intertwined in the history, culture, and economy of the communities in the region, and provide people with valuable ecosystem services. Due to the strong connectivity between communities and the environment, the risks associated with flooding, coastal storms, erosion, and sea level rise are heightened. Understanding the communities adjacent to the Bay in terms of their vulnerability to climate and coastal hazard impacts requires integrated science techniques and methods. This project aims to provide the Choptank HFA partners with information that can be used to identify and prioritize areas that have the potential to be negatively impacted by climate-related hazards, such as storm surge and sea level rise, by implementing a framework for an integrated social-environmental vulnerability assessment.

A variety of ecological, social, economic, and cultural indicators are significant when considering the potential impacts of sea level rise and other climate-related shifts (e.g., changes in magnitude or periodicity of precipitation) on coastal communities. Using existing indicators of vulnerability such as the Social Vulnerability Index (SoVI; Cutter, Boruff, and Shirley, 2003), as well as novel approaches to indicator development applied to coastal communities (Dillard et al., 2013; Jepson and Colburn, 2013; Messick and Dillard, 2016), a set of appropriate metrics were identified and/or developed for this assessment. Social, structural, and environmental vulnerability were examined using data collected on population demographics, economic characteristics, distribution of natural resources, value of natural resources, and characteristics of commercial and residential structures. These vulnerabilities were then investigated alongside various flood hazard risks, including stormwater flooding, storm surge, and sea level rise. This work built upon a range of NOAA methods and products (e.g., Office for Coastal Management's (OCM) Digital Coast, National Marine Fisheries Service (NMFS) Social Indicators, National Centers for Coastal Ocean Science (NCCOS) Community Well-being Indicators, NCCOS Hydrologic Modeling, and NCCOS Biogeographic Assessment Framework).

The overarching goal of this project was to expand upon the Integrated Vulnerability Assessment Framework (Framework) developed for the Town of Oxford and Talbot County, Maryland (Messick and Dillard, 2016), which integrated measures of vulnerability with measures of risk in a spatial assessment. In both implementations of the Framework, the scientific assessment incorporated community and stakeholder engagement to ensure that vulnerability was appropriately identified and translated in a way that would serve as a foundation for the selected study area to address risk and identify adaptation strategies for future planning. The results of the vulnerability assessment for the Choptank HFA study area can be used to inform adaptation planning for coastal flooding within the Choptank HFA.

This project represents continued collaboration across the social and environmental sciences, as well as across federal, regional, and non-governmental partners. This project further demonstrates that this methodological approach has been tailored for maximum applicability across coastal communities of various sizes and in various regions. This approach can provide the science needed to inform management actions that contribute to the resilience of coastal communities in the face of climate and coastal hazard impacts.

1.1. STUDY AREA

1.1.1. Site Selection and Background

Following the integrated vulnerability assessment for the Town of Oxford and Talbot County, MD (Messick and Dillard, 2016), this methodology was expanded to a larger area within the Chesapeake Bay, specifically the Choptank HFA, to demonstrate the Framework's flexibility across study area sizes and geographies.

The Choptank watershed is situated on the Eastern Shore of Maryland, midway along the Chesapeake Bay, and in the mid-Atlantic region of the United States. The Choptank River drains five counties: Dorchester, Talbot, Queen Anne's, and Caroline in Maryland, and Kent in Delaware, for a total watershed area of 1,780 km^2. Of this area, 278 km^2 is estuarine with semi-diurnal tides and strong wind-driven effects. The estuary measures up to 17m in depth (Yarbro et al., 1983).

The Choptank watershed is primarily rural, and the landscape is dominated by agriculture (62%) and forest (26%), with a small amount of urban space (5%; Fisher et al., 2006b). This proportion of land use has been relatively stable since around 1850, with only a minor increase in the footprint of towns, and Easton, Cambridge, Denton, and Centreville are the most populous cities. Overall, human population density is low, as expected for such an agricultural region, at 59 people per square kilometer (Fisher et al., 2006a). Nevertheless, the population is expected to grow fairly rapidly, especially around towns and cities (NOAA, 2015).

Many of the region's citizens are dependent on commercial fishing for their livelihood. One of the largest fisheries in the region is the oyster fishery, which is estimated at 2% of historic levels. As a result, three large-scale restoration projects are ongoing in Harris Creek, Broad Creek, and the Tred Avon River. Within these waterbodies, the Maryland Department of Natural Resources has set aside a series of sanctuaries to protect broodstock (NOAA, 2015). Other major fisheries include blue crabs, striped bass (known locally as rockfish), and bait fish. Shellfish aquaculture is also a small, yet rapidly growing facet of the fishing economy and landscape (Green and Tracy, 2013).

The Choptank watershed was listed as a NOAA HFA in an effort to support habitat conservation and restoration within this important ecological corridor (NOAA, 2014). A primary concern within this area is agricultural runoff and its effects on water quality. Following national trends, the Choptank watershed has quadrupled fertilizer applications since 1950, causing increased eutrophication rates and more frequent hypoxic events (Fisher et al., 2006b). Hypoxia and sedimentation have resulted in an 85% reduction in submerged aquatic vegetation, a dominant ecosystem type in the relatively shallow river basin, since 1997 (Whitall et al., 2010). Another primary environmental concern in the region is wetland loss, estimated to be 11% of the total Choptank watershed, primarily in the upper agricultural reaches (McCarty et al., 2008).

Due to this area's strong ecological importance and interest in expanding the application of the Framework, the Choptank HFA was chosen as the study area for the second implementation of the integrated vulnerability assessment. The study area was an ideal choice due to several factors. First, the site represented an innovation in application of the Framework through its use of an ecological unit (the watershed), as the scale of analysis previously focused on the human community and socially defined boundaries. Second, because the HFA represented an area with high investment in restoring, improving, and protecting habitat, climate impacts to these investments were of concern. Additionally, there was interest in exploring where areas of social, structural, and natural resource vulnerability may benefit from adaptation, restoration, or conservation activities. Finally, the selection of this site allowed for integration with a number of related projects, including those within the Choptank River Complex Habitat Focus Area Implementation Plan for fiscal years 2015-17. For example, under the three primary objectives, 1) Habitat Restoration and Protection, 2) Integrating Science to Inform Management, and 3) Community Engagement to Conserve Habitat, the Framework and results offer direct links to the identification of wetland restoration priorities (Objective 1), the ecological assessment of the watershed (Objective 2), and the Envision the Choptank community engagement project (Objective 3).

1.1.2. Climate Profile

The headwaters of the Choptank River Watershed begin on the western border of Delaware, and the Choptank River drains into the Chesapeake Bay approximately 80 kilometers across the watershed to the southwest on Maryland's Eastern Shore. The watershed's humid subtropical climate is primarily influenced by both the Chesapeake Bay and the Atlantic Ocean, and is characterized by hot humid summers and cold rainy winters (Arguez et al., 2010).

Oxford wetland protection area. Photo credit: Maria Dillard, NOAA NCCOS

Monthly temperature and precipitation averages were collected from two sites within the Choptank HFA[1] from 1981 through 2010 (Arguez et al., 2010). During this 30-year period, coastal temperatures were highest in July and August, and lowest in December through February. The difference between the monthly minimum temperature and monthly maximum temperature was about 18°F throughout the year, and annual precipitation averaged 47 inches, with approximately 4 inches per month. The Choptank HFA extends to the interior of the Delmarva Peninsula, and the inland climate data indicate that the hottest and coldest months remained consistent when compared to the coast (although average monthly temperatures were about 3°F lower), and the difference between the monthly minimum and maximum temperatures was 20°F throughout the year. Annual precipitation averaged 45 inches, and was also distributed fairly evenly throughout the year (Arguez et al., 2010).

[1]These data were collected from two weather stations: one at Royal Oak near Oxford and Cambridge on the immediate coast of the Bay, and the other inland at Greenwood, Delaware, located 10 miles east of the middle section of the HFA (Arguez et al., 2010).

Low elevation coastal areas in the Choptank watershed are particularly susceptible to flooding hazards such as sea level rise, storm surge, and stormwater flooding. Storm surges have been damaging to the Eastern Shore, and this hazard will intensify with rising sea levels (Boesch et al., 2013; FEMA, 2013). Mean sea level rise for Denton, MD has been 3.69 mm/year based on historical data (Tides and Currents, 2013).

In addition to storm surge and sea level rise in coastal areas, stormwater flooding can be a hazard throughout the watershed. Areas that convert the most rainfall to runoff are those with soils that are fairly impenetrable to rainfall (65% of the land in the Choptank watershed) and with land use that is urban (5%) or cultivated (46%). In addition to posing a flooding hazard, stormwater runoff is a primary driver of downstream erosion, sedimentation, and water quality degradation. For example, when runoff from heavy storms overwhelms urban drainage infrastructure, overflows add even more contaminants, and back-ups increase the magnitude of flooding (Georgakakos et al., 2014).

In the Northeast US (a region that includes Delaware and Maryland), the rainfall amount of the heaviest 1% of storms increased by 71% from 1958 to 2012 (Walsh et al., 2014). Due to climate change, scientists have predicted increased frequency and intensity of heavy storms, which increase vulnerability to stormwater flooding (Bates et al., 2008; Pryor et al., 2014).

This vulnerability assessment is a crucial step in understanding overall vulnerability and the potential impacts of a range of flood risks. Additional tools may be used to investigate specific flood risks such as stormwater flooding since modeling stormwater runoff for present and projected climate conditions can inform decision making for community land use planning. Appendix A provides more information on an associated NCCOS product—the Stormwater Runoff Modeling System (SWARM)—used in this study. SWARM was applied to the Choptank HFA Maryland towns of Denton and Cambridge to demonstrate the type of additional information that can be derived from modeling stormwater runoff scenarios for specific localities (Blair et al., 2014a; Blair et al., 2014b).

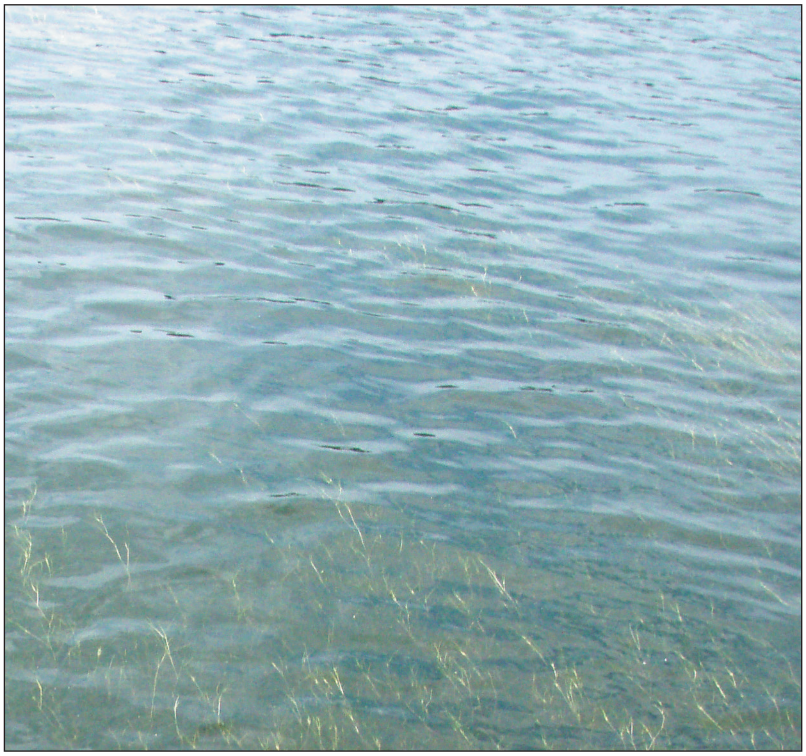
1.1.3. Ecological Profile

The ecology of the Choptank watershed includes significant natural resources, which provide a range of provisioning, regulating, supporting, and cultural ecosystem services. In order to evaluate climate vulnerability and resilience with a specific focus on flood risk, the natural resources of submerged aquatic vegetation (SAV), beaches, marsh buffer, and forested areas were selected. The protective areas of oyster sanctuaries, green infrastructure, and forest conservation easements were also selected. These resources were selected because they supply important ecosystem services for the community, and are likely to be impacted by flood hazards. A further criterion was the availability of spatial data for these natural resources across the study area. The spatial extent of each of these eight natural resources is included in Appendix B: Mapbook Supplement as Figure B-12.

SAV is a valuable resource for several important reasons. As aquatic plants, they are prodigious primary producers, forming the foundation of food webs. Some animals feed directly on living vegetation (e.g., ducks, fishes, shrimp, snails), while others filter feed detritus from dead plants from the water column (e.g., clams, oysters; Stevenson et al., 1979). The structure of the vegetation provides protection from predators for fish, crabs, and other aquatic animals, and also improves water quality by reducing turbidity as it diminishes flow and allows sediment to settle from the water column. Additionally, SAV helps reduce the nutrient levels in water by utilizing nitrogen and phosphorous for growth (Stevenson et al., 1979).

Beaches serve as habitat for plants and animals. Living plants and detritus deposited on the beach provide food for a community of animals including worms, bivalves, and others. These animals draw predators which rely on the beach for their foraging (Beachapedia, 2013). Beaches also act as important buffers, providing stability and bank protection through the reduction of erosion (Berman et al., 2006).

Wetlands are areas saturated with water, either continuously or periodically, and include areas with woody plant cover such as brush and trees, in addition to the herbaceous plant cover of marshes (for more information on marshes, please see the next paragraph). In the Choptank watershed, salt water wetlands are dominated by marsh, and fresh water wetlands are dominated by forest. All wetland types provide habitat for diverse plant and animal groups, and also function to reduce pollutants in waterways by filtering runoff (Caroline County, 2010). Wetlands are well regulated, and Maryland's Nontidal Wetlands Protection Act of 1989 lists statutory wetland functions of "ground water recharge and discharge, stormwater and flood control, improved water quality, toxic retention, nutrient removal and transformation, sediment stabilization and retention, aquatic diversity and habitat, [and] wildlife diversity and habitat" (Maryland Department of the Environment, 2016). Within the Choptank HFA study area for this report, wetlands cover 25% of the land area, and of total wetland area, 78% is fresh water forested and 14% is salt water marsh (C-CAP, 2010).



Submerged aquatic vegetation bed in the Choptank River.
Photo credit: Ben Fertig, University of Maryland IAN

Marshes , both salt and fresh water, contain plant species that are important primary producers at the base of the food web and form an herbaceous/non-woody plant cover. Normally adjacent to waterbodies (streams, rivers, estuaries), wetlands serve as buffers, protecting the water and neighboring land. They mitigate adverse effects of urban and agricultural land use on waterways by slowing and filtering runoff, and they provide protection from storms by dissipating waves and resisting erosion (Möller et al., 2014). Additionally, the extensive root system of salt marsh plants act as a carbon sink, sequestering and retaining carbon in their sediments (Chmura et al., 2011).

Oyster sanctuaries have been established to protect designated areas containing oysters and oyster bar habitat, and wild harvesting of oysters is prohibited (Maryland Department of Natural Resources, 2016b). Oysters improve water quality by filtering algae. Oyster bars, built from living oysters and accumulated oyster shells, can be extensive, and are structured habitat, as well as refuge from predation, for fishes and crabs (NOAA Chesapeake Bay Office, 2016). The oyster species found in the Chesapeake Bay and along the east coast and Gulf of Mexico is the Eastern oyster, *Crassostrea virginica*. This species inhabits waters with a wide range of salinities – from lightly brackish to full salinity sea water, and the shell of an adult varies from 2 to 14 inches. Large oyster bars are formed in both intertidal and subtidal waters (NOAA, 2016).

Forests hold great importance, and in the riparian zone adjacent to waterbodies, forests reduce pollutant concentrations by absorbing and slowing runoff. Their deep root systems stabilize stream banks by trapping soil to prevent erosion. These trees provide shade, which cools the immediate water area and decreases heat-induced stress for sensitive aquatic animals. Interior forests provide a summertime habitat of moderate temperatures and light. Birds and other animals nest in cavities of upright dead trees, and decomposing parts of fallen trees provide food and habitat for many smaller animals (Chesapeake Bay Program, 2012).

Conservation easements are legal agreements used to protect forests, wetlands, historic farm land, and other natural resources, by placing conditions on the use of the land. Placing a conservation easement on a property is a voluntary decision by a landowner, and the particular easement remains with the property even after land ownership changes. In Delaware, easements are held by Delaware State Parks within the Division of Parks and Recreation (Delaware Department of Natural Resources and Environmental Control, 2016), and in Maryland by the Maryland Environmental Trust within the Department of Natural Resources (Maryland Department of Natural Resources, 2016a). Additionally, both states have conservation easements that are held by other governmental and non-governmental entities (National Conservation Easement Database, 2016).

Green infrastructure provides important ecosystem services. At large scales, green infrastructure mitigates habitat fragmentation by providing a network of lands with hubs (e.g., large tracts of forests and wetlands) and corridors (linear features like ridgelines to connect the hubs). At site scales, it can be an approach to manage stormwater runoff and also provide benefits ranging from environmental to economic (EPA, 2016). At all scales, green infrastructure promotes resiliency in the face of climate change impacts. Delaware promotes the use of green infrastructure at different scales – from site to regional – and their Primer on Green Infrastructure lists the ecological benefits as flood retention, temperature moderation, habitat provision, carbon capture, and pollutant absorption (de Mooy, 2016). In Maryland, the Department of Natural Resources designates green infrastructure based upon the importance of the land at the regional or state level. Two examples are interior forest-wetland associations with a minimum of 250 acres, and sensitive species habitat situated within a natural area of a minimum of 100 acres (Maryland Department of Natural Resources, 2002).

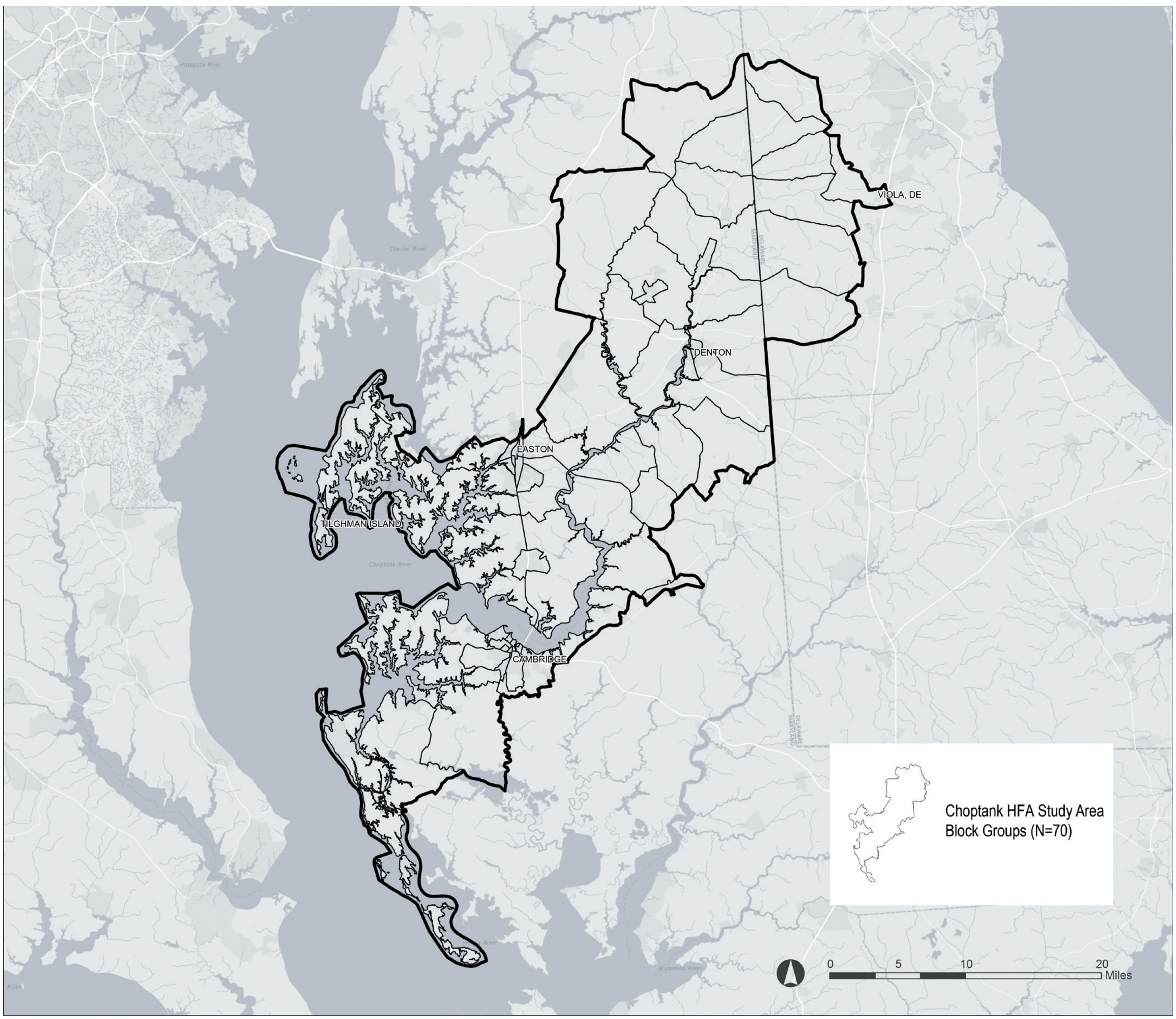


Figure 1.1. Choptank HFA study area block groups.

1.1.4. Socioeconomic Profile

Figure 1.1 shows the census-defined Choptank HFA study area that includes 70 Census block groups within the five-county area. Within these block groups, the 2014 American Community Survey (ACS) 5 Year Estimates projected a total population of 100,766, ranging from 383 persons in one block group to 3,353 persons in another (US Census Bureau, 2014). This estimate was a 1.5% increase from the 2010 Decennial Census figure of 99,238 (US Census Bureau, 2010). Due to the size and scope of this area, there was demographic diversity among block groups; however, the aggregated demographics that follow provide averages across the Choptank HFA in 2014.

The Choptank HFA study area had an average median household income of $59,064 with a standard deviation (SD) of 20,541.3, and an average median per capita income of $28,166 with a SD of 14,464.5. On average, 12.8% of the population (SD of 10.1) lived in poverty, while 4.8% of households (SD of 6.1) earned over $200,000 annually. Inhabitants had an average median age of 42.5 years (SD of 9.1), with only 5.2% of the population (SD of 3.2) under the age of 5, and 19.8% of the population (SD of 11.3) over the age of 65. Average household size was 2.5 persons with a SD of 0.4. On average, 30.7% of housing units (SD of 20.4) were rented, with an average median rent of $1,013 a month (SD of 283.8), and 16.2% of housing units (SD of 11.8) were vacant. Approximately 6% of the population (SD of 10.5) lived in mobile homes (US Census Bureau, 2014).

Just over one fifth of the Choptank HFA study area population (SD of 20.6) was of a racial or ethnic identity other than white alone. Approximately half of the population (52.1% with a SD of 4.9) was female, and female headed households (without a spouse) comprised 13.8% of the population (SD of 10.7). Further, this area had 69.3% of its population (SD of 11.1) in family households, and 65.6% of children (SD of 24.7) lived in married-couple families (US Census Bureau, 2014).

Within the study area, 64.1% of the population (SD of 45.6) was considered rural (US Census Bureau 2010), and 3.5% of the population (SD of 4.1) was employed in extractive industries, including agriculture, forestry, fishing, hunting, mining, quarrying, and oil and gas extraction. Conversely, 47.8% of the population (SD of 12.3) was employed in service industries, which include retail trade, administrative and support services, arts, entertainment and recreation, and accommodation and food services (US Census Bureau, 2014).

On average, there was an unemployment rate of 9.4% (SD of 5.9) across the study area, and 14.7% of the population aged 25 years or older (SD of 9.0) was without a high school diploma. Of the study area households, 36.5% (SD of 11.7) had social security income, and 15.7% (SD of 12.9) had received food stamps or supplement nutrition assistance program (SNAP) benefits in the 12 months prior to Census data collection. Additionally, 1.4% of households (SD of 3.7) spoke English as a second language and had limited English proficiency, and 7.5% of housing units (SD of 9.9) did not have access to a vehicle (US Census Bureau, 2014).

Chapter 2
Methodology for an Integrated Vulnerability Assessment

Photo credit: Seann Regan, NOAA NCCOS/JHT

In order to gain an understanding of the populations, economies, and the built and natural environments that may be affected by climate stressors, this project utilized an integrated approach to assess vulnerability. The methodology involved first defining the climate impacts of most relevance for the Choptank HFA, followed by data collection and analysis. The analyses spanned from indicator development to the examination of integrated vulnerability and risk. Analyses included assessing existing vulnerabilities isolated from any climate stressor, assessing vulnerabilities in relation to specific climate change risks, and finally, intersecting and assessing integrated vulnerabilities and risks in order to prioritize areas for adaptation activity focused on coastal flooding.

2.1. IDENTIFYING CLIMATE IMPACTS OF MOST CONCERN

The coastal flood risks utilized for analysis within the Choptank HFA have a strong basis in the Framework initially developed for the Town of Oxford, Maryland (Messick and Dillard, 2016). It was determined by the project science team and Choptank HFA partners[3] that the climate impacts of most concern for the Town of Oxford were also of concern in the larger Choptank HFA study area. These included hurricane storm surge, sea level rise, and stormwater flooding; however, due to the increasing intensity of storm events and the current projections related to sea level rise, it was determined that category 2 storm surge and sea level rise of 2 feet should also be analyzed in addition to the previous flood hazard levels (category 1 and sea level rise of 1 feet). This addition allowed for the results of this assessment to inform long term planning to a greater extent.

2.2. INDICATOR SELECTION AND DEVELOPMENT

The indicators selected for use in this vulnerability assessment were primarily derived from the extensive list of indicators previously developed for the initial implementation of the Framework (Messick and Dillard, 2016). Changes from previously selected indicators, as well as additions, were largely a result of the units of analysis selected for the study area. For example, different socioeconomic indicators were included due to the change from Census block in the previous assessment to Census block group as the unit of analysis.

2.3. DATA COLLECTION PROCESS

An overarching goal of the initial project was to develop a method that would be transferrable to multiple geographies. In this iteration, the project team moved from working within county and town boundaries to that of a watershed. This required some modification of the boundary delineated for the Choptank HFA. Since the vulnerability analyses utilized Census data, the ecological boundary of the Choptank HFA was modified to a Census-derived boundary. Because the Census boundaries did not naturally align to those of the watershed, the study area was created by merging these boundaries using the following process. The project team first took all block groups whose centroid point fell within the HFA boundary (i.e., 50% of the block group was contained within the ecological boundary). In order to prevent fragmentation, the team then selected additional block groups that intersected the HFA boundary line, particularly in cases where high population areas might fall both inside and outside the ecological boundary. This led to a slightly larger area in contrast to the original HFA boundary. A comparison between boundaries is shown in Figure 2.1. Due to the nature of census boundaries being imprecise at the shoreline, the census geographies were clipped using local and high resolution shoreline boundary data.

The Framework promotes the utilization of data from national and state-level sources in order to ensure that the Framework can be replicated in different geographic locations without experiencing significant data limitations. As an example, much of the data collected for the socioeconomic vulnerability analysis came from the US Census Bureau. Census datasets are easily accessible for a wide range of geographic scales and for all mainland US locations.

Data collection was conducted by the project science team following the methodology for the initial implementation of the Framework (Messick and Dillard, 2016). The geographic scale of the collection was

[3] The partners for this project included a variety of individuals and entities that are engaged in the implementation of the activities supporting the HFA. For example, the team worked with other NOAA scientists, academic researchers, representatives from non-governmental organizations focused on conservation, and other regional decision makers.

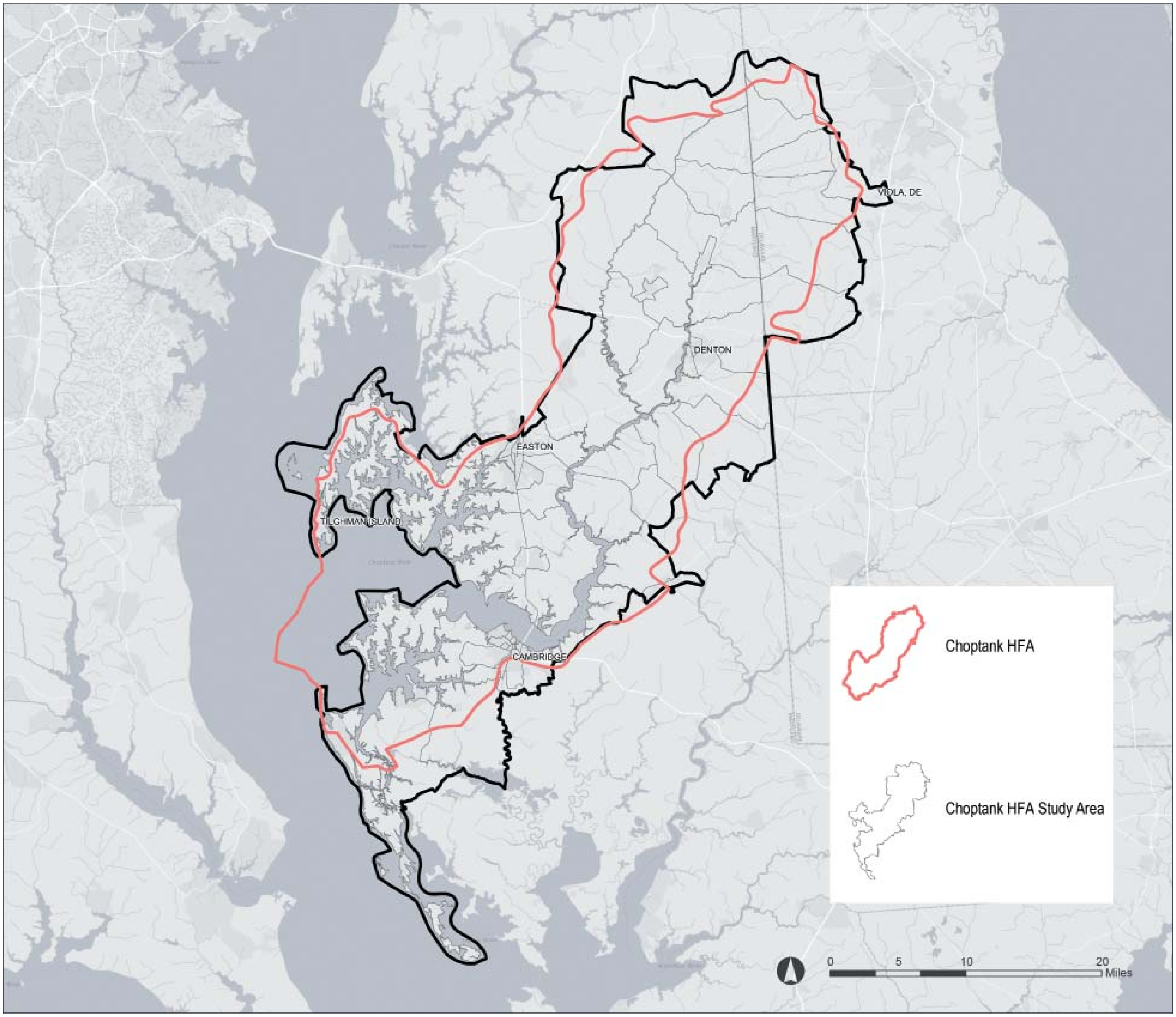


Figure 2.1. Choptank HFA study area boundary.

increased to the modified boundary for the Choptank HFA, and the primary unit of analysis became the US Census block group. Social data were collected at the Census block group level, structural data were collected at the parcel level, and environmental data were collected using best available resolution data. All data were aggregated to the Census block group for the assessment. Data were collected for the most recent time period available, and data format was generally limited to a data file (e.g., .xls, .txt, .csv), shapefile, or geodatabase. All collected data included available metadata and supporting documentation. The science team kept data on a centralized network server and all data was subject to quality assurance and quality control procedures before use.

2.4. MEASUREMENT AND ANALYSIS FOR BASE CONDITION VULNERABILITIES AND COASTAL FLOOD RISKS

This study utilized a "vulnerability of places" framework (e.g., Cutter, 2008; Cutter et al., 2009) to examine social and environmental vulnerability to climate variability and change. The science team began by measuring the risk of particular impacts of climate variability that were of most relevance for the HFA and communities within the watershed. Using risk of exposure to flood hazards as the basis of the assessment, the team then measured vulnerabilities of the population and environment (both natural and built) to a stressor. Social vulnerability indicators were used to create an index, an example of which is shown in Figure 2.2, to measure the vulnerability of the population to climate stressors. Structural vulnerability indicators were used to create an index to measure vulnerability of the built infrastructure to climate stressors. Natural resource distribution indicators were used alongside a benefit transfer methodology to create an index to measure vulnerability of the natural environment to climate stressors based upon the value that these resources provide to homeowners with adjacent property.

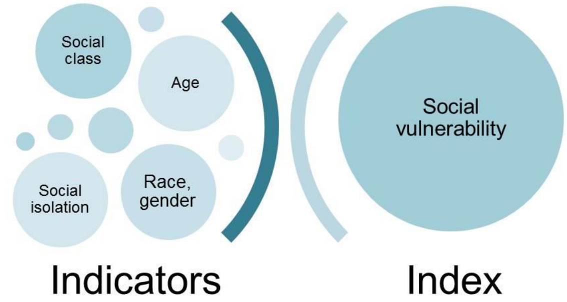


Figure 2.2. From indicators to index: An example using social vulnerability.

Similar to the approach used by Wu et al. (2002), indicators of social vulnerability, structural vulnerability, and natural resource vulnerability were employed alongside indicators of risk to short term (i.e., storm surge and stormwater flooding) and long term (i.e., sea level rise 2 feet) flood risks. The first phase of analysis included examination of the spatial distribution of short and long term flood risks within the Choptank HFA. The next phase of analysis involved intersecting each type of vulnerability with each type of risk in order to define the spatial areas where vulnerabilities and risks overlapped. In the final phase of analysis, all vulnerabilities were integrated and intersected with short or long term flood risks, as outlined in Figure 2.3. By combining measures of risk with measures of vulnerability, overall measures of potential priority for coastal flooding adaptation activities for the Choptank HFA were developed.

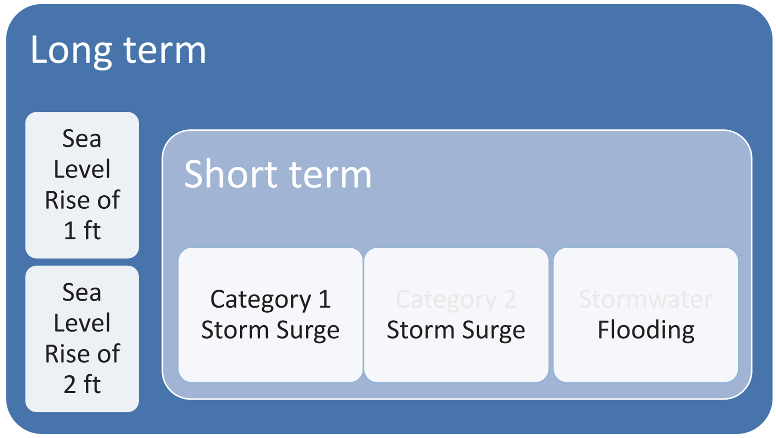


Figure 2.3. Delineation of short and long term flood risks.

For each vulnerability and risk analysis conducted, current secondary data were used. Due to the dynamic nature of both human populations and ecological systems, these data do not take into account or predict future changes in populations, development, or natural resource distribution, nor take into account changes in storm surge, stormwater flooding, and sea level rise inundation modeling as a result of these changes in social, built, and natural environments. This work represents a snapshot-in-time assessment of the Choptank HFA study area, and highlights areas that are vulnerable under current conditions and may benefit from adaptation action in the near future. Ideally, this methodological approach would continue to be used for ongoing assessment (e.g., every one to five years) and/or used as a basis for modeling future conditions.

2.4.1. Social Vulnerability

Secondary data from the 2014 American Community Survey Five Year Estimates were utilized to develop the social vulnerability measure for Census block groups in the Choptank HFA. As with the previous study site, this assessment utilizes a modified version of the SoVI methodology developed by Susan Cutter and colleagues (2003). In this analysis, the variables were modified due to the change of scale from county to Census block group, as well as to maintain a favorable subject to item ratio.

Each variable was first normalized on a 0-1 scale, and then standardized using z-scores. Principle components analysis (PCA) was used to determine the factors and variables to include in the final index.[4] The conditions of the PCA analysis included use of a Varimax rotation with a default of 25 iterations and a required factor loading of at least 0.40. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy was 0.812, and the Bartlett's Test of Sphericity was significant (2,403.159, $p \leq 0.001$), which indicated that a factor analysis was suitable for the selected variables.

[4] PCA is a variable reduction technique that is often used in indicator and index development. The method is designed to reduce the number of variables to the smallest number of components that explain the most variance (Thompson, 2008).

This social vulnerability index was comprised of six factors: 1) Social Class, 2) Age, 3) Wealth, 4) Social Isolation, 5) Rurality, and 6) Service Industry Employment and Gender, and included a total of 22 variables. These factors collectively explained 71.68% of the variance in the total variability among data for the 22 variables included in the factor analysis for the counties comprising the Choptank HFA.[5] The variance accounted for by individual factors is in Table 2.1. For example, the Social Class factor explained far more of the total variability (40.438%) than Social Isolation (5.867%); however, when combined, these components provided a more well-rounded measurement of social vulnerability for the study area. These factors closely aligned with those typically included in other social vulnerability assessments (e.g., Cutter et al., 2003; Chakraborty et al., 2005; Dunning et al., 2011; Messick and Dillard, 2016). Each of these six factors are displayed.

Table 2.1. Social vulnerability index components.

Factor Name	Cardinality	% Variance Explained	Variables	Loading
Social Class	+	30.438	% Households participating in SNAP	0.834
			% Population in poverty	0.828
			% with no vehicle	0.678
			% non-white	0.674
			% unemployed	0.669
			% female headed households with no spouse	0.601
Age	+	14.56	% population over 65	0.908
			Median age	0.844
			% households with >60 year old	0.836
			Average household size	-0.79
Wealth	-	10.512	% households with incomes over $200K	0.774
			Median value of housing unit	0.654
			Median rent	-0.636
			Per capita income	0.602
Social Isolation	+	5.867	% with limited English proficiency	0.838
			% with no health insurance	0.77
			% with no high school diploma/GED	0.645
Rurality	+	5.696	% rural population	0.741
			% employed in extractive sectors	0.684
Service Industry Employment and Gender	+	4.606	% employed in service sectors	0.707
			% female	0.687
			% children in married households	-0.542

The resulting factors were adjusted for directionality and placed in an additive model to achieve a single social vulnerability index score. The social vulnerability index score for each Census block group is presented as a relative score using min-max normalization,[6] such that block groups closer to a value of 1 are more socially vulnerable compared to other block groups in the study area. Each of the six factors are displayed in Appendix B: Mapbook Supplement as Figures B-2: B-7, and the composite social vulnerability base condition is shown in Figure B-1.

[5] In order to have an adequate subject-to-item ratio for the PCA analysis, this analysis was conducted for all block groups in the five counties that intersect the Choptank HFA boundary. The subject-to-item ratio is important for the robustness of the analysis.

[6] Min-max normalization scaling is when the normalized value of xi for variable X in the *i*-th row is calculated as:

Normalized (xi) = xi - X_{min} / (X_{max} - X_{min}), where Xmin = the minimum value for variable X, and Xmax = the maximum value for variable X (Salzman, 2003).

The changes in final variables between the two studies are outlined in Table 2.2. Variables that were used in both analyses are not included.

The final score was normalized to fit a 0-1 range with block groups closer to 1 being more socially vulnerable. The scores were displayed as quintiles, and the final score applies to the entire block group, representing an assessment of all indicators and factors.

Table 2.2. Variation in final variables between studies.

Variables	Town of Oxford/ Talbot County Analysis	Choptank HFA Analysis
Median Income	Y	N
Per Capita Income	N	Y
Households With Incomes Over $200,000	N	Y
Households Participating In Snap	N	Y
Population In Poverty	N	Y
Urban Population	Y	N
Rural Population	N	Y
Renter-Occupied Housing Units	Y	N
Vacant Housing Units	Y	N
Median Rent	N	Y
Labor Force Size	Y	N
Population In Extractive Work Sectors	N	Y
Population In Service Work Sectors	N	Y
Population With No Health Insurance	N	Y
Population With Children In Married Households	N	Y

2.4.2. Structural Vulnerability

In order to arrive at a measure of structural vulnerability for Census block groups, secondary data was collected at a finer spatial resolution from county parcel records collected for tax assessment purposes, and these data were then aggregated to Census block group geographies. There were three indicators taken from these data used in the assessment of both residential and commercial buildings based on knowledge of risks in the area and a literature review. The first indicator utilized was the construction material of the primary building structure. According to the Federal Emergency Management Agency (FEMA), buildings constructed of block or concrete will stand up to flooding better than those with wooden structures due to potential water exposure (Li and Ellingwood, 2006; FEMA, 2015). For this analysis, percentage of wood-based construction at the block group level was used as a measure of vulnerability to flood risk. The second indicator was presence or absence of a basement. Basements and structures with floor subgrade below ground level are generally more susceptible to flooding (FEMA, 2015). The percentage of structures within the block group that included a basement was used as a measure of vulnerability. The final indicator was the grade of the primary structure. These values provide some insight into the overall quality of a building and its potential to withstand floods or storms. The percentage of buildings with below average grade in a block group was used as the final measure of vulnerability. The parcel data for the State of Maryland contained a numerical grade for each property based on a visual inspection of its condition by a tax assessor. The range of building grade was from 1 to 9, with 1 being extremely poor and 9 being excellent. The State of Delaware utilizes a different rating system for reporting structure grade and quality. For these analyses, a crosswalk file was created so that the two different scales could be run through the same method and be comparable, as shown in Table 2.3.

Table 2.3. Crosswalk calculation between Maryland and Delaware.

Maryland Scoring		Delaware Scoring
1 (low)	=	E-, E, E+ (low)
2	=	D-
3	=	D
4	=	D+, C-
5 (average)	=	C, (average)
6	=	B-, C+
7	=	B
8	=	B+
9 (high)	=	A-, A, A+ (high)

**Manufactured homes were changed to low score (1)*

In order to create a single index for measuring block group-level structural vulnerability, each variable was scaled with higher numbers that represent higher potential vulnerability. For assessment of primary construction material, the proportion of wood-based structures per block group was used, with 0 representing no wood-based structures in the block group, and 1 representing a block group completely composed of wood-based structures. The second variable utilized parcel level data to determine the percentage of structures within each block group to have a basement present. Similarly, 0 indicates that no structures within a block group have a basement, and 1 indicates that 100% of structures within the block group have a basement.

The final variable, grade of current structure, was scaled in a slightly different manner. For each block group, the average grade of parcels was calculated, and then scaled using min-max normalization. In this case, 0 represents the highest average building grade, while 1 represents the lowest average building grade. These data were then utilized to calculate a percentage of buildings with below average grade in a block group.

The components of structural vulnerability were combined in an additive index, where each variable is equally weighted. The final score was normalized to fit a 0-1 range with block groups closer to 1 being more structurally vulnerable. As with social vulnerability, the scores were displayed as quintiles. The final score applies to the entire block group and represents assessment of both commercial and residential structures. Each of the three components are displayed in Appendix B: Mapbook Supplement as Figures B-9:B-11, and the composite structural vulnerability base condition is shown in Figure B-8.

2.4.3. Natural Resource Vulnerability

The purpose of the natural resource vulnerability analysis was twofold: to determine the spatial extent and concentrations of valuable natural resources within the Choptank HFA, and to assess their vulnerability to climate and coastal flood risks, such as projected sea level rise and hurricane storm surge. The analysis used value to property owners as an indicator of vulnerability, such that with greater value comes greater impact on the surrounding communities in the event of resource loss. For the purposes of this community vulnerability assessment, it was important to examine the environment in relation to its social value. By focusing on resources that supply ecosystem services for the community, the analysis was restricted to impacts on the natural environment that would be incurred by the human population in the event of a flood hazard, whether the risk was short or long term.

The project science team determined which variables were best to include in the natural resource analysis by considering which resources were important (in terms of ecosystem services and economic value provided) to the study area, which resources would conceivably be adversely impacted by the selected risks, and the availability of the data. Some resources, such as fish, were excluded from the analysis because this resource is not as likely to be impacted by the selected risks. Resources such as natural shoreline are included through the measurement of marsh and beaches.

It was determined that higher natural resource quantity and value corresponded to higher natural resource vulnerability. Block groups with increased quantities of natural resources, increased biodiversity of natural resources, and thus, increased monetary value, were considered to be more vulnerable than block groups with fewer resources, lesser biodiversity, and lesser value. Block groups with more resources and/or resource values were considered to be at a higher risk of loss due to flood inundation and climate change, and as a result, were considered more vulnerable.

Eight habitats were investigated to discern an associated value provided by each habitat type that accrues to property owners in the Choptank HFA, and analysis for each habitat is described below. Due to time and budget constraints preventing primary data collection, the benefit transfer method is employed below.[7] Discerning a value that accrues to property owners from habitat presence can be accomplished through the hedonic method, which calculates value accrual to property owners that is capitalized into property prices. Since values are investigated based on proximity and location, it must be noted that these monetary benefits are localized (i.e. they only accrue to properties adjacent to or near the habitat).

After calculating the total value of natural resources for each block group in the study area by summing each habitat-specific value for each block group and taking into account habitat proximity to properties (any block group within 100 m of a habitat), the associated values per block group were scaled ordinally on a 1 to 5 scale. To depict the information, an ordinal scale was chosen over the values themselves as a way to alleviate some of the error that is inherent with the benefit transfer method. Since the habitat values were transferred from

[7] The benefit transfer method is used here to estimate economic values for natural resources and ecosystem services by transfer ring available values from completed studies in other locations and/or contexts. It is important to note that any application of benefit transfer methodology includes some inherent unquantifiable margin of error (Boutwell and Westra, 2013). A key step to minimizing this error, however, is to identify locations as close and as similar as possible to the study area.

other studies, it is believed that reporting the specific calculated natural resource values per block group would not be as robust; however, these values do give a good indication of which block groups are "more" or "less" valuable in terms of their natural resource prevalence. The calculated natural resource values for each block group were divided into quintiles and assigned a numeric score of 1 (least valuable) to 5 (most valuable) in order to illustrate the spatial distribution of natural resource value and associated vulnerability within the Choptank HFA. Natural resource valuation, and hence, vulnerability, is displayed in Appendix B: Mapbook Supplement as Figure B-13.

Kayak launch area. Photo credit: Seann Regan, NOAA NCCOS/JHT

2.4.3.1. Benefit Transfer Methodology Per Habitat

Guignet et al. (2014) found that SAV provides an average value accrual to property owners of $0.34 per acre per household for the eleven Maryland counties adjacent to the Chesapeake Bay in year 2009 dollars ($0.38 in 2015 dollars). The valuation method utilized was a hedonic pricing regression model to calculate SAV's implicit effect on property price, and data from Talbot, Dorchester, and Kent Counties are incorporated into this analysis. The analysis is based on residential transaction data from 1996-2008, and an SAV baseline of 85,914 acres. It is believed this value is transferrable to relevant properties within the Choptank HFA (with some margin of error) since the HFA contains parts of the three aforementioned counties.

Paul (2011) found that beaches in Delaware provide an average value accrual to property owners of $24,800 per acre per household in year 2000 dollars. This figure is based on calculations done by Parsons and Powell (2001), in which they used a semi-log hedonic pricing model to determine how beach retreat on Delaware's coast affects property values. It is believed that this value is transferrable to the Choptank HFA (with some margin of error[8]) because part of the HFA lies in Delaware; however, in order to make this value more representative of the Choptank HFA, it is adjusted based on the difference between the median property values on Delaware's beaches and the median property values in the Choptank HFA. Based on the 2014 US Census American Community Survey (ACS) Five Year Estimates, the weighted average median owner-occupied home value in Bethany, South Bethany, Fenwick Island, Rehobeth Beach, and Dewey Beach, Delaware (the communities used in the Delaware study) is $690,056.80, and the weighted average median owner-occupied home value in the five counties that overlap with the Choptank HFA (Talbot, Queen Anne's, Caroline, Dorchester, and Kent) is $240,055.71. The median home value in the Choptank is 34.79% of the median home value on Delaware's beaches. Therefore, if the figure of $24,800 is multiplied by 34.79%, it is believed that this value is transferrable to relevant properties within the Choptank HFA. Using this home value difference adjustment yields a value accrual result of $8,627.38 per acre per household in year 2000 dollars ($11,874.77 in 2015 dollars).

[8] See previous footnote. The margin of error cannot be quantified with the benefit transfer methodology.

Mahan (1997) found that wetlands in Multnomah County, Oregon provide an average value accrual to property owners of $34.55 per acre per household in 1994 dollars. This value was derived through a linear hedonic pricing model. Based on the 2014 US Census ACS Five Year Estimates, the median owner-occupied home value in Multnomah County, OR is $270,200, and the weighted average median owner-occupied home value in the five counties that overlap with the Choptank HFA (Talbot, Queen Anne's, Caroline, Dorchester, and Kent) is $240,055.71. The median home value in the Choptank is 88.84% of the median home value in Multnomah County, OR. Therefore, if the figure of $34.55 is multiplied by 88.84%, it is believed that this value is transferrable relevant properties within the Choptank HFA (with some margin of error). Using this home value difference adjustment yields a value accrual result of $30.70 per acre per household in year 1994 dollars ($49.09 in 2015 dollars).

Feagin et al. (2010) found that marshes in Galveston, TX provide an average value accrual to property owners of $253.90 per acre per year in 2006 dollars. This value was derived by obtaining property parcel value data from Galveston County's tax appraisal database. The authors then estimated the value of every square meter (1 x 1 m pixel) within a parcel, as based upon the total value of a parcel and improvement divided by its area. They then found the plant community zone that occupied each pixel, and summarized the values from every pixel in the study area according to the plant community zone. When dividing the per acre value by the number of owner-occupied households in Galveston (26,815) according to the 2009 US Census ACS Five Year Estimates (2009 is the year in which property value data were obtained in the study), a value of $0.01 per acre per household is derived. Based on the 2014 US Census American Community Survey five year estimates, the median value of an owner-occupied home in Galveston, Texas is $136,700, and the weighted average median owner-occupied home value in the five counties that overlap with the Choptank HFA (Talbot, Queen Anne's, Caroline, Dorchester, and Kent) is $240,055.71. The median home value in the Choptank is 75.61% more than the median home value in Galveston, Texas. Therefore, if the figure of $0.01 is multiplied by 175.61%, it is believed that this value is transferrable to relevant properties within the Choptank HFA (with some margin of error). Using this home value difference adjustment yields a value accrual result of $0.02 per acre per household in year 2006 dollars (also $0.02 in 2015 dollars).

Trying to discern the effect that oyster sanctuaries have on nearby property values proved difficult. Several studies have shown that oyster reefs and oyster sanctuaries provide benefits in the form of increased water quality through nitrogen removal, phytoplankton removal, and seagrass enhancement (Hicks et al., 2004; Lipton, 2006; Grabowski, 2012). Additionally, separate studies have been done that illustrate how higher water quality can have a positive effect on the prices of nearby homes and properties (Leggett and Bockstael, 2000; Poor et al., 2007). The Poor et al. (2007) study was based in the St. Mary's River watershed in Maryland, and found that the marginal implicit price (determined through a semi-log hedonic model) associated with a one milligram per liter change in dissolved inorganic nitrogen was $17,642 per home in year 2003 dollars. Newell et al. (2005) found that the nitrogen removal rate of eastern oysters (the prominent oyster of the Chesapeake Bay) in the Choptank Estuary is 7.53 kilograms per hectare per year, which equates to 3,049,129.45 milligrams per acre per year. Based on an estimated 590,625,000,000 gallons (2,235,758,962,500 liters) of water in the Choptank HFA, eastern oysters remove 0.0000013638 milligrams per liter per acre per year, which when multiplied by the implicit price of one mg/L of nitrogen removed ($17,642), yields a value of $0.02 per acre per household in year 2003 dollars ($0.03 in 2015 dollars).

Weber (2007) found that in Cecil County, MD, forested areas provide a value accrual to property owners of $42 per acre per household in year 2006 dollars ($49.38 in 2015 dollars). The ecosystem service values stated in this report comprise a meta-analysis of ecosystem service valuation literature, and this specific figure of $42 was taken from a study that utilized the hedonic method. It is believed that this value is transferrable to relevant properties within the Choptank HFA (with some margin of error) due to its close proximity to Cecil County and the fact that both areas are positioned on the eastern shore of Maryland on the Bay side.

Geoghegan et al. (2003) found that conservation easements provide an average value accrual to property owners of $6.46 per acre per household in Calvert County, MD in year 2002 dollars ($8.51 in 2015 dollars). The valuation method utilized was a log-transformed hedonic pricing regression model to calculate permanent open space's implicit effect on property price. The analysis is based on data from the State of Maryland, Office of Planning's (2002) encoded database of land parcels and associated sales transactions that occurred between July 1993 and June 1996. It is believed this value is transferrable to relevant properties within the Choptank HFA (with some margin of error) since the data that is used come from another relatively rural county in Maryland.

Oxford waterside park. Photo credit: Maria Dillard, NOAA NCCOS

Weber (2007) found that in Cecil County, MD, green infrastructure hubs and corridors provide a total ecosystem service value of $1,655,219,377 per year in year 2006 dollars. By applying the percentage of total ecosystem service value that is attributed to increases in property values (roughly 0.06%) in the other habitats outlined in the report (upland forests, riparian forests and wetlands, non-riparian wetlands, and tidal marshes), multiplying by the total value of green infrastructure hubs/corridors as stated in the report ($1,655,219,377), and then dividing by the number of acres of green infrastructure hubs/corridors in Cecil County, MD (67,353), it is found that green infrastructure hubs and corridors provide an average value accrual to property owners of $15.11 per acre per household in 2006 dollars ($17.76 in 2015 dollars). It is believed that this value is transferrable to relevant properties within the Choptank HFA (with some margin of error) due to its close proximity to Cecil County and the fact that both areas are positioned on the eastern shore of Maryland on the Bay side.

2.4.4. Coastal Flood Risks

The sea level rise layer selected for this study was a product of the NOAA Office of Coastal Management/Digital Coast. Sea level rise of 1 and 2 feet was used to assess risk in the socioeconomic, environmental, and infrastructure vulnerability analyses via intersection with Choptank HFA study area Census block groups. Detailed information regarding the creation and appropriate use of this data is available online at the Digital Coast website (coast.noaa.gov/slr/).

The storm surge data selected for this study was generated by the Army Corp of Engineers, Philadelphia District, and utilized the Sea, Lake and Overland Surges from Hurricanes (SLOSH) Model. SLOSH[9] is a computerized model run by the National Weather Service to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes. The model creates estimates by assessing the pressure, size, forward speed, track, and wind data from a storm. Graphical output from the model displays color-coded storm surge heights for a particular area. The calculations are applied to a specific location's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, and other physical features (US National Hurricane Center, 2015).

The stormwater flood prone areas layer was created in order to better analyze and prepare for this climate impact. This layer considered conditions which contribute to, or are favorable for stormwater flooding, and identifies these locations throughout the study area.

[9] More information about the SLOSH model can be found at the National Hurricane Center's website (www.nhc.noaa.gov/surge/slosh.php).

Literature relating to stormwater flooding suggests that several conditions make this type of flooding more likely, with the most impactful conditions being elevation, land cover, and soil type. Coastal areas with low elevations are prone to stormwater flooding due to slow drainage from flat land and high water tables. In these areas, flooding is intensified when rainfall occurs during high tides. Developed land cover classes create an additional likelihood of stormwater flooding due to the increase in impervious surfaces. Because impervious surfaces (e.g., parking lots, roads, buildings, compacted soil) do not allow rain to infiltrate into the ground, more stormwater runoff is generated when compared to undeveloped land. Finally, soil type plays a role in determining how prone an area is to stormwater flooding. Rain water is unable or less likely to infiltrate into the soil in locations where soil is compacted or poorly drained, thus increasing stormwater runoff. The variables selected for this analysis are included in Table 2.4.

Table 2.4. Variable descriptions for stormwater flooding analysis.

Variable	Description	Data Type	Source
Elevation	Elevations <=2 feet are considered flood prone.	30x30 meter DEM	National Map Viewer, 2015
Land Cover	Developed land cover classes (low, medium, high, open) are considered flood prone.	30x30 meter raster	C-CAP Land Cover Atlas, 2010
Soil Type	Soils within hydrologic soil groups C and D are considered flood prone due to low infiltration rates and high runoff potential.	Shapefile	USDA NRCS, 2013

2.5. METHODS FOR INTERSECTING VULNERABILITY WITH RISK

The creation of the social vulnerability, structural vulnerability, and natural resource vulnerability layers was only the first step of the analysis in determining where populations, structures, and valuable resources are most at risk from flood hazards. The second component of the analysis involved assessing the risk in relation to vulnerability based on various potential flooding scenarios. Since a goal of this project was to have each analysis (socioeconomic, infrastructure, and natural resources) comparable to the next, the base condition scores for all vulnerabilities and flood risks were aggregated to the Census block group level for the entirety of the HFA study area. Creating a score for each block group provided a means for comparison between the analyses and also displayed the complicated relationship between natural resources, infrastructure, and socioeconomic values in terms of vulnerability to climate related flood risks.

For all vulnerability types, bivariate choropleth maps (i.e., maps that depict two variables at once) were created to include a single vulnerability and a single risk, both scaled low, medium, or high, and intersected in one map. These maps (Figures B-18:B-34) serve as a visual tool to depict areas where high vulnerability intersects with high flood risk. Such maps can help prioritize actions and aid in decision making when considering particular vulnerabilities and risks. Areas with high vulnerability and high risk would be of primary importance, while areas of low vulnerability and low risk would be of lesser concern.

Flood risk scores per block group were transformed to a 1 to 3 scale, as required for bivariate choropleth analysis. Table 2.5 shows percent inundation per block group for each of the flood risks.

Table 2.5. Bivariate mapping break points for flood risks (percent inundation).

	Low	Medium	High
Sea Level Rise	0-0.999%	1-15%	16% +
Storm Surge	0-0.999%	1-15%	16% +
Stormwater Flooding	0-5%	6-40%	41% +

Social and structural vulnerability scores per block group were also transformed to a 1-3 scale. A continuous scaling system was utilized for each, and scores were broken into quantiles of low, medium, and high.

Similar to the process for flood risks and other vulnerabilities, the natural resource values per block group were transformed to a 1-3 scale. To operationalize this, the mean and standard deviation of the natural resource values per block group were calculated, and natural resource vulnerability was displayed. Table 2.6 shows the break points for the three groups.

The "middle value" group (2) contains block groups that have natural resource values within a half a standard deviation of the mean in either direction, while the "high value" group (3) consists of block groups with natural resource values greater than a half standard deviation above the mean, and the "low value" group (1) consists of block groups with natural resource values greater than a half standard deviation below the mean.

Table 2.6. Bivariate mapping break points for natural resource vulnerability.

Low	Medium	High
> ½ standard deviation below the mean	Within ½ standard deviation of the mean	> ½ standard deviation above the mean

2.6. METHODS FOR MAPPING COASTAL FLOODING ADAPTATION ACTION AREAS

Adaptation areas were determined through the combination of integrated vulnerability and coastal flooding risk scores to prioritize high vulnerability/high risk areas across the study site. These priority scores and subsequent maps reflect areas that could be prioritized for coastal flooding adaptation management action, and not overall vulnerability. These maps (Figures B-35:B-37) are presented as examples of how these data might be used for mapping priority areas for short and long term management action to mitigate coastal flooding. A variety of adaptation, restoration, and conservation management actions can be similarly supported by this type of analysis.

The block group-level integrated adaptation priority scores were determined through a combination of risk and vulnerability analyses. The risk components utilized in the potential priority mapping for short term risks include stormwater flooding and category 2 storm surge impact per block group (category 1 storm surge impact was inherently included within category 2 storm surge). The risk components utilized in the potential priority mapping for long term risks included sea level rise of 2 feet in addition to the short term risks (similarly to storm surge, sea level rise of 1 ft was inherently included within sea level rise of 2 ft). For vulnerability, block scores calculated from the social, structural, and natural resources analyses were combined into an additive index composite score. Each Census block group was scored as an index value from 0 to 1. Index values are a summation of the block group scores from each analysis. In terms of mapping the index scores, the data were classified into quintiles so that priority tiers could be created. The block groups range from Tier 1 to Tier 5, where Tier 1 block groups are associated with the highest overall vulnerability and risk, and Tier 5 block groups represent areas with lowest overall vulnerability and risk, according to these analyses. Moving forward, the underlying data can be used alone or in combination with additional datasets to generate priority maps for different management actions (e.g., designating new areas for conservation).

Chapter 3
Results

Photo credit: Dave Dewitt, University of Maryland IAN

The corresponding maps for the results of the vulnerability assessment for the Choptank HFA study area are included as Appendix B: Mapbook. The maps are described in terms of the information they provide and how the information should be interpreted. The first series of maps highlights the spatial distribution of single vulnerabilities (Figures B-1:B-13) and risks (Figures B-14:B-16) for the Choptank HFA study area. The next series of maps combines vulnerabilities and risks (Figures B-18:B-34), and the final series of maps (Figures B-35:B-47) show geographic areas of the Choptank HFA study area that could be prioritized for coastal flooding adaptation activities through the identification and ranking of integrated vulnerability and risks for short and long term action.

3.1. WHAT ARE THE VULNERABILITIES AND FLOOD RISKS?

3.1.1. Using the Bivariate Choropleth Maps

The bivariate choropleth maps created for the social, structural, and natural resource vulnerability analyses allow for two variables (vulnerability and risk) to be displayed in one map. The two variables are intersected and each is scaled as low, medium, or high. The intersection of the variables makes it possible for each block group to have one of nine scoring combinations. Figure 3.1, a slightly more detailed version of the matrix found on each map in Section 3 of Appendix B, uses general vulnerability and flood risk as an example. Vulnerability increases from left to right, and flood risk increases from bottom to top. Vulnerability is characterized by shades of reds, while flood risk is characterized by shades of blue. Additionally, each corner of the matrix represents a different extreme (later referenced as extreme categories or groupings) in terms of variable scoring. Brown block groups on the map indicate areas with both high risk and high vulnerability, while light grey block groups indicate the opposite. Similarly, bright blue block groups indicate areas with high flood risk, but low vulnerability, while bright red block groups indicate areas with low flood risk, but high vulnerability.

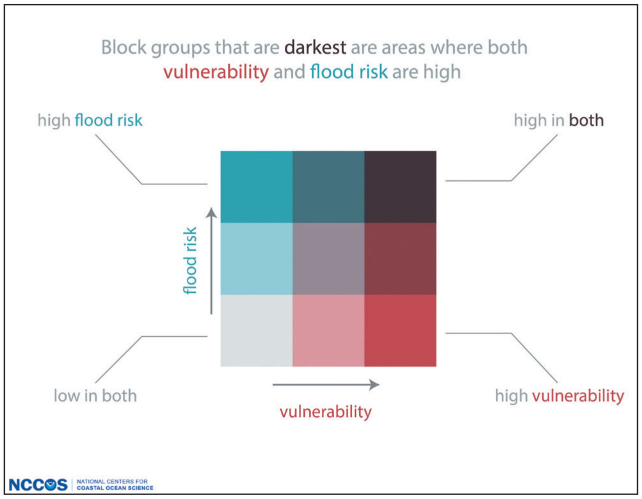


Figure 3.1. Legend for bivariate choropleth maps.

3.1.2. Social Vulnerability and Flood Risks

Social vulnerability by block group in the Choptank HFA study area is highly variable, but there are some important patterns. Composite social vulnerability tends to be low in the western reaches of the study area, with the exception of Tilghman Island and Easton, where social vulnerability ranges from medium to medium-high. Social vulnerability is highest in the northeast region of the study area and in the southernmost block groups. Social vulnerability is also high around Cambridge, Denton, and Easton (see Figure B-1). For a breakdown of social vulnerability by each of the six factors analyzed, see Figures B-2:B-7.

Combinations of social vulnerability and flood risks are detailed in Figures B17:B-22. Table 3.1 shows the count of block groups that fall into each extreme category of the bivariate mapping. Extreme groupings for this intersection include 1) low risk and low vulnerability, 2) low risk, yet high vulnerability, 3) high risk, yet

Table 3.1. Count of block groups by flood risk and social vulnerability.

low vulnerability, and 4) high risk and high vulnerability. This table shows that block groups of low risk/high social vulnerability are more numerous when compared to the other extreme groupings. This table also highlights that of the flood risks, more block groups fall into the high risk/high vulnerability category with stormwater flooding. This is an interesting finding given the more frequent occurrence of this type of flooding. The combination with the highest count of block groups across all flood risks is low flood risk and high social vulnerability. Count of high risk/high vulnerability block groups is highest for stormwater flooding, and count of high risk/low vulnerability block groups is lowest for sea level rise of 1 foot.

3.1.2.1. Sea Level Rise of 1 and 2 Feet
As shown in Figures B-18 and B-19, locations within the Choptank HFA study area that have both high social vulnerability and high sea level rise risk (1 foot) are situated in the southernmost block groups, at Tilghman Island, and centered in the middle of the study area, just northeast and south of Easton. Other notable block groups include the areas around Cambridge, Easton, and Denton. As sea level rise risk increases (2 feet), the southern portion of Tilghman Island increases in overall vulnerability/risk.

Locations that have both low social vulnerability and low sea level rise risk (1 and 2 feet) are immediately to the northwest and east of Denton.

3.1.2.2. Category 1 and 2 Storm Surge
As shown in Figures B-20 and B-21, locations within the Choptank HFA study area that have both high social vulnerability and high storm surge risk (category 1) are similar to high social vulnerability/high sea level rise risk areas, and include the southernmost block groups, Tilghman Island, and the center of the study area. Areas near Cambridge, Easton, and Denton have high social vulnerability and risk as well. When storm surge increases (category 2), so does combined vulnerability and risk for Tilghman Island, block groups located to the southeast of Easton, and within and northeast of Cambridge. A block group south of Denton increases in this combined vulnerability and risk as well.

Locations that have both low social vulnerability and low storm surge risk (category 1 and 2) are to the northwest and just northeast of Denton, similar to the low social vulnerability/low sea level rise risk areas.

3.1.2.3. Stormwater Flood Prone Areas
As shown in Figure B-22, areas that have both high social vulnerability and high stormwater flooding risk are located in the southernmost reaches of the study area, near Tilghman Island, around Cambridge, Easton, and Denton, and centrally between those three municipalities. Interestingly, urban areas have higher combined vulnerability and risk to stormwater flooding than they do to sea level rise risk.

Areas that have both low social vulnerability and low stormwater flooding are near the center of the study area, roughly equidistant from Cambridge, Easton, and Denton, and to the northwest, northeast and south of Denton.

3.1.3 Structural Vulnerability and Flood Risks
Structural vulnerability by block group is generally higher in the landward portion of the Choptank HFA study area. The areas of highest vulnerability are within the east-central region of the study area, and in Maryland's northern study area block groups. Across the state border into Delaware, structural vulnerability decreases slightly, but still maintains medium to medium-high scores. Structural vulnerability is lowest in the southwestern reaches of the study area (see Figure B-8).

Combinations of structural vulnerability and flood risks are detailed in Figures B-23:B-28. Table 3.2 shows the count of block groups that fall into each of the extreme categories of the bivariate mapping. Extreme groupings for this intersection include 1) low risk and low vulnerability, 2) low risk, yet high vulnerability, 3) high risk, yet low vulnerability, and 4) high risk and high vulnerability. Similar to this analysis for social vulnerability, block groups of low risk/high social vulnerability are more numerous when compared to the other extreme categories; however, it is important to note that block groups that are high risk/low vulnerability are also important to investigate further when planning for adaptation activities. Zero block groups are low

Table 3.2. Count of block groups by flood risk and structural vulnerability.

	Low Risk/ Low Vulnerability	Low Risk/ High Vulnerability	High Risk/ Low Vulnerability	High Risk/ High Vulnerability
Sea Level Rise (1 ft)	3	14	2	0
Sea Level Rise (2 ft)	3	13	5	0
Storm Surge (Cat 1)	2	18	6	0
Storm Surge (Cat 2)	0	17	12	1
Stormwater Flooding	0	14	11	3

risk/low structural vulnerability for storm surge impact (category 2) and stormwater flooding, and conversely, zero block groups are high risk/high structural vulnerability for sea level rise impact (1 and 2 feet) and storm surge impact (category 1). Many more block groups fall into the inverse extremes (low/high and high/low).

3.1.3.1. Sea Level Rise of 1 and 2 Feet

As shown in Figures B-24 and B-25, areas that have both high structural vulnerability and high sea level rise risk (1 foot) are concentrated in the center of the study area between the municipalities of Cambridge, Easton, and Denton. High structural vulnerability and risk is also located around Tilghman Island. As sea level rise risk increases (2 feet), an additional block group northwest of Denton increases in vulnerability and risk, as does the southern block group of Tilghman Island.

Areas of low structural vulnerability and low sea level rise risk (1 foot) are located within a few block groups in Cambridge. These areas remain low in vulnerability and risk as sea level rise increases (2 feet).

3.1.3.2. Category 1 and 2 Storm Surge

As shown in Figures B-26 and B-27, areas that have both high structural vulnerability and high storm surge risk (category 1) exist in the same region as high structural vulnerability/high sea level rise risk: between the municipalities of Cambridge, Easton, and Denton, and around Tilghman Island. As storm surge increases (category 2), Tilghman Island and Cambridge increase in vulnerability and risk, and some block groups in the central region of the study area increase in vulnerability/risk as well.

Areas of both low structural vulnerability and low storm surge risk (category 1) are located within the same few Cambridge block groups as for low structural vulnerability/low sea level rise risk. As storm surge risk increases (category 2), flood risk increases for these Cambridge block groups, but structural vulnerability remains the same.

3.1.3.3. Stormwater Flood Prone Areas

As shown in Figure B-28, areas that have both high structural vulnerability and high stormwater flooding are largely similar to high structural vulnerability/high stormwater flood risk areas, and are located between the municipalities of Cambridge, Easton, and Denton, and at Tilghman Island. There are also two block groups north of Denton that have high combined risk/vulnerability.

There are few areas that have both low structural vulnerability and low stormwater flooding, but the block groups surrounding Denton and in the southern portion of Delaware have medium vulnerability and low stormwater flooding.

3.1.4. Natural Resource Vulnerability and Flood Risks

Natural resource vulnerability by block group is generally higher closer to the shoreline. The southwestern reaches of the Choptank HFA study area are high in natural resource value, as is the central region of the study area between the municipalities of Easton and Denton. North of Denton, natural resource values are low, but there is a clear delineation at the Maryland/Delaware border: natural resource values by block group are higher in Delaware than they are in the northern parts of the Maryland portion of the study area (see Figure B-13).

Combinations of natural resource vulnerability and flood risks are detailed in Figures B-29:B-34. Table 3.3 shows the percentage of block groups that fall into each of the extreme categories of the bivariate mapping. Extreme groupings for this intersection include 1) low risk and low vulnerability, 2) low risk, yet high vulnerability, 3) high risk, yet low vulnerability, and 4) high risk and high vulnerability. These results suggest that while there are a number of block groups not requiring action due to the combination of low risk/low vulnerability, there is reason to emphasize planning and investment on both the high risk/high vulnerability and the low risk/high vulnerability block groups to maintain and protect the value of the natural resources alone. This tabulation differs largely from those of social and structural vulnerability, in that block groups of low risk/low vulnerability are more numerous when compared to the other extreme groupings. The count of high risk/high vulnerability block groups increase as sea level rise impact increases (2 block groups for 1 foot to 3 block groups for 2 feet), and also as storm surge impact increases (4 block groups for category 1 to 6 block groups for category 2).

Table 3.3. Count of block groups by flood risk and natural resource vulnerability.

	Low Risk/ Low Vulnerability	Low Risk/ High Vulnerability	High Risk/ Low Vulnerability	High Risk/ High Vulnerability
Sea Level Rise (1 ft)	19	2	0	2
Sea Level Rise (2 ft)	19	2	0	3
Storm Surge (Cat 1)	21	3	0	4
Storm Surge (Cat 2)	18	2	2	6
Stormwater Flooding	7	6	12	5

3.1.4.1. Sea Level Rise of 1 and 2 Feet

As shown in Figures B-30 and B-31, areas that have both high natural resource vulnerability and high sea level rise risk (1 foot) are located in the southern portion of the Choptank HFA study area, south of Cambridge. Other high vulnerability/high risk areas occur in the bottom half of the study area, as far north as Denton. As sea level rise risk increases (2 feet), high vulnerability/high risk areas increase to the east and west of Cambridge, north of Denton, southwest of Easton, and at Tilghman Island.

Areas of both low natural resource vulnerability and high sea level rise risk (1 foot) exist in the northern and central regions of the study area, as well as sporadically along the eastern border. Other low vulnerability/low risk areas are located within the municipalities of Cambridge, Easton, and Denton. These areas generally remain low vulnerability/low risk as sea level rise risk increases (2 feet).

3.1.4.2. Category 1 and 2 Storm Surge

As shown in Figures B-32 and B-33, areas of both high natural resource vulnerability and high storm surge risk (category 1) are similar to high vulnerability/high sea level rise risk areas, and include the central region of the study area between Cambridge, Easton, and Denton, and around Tilghman Island. The highest vulnerability/risk block groups are in southern portion of the study area, to the west and south of Cambridge. As storm surge risk increases (category 2), the areas around Tilghman Island, west of Easton, and northeast of Cambridge become high vulnerability/high risk areas. Some block groups between Cambridge and Denton increase in combination vulnerability/risk as well.

Areas of both low natural resource vulnerability and low storm surge risk (category 1) are also similar to low vulnerability/low sea level rise risk areas, and are located in the northern portion of the study area, in the central region, sporadically along the eastern border, and within Cambridge and Easton. As storm surge risk increases (category 2), low vulnerability/low risk areas remain in roughly the same locations.

3.1.4.3. Stormwater Flood Prone Areas

As shown in Figure B-34, areas that have both high natural resource vulnerability and high stormwater flood risk are primarily located in the southern reaches of the Choptank HFA study area, to the west and south of Cambridge. Other high vulnerability/high risk areas are located between Cambridge and Easton, west of Easton through Tilghman Island, and northeast of Easton.

Oxford flooding. Photo credit: Eric Messick, NOAA NCCOS/JHT

Areas that have both low natural resource vulnerability and low stormwater flood risk are in the north and central parts of the study area.

3.1.5. Comparisons of Vulnerabilities, Valuation, and Risk

The northern portion of the Choptank HFA study area shares high social vulnerability, high structural vulnerability, and medium-high natural resource vulnerability. High social vulnerability is also present in the southernmost block group, and although this area is low in structural vulnerability, it is high in natural resource vulnerability. High structural vulnerability and high natural resource vulnerability share similar block groups in the central region of the study area, but are inverted in the coastal block groups, in which structural vulnerability is low, but natural resource vulnerability is high. Social vulnerability varies between low and high in these coastal block groups.

While social vulnerability is generally high in and around the communities of Cambridge, Easton, Denton, and Viola, natural resource vulnerability is low within these municipalities, with the exception of Viola. Structural vulnerability within these areas varies, with high vulnerability in and around Easton, Denton, and Viola, but low vulnerability in and around Cambridge.

When intersected with flood inundation risk, the southernmost block groups are highly vulnerable in terms of social and natural resource vulnerability, as well as highly vulnerable in each of the five flood risks. This is not the case for structural vulnerability. Block groups located centrally have similarly varying levels of combined flood risk and social, structural, and natural resource vulnerability.

The municipalities of Cambridge, Easton, and Denton generally have high combined social vulnerability and flood risk, as well as high combined structural vulnerability and flood risk across the five inundation scenarios. Conversely, these municipalities generally have low combined natural resource vulnerability. Although rarely the area with highest combined vulnerability and risk, Tilghman Island and the surrounding region commonly have higher combined vulnerability and risk in comparison to many of the other coastal block groups.

3.2. WHERE ARE THE POTENTIAL PRIORITIES FOR ACTION?

3.2.1. Coastal Flooding Adaptation Areas (Short Term)

In this example, shown in Figure B-35, coastal flooding adaptation scores for short term flood hazards were determined through a combination of risk analysis (category 2 storm surge and stormwater flooding risk) and vulnerability analysis (social, structural, and natural resource vulnerability). Tier 1 block groups are associated with the highest composite vulnerability and risk, and may indicate areas where adaptation measures could be targeted to address short term flood hazards within the study area.

Tier 1 areas (high overall vulnerability and risk) are located closest to the coast, and are concentrated along the southwestern parts of the Choptank HFA study area. Tier 3 areas (medium overall vulnerability and risk) are scattered throughout the central and northeastern regions of the study area. Tier 5 areas (low overall vulnerability and risk) are also scattered throughout the central region of the study area, and also just south of the northernmost block groups.

3.2.2. Coastal Flooding Adaptation Areas (Long Term)

In this example, shown in Figure B-36, coastal flooding adaptation scores for long term flood hazards were determined through a combination of risk analysis (short term risks and sea level rise of 2 feet) and vulnerability analysis (social, structural, and natural resource vulnerability). Tier 1 block groups are associated with the highest composite vulnerability and risk, and may indicate areas for prioritization of adaptation measures that address long term flood hazards within the study area.

Tier 1 areas (high overall vulnerability and risk) for long term risks include the same southwestern block groups as were listed for short term risks, with the addition of one new coastal block group between Tilghman Island and Easton. Some areas to the northwest and northeast of Cambridge increased from Tier 3 to Tier 2 areas (medium to medium-high). Some block groups in the central parts of the HFA study area increased in potential priority as well. Some increased from Tier 3 to Tier 2 (medium to medium-high), some from Tier 4 to Tier 3 (medium-low to medium), and others from Tier 5 to Tier 4 (low to medium-low). In the northern parts of the study area, most block groups maintained their short term potential priority rankings, although an area north of Denton increased in ranking from Tier 4 to Tier 3 (medium-low to medium), a block group west of Denton increased from Tier 5 to Tier 4 (low to medium-low), and an area within the municipality of Denton increased from Tier 3 to Tier 2 (medium to medium-high).

Corner of Bank Street flooding. Photo credit: Eric Messick, NOAA NCCOS/JHT

Chapter 4
Discussion

Photo credit: Eric Messick, NOAA NCCOS/JHT

On a block group-by-block group basis, this assessment considered vulnerability of society, commercial and residential buildings, and natural resources alongside the distribution of flood risks. Through the comparison of overlapping and intersecting vulnerabilities, the assessment demonstrates how the social environment, the built environment, and a range of natural resources form an interactive coastal landscape and seascape. The connectivity of these coastal ecosystem components contributes to a sense of place for many of the associated communities—a sense of place that is threatened by the impacts of a changing climate. Ultimately, this increasingly holistic approach of assessing vulnerability and climate change risk creates the foundation for more successful coastal management and adaptation, whether focused on coastal flooding or other climate impacts.

4.1. COMPARISON TO OTHER PRIORITIZATION EFFORTS

This assessment complements the work of several completed and ongoing regional projects and incorporates a social component often overlooked in many environmental studies. Due to its unique construction, the Framework offers a more comprehensive understanding of the Choptank Watershed Complex, and can further be used as a tool to incorporate a socioeconomic context into existing environmental work. An example of this type of comparison is shown in Figure 4.1, which compares this study's integrated vulnerability priority areas with The Nature Conservancy's (TNC) Chesapeake Habitat Tool (http://maps.tnc.org/chesapeakehabitat/). This comparison highlights areas where potential co-benefits exist for a range of activities, including adaptation, restoration, and conservation.

The TNC Chesapeake Bay Habitat Prioritization working group decided upon default weights in consultation with local stakeholders and subject matter experts. These weights can be altered by users in the online tool. To prioritize the 250 m by 250 m grid cells, Table 4.1 describes the metrics, subcategories, and weights the TNC group used in their analysis (TNC, 2016). In Figure 4.1, the science team reclassified the 20 tiered system from the TNC into a five tiered system, utilizing the same weights and calculations.

Figure 4.1 compares our short term coastal flooding adaptation areas with the TNC's wetland habitat restoration priority areas. Both left hand maps highlight the southern portion of the HFA as priority areas, which suggests that this is an ideal space for further investigation when considering investment and design of a habitat restoration projects with multiple benefits to the ecosystem, including human communities. The inset maps on the right show the municipal area of Easton. Easton's urbanized landscape ranges from medium to high in vulnerability and risk, and the habitat restoration priority tool, shown in Figure 4.1, highlights specific areas within the municipality that could benefit from habitat restoration activity. These, and other, tools can be contrasted and compared to further understand the complexity of prioritization for management action. Neither prioritization tool is intended to be a mechanism for selecting a project site; instead, both are geared toward focusing attention on ideal sites for further on-the-ground investigation. In this way, the prioritization tools can be used to identify areas for investment in research aimed at siting and designing effective restoration projects.

Many natural resources help to mitigate flooding impacts on the built environment in and of themselves. While the project team determined that presence of natural resources made an area more vulnerable to climate impacts due to the increased potential loss of high monetary value and biodiversity, especially in the face of gradual sea level rise and rising ocean temperatures, some of these natural resources may also have value associated with their ability to protect property and lives through the mitigation of flooding impacts. Consequently, these resources can decrease an area's vulnerability to flooding impacts when present in a given area. For example, oyster sanctuaries help to dissipate storm surge and lessen the intensity of surge as it makes landfall (Mukherjee, Balakrishnan, and Shanker, 2009; Scyphers et al., 2011; Harman et al., 2015). Similarly, marshes assist in wave attenuation, shore stabilization, and help to reduce flooding following a storm event by absorbing excess water and reducing the length of time a coastal area remains flooded after an event (Tiner, 1984; Shepard, Crain, and Beck, 2011).

Strategic placement for most of these natural resources, however, is crucial. In most locations wetlands reduce flooding, but in some places they can actually increase predicted surge heights and damages. These effects are often related to the modification of flow patterns around the wetland, such as with a damming or blocking effect, mimicking those of artificial defenses (Loder et al., 2009). A recent study found that within the Chesapeake Bay, modeled storm surge heights increased in front of wetlands and decreased behind them (Narayan et al., 2016).

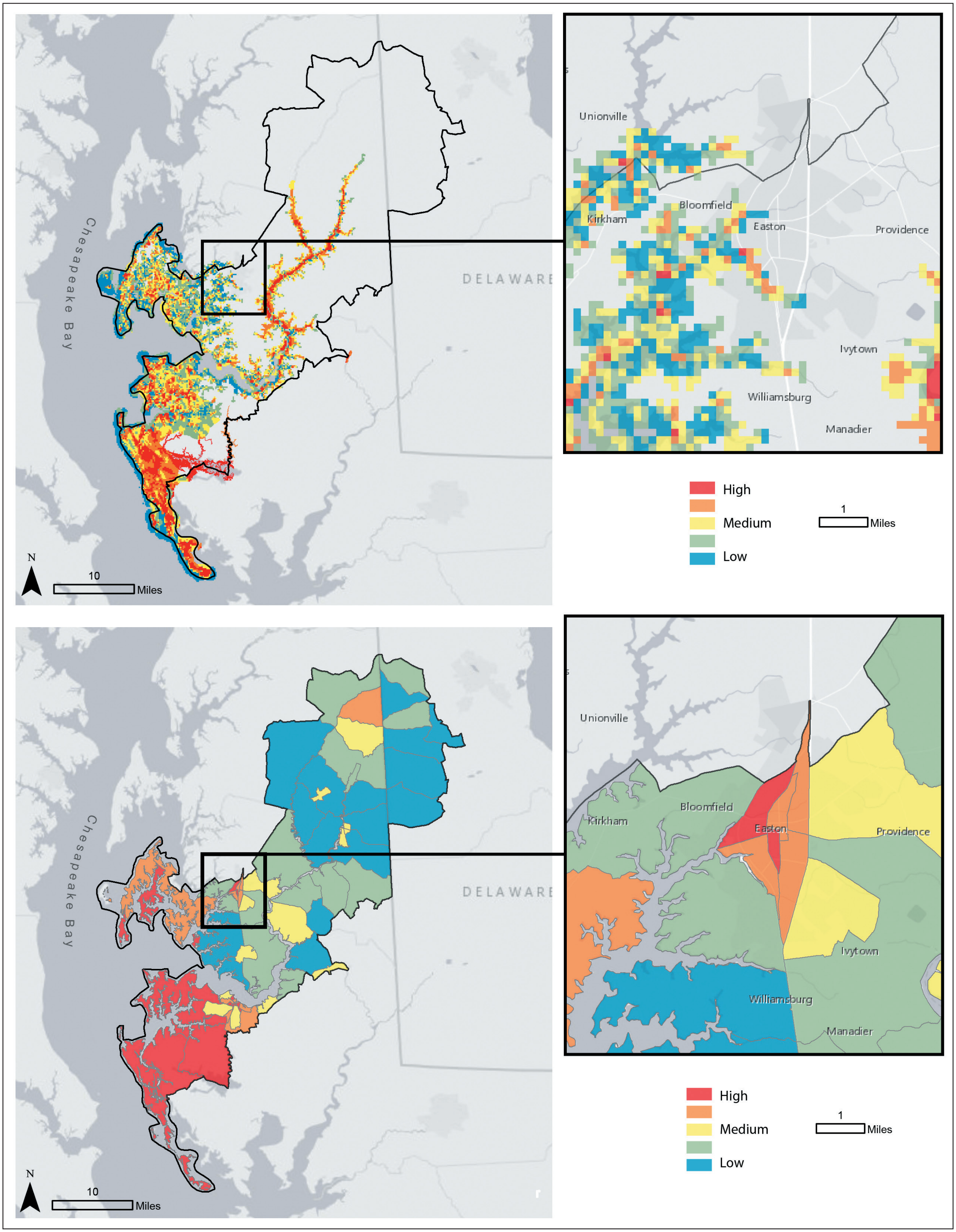


Figure 4.1. Comparison of TNC priority areas (above) with coastal flooding adaptation areas (below).

Table 4.1. TNC Chesapeake Habitat Tool metrics, subcategories, and weights.

Metric	Subcategory	Weight Applied
Sea Level	Potential Wetland Migration Cost	25%
Shoreline Condition	Fetch	25%
Land Use Type	Forested, Extensive Marsh, and Scrub/Shrub Area	10%
Land Use Class	Dominant Shoreline	10%
Nearby	Area of SAV within 500m of Cell	12.50%
Nearby	Area of Oyster Bar within 500m of Cell	12.50%
Watershed	Percent Impervious Surface in the HUC12 Subwatershed	5%

Other findings have shown that the protection benefits from coastal wetlands are non-linear with regard to wetland width, and suggest that most of the protection is provided within the first several hundred meters (Barbier et al., 2008; Narayan et al., 2016). The need for understanding exactly how and where wetlands will affect flooding is critical to ultimately integrate various nature-based infrastructure into coastal risk management practice (Narayan et al., 2016).

If placed strategically, the mitigating qualities described above of wetlands and other natural resources increase the importance of natural resources and their capability for making an area more or less vulnerable. Similarly, the multiple values for these natural resources can increase the potential vulnerability of communities if resources are lost due to the impacts of climate change. As a result, if priority areas for restoration and conservation overlap with priority areas for adaptation as outlined in this report, targeted efforts can be made that result in co-benefits for both communities and the natural environment.

4.2. NEXT STEPS WITHIN THE CHOPTANK HFA

The results of this assessment can be used in a variety of ways within the Choptank HFA. Components of the assessment can provide a better understanding of the social characteristics of the populations within the Choptank HFA in order to increase efficacy of outreach and engagement efforts, improve stakeholder survey design and sampling of important sub-populations, and highlight the different relationships between communities and natural resources that exist throughout the HFA based on resource proximity. The social vulnerability, structural vulnerability, and natural resource vulnerability results can support the identification of geographic areas where additional benefits may be accrued through the protection, restoration, and conservation of critical habitat. For example, these co-benefits may include maintaining concentrations of natural resource value and reducing flood risks for socially vulnerable populations.

These results can also be used to tailor priority mapping efforts to the unique needs of managers and partners working in the HFA. While the project team carried out one example of priority mapping in order to highlight areas of priority for coastal flooding adaptation action in the short and long term, other priority mapping may be of value for the HFA. The results of the vulnerability assessment can be easily combined with other datasets in order to rank geographic areas of the HFA for management actions, such as wetland restoration or improved land use planning. Prioritization of restoration areas could incorporate the social vulnerability component and/or coastal flooding risks for a different means of assessing potential benefits (and risks) of investment. An example of this was shown in the preceding section to explore the results of this work alongside an assessment of habitat restoration priority for the same region.

Lastly, this assessment can be used to inform ongoing science carried out within the Choptank HFA and will assist in laying the foundation for future community planning and associated engagement activities. The accompanying mapbook supplement, included as Appendix B, can be used as a planning document and tool for local governments, community urban planning groups, and community workshops. Its “stand-alone” nature allows for easy perusal between vulnerabilities and risks, and allows for users to compare and contrast these aspects individually and in combination. This visual aid can encourage planning conversation and enable communities to consider tradeoffs between management actions to combat effects of climate change on both regional and localized scales, as well as provide the foundation for additional funding to examine vulnerabilities at an even finer scale.

Chapter 5
Conclusions

Photo credit: Jane Hawkey, University of Maryland IAN

This project represents the second application of the Integrated Vulnerability Assessment Framework focused on coastal areas facing the impacts of climate variability and change. The Framework has been improved through the integration of new components such as the valuation of natural resources to define vulnerability and the refinement of existing components such as the composite index used to assess areas to target for adaptation. This assessment was successfully implemented at a different unit of analysis and geographic scale, and incorporated the integration of administrative and ecological boundaries. The design of the Framework provides a level of flexibility that can be applied to multiple geographies and contexts.

Despite the emphasis on the combined results (e.g. adaptation area maps and risk/vulnerability intersection maps), the individual components of the assessment may also be independently useful in certain contexts, including other management and planning purposes. The method allows for management action based on various time horizons, management needs, levels of political and public support, and amounts of funding. The assessment provides a scientific rationale for subsequent management actions to address short and long term coastal flooding risks.

The success of both applications of the approach provides support for continued work to build upon the method and to continue its expansion to new areas of interest. Results from the Town of Oxford and Talbot County, Maryland vulnerability assessment (Messick and Dillard, 2016) have informed the Town of Oxford's prioritization of stormwater mitigation projects and continue to be used to support grant applications for adaptation funds. With scientific research results to bolster the application's strength, town representatives have increased confidence in the likelihood of obtaining these grants. Opportunities have been identified that will incorporate vulnerability assessment results into an interactive web-based flood risk mapping tool and into an update of the hazard mitigation plan in Talbot County. Within the Choptank HFA, results of the assessment are being considered for evidence of co-benefits of habitat restoration, and the results are being used to better understand the communities that are dependent on the HFA. Furthermore, this project's methodology is being explored as part of an effort to showcase management applications of improved models of storm surge and sea level rise, such as with models developed by the NCCOS Ecological Effects of Sea Level Rise Program (NCCOS, 2016).

Future uses of the Framework may include the assessment of vulnerability in relation to coastal protection (e.g., siting areas for investment in green/gray/hybrid shoreline protection), as well as in investigating social variability within coastal communities. Future research should also include the continued improvement of the Framework. For example, methods of spatial refinement of social data and, therefore, of the assessment of risk to human populations and structures are ideal next steps. This might be accomplished through dasymetric analysis using land cover and other spatial data to help determine where populations are distributed as opposed to assumptions of even spatial distribution of social and economic data. Additionally, there is value in scaling the assessment down to smaller geographic units in order to capture the true variability in vulnerability and risk. This continuation and refinement of work will provide valuable science to decision makers and planners that will inform management decisions. Without these types of analyses in multiple locations, coastal communities are at a disadvantage in the face of climate change and related impacts.

The Choptank HFA integrated vulnerability assessment analysis and future iterations of the Framework will provide meaningful information to better protect, advance, and manage climate change impacts within local communities in various coastal geographies of the US and beyond.

References

Photo credit: Maria Dillard, NOAA NCCOS

Arguez, A., I. Durre, S. Applequist, M. Squires, R. Vose, X. Yin, and R. Bilotta. 2010. 1981-2010 US Climate Normals: Monthly for GHCND Stations USC00187806 and USC00073595. NOAA's National Centers for Environmental Information. Accessed 2016.

Barbier, E.B., E.W. Koch, B.R. Silliman, S.D. Hacker, E. Wolanski, J. Primavera, E.F. Granek, S. Polasky, S. Aswani, and L.A. Cramer. 2008. Coastal ecosystem-based management with nonlinear ecological functions and values. Science 319: 321–323.

Bates, B.C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof (eds.). 2008. Climate change and water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva. 210 pp.
Online: http://ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf (Accessed 20 January 2016)

Beachapedia. 2013. State of the Beach/State Reports/MD/Beach Ecology. Maryland Department of Natural Resources. Online: http://www.beachapedia.org/State_of_the_Beach/State_Reports/MD/Beach_Ecology (Accessed 27 October 2016)

Berman M., H. Berquist, S. Kiilleen, K. Nunez, K. Reay, T. Rudnicky, D. Schatt, and D. Weiss. 2006. Development of the Maryland Shoreline Inventory, Methods and Guidelines for Talbot County. Comprehensive Coastal Inventory Program, Center for Coastal Resources Management, Virginia Institute of Marine Science, Maryland Coastal Zone Management Program, Department of Natural Resources, pursuant to NOAA Awards No. 14-03-889 CZM049 and No. 14-04-942 CZM 086. 27 pp. Online: http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/maryland/talbot/TalbotCounty.pdf (Accessed 27 October 2016)

Blair, A., D. Sanger, D. White, A.F. Holland, L. Vandiver, C. Bowker, S. White. 2014a. Quantifying and Simulating Stormwater Runoff in Watersheds. Hydrological Processes 28(3): 559-569.

Blair, A., S. Lovelace, D. Sanger, A.F. Holland, L. Vandiver, S. White. 2014b. Exploring Impacts of Development and Climate Change on Stormwater Runoff. Hydrological Processes 28(5): 2844-2854.

Boesch, D.F., L.P. Atkinson, W.C. Boicourt, J.D. Boon, D.R. Cahoon, R.A. Dalrymple, T. Ezer, B.P. Horton, Z.P. Johnson, R.E. Kopp, M. Li, R.H.Moss, A Parris, C.K. Sommerfield. 2013. Updating Maryland's Sea-level Rise Projections. Special Report of the Scientific and Technical Working Group to the Maryland Climate Change Commission, University of Maryland Center for Environmental Science. Cambridge, MD. 22 pp.

Boutwell, J. and J. Westra. 2013. Benefit Transfer: A Review of Methodologies and Challenges. Resources 2: 517-527.

Caroline County. 2010. Caroline County Comprehensive Plan – Caroline County Maryland. County Commissioners of Caroline County, Maryland, State of Maryland. Online: http://www.carolinemd.org/DocumentCenter/View/144 (Accessed 27 October 2016)

Chakraborty, J., G.A. Tobin, and B.E. Montz. 2005. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. Natural Hazards Review 6(1): 23-33.

Chesapeake Bay Program. 2012. Forests. Online: http://www.chesapeakebay.net/issues/issue/forests#inline (Accessed 27 October 2016)

Chmura, G.L., L. Kellman, and G.R. Guntenspergen. 2011. The greenhouse gas flux and potential global warming feedbacks of a northern macrotidal and microtidal salt marsh. Environmental Research Letters 6. 6 pp.

Coastal Change Analysis Program (C-CAP). 2010. Coastal Change Analysis Program Regional Land Cover and Change. NOAA Office for Coastal Management, National Oceanic and Atmospheric Administration. Online: https://coast.noaa.gov/dataregistry/search/collection/info/ccapregional (Accessed 27 October 2016)

Cutter, S.L. 2008. A Framework for Measuring Coastal Hazard Resilience in New Jersey Communities. White Paper for the Urban Coast Institute. 12 pp.

Cutter, S.L., B.J. Boruff, and W.L. Shirley. 2003. Social Vulnerability to Environmental Hazards. Social Science Quarterly 84(2): 242-261.

Cutter, S.L., C.T. Emrich, J.J. Webb, and D. Morath. 2009. Social Vulnerability to Climate Variability Hazards: A Review of Literature. 44 pp. Hazards and Vulnerability Research Institute, University of South Carolina. Columbia, SC.

de Mooy, J. 2016. Green Infrastructure Primer: A Delaware Guide to Using Natural Systems in Urban, Rural, and Coastal Settings. Delaware Department of Natural Resources and Environmental Control. 48 pp.
Online: http://www.dnrec.delaware.gov/GI/Documents/Green%20Infrastructure/Green_Infra_Primer2016_FINAL%20web%20version.pdf (Accessed 27 October 2016)

Delaware Department of Natural Resources and Environmental Control. 2016. What is a Conservation Easement? Delaware State Parks.
Online: http://www.dnrec.delaware.gov/OpenSpaces/Documents/What%20is%20a%20Conservation%20Easement.pdf (Accessed 14 October 2016)

Dillard, M., T.L. Goedeke, S. Lovelace, and A. Orthmeyer. 2013. Monitoring Well-being and Changing Environmental Conditions in Coastal Communities: Development of an Assessment Method. NOAA Technical Memorandum NOS NCCOS 174. 176 pp.

Dunning, C.M. and S. Durden. 2011. Social Vulnerability Analysis Methods for Corps Planning. US Army Corps of Engineers.

Environmental Protection Agency (EPA). 2016. What is Green Infrastructure? Online: https://www.epa.gov/green-infrastructure/what-green-infrastructure (Accessed 13 October 2016)

Feagin, R., M. Martinez, G. Mendoza-Gonzalez, and R. Costanza. 2010. Salt Marsh Zonal Migration and Ecosystem Service Change in Response to Global Sea Level Rise: A Case Study from an Urban Region. Ecology and Society 15(4): 14. Online: http://www.ecologyandsociety.org/vol15/iss4/art14/ (Accessed 27 October 2016)

Federal Emergency Management Agency (FEMA). 2013. Flood Insurance Study: Talbot County, Maryland and Incorporated Areas. Flood Insurance Study Number 24041CV000A. 40 pp.

Federal Emergency Management Agency (FEMA). 2015. Flood Insurance Study: Caroline County, Maryland and Incorporated Areas. Flood Insurance Study Number 24011CV000A. 72 pp.

Fisher, T.R., J.A. Benitez, K. Lee, and A.J. Sutton. 2006a. History of land cover change and biogeochemical impacts in the Choptank River basin in the mid□Atlantic region of the US. International Journal of Remote Sensing 27(17): 3683–3703.

Fisher, T.R., J.D. Hagy, W.R. Boynton, and M.R. Williams. 2006b. Cultural eutrophication in the Choptank and Patuxent estuaries of Chesapeake Bay. Limnology and Oceanography 51(1 part 2): 435–447.

Geoghegan, J., L. Lynch, and S. Bucholtz. 2003. Capitalization of Open Spaces into Housing Values and the Residential Property Tax Revenue Impacts of Agricultural Easement Programs. Agricultural and Resource Economics Review 32(1): 33-45.

Grabowski, J., R. Brumbaugh, R. Conrad, A. Keeler, J. Opaluch, C. Peterson, M. Piehler, S. Powers, and A. Smyth. 2012. Economic Valuation of Ecosystem Services Provided by Oyster Reefs. BioScience 62(10): 900-909.

Green, C.M. and T.P. Tracy. 2013. Fostering shellfish aquaculture production in Maryland and other states. Department of Legislative Services, Office of Policy Analysis. Annapolis, Maryland. 29 pp.

Guignet, D., C. Griffiths, H. Klemick, and P. Walsh. 2014. The Implicit Price of Aquatic Grasses. US Environmental Protection Agency National Center for Environmental Economics: Working Paper Series Working Paper #14-06.

Harman, B.P., S. Heyenga, B.M. Taylor, and C.S. Fletcher. 2015. Global lessons for adapting coastal communities to protect against storm surge inundation. Journal of Coastal Research 31(4): 790-802.

Hicks, R., T. Haab, and D. Lipton. 2004. The Economic Benefits of Oyster Reef Restoration in the Chesapeake Bay. Final Report Prepared for the Chesapeake Bay Foundation. 92 pp.

Jepson, M. and L. Colburn. 2013. Development of Social Indicators of Fishing Community Vulnerability and Resilience in the U.S. Southeast and Northeast Regions. Department of Commerce (ed.). 64 pp.

Leggett, C. and N. Bockstael. 2000. Evidence of the Effects of Water Quality on Residential Land Prices. Journal of Environmental Economics and Management 39(2): 121-144.

Li, Y. and B.R. Ellingwood. 2006. Hurricane damage to residential construction in the US: Importance of uncertainty modeling in risk assessment. Engineering Structures 28: 1009-1018.

Lipton, D., J. Kirkley, and T. Murray. 2006. A Background Economic Analysis for the Programmatic Environmental Impact Statement Regarding the Restoration of the Chesapeake Bay Oyster Fishery Using the Non-Native Oyster, *Crassostrea ariakensis*. Maryland Department of Natural Resources. 54 pp.

Loder, N.M., M.A. Cialone, J.L. Irish, and T.V. Wamsley. 2009. Sensitivity of hurricane surge to morphological parameters of coastal wetlands. Estuarine Coastal Shelf Sciences 84(4): 625–636.

Mahan, B. 1997. Valuing Urban Wetlands: A Property Pricing Approach. Evaluation of Environmental Investments Research Program, US Army Corps of Engineers. IWR Report 97-R-1. Portland, OR. 82 pp.

Maryland Department of Natural Resources. 2002. Upper Choptank River Watershed Characterization. State of Maryland. 104 pp. Online: http://www.agnr.umd.edu/FileExchange/Upper_Choptank_Rvr_Chrctrzn_sept_02.pdf (Accessed 27 October 2016)

Maryland Department of Natural Resources. 2016a. Conservation Easement Overview. Maryland.gov. Online: http://dnr2.maryland.gov/met/pages/land_conservation.aspx (Accessed 27 October 2016)

Maryland Department of Natural Resources. 2016b. Sanctuaries: Ecological Restoration – Sanctuaries & Reserves. Maryland.gov. Online: http://dnr2.maryland.gov/fisheries/Pages/oysters/sanctuaries.aspx (Accessed 27 October 2016)

Maryland Department of the Environment. 2016. About Wetlands. Maryland State Government. Online: http://www.mde.state.md.us/programs/Water/WetlandsandWaterways/AboutWetlands (Accessed 27 October 2016)

McCarty, G.W., L.L. McConnell, C.J. Hapeman, A. Sadeghi, C. Graff, W.D. Hively, M.W. Lang, T.R. Fisher, T. Jordon, C.P. Rice, E.E. Codling, D. Whitall, A. Lynn, J. Keppler, and M.L. Fogel. 2008. Water quality and conservation practice effects in the Choptank River watershed. Journal of Soil and Water Conservation 63(6): 461–474.

Messick, E. and M. Dillard. 2016. Identifying Priorities for Adaptation Planning: An Integrated Vulnerability Assessment for the Town of Oxford and Talbot County, Maryland. NOAA Technical Memorandum NOS NCCOS 212. 149 pp.

Möller, I., M. Kudella, F. Rupprecht, T. Spencer, M. Paul, B.K. van Wesenbeeck, G. Wolters, K. Jensen, T.J. Bouma, M. Miranda-Lange, and S. Schimmels. 2014. Wave attenuation over coastal salt marshes under storm surge conditions. Nature Geosci 7: 727-31.

Mukherjee, N., M. Balakrishnan, and K. Shanker. 2009. Chapter 10: Bioshields and Ecological Restoration in Tsunami-Affected Areas in India. Pp 131-144. In: E. Moksness, E. Dahl, and J. Stottrup (eds.), Integrated Coastal Zone Management. Wiley-Blackwell, Oxford, UK.

Narayan, S., M.W. Beck, P. Wilson, C. Thomas, A. Guerrero, C. Shepard, B.G. Reguero, G. Franco, C.J. Ingram, and D. Trespalacios. 2016. Coastal Wetlands and Flood Damage Reduction: Using Risk Industry-based Models to Assess Natural Defenses in the Northeastern USA. Lloyd's Tercentenary Research Foundation, London.

National Centers for Coastal Ocean Science (NCCOS). 2016. The Ecological Effects of Sea Level Rise Program. Our Research Areas, NCCOS, National Ocean Service, National Oceanic and Atmospheric Administration. Online: https://coastalscience.noaa.gov/research/climate/sea_level_rise (Accessed 27 October 2016)

National Conservation Easement Database. 2016. All States and All Easements.
Online: http://www.conservationeasement.us/reports/easements (Accessed 14 October 2016)

National Hurricane Center. 2015. Sea, Lake, and Overland Surges from Hurricanes (SLOSH). National Weather Service, National Oceanic and Atmospheric Administration. Online: http://www.nhc.noaa.gov/surge/slosh.php (Accessed 27 October 2016)

National Oceanic and Atmospheric Administration (NOAA). 2014. NOAA selects two areas in the North Atlantic for targeted habitat conservation efforts. National Marine Fisheries Service, Greater Atlantic Region Fisheries Office.
Online: https://www.greateratlantic.fisheries.noaa.gov/mediacenter/2014/TwoAreasSelectedinNorthAtlanticforHabitatConservation_efforts.html
(Accessed 5 May 2014)

National Oceanic and Atmospheric Administration (NOAA). 2015. Choptank River Complex Habitat Focus Area StoryMap. ESRI.
Online: http://noaa.maps.arcgis.com/apps/MapSeries/index.html?appid=8c59862bed7646f290875be579e531bc
(Accessed 27 October 2016)

National Oceanic and Atmospheric Administration (NOAA). 2016. Oyster Reef Ecology. Habitat Conservation: National Marine Fisheries Service. Online: http://www.habitat.noaa.gov/pdf/ecology_of_oysters.pdf (Accessed 27 October 2016)

Newell, R.I.E., T.R. Fisher, R.R. Holyoke, and J.C. Cornwell. 2005. Influence of Eastern Oysters on Nitrogen and Phosphorus Regeneration In Chesapeake Bay, USA. pp 93-120. In: R. Dame and S. Olenin (eds.), The Comparative Roles of Suspension Feeders in Ecosystems: 2005. Vol 47. NATO Science Series: IV - Earth and Environmental Sciences. Springer, Netherlands. 360 pp.

NOAA Chesapeake Bay Office. 2016. Oyster Reefs. National Oceanic and Atmospheric Administration. Online: http://chesapeakebay.noaa.gov/oysters/oyster-reefs (Accessed 27 October 2016)

Parsons, G. and M. Powell. 2001. Measuring the Cost of Beach Retreat. Coastal Management. 29(2): 91-103.

Paul, A. 2011. The Economic Benefits of Natural Goods and Services: A Report for the Piedmont Environmental Council. Yale School of Forestry and Environmental Studies, The Berkley Scholars Conservation Program and The Piedmont Environmental Council. 40 pp.

Poor, P., K. Pessagno, and R. Paul. 2007. Exploring the Hedonic Value of Ambient Water Quality: A Local Watershed-Based Study. Ecological Economics 60(4): 797-806.

Pryor, S.C., D. Scavia, C. Downer, M. Gaden, L. Iverson, R. Nordstrom, J. Patz, and G.P. Robertson. 2014. Chapter 18: Midwest. Pp. 418–440. In: Melillo, J.M., T.C. Richmond, and G.W. Yohe (eds.), Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. 841 pp. doi:10.7930/J0Z31WJ2.

Salzman, J. 2003. Methodological Choices Encountered in the Construction of Composite Indices of Economic and Social Well-being. Center for the Study of Living Standards. 32 pp.

Scyphers, S.B., S.P. Powers, K.L. Heck, and D. Byron. 2011. Oyster reefs as natural breakwaters mitigate shoreline loss and facilitate fisheries. PLoS ONE 6(8): e22369. doi: 10.1371/journal.pone.0022396.

Shepard, C.C., C.M. Crain, and M.W. Beck. 2011. The Protective Role of Coastal Marshes: A Systematic Review and Meta-analysis. PLoS ONE 6(11): e27374. doi: 10.1371/journal.pone.0027374.

Stevenson, J.C., C.B. Piper, and N. Confer. 1979. Decline of Submerged Plants in Chesapeake Bay. Chesapeake Bay Field Office, US Fish and Wildlife Service. Annapolis, MD. Online: https://www.fws.gov/chesapeakebay/savpage.htm (Accessed 27 October 2016)

The Nature Conservancy (TNC). 2016. Chesapeake Bay Habitat Tool: A tool to prioritize coastal habitats. Online: http://maps.tnc.org/chesapeakehabitat/ (Accessed 27 October 2016)

Thompson, B. (ed.). 2008. Exploratory and Confirmatory Factor Analysis: Understanding Concepts and Applications. Washington, DC: American Psychological Association. 195 pp.

Tides and Currents. 2013. Sea Level Trends. National Oceanic and Atmospheric Administration. Online: http://tidesandcurrents.noaa.gov/sltrends/sltrends.html (Accessed 17 August 2016)

Tiner, R.W. 1984. Wetlands of the United States: Current Status and Recent Trends. National Wetlands Inventory, Fish and Wildlife Service, US Department of the Interior. Newton Corner, MA. 59 pp.

United States Census Bureau. 2010. American FactFinder. 2010 Census, US Census Bureau, 2010.
Online: http://factfinder2.census.gov (Accessed 13 January 2016)

United States Census Bureau. 2014. 2010-2014 American Community Survey. American FactFinder. US Census Bureau's American Community Survey Office, 2014.
Online: http://factfinder2.census.gov (Accessed 13 January 2016)

Virginia Institute of Marine Science (VIMS). 2016. Digital Shoreline Situation Report (SSRs) – Description and Disclaimer (Talbot County, Maryland). Center for Coastal Resources Management. Online: http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/maryland/talbot/talbot_disclaimer.htm (Accessed 17 October 2016)

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, and J. Willis. Chapter 2: Our Changing Climate. Pp. 19–67. In: Melillo, J.M., T.C. Richmond, and G.W. Yohe (eds.), Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. 841 pp. doi:10.7930/J0Z31WJ2.

Weber, T. 2007. Ecosystem services in Cecil County's Green Infrastructure: Technical Report for the Cecil County Green Infrastructure Plan. The Conservation Fund. Annapolis, MD.

Whitall, D., W.D. Hively, A.K. Leight, C.J. Hapeman, L.L. McConnell, T. Fisher, C.P. Rice, E. Codling, A.M. Sadeghi, A. Gustafson, and K. Bialek. 2010. Pollutant fate and spatio-temporal variability in the Choptank river estuary: Factors influencing water quality. Science of the Total Environment 408(9): 2096–2108.

Wu, S., B. Yarnal, and A. Fisher. 2002. Vulnerability of coastal communities to sea-level rise: a case study of Cape May County, New Jersey, USA. Climate Research 22: 255-270.

Yarbro, L.A., P.R. Carlson, T.R. Fisher, J.P. Chanton, and W.M. Kemp. 1983. A Sediment Budget for the Choptank Estuary in Maryland, River. Estuarine, Coastal and Shelf Science 17: 555–570.

Appendix A: SWARM Demonstration

Photo credit: Jane Hawkey, University of Maryland IAN

The amounts of runoff generated by single storm events at different rainfall depths and climate change scenarios can be quantified by applying a stormwater runoff modeling system (SWARM; Blair et al., 2014a; Blair et al., 2014b), and a synopsis of SWARM is shown below for the Choptank HFA municipalities of Denton and Cambridge.

Table A-1. Characteristics of municipalities.

Watershed	Area (ha)	IC (%)	I_a (mm)	Developed	Agriculture	Undeveloped	Wetland	Wa-ter	HSG (C+D)
Denton	1,370	14	7.2	29%	27%	33%	11%	1%	37%
Cambridge	2,724	23	3.4	46%	28%	12%	14%	0%	91%

*Area units are hectares. 'IC' is Impervious Cover, an indicator of development. 'I_a' is initial abstraction, an indicator of runoff potential (the lower the I_a, the greater the potential). 'Developed' is the urbanized portion of the total municipality; 'Undeveloped' is the non-urbanized portion; 'Wetland' is the marsh portion; 'Water' is the open water portion. 'HSG' is Hydrologic Soil Group, and C and D are the least permeable of the soil groups.

Stormwater-related characteristics of the municipalities show that over half of the land is either urban or cultivated – 56% for Denton and 74% for Cambridge (Table A-1). For low permeability soils, the Denton watershed is at 37% and Cambridge at 91%. Another stormwater-related characteristic is the initial abstraction, the amount of rain required in order to generate runoff. For Denton, the required rainfall is 7.2 mm (0.28 in) and for Cambridge, it is 3.4 mm (0.13 in).

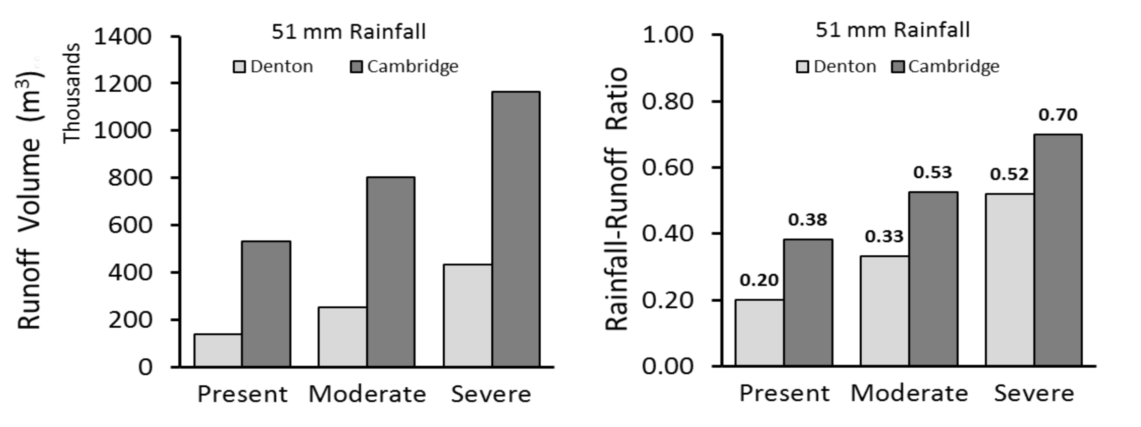
Table A-2. Stormwater runoff modeling results for 4 rainfall depths.

Rainfall Depth	Climate Scenario	Denton		Cambridge	
		Volume (m^3)	Ratio	Volume (m^3)	Ratio
13 mm (0.5 in)	Present	2,818	0.02	30,459	0.09
	Moderate Change	12,140	0.06	67,359	0.18
	Severe Change	35,839	0.17	141,497	0.34
25 mm (1 in)	Present	28,195	0.08	146,436	0.21
	Moderate Change	65,644	0.17	257,996	0.34
	Severe Change	138,605	0.33	439,033	0.53
51 mm (2 in)	Present	139,531	0.20	530,230	0.38
	Moderate Change	253,948	0.33	801,983	0.53
	Severe Change	433,929	0.52	1,162,650	0.70
102 mm (4 in)	Present	513,924	0.37	1,580,365	0.57
	Moderate Change	795,202	0.52	2,126,799	0.70
	Severe Change	1,156,983	0.69	2,744,861	0.83

*Present is based on average antecedent runoff conditions (ARC). Moderate and Severe climate change scenarios are based on a 10% increase in rain at semi-wetter ARC and a 20% increase in rain at wetter ARC, respectively. Volume is in cubic meters. 'Ratio' is the proportion of rainfall that is converted to runoff.

Four rainfall depths were used, and at each depth, runoff at present climate conditions and at two climate change scenarios based on the general predictions already mentioned of increasing frequency and intensity of heavy storms were modeled (Table A-2, and Figure A-1). Numerous possibilities exist for climate change scenarios, and the two established reflect a moderate change (10% increase in rainfall and semi-wet runoff conditions) and a severe change (20% increase in rainfall and wet runoff conditions).

The modeling results show output for two key runoff measurements: volume and ratio. Volume is the quantity of runoff; for the same storm event, Cambridge will always have greater volume than Denton because of its larger size – 2,724 hectares compared to 1,370 ha. Ratio shows



*'Present' is based on average antecedent runoff conditions (ARC). 'Moderate' and 'Severe' scenarios are based on a 10% increase in rain at semi-wetter ARC and a 20% increase in rain at wetter ARC, respectively. The chart at left shows volume in cubic meters. The chart at right shows rainfall-runoff ratio which is the proportion of rainfall that is converted to runoff.

Figure A-1. Bar charts show modeled runoff at different climate change scenarios.

the relationship between the total rainfall and the amount of that rainfall that is converted to runoff. Ratio removes the effect of size since it is dependent only on the rainfall total and the quantified runoff. Cambridge is expected to have higher ratios than Denton based on the land use and soil characteristics discussed previously.

For all rainfall depths, climate scenarios create dramatic increases in the amount of runoff and the ratio of rainfall converted to runoff. At the 2 inch depth, Denton's runoff volume almost doubles at the moderate climate scenario and more than triples at the severe scenario; ratio increases from 0.20 to 0.33 to 0.52. For Cambridge, volume increases by 50% at the moderate climate scenario and more than doubles at the severe scenario; ratio increases from 0.38 to 0.53 to 0.70. Because modeling provides quantified output, it can be used to illustrate possible impacts of heavier rain events on the flooding hazard of stormwater.

More information concerning SWARM can be found in Blair et al. 2014a (methods), Blair et al. 2014b (applications), and Blair and Sanger 2016 (climate scenarios).

REFERENCES

Blair, A., D. Sanger, D. White, A.F. Holland, L. Vandiver, C. Bowker, and S. White. 2014a. Quantifying and Simulating Stormwater Runoff in Watersheds. Hydrological Processes 28(3): 559-569.

Blair, A., S. Lovelace, D. Sanger, A.F. Holland, L. Vandiver, and S. White. 2014b. Exploring Impacts of Development and Climate Change on Stormwater Runoff. Hydrological Processes 28(5): 2844-2854.

Blair, A. and D. Sanger. 2016. Climate Change and Watershed Hydrology – Heavier Precipitation Influence on Stormwater Runoff. Geosciences 6(3):34. doi: 10.3390/geosciences6030034

Appendix B
Mapbook Supplement

Photo credit: Jane Hawkey, University of Maryland IAN

CHOPTANK MAPBOOK SUPPLEMENT

AN EXTENSION OF NOAA'S TECHNICAL MEMORANDUM NOS NCCOS 225

January 2017

NOAA NCCOS Center for Coastal Monitoring and Assessment

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COASTAL OCEAN SCIENCE

Introduction:

The overarching goal of this project was to evaluate a coastal area's vulnerability to localized impacts of climate change. This work builds upon a previous community vulnerability project evaluating vulnerability in the Town of Oxford and Talbot County, Maryland (Messick and Dillard, 2016). Both studies utilize a "vulnerability of places" framework (e.g., Cutter, 2008; Cutter *et al.*, 2009) to examine social and environmental vulnerability to climate variability and change. The scientific assessments incorporated regional and stakeholder engagement to ensure that vulnerability was appropriately identified and translated in a way that would serve as a foundation for the region to address risk and identify priority areas for adaptation planning for coastal flooding. The following series of maps is an integral part in achieving this project's goals by providing a strong visual aid to community and regional adaptation planners and managers.

This study was conducted for the National Oceanic and Atmospheric Administration's (NOAA) Choptank Habitat Focus Area (HFA). The Choptank HFA is located within the Eastern Shore of Maryland, and extends the length and width of the Choptank watershed. This area encompasses four Maryland counties (Caroline, Dorchester, Queen Anne's, and Talbot) and one Delaware county (Kent). The study area used for this analysis was Census derived, and was modified from the Choptank HFA ecological boundary to include complete block groups. Because much of the Choptank HFA is low-lying and tidally influenced, it is frequently exposed to coastal flooding events. These events may occur as a result of a single event or combination of events with differing impacts throughout the area. Similarly, retreat of floodwaters varies by area and is dependent on tide, wind, temperature, and local topography. With changing climate conditions like sea level rise and increased frequency and intensity of heavy precipitation events, this area's flooding issues are expected to worsen.

This project represents strong collaboration across the social and natural sciences, as well as across federal and state partners. While the initial vulnerability assessment tool development was largely focused on a town and county in the Chesapeake Bay, the methodological approach has been tailored for maximum applicability across coastal communities of various sizes in all regions of the US. This work is an example of this applicability. The scope of the assessment has been extended from one county to a watershed that encompasses parts of five counties. Additionally, this assessment has been performed in coordination with Choptank HFA partners primarily focused on habitat restoration goals. In addition to strengthening the NCCOS integrated vulnerability framework, this work further builds upon a range of NOAA methods and products (e.g., Digital Coast, NMFS Social Indicators, NCCOS Community Well-being Indicators, NCCOS Hydrologic Modeling).

This mapbook is structured as follows: Section 1 provides base condition vulnerability maps, Section 2 provides flood risk maps, Section 3 provides maps on the intersection of base vulnerabilities and flood risks, and Section 4 provides potential priority maps for coastal flooding adaptation action. For more detailed information on the contents of this mapbook, please refer to NOAA Technical Memorandum NOS NCCOS 225.

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SECTION 1: BASE CONDITION

Section 1 provides base condition maps of social vulnerability, structural vulnerability, natural resource distribution, and natural resource valuation for the Choptank HFA.

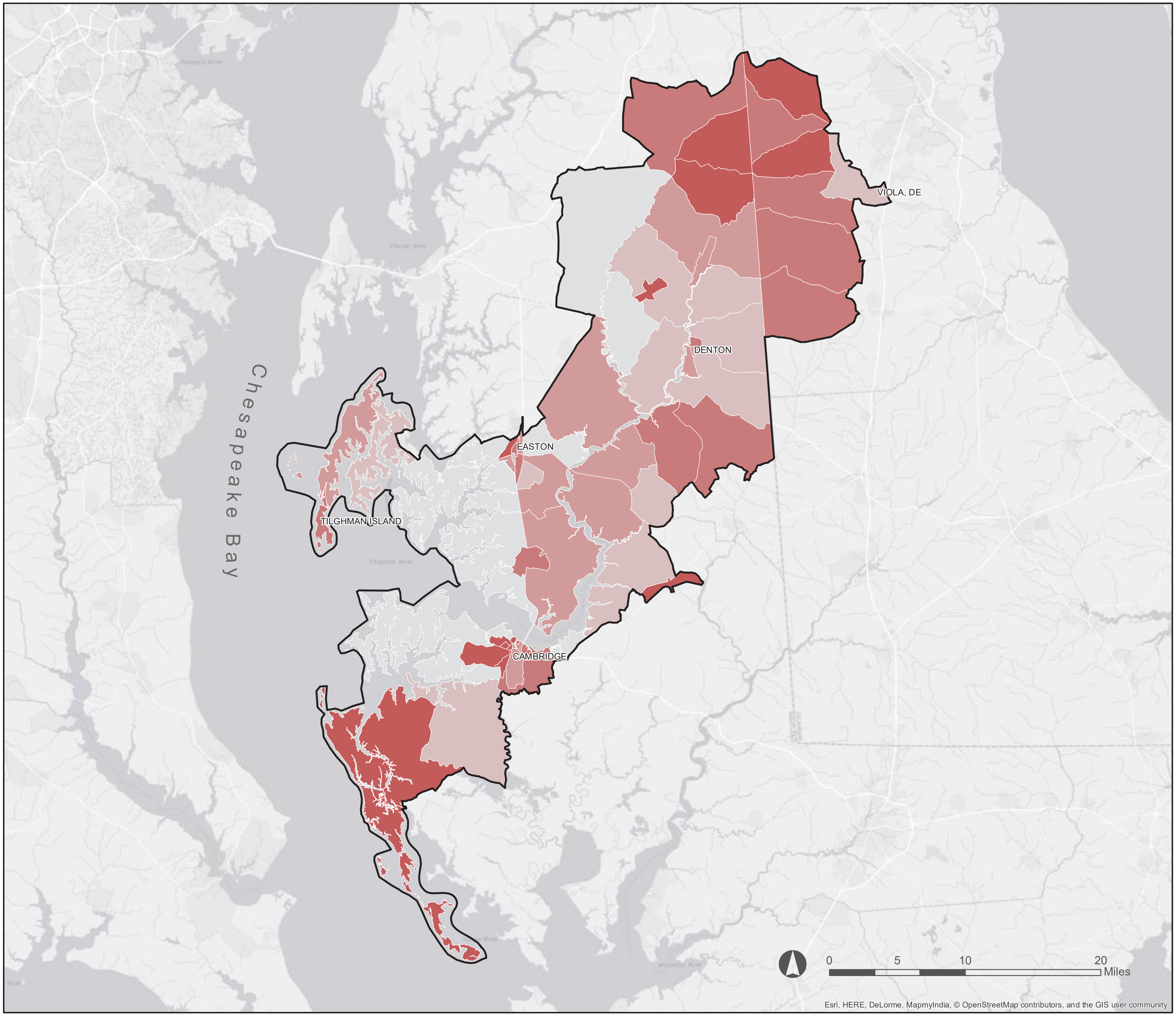
The science team began by measuring the risks of flooding due to climate change, and then measured the frequency of these flood events and their impacts on the study area's human population and natural and built environment. Socioeconomic vulnerability indicators were used to create an index that would help managers measure the vulnerability of their community's population to climate stressors and flood events. Structural vulnerability indicators were also used to create an index that would help managers measure the vulnerability of their community's built environment and infrastructure to climate stressors and flood events. Lastly, natural resource valuation indicators were used to create an index that would help managers measure the value and, therefore, the vulnerability of their natural environment to these stressors and flood events.

To develop the social vulnerability measure for Census block groups throughout the HFA, secondary data from the 2010 U.S. Decennial Census, and American Community Survey 2014 5 year estimates were utilized. Because there is a rich base of literature for social vulnerability, the approach to deriving the social vulnerability value for this project was closely modeled after the Social Vulnerability Index (SoVI) methodology developed by Susan Cutter and colleagues (2003). The final social indicators used in this study, which were comprised of 22 total variables, were: 1) social class, 2) age, 3) wealth, 4) social isolation, 5) rurality, and 6) service industry employment and gender.

In order to arrive at a structural vulnerability measure for the census block groups throughout the HFA, an approach was used that involved an initial collection of secondary data from county parcel records to determine structural vulnerability. Guidelines from the Federal Emergency Management Agency (FEMA) were utilized in selecting final indicators for structural vulnerability. The following indicators used in this assessment were: 1) the structure grade, 2) presence of a basement, and 3) structure material (e.g., wood-based or other).

The purpose of the natural resource valuation analysis was to determine the spatial extent and relative value of important natural resources within the study area, and to therefore assess their vulnerability to climate and coastal hazards. The science team determined final indicators to include in the natural resource analysis through the following criteria: 1) importance in terms of economic value to property owners through an ecosystem services framework, 2) the likelihood of resources to be adversely impacted by the selected flood hazards, and 3) the availability of data. The analysis included the following resources: 1) wetlands, 2) beaches, 3) marsh, 4) green infrastructure, 5) submerged aquatic vegetation, 6) oyster sanctuaries, 7) forested areas, and 8) forest conservation easements.

Composite Social Vulnerability



Choptank Study Area

Social composition impacts a community's vulnerability in the event of flood hazards. Scores are based on a series of components that measure aspects of social vulnerability within this population. These include: 1) social class, 2) age, 3) wealth, 4) social isolation, 5) rurality, and 6) service industry employment and gender. For example, a younger population with higher social class and low social isolation indicates a lower social vulnerability score.

Dark red areas correspond with higher scores and higher social vulnerability, while light red areas correspond with lower scores and lower vulnerability.

Figure B-1

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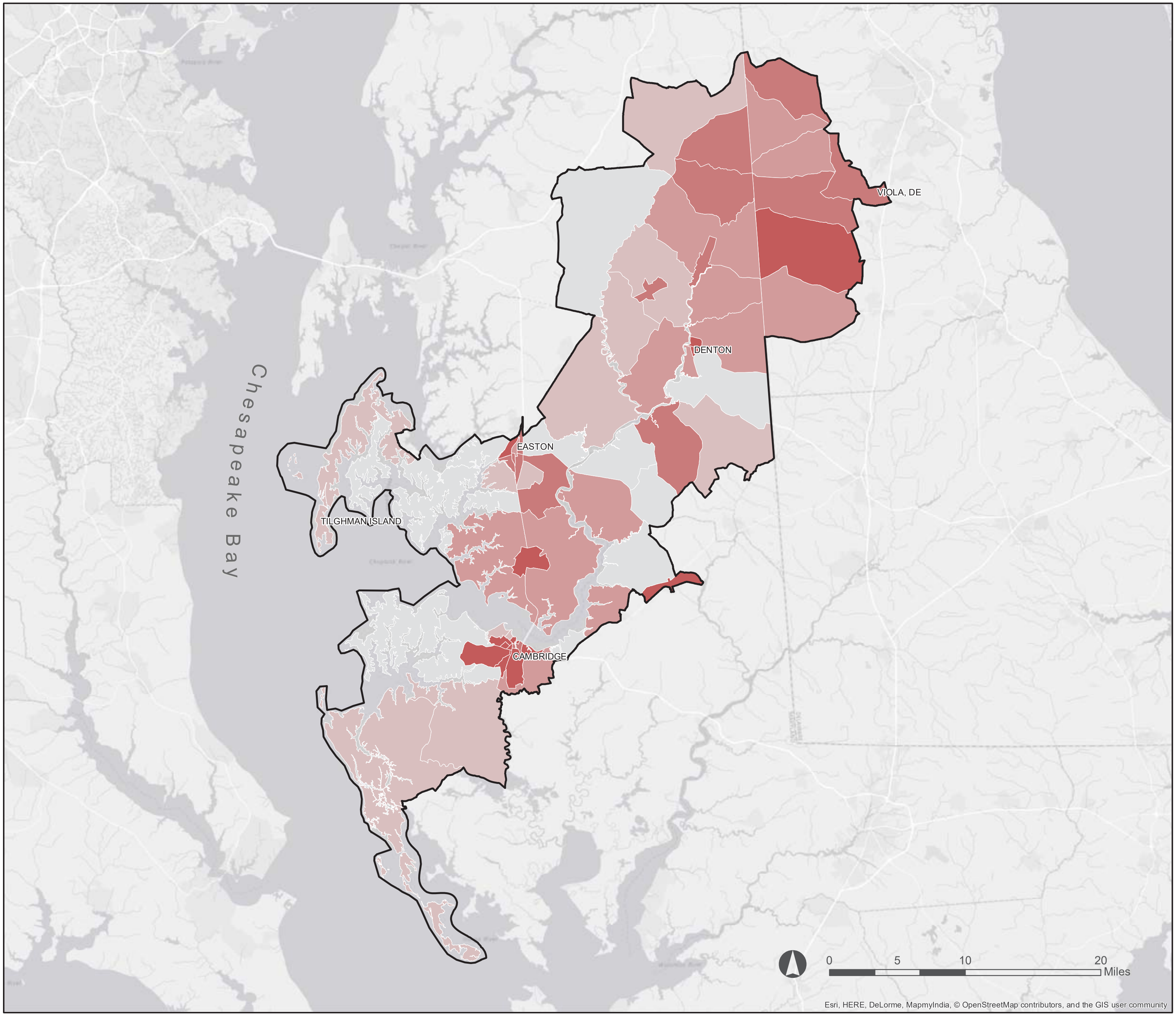
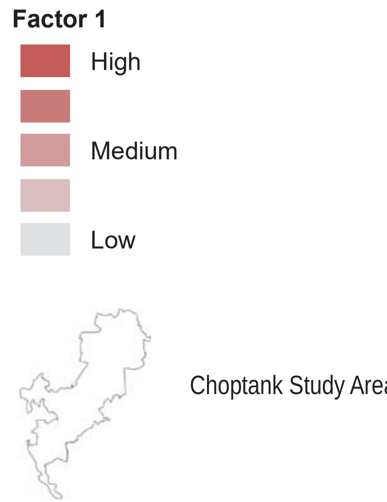
Social Class Component of Social Vulnerability





This factor is composed of six variables that include: percentage of households participating in SNAP, percentage of population in poverty, percentage of population without a vehicle, percentage of non-white population, percentage of unemployed population, and percentage of female headed households without a spouse.
This factor is one of six which combines to determine the social vulnerability index score as shown on the Composite Social Vulnerability map.

High (dark red) to low (grey) indicates the amount to which this factor contributes to the overall Social Vulnerability Score. This factor explains 30.438% of the model variance.

Figure B-2

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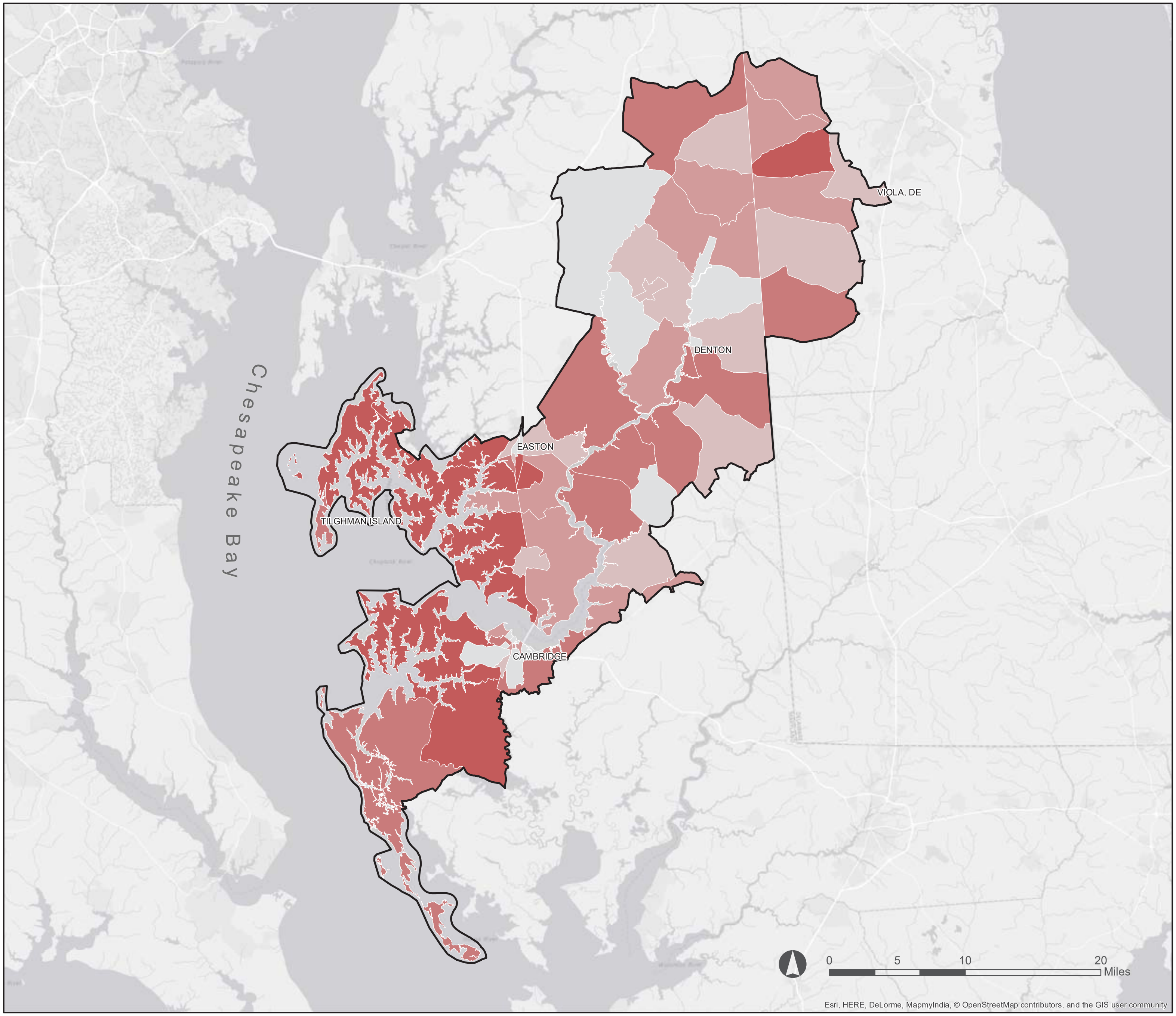
Age Component of Social Vulnerability



Factor 2

High

Medium

Low

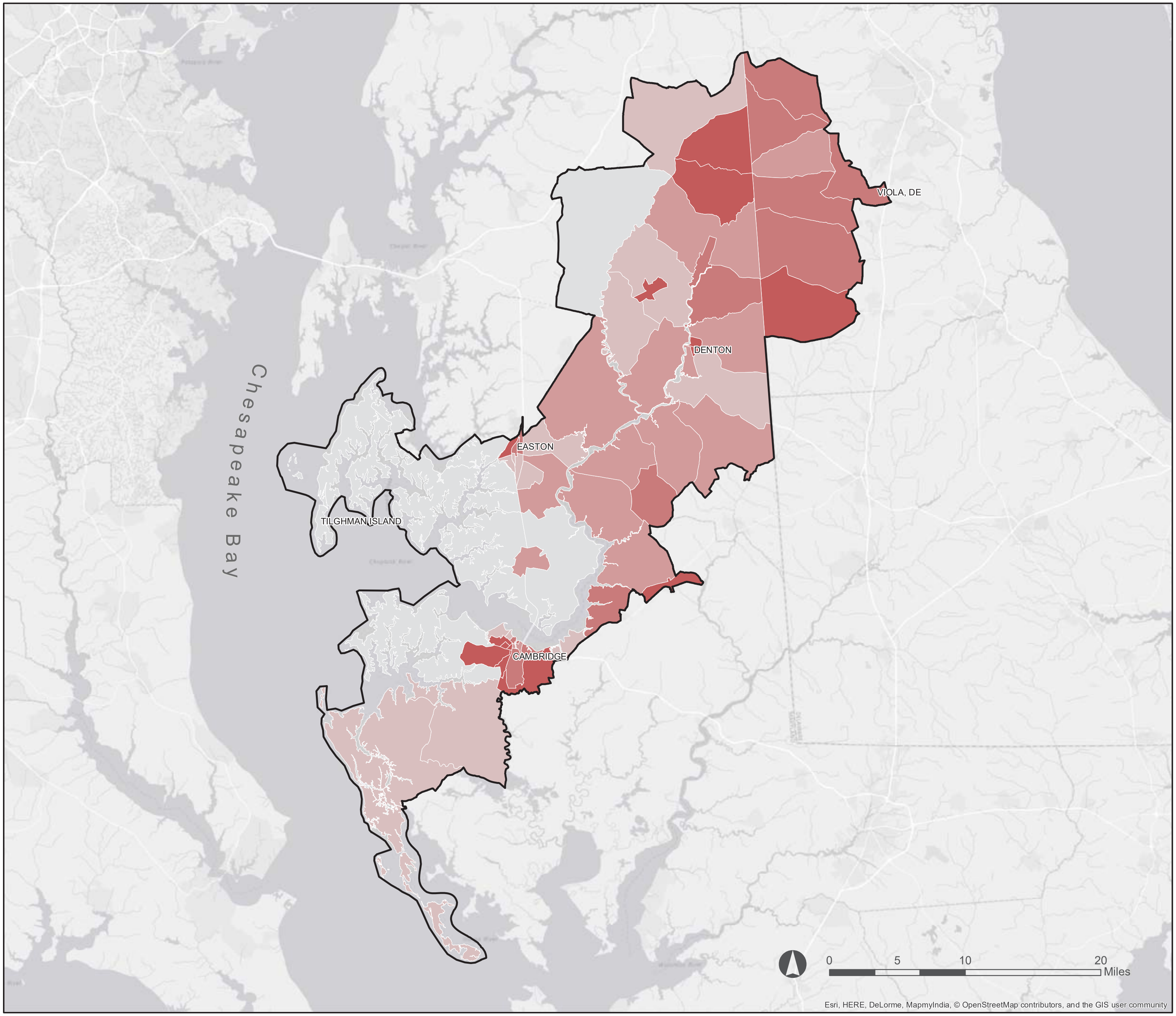
Choptank Study Area

This factor is composed of four variables that include: percentage of population over 65, median age, percentage of households with occupants over the age of 60, and average household size.
This factor is one of six which combines to determine the social vulnerability index score as shown on the Composite Social Vulnerability map.

High (dark red) to low (grey) indicates the amount to which this factor contributes to the overall Social Vulnerability Score. This factor explains 14.560% of the model variance.

Figure B-3

Wealth Component of Social Vulnerability



Factor 3

- High
- Medium
- Low

Choptank Study Area

This factor is composed of 4 variables that include: percentage of households with incomes over $200,000, median value of housing unit, median rent, and per capita income. Wealth exhibits a negative cardinality, meaning it contributes to overall social vulnerability inversely, and is symbolized to represent this.
This factor is one of six which combines to determine the social vulnerability index score as shown on the Composite Social Vulnerability map.

High (dark red) to low (grey) indicates the amount to which this factor contributes to the overall Social Vulnerability Score. This factor explains 10.512% of the model variance.

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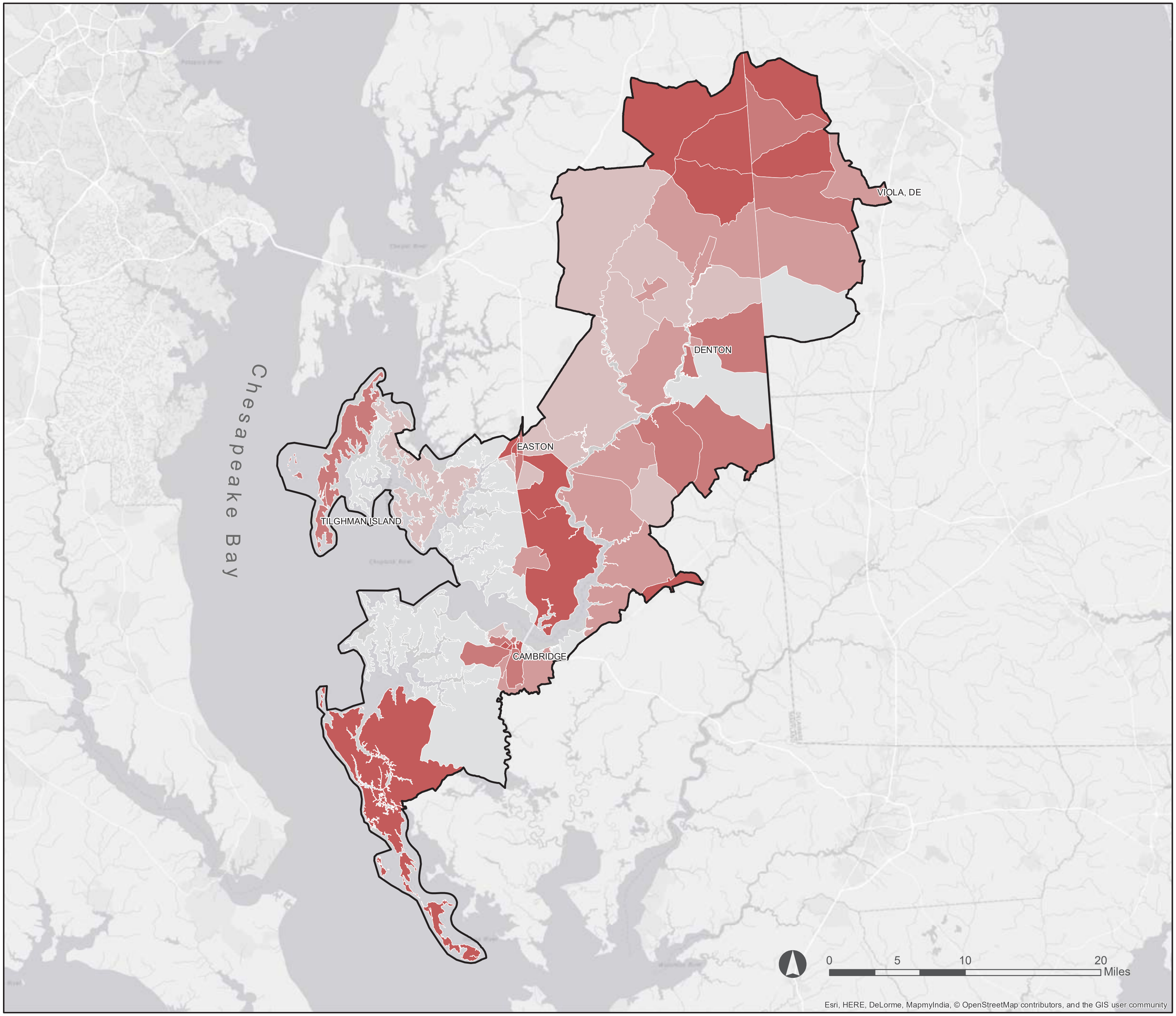
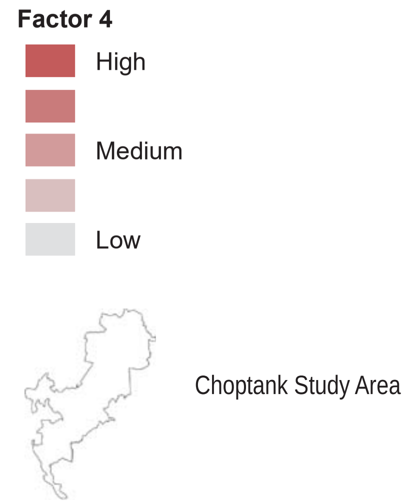
Figure B-4

Social Isolation Component of Social Vulnerability





This factor is composed of 3 variables that include: percentage of population with no high school diploma, percentage of population with limited English proficiency, and percentage of population with no health insurance.
This factor is one of six which combines to determine the social vulnerability index score as shown on the Composite Social Vulnerability map.

High (dark red) to low (grey) indicates the amount to which this factor contributes to the overall Social Vulnerability Score. This factor explains 5.867% of the model variance.

Figure B-5

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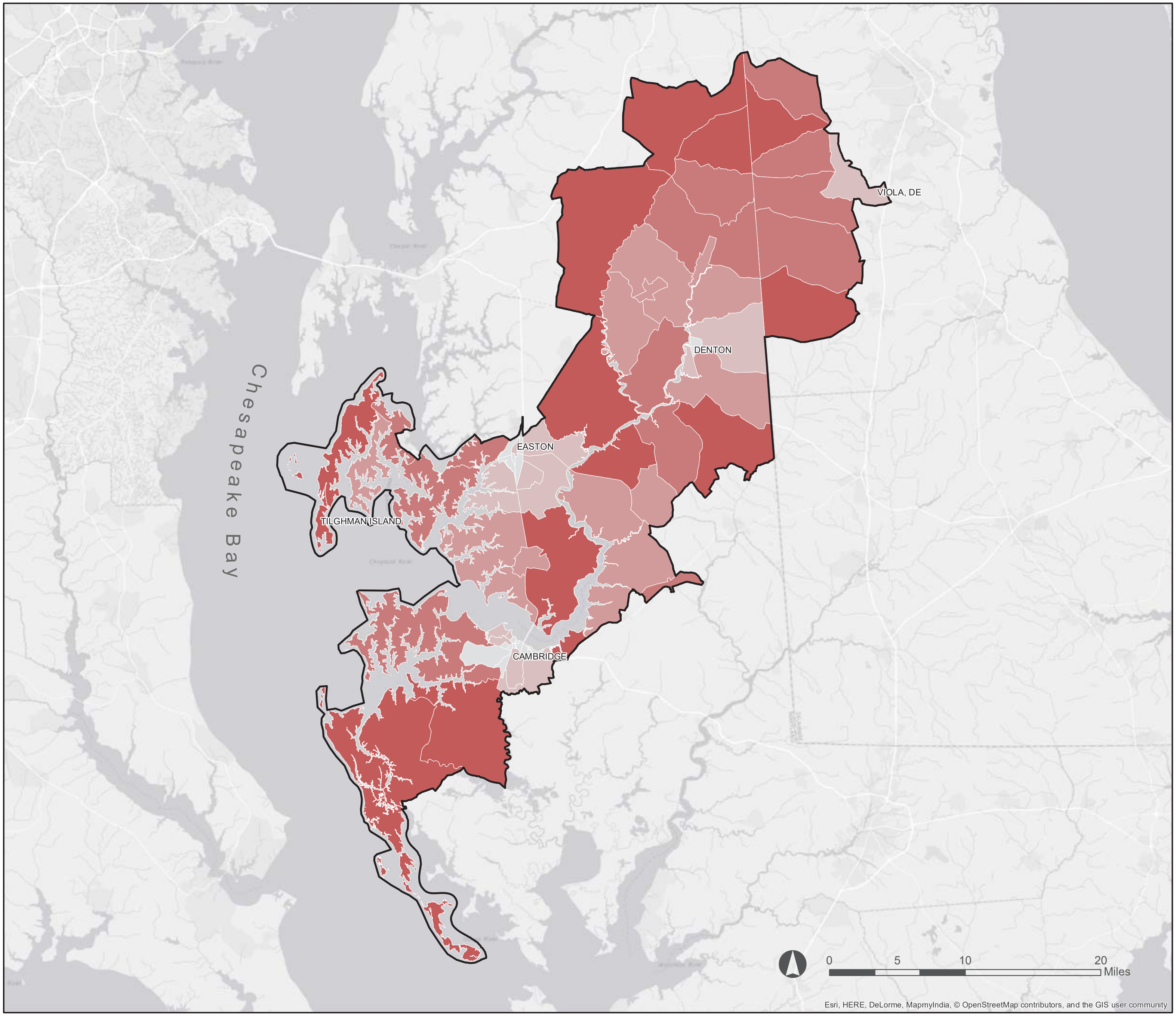
Rurality Component of Social Vulnerability



Factor 5

High

Medium

Low

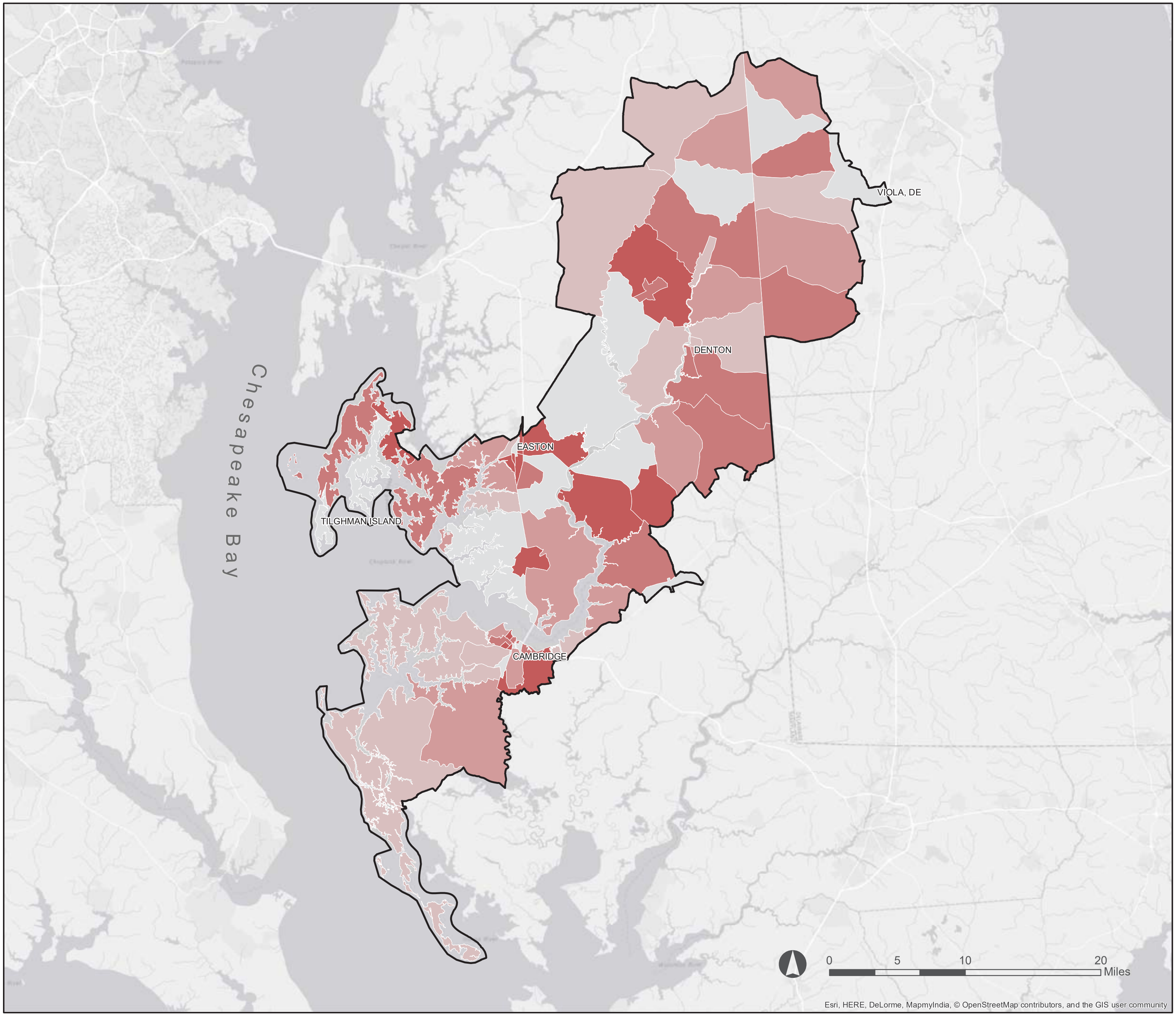
Choptank Study Area

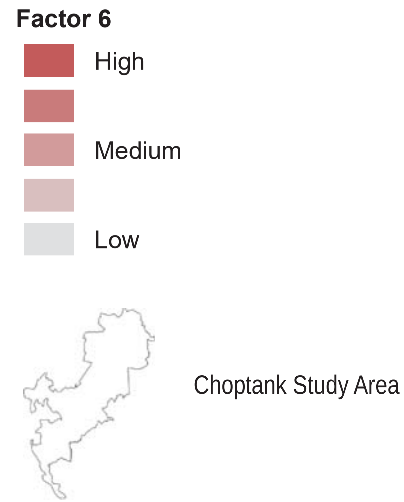
This factor is composed of 2 variables that include: percentage of population that is rural and percentage of population that is employed in extractive work sectors. This factor is one of six which combines to determine the social vulnerability index score as shown on the Composite Social Vulnerability map.

High (dark red) to low (grey) indicates the amount to which this factor contributes to the overall Social Vulnerability Score. This factor explains 5.696% of the model variance.

Figure B-6

Service Industry **Employment** and Gender Component of Social Vulnerability





This factor is composed of 3 variables that include: percentage of population that is female, percentage of population that is employed in service industry sectors, and percentage of population that has children in married households.
This factor is one of six which combines to determine the social vulnerability index score as shown on the Composite Social Vulnerability map.

High (dark red) to low (grey) indicates the amount to which this factor contributes to the overall Social Vulnerability Score. This factor explains 4.606% of the model variance.

Figure B-7

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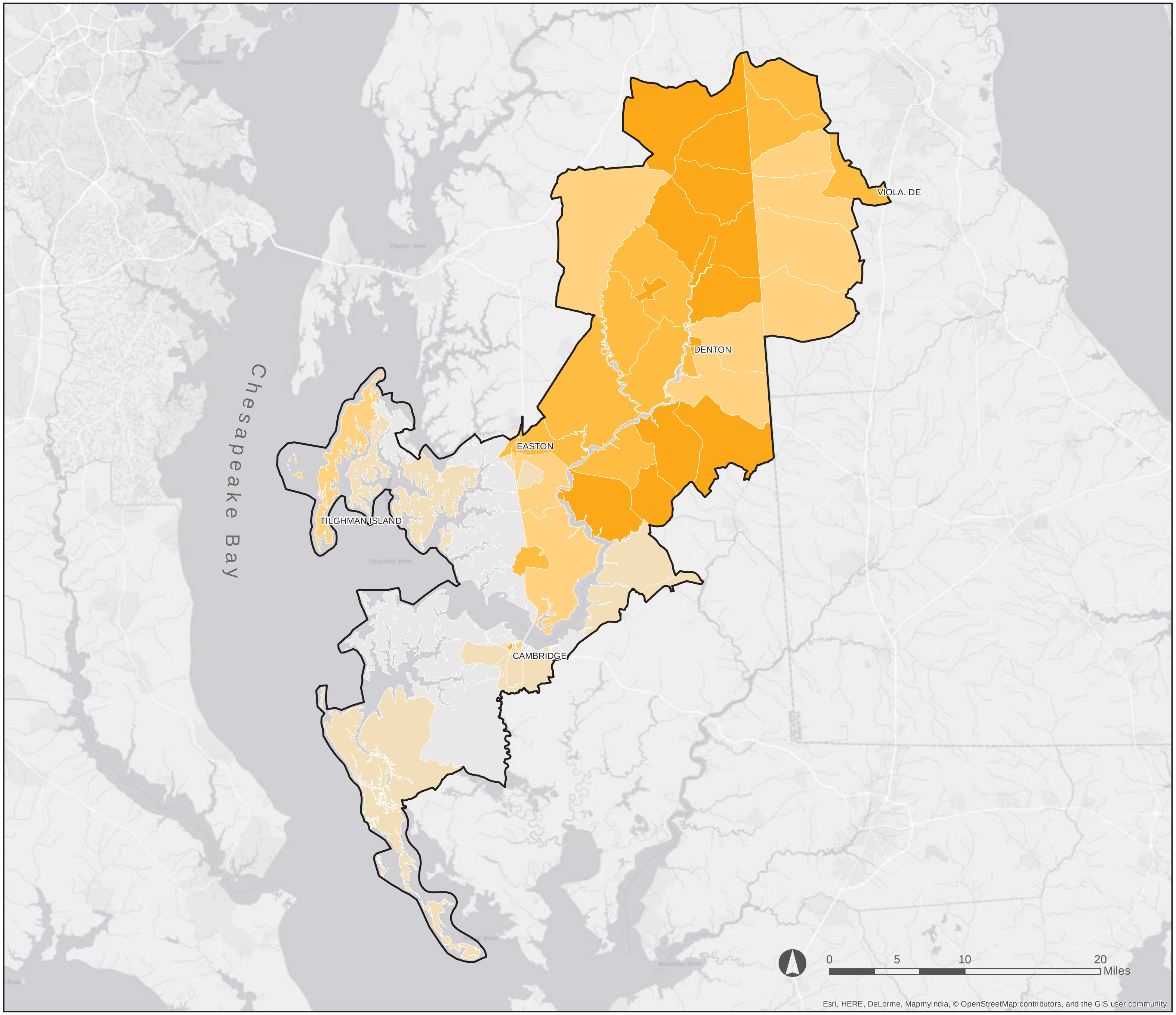
Composite Structural Vulnerability



Construction quality impacts a community's vulnerability in the event of flood hazards. Scores for this analysis are based on the following three variables: structure grade, proportion of wood-based structures, and proportion of structures with basements. Structure grade refers to the overall quality of construction, and a higher grade is associated with lower structural vulnerability. Wood-based structures may be more vulnerable to flood hazards and as a result, areas with more wood-based structures are more vulnerable.
Lastly, a basement increases a structure's vulnerability in the event of a flood.
Dark orange areas correspond with higher scores and higher structural vulnerability, while light orange areas correspond with lower scores and lower vulnerability.

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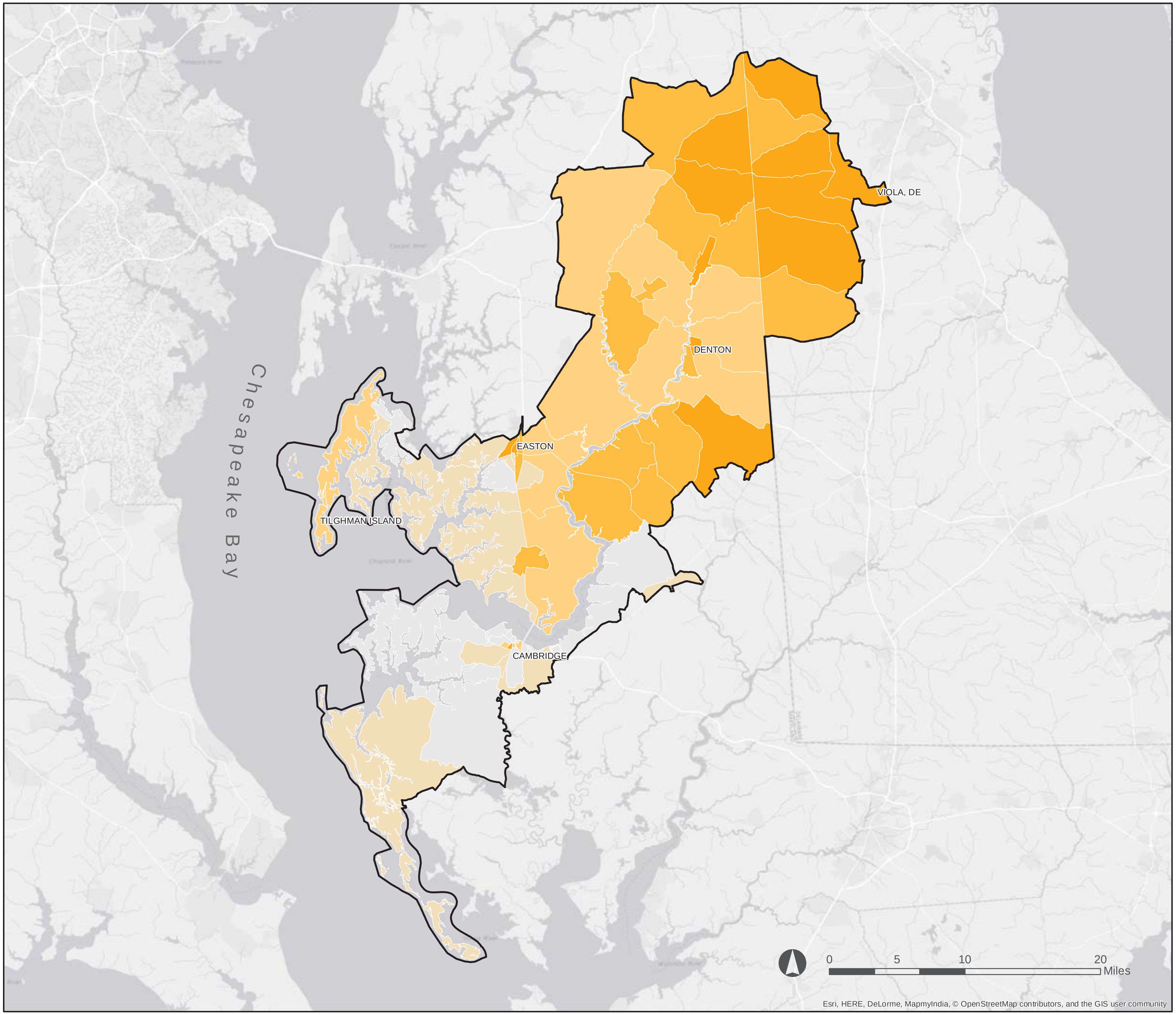
Figure B-8

Structure Grade Component of Structural Vulnerability



This component utilizes parcel level data to determine the percentage of structures within each block group that have a structure grade below average.

This component is one of three which combine to determine the structural vulnerability index score as shown on the Composite Structural Vulnerability map.

Dark orange areas correspond with higher percentages, while grey areas correspond with lower percentages.

Figure B-9

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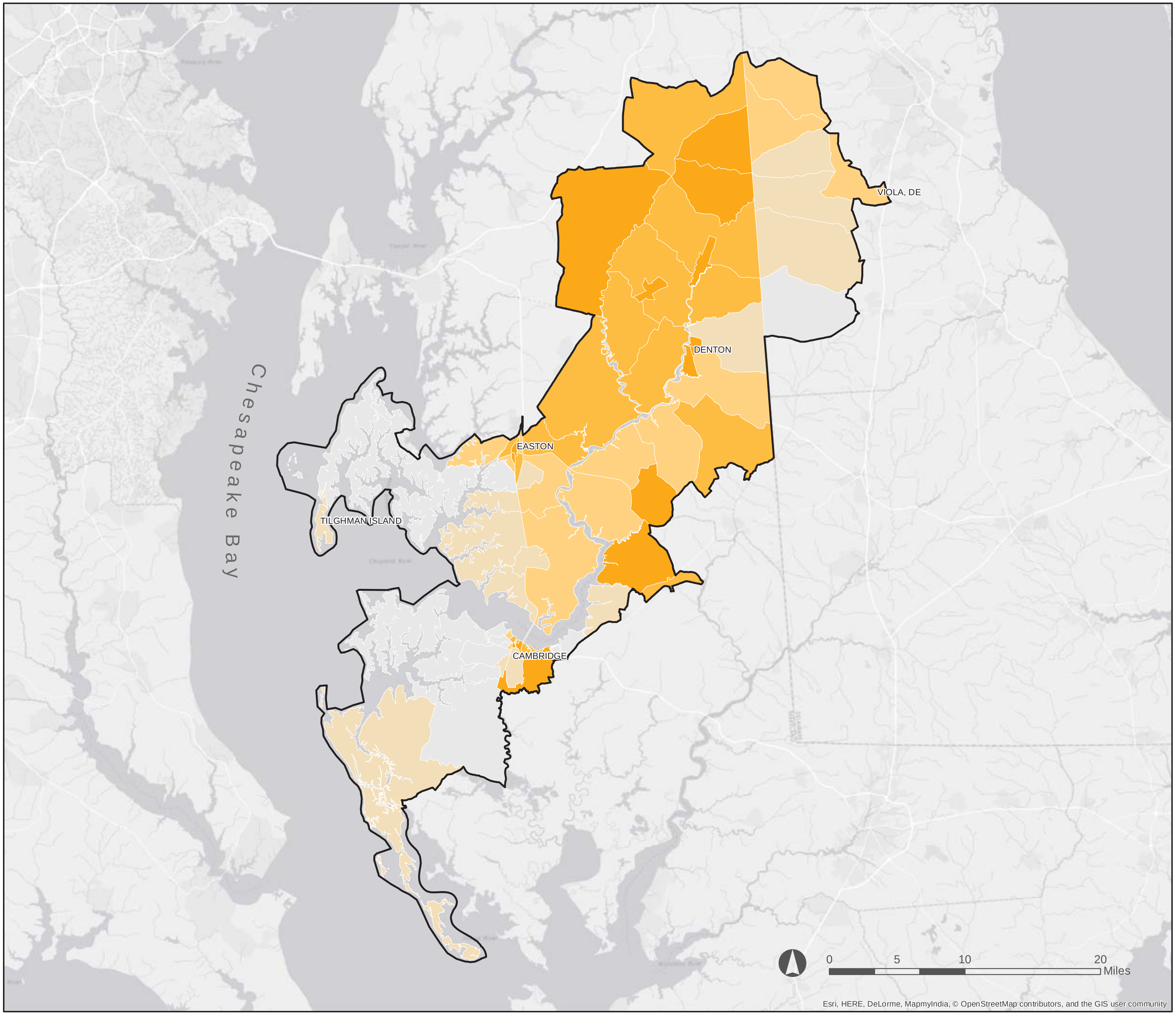
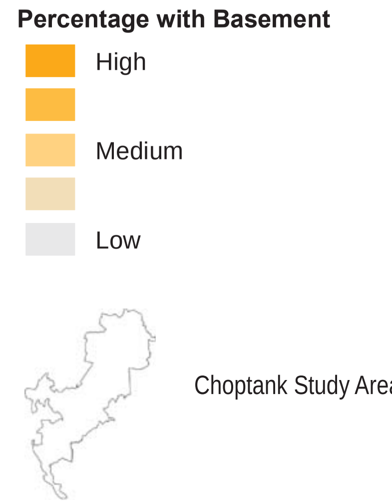
Basement Component of Structural Vulnerability





This component utilizes parcel level data to determine the percentage of structures within each block group with a basement. Basements and structures with floors below ground level are more susceptible to flooding.

This component is one of three which combine to determine the structural vulnerability index score as shown on the Composite Structural Vulnerability map.

Dark orange areas correspond with higher percentages, while grey areas correspond with lower percentages.

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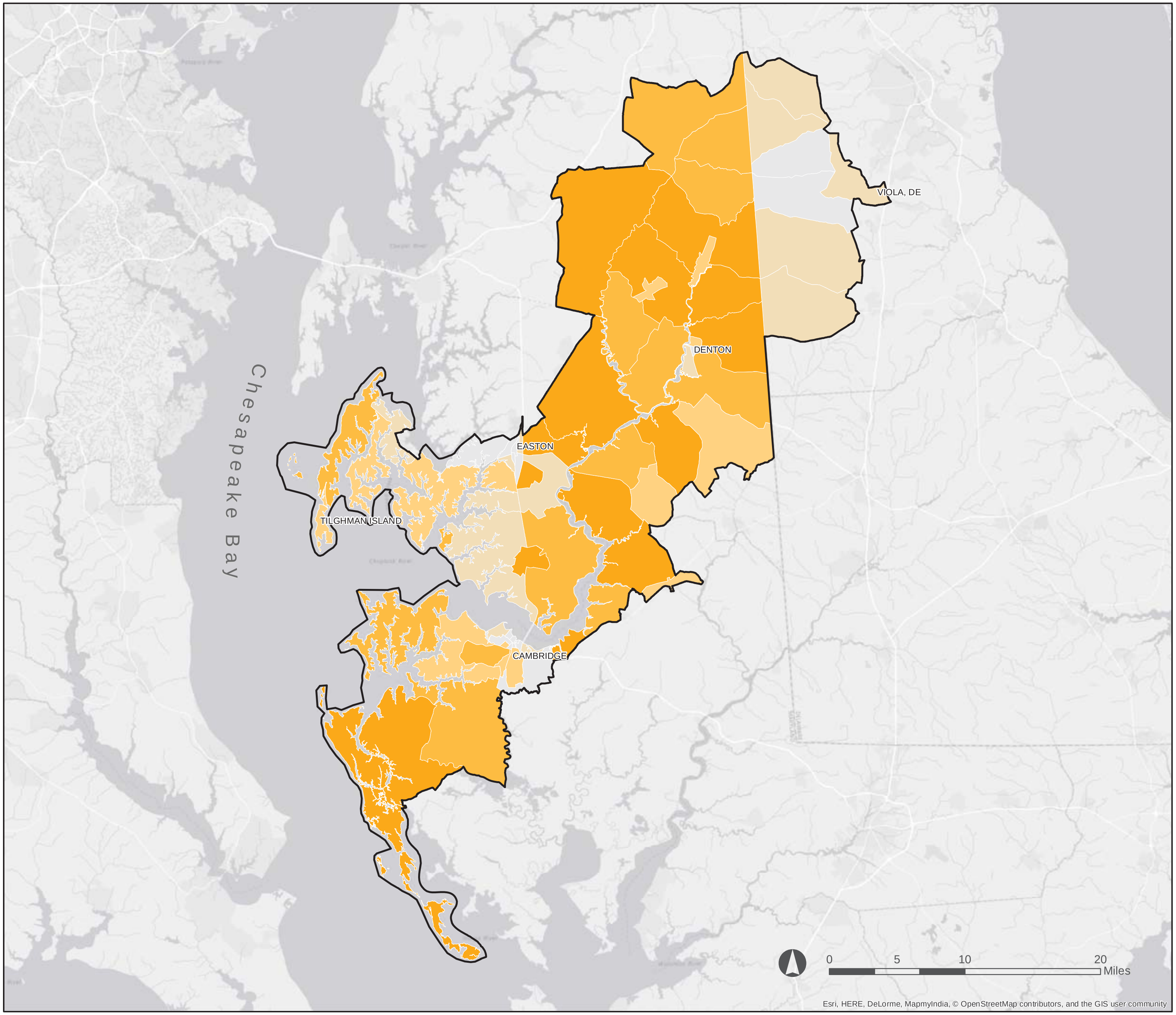
Figure B-10

Structure Material Component of Structural Vulnerability



Percentage Wood-Based Structures

- High
- Medium
- Low

Choptank Study Area

This component utilizes parcel level data to determine the percentage of structures within each block group with wood-based foundations. FEMA suggests that wood-based foundations are more vulnerable to flood hazards.

This component is one of three which combine to determine the structural vulnerability index score as shown on the Composite Structural Vulnerability map.

Dark orange areas correspond with higher percentages, while grey areas correspond with lower percentages.

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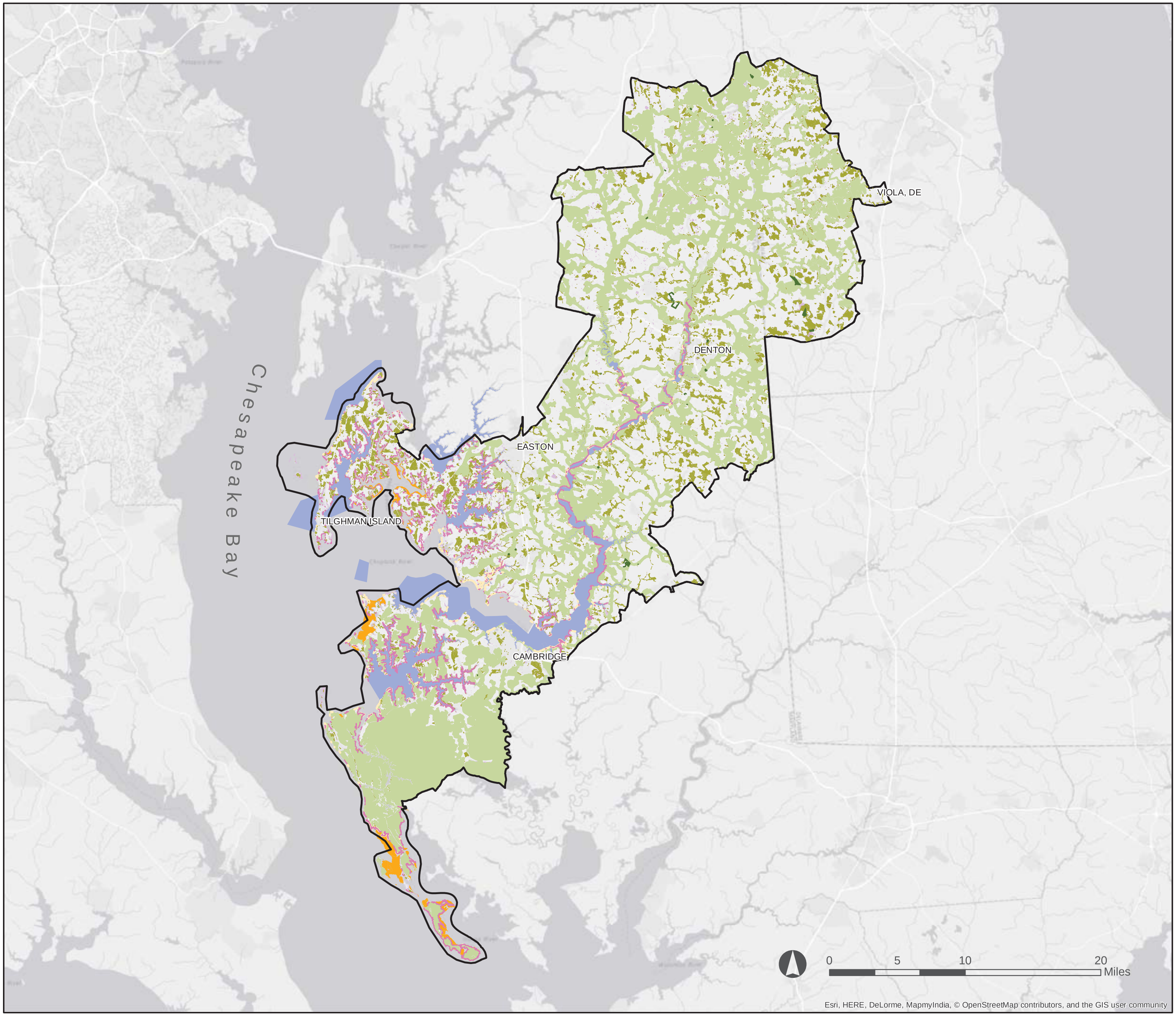
Figure B-11

Distribution of Natural Resources



This map displays the distribution of natural resources and their spatial extent throughout the Choptank HFA. In total, eight natural resources are displayed: wetlands, beaches, marsh, green infrastructure, submerged aquatic vegetation, oyster sanctuaries, forested areas, and forest conservation easements.

Figure B-12

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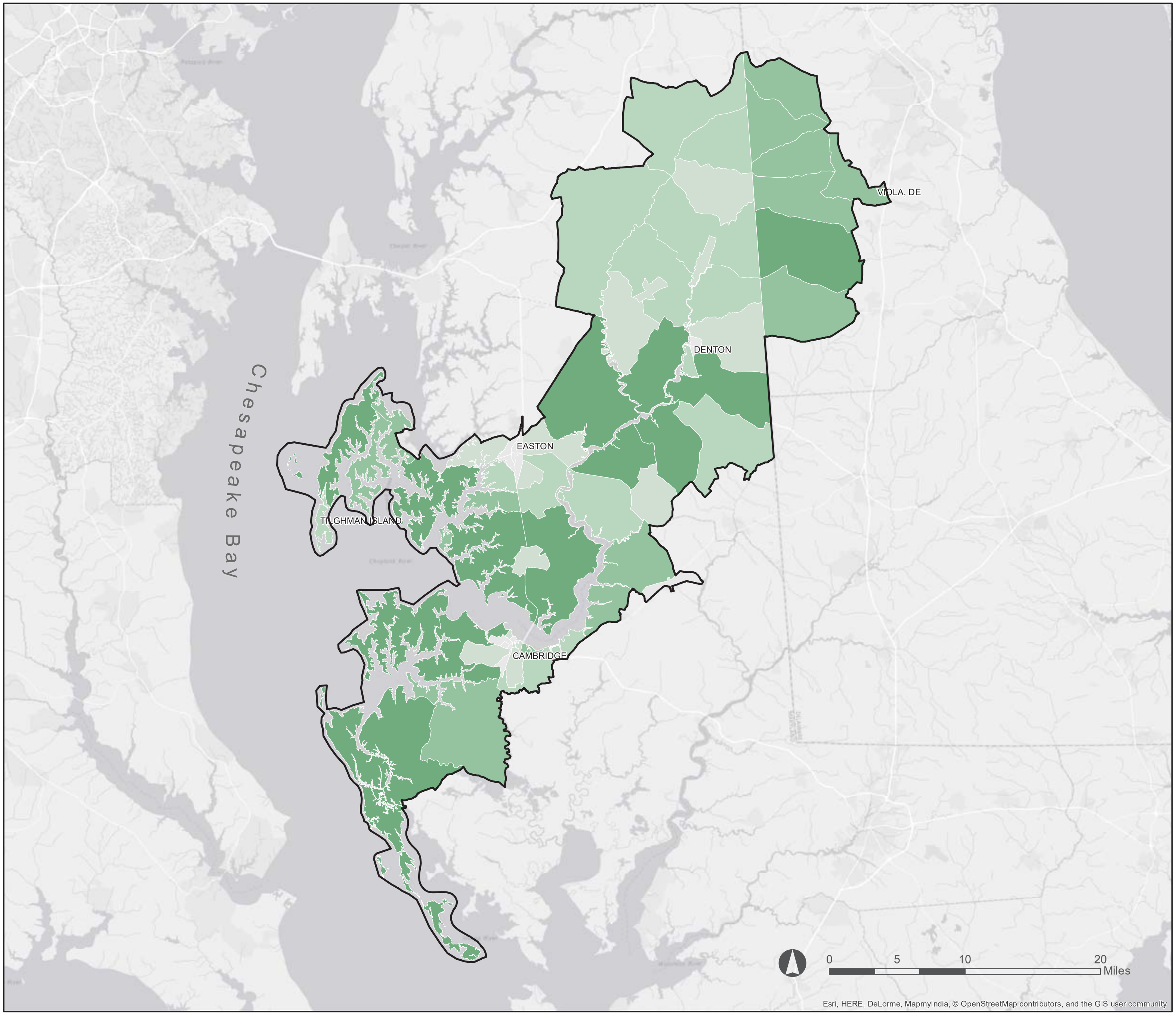
Valuation of Natural Resources



Value Score

- High
-
- Medium
-
- Low

Choptank Study Area

Natural resources have been shown to provide monetary value to nearby and adjacent properties that is inherently included in property prices. The above value scores are based on an ordinal scale. Habitats included in this analysis are: wetlands, beaches, marsh, green infrastructure, submerged aquatic vegetation, oyster sanctuaries, forested areas, and forest conservation easements.

Dark green areas correspond with higher natural resource value, while light green areas correspond with lower natural resource value.

Figure B-13

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SECTION 2: FLOOD RISK

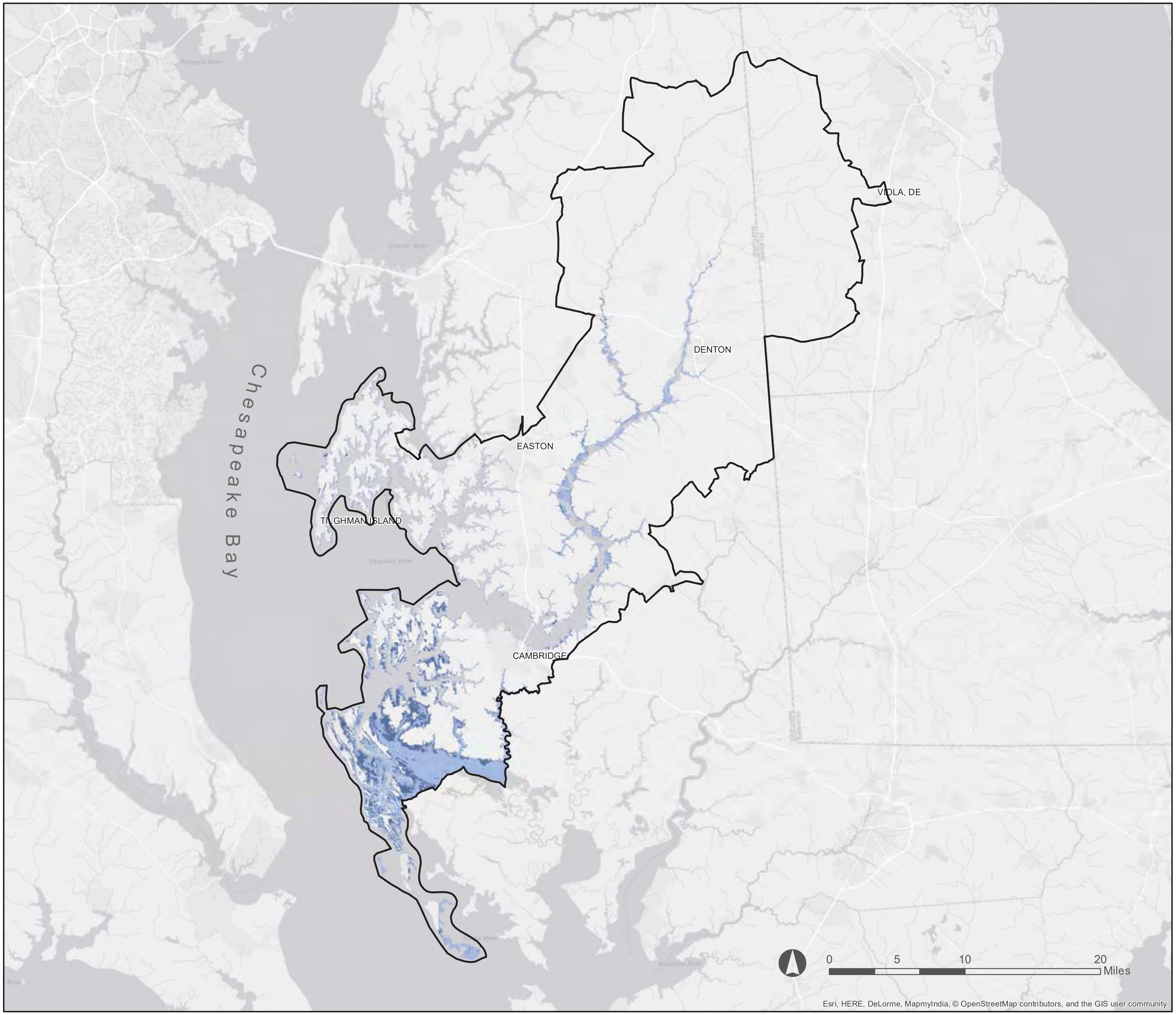
Section 2 provides maps of projected sea level rise inundation of 1 and 2 ft, category 1 and 2 hurricane storm surge areas, and stormwater flood prone areas. Similar to the approach used by Wu and colleagues (2002), indicators of social vulnerability, structural vulnerability and natural resource valuation were analyzed against short term risks (storm surge and stormwater flooding) and long term risks (sea level rise). The first phase of analysis examined these risks and where they were most likely to occur within the study area.

The sea level rise layers selected for this study are a product of the NOAA Office of Coastal Management. Sea level rise of 1 and 2 feet were used to assess risk in the socioeconomic, environmental, and infrastructure analyses via intersection with Choptank HFA census block groups, spatially.

The storm surge data selected for this study were created by the Army Corps of Engineers, Philadelphia District, and utilize the Sea, Lake and Overland Surges from Hurricanes (SLOSH) Model. SLOSH is a computerized model run by the National Weather Service to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes. The model creates estimates by assessing the pressure, size, forward speed, track, and wind data from a storm (National Hurricane Center, 2015).

The stormwater flood prone areas layer considers conditions which contribute to or are favorable for stormwater flooding, and identifies these locations throughout the study area. Based upon literature relating to favorable conditions for stormwater flooding, the indicators used in the measurement of stormwater flooding risk were: 1) elevation, 2) land cover class, and 3) soil type. Coastal areas with low elevations are prone to stormwater flooding due to slow drainage from flat land and high water tables. Urban areas create an additional likelihood of stormwater flooding due to the increase in impervious surfaces, which encourages stormwater runoff. Lastly, rain water is unable or less likely to infiltrate locations where soil is compacted or poorly drained.

Projected Sea Level Rise of 1 and 2 ft



Sea Level Rise (1 ft)

Sea Level Rise (2 ft)

Choptank Study Area

Projected sea level rise is shown as the amount of the total land area that would be inundated in a sea level rise scenario, at 1 foot and 2 feet above mean higher high water (MHHW).

Light blue corresponds with 1 ft of projected sea level rise impact, while dark blue corresponds with 2 ft of projected sea level rise impact.

Figure B-14

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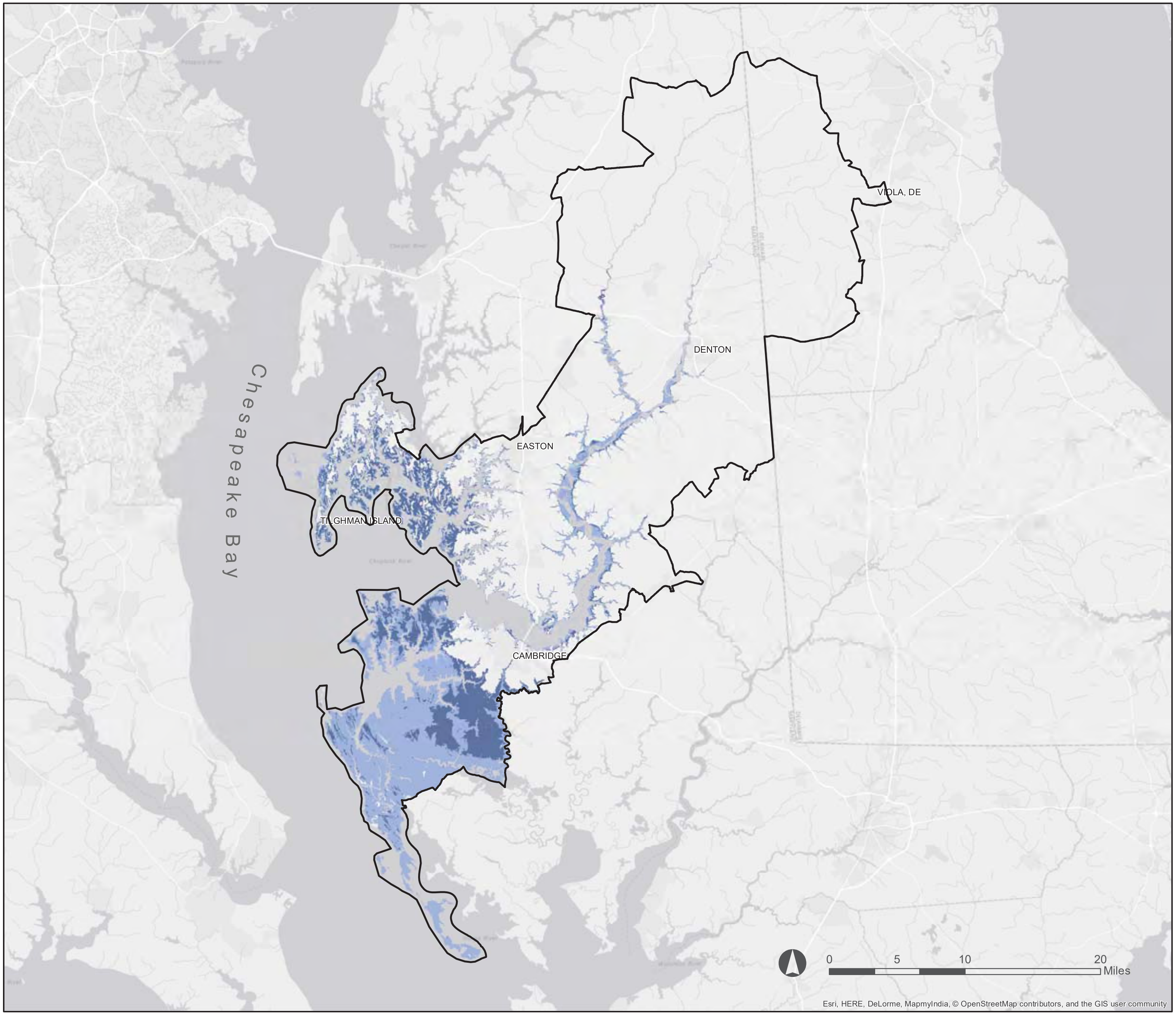
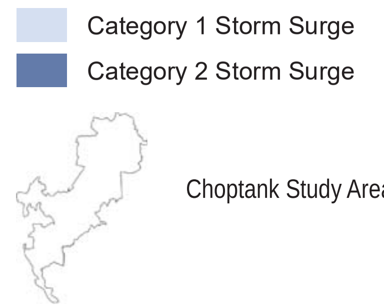
Category 1 and 2 Storm Surge Impact





Storm surge is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tides. In the case of a category 1 hurricane event, storm surge can range from 3 to 5 feet. Unlike projected sea level rise, which poses a future risk, storm surge is a short term risk and presently threatens persons and property within the hazard area.

Category 1 and category 2 storm surge impact is shown as the total land area that would be exposed to storm surge.

Light blue corresponds with category 1 storm surge impact, while dark blue corresponds with category 2 storm surge impact.

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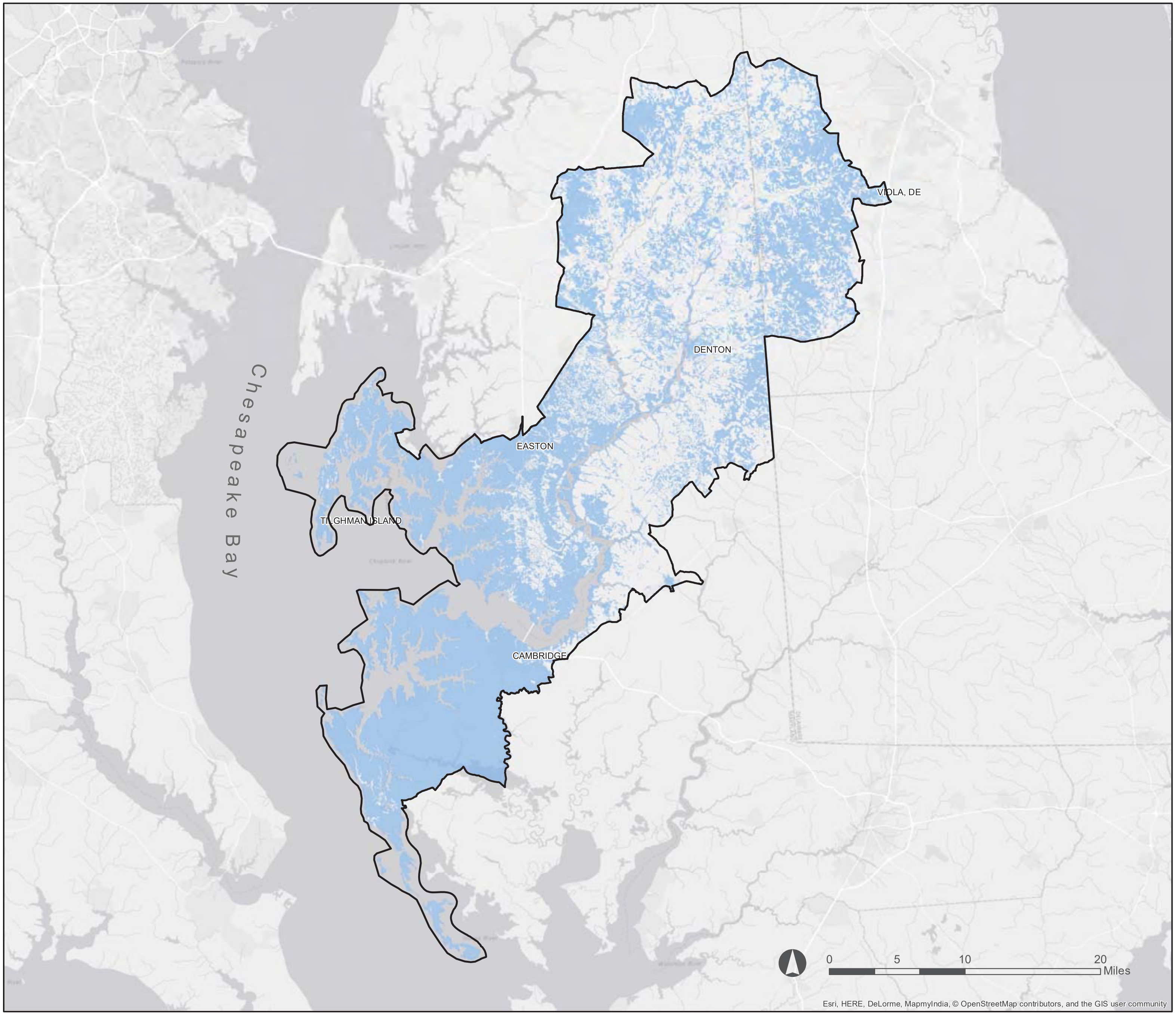
Figure B-15

Potential Stormwater Flooding



Stormwater flooding is shown as the total land area that would be impacted by stormwater flooding. Scores are a summation of the presence of three conditions: elevation (0- 2 ft), developed land cover, and poorly drained soils.

Figure B-16

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SECTION 3: VULNERABILITIES AND FLOOD RISK

Section 3 provides maps that intersect social vulnerability, structural vulnerability, or natural resource vulnerability with sea level rise risk, storm surge risk, or stormwater flooding risk for the Choptank HFA study area.

This series of maps provides managers with the ability to easily compare analyses of the different indicators (socioeconomic, structural, and natural resource) to one another and to visualize spatial patterns in vulnerabilities and risks. By creating a score for each block group, the complicated relationship between the indicator values and the vulnerabilities to climate related flood hazards can be depicted. The scores and common color gradient also make it possible for managers to easily compare the different analyses.

For each base vulnerability, bivariate choropleth maps (maps that depict two variables at once along a bidirectional color gradient) were created to include a single vulnerability and a single risk, both scaled low, medium, or high, and intersected in one map. These maps serve as a visual tool to expose areas where high vulnerability corresponds to high risk. Such maps can help prioritize actions and aid in making decisions when considering particular vulnerabilities and risks. Areas with high vulnerability and high risk would be of primary importance, while areas of low vulnerability and low risk would be of less concern.

Some highlights from this section include that when social and natural resource vulnerability are intersected with all coastal flood risks, the southernmost block groups are of most concern. This is not the case for structural vulnerability. Block groups located centrally have similarly varying levels of combined flood risk and social, structural, and natural resource vulnerability. The municipalities of Cambridge, Easton, and Denton generally have high combined social vulnerability and flood risk, as well as high combined structural vulnerability and flood risk across the five coastal flood hazard scenarios. Conversely, these municipalities generally have low combined natural resource vulnerability. Although rarely the area with the highest combined vulnerability and risk within the study area, Tilghman Island and the surrounding region commonly have higher combined vulnerability and risk in comparison to many of the other coastal block groups.

Legends of how to read these maps are included at the beginning of each subsection.

Block groups that are **darkest** are areas where both vulnerability and flood risk are high

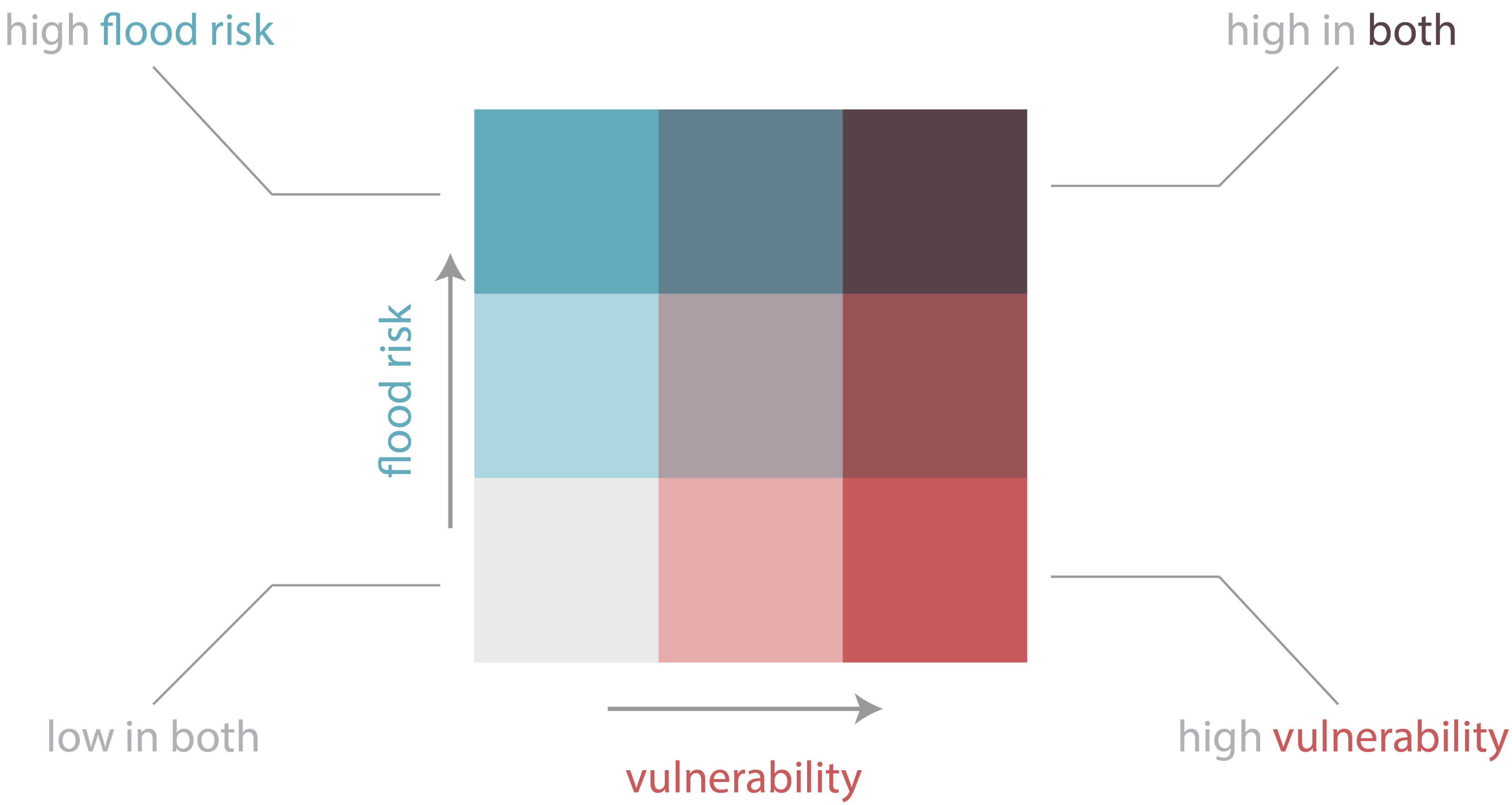

Figure B-17

Social Vulnerability and Sea Level Rise Risk of 1 ft

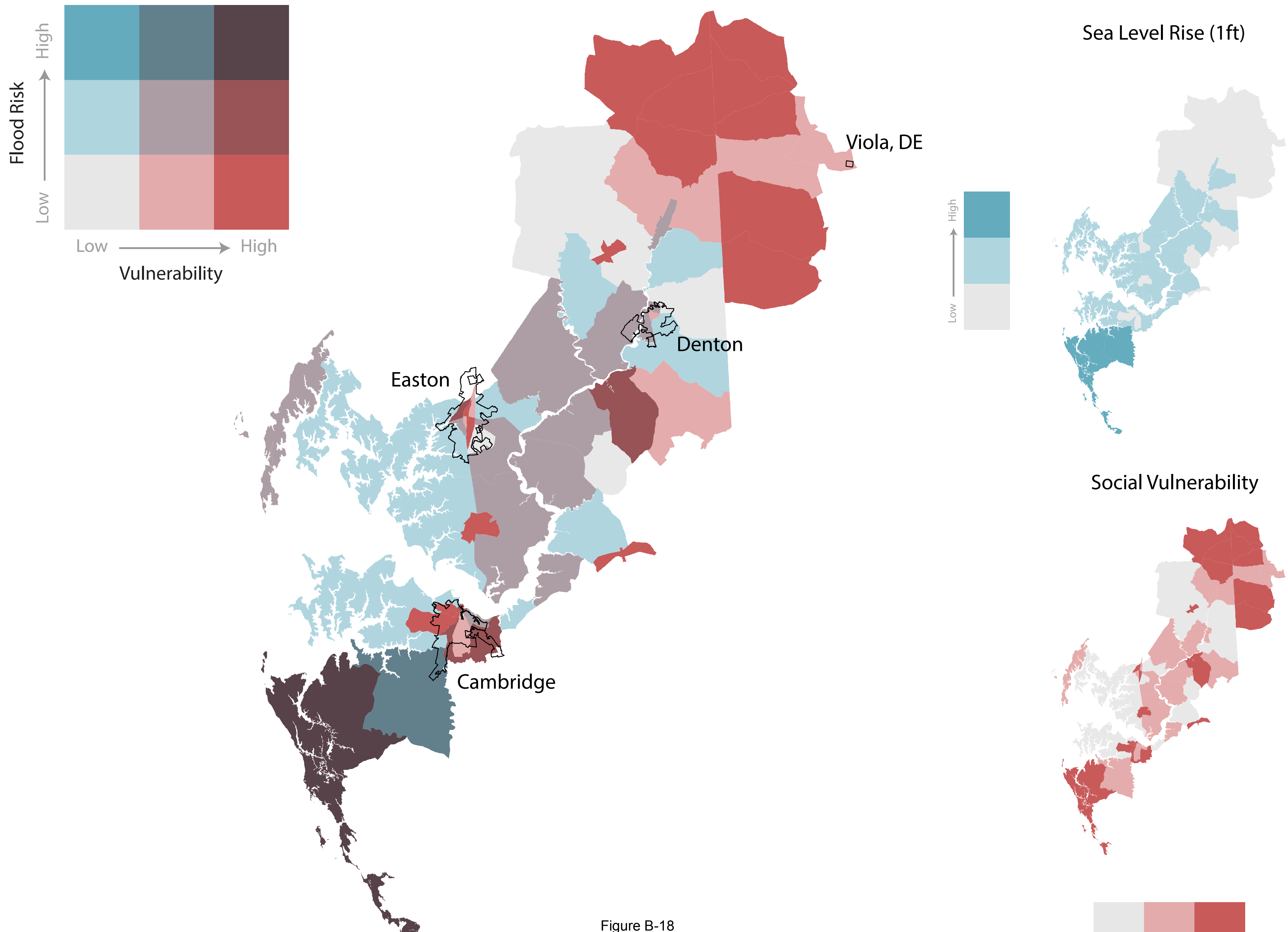

Figure B-18

Social Vulnerability and Sea Level Rise Risk of 2 ft

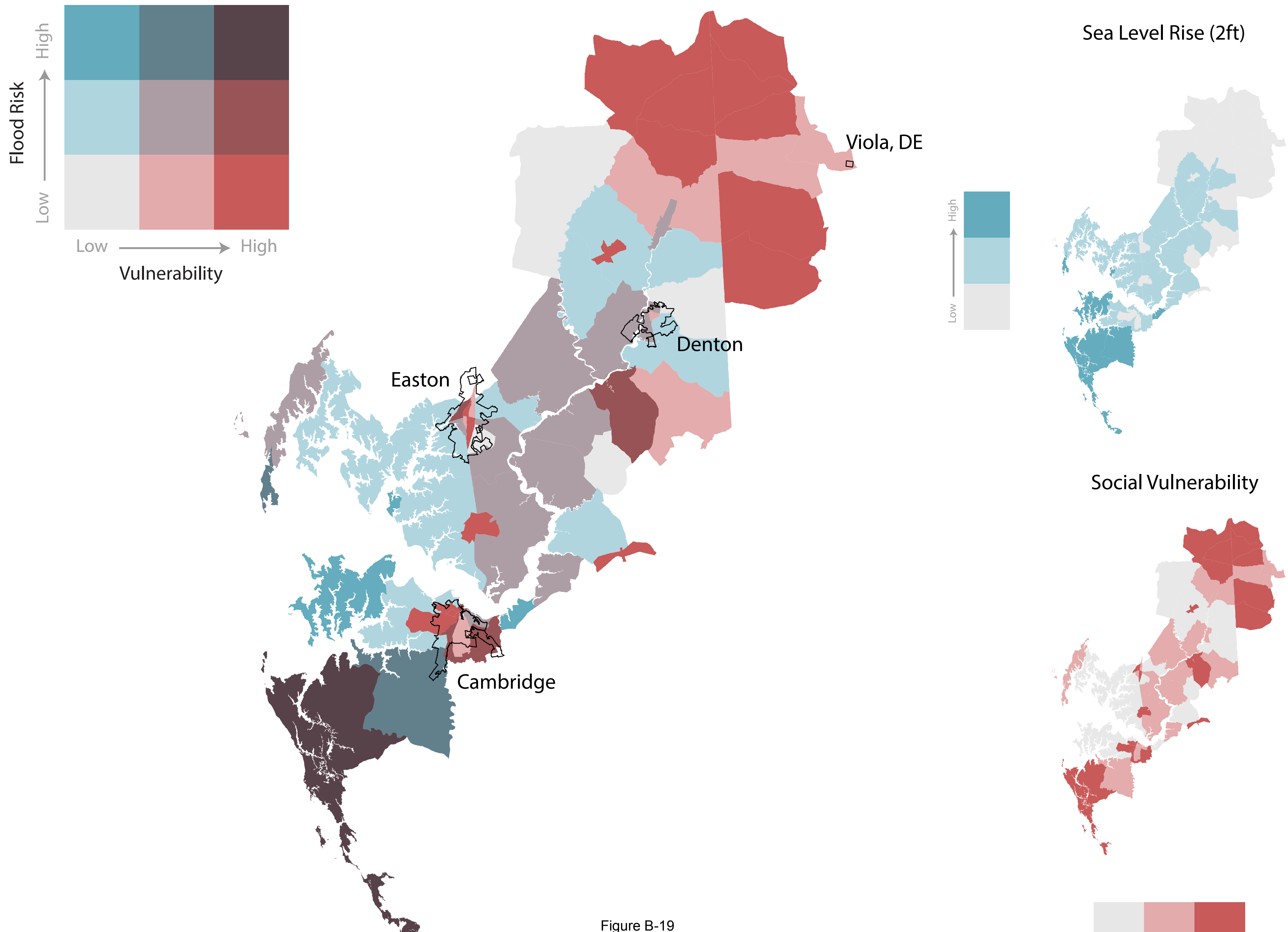

Figure B-19

Social Vulnerability and Category 1 Storm Surge Risk

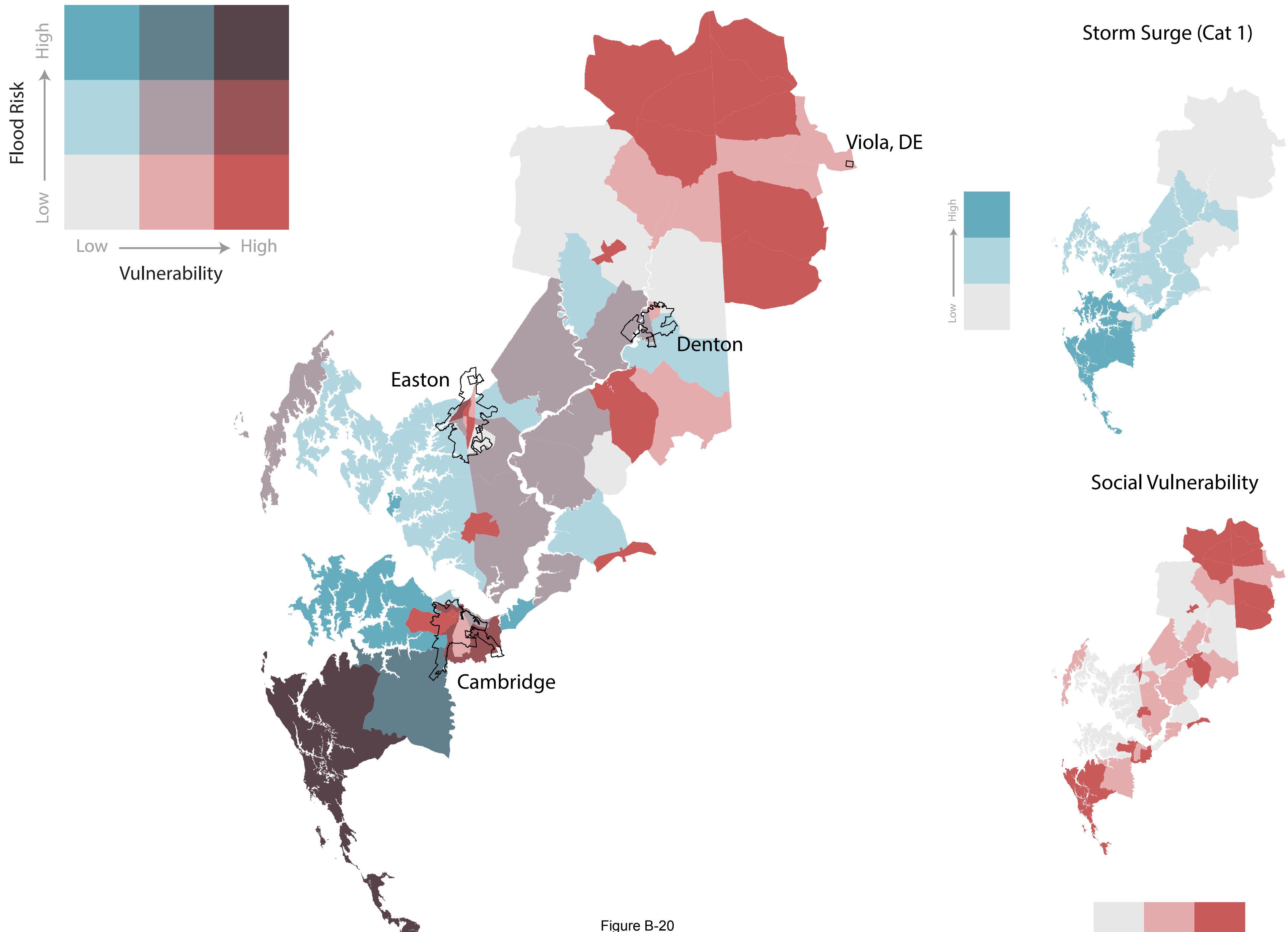

Figure B-20

Social Vulnerability and Category 2 Storm Surge Risk

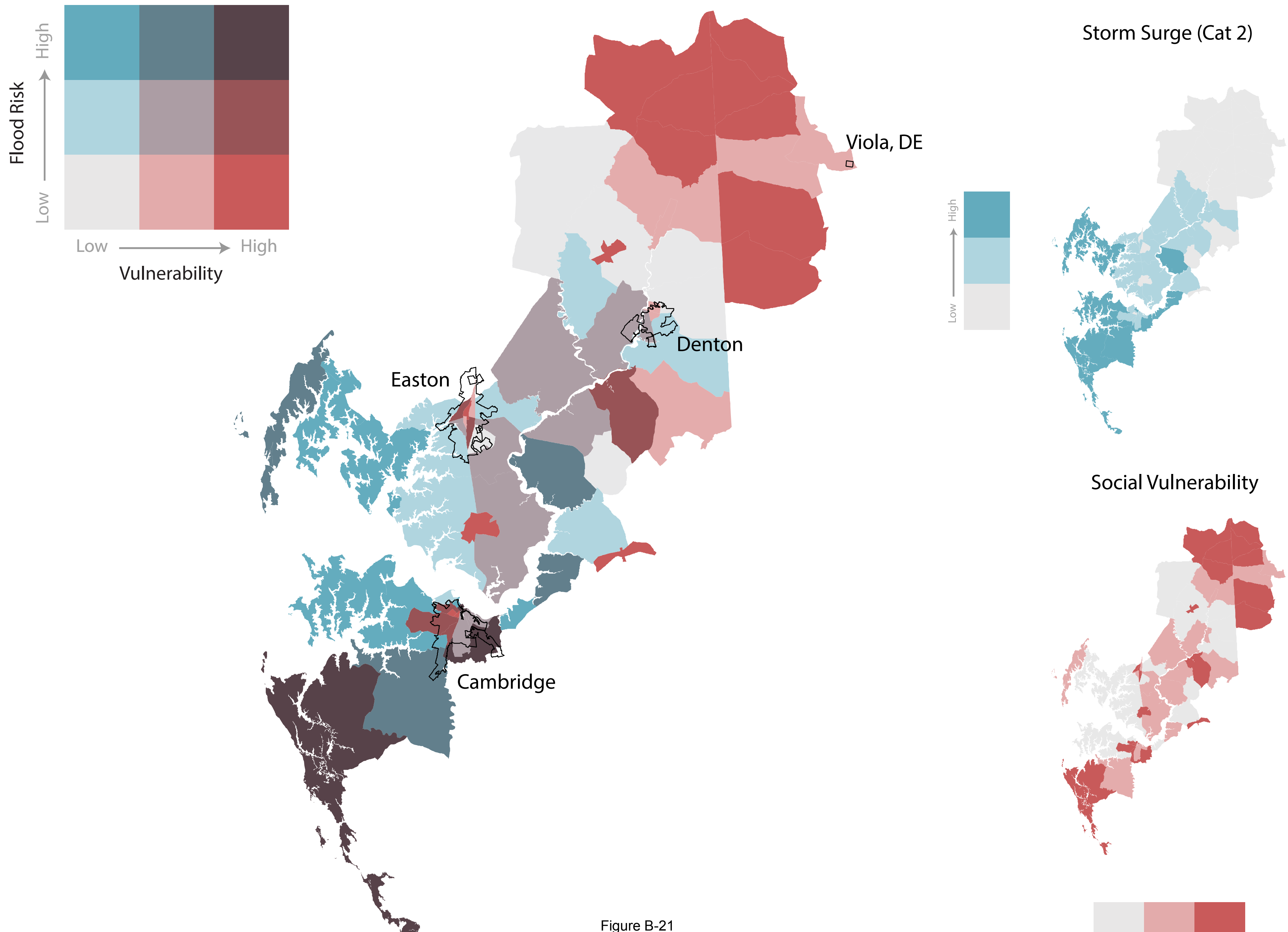

Figure B-21

Social Vulnerability and Stormwater Flooding Risk

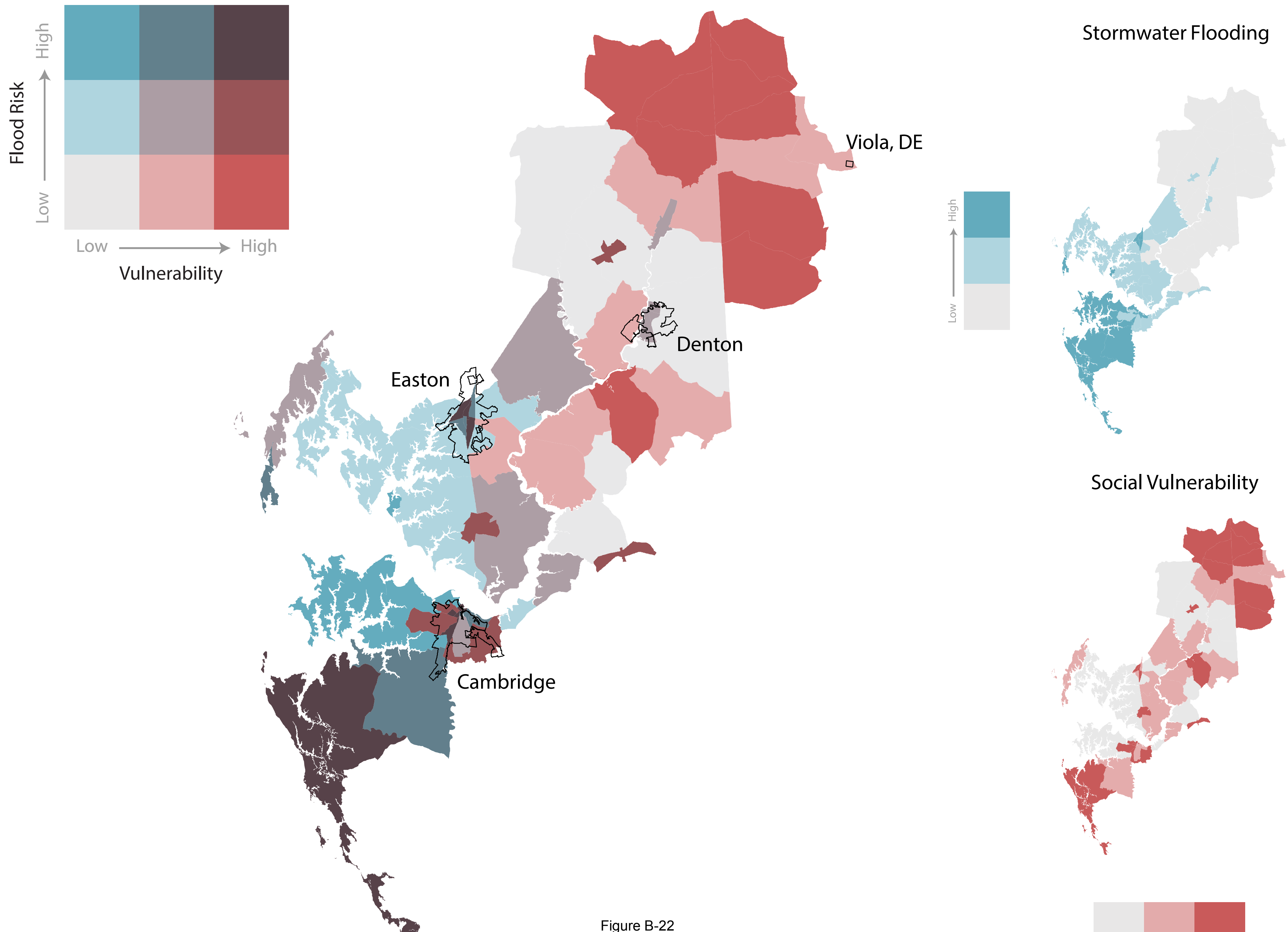

Figure B-22

Block groups that are **darkest** are areas where both vulnerability and flood risk are high

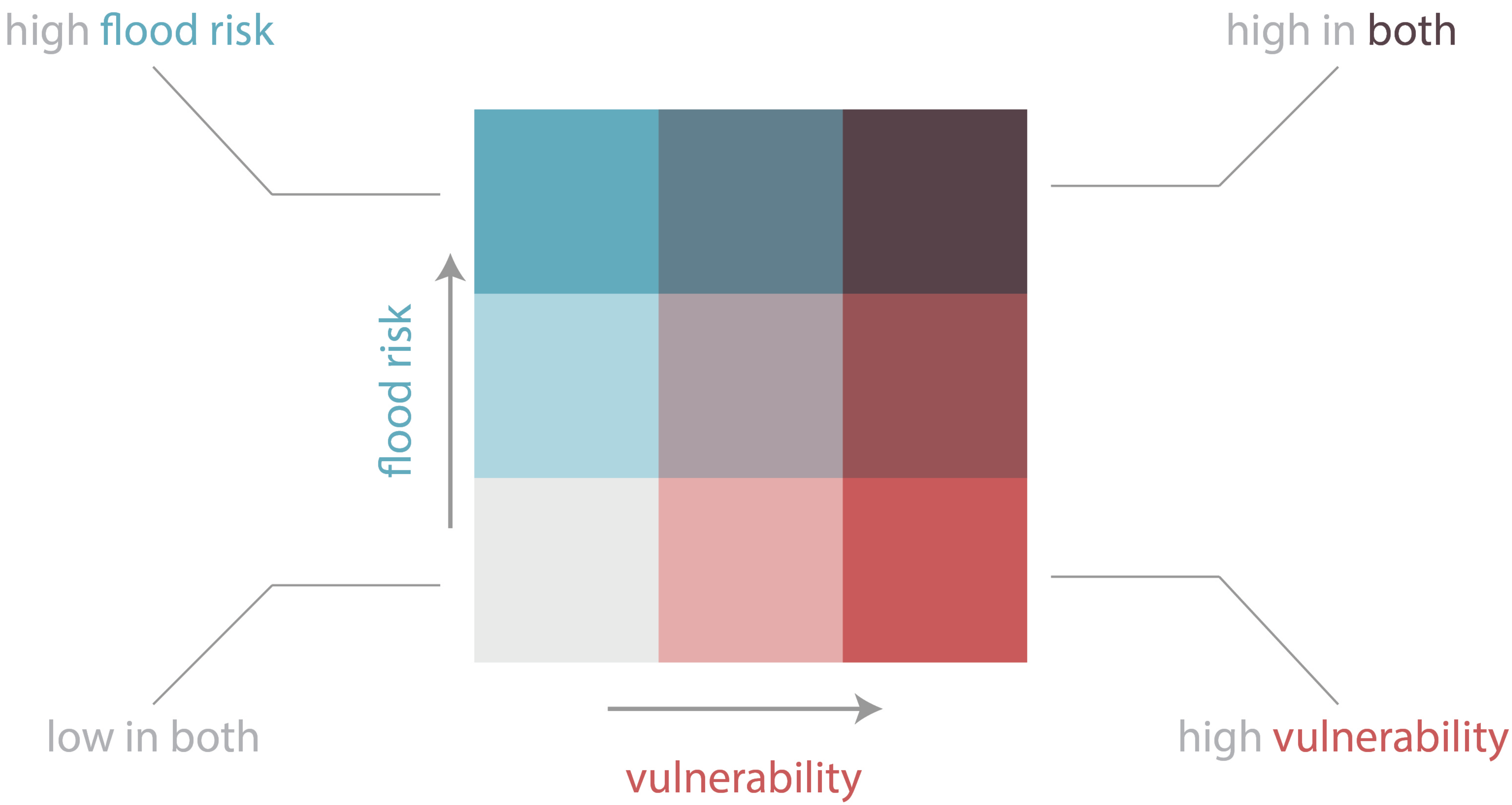

Figure B-23

Structural Vulnerability and Sea Level Rise Risk of 1 ft

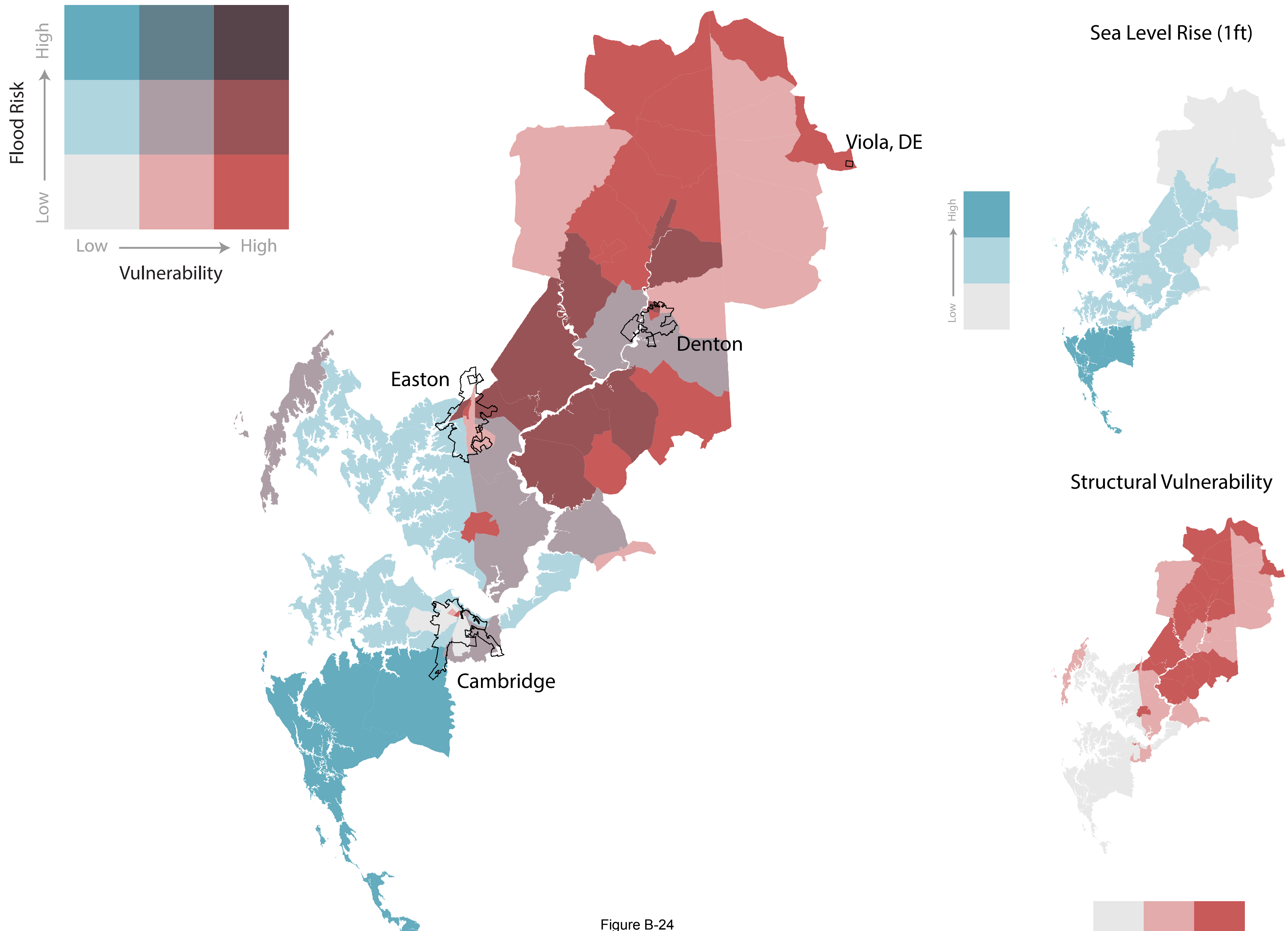

Figure B-24

Structural Vulnerability and Sea Level Rise Risk of 2 ft

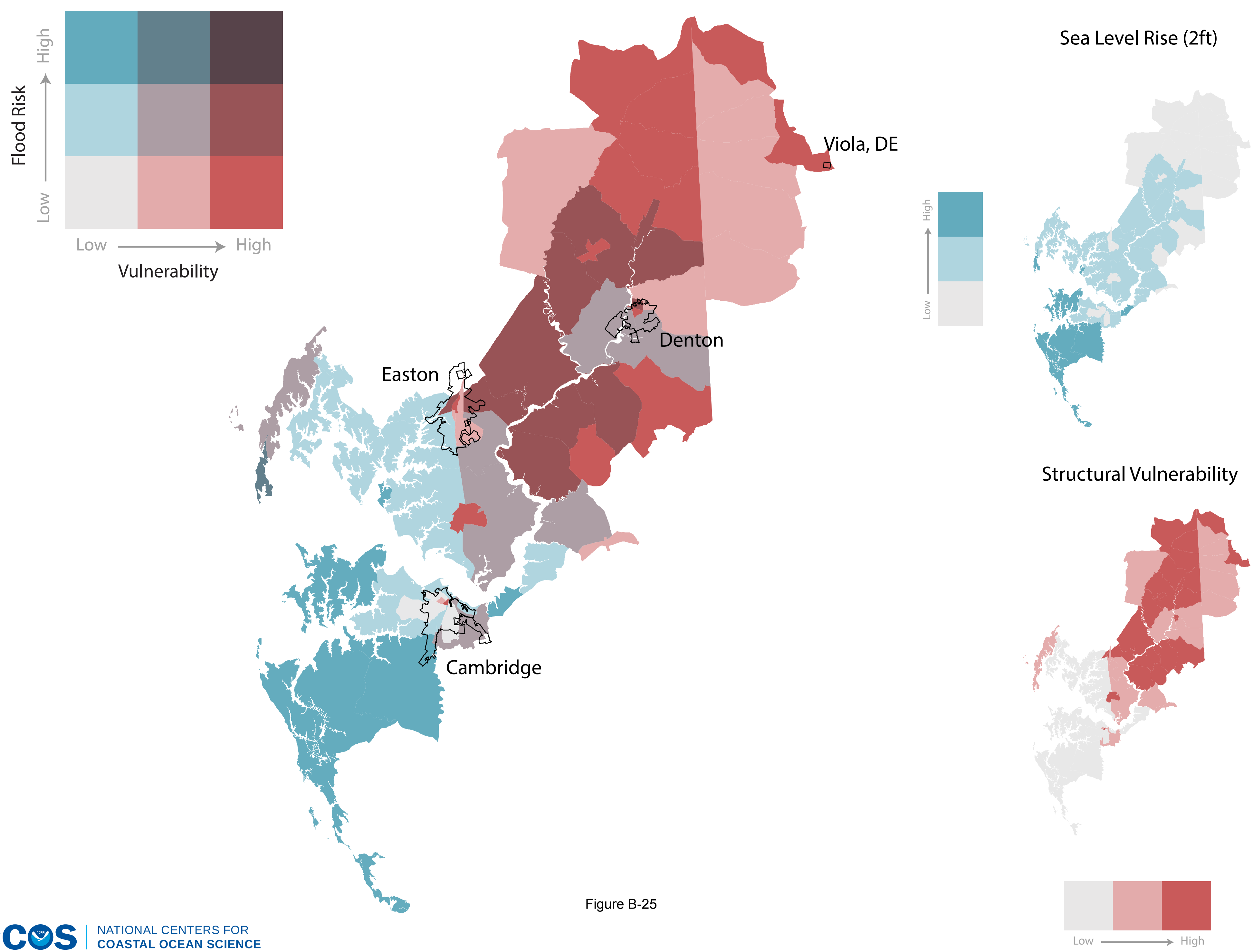

Figure B-25

Structural Vulnerability and Category 1 Storm Surge Risk

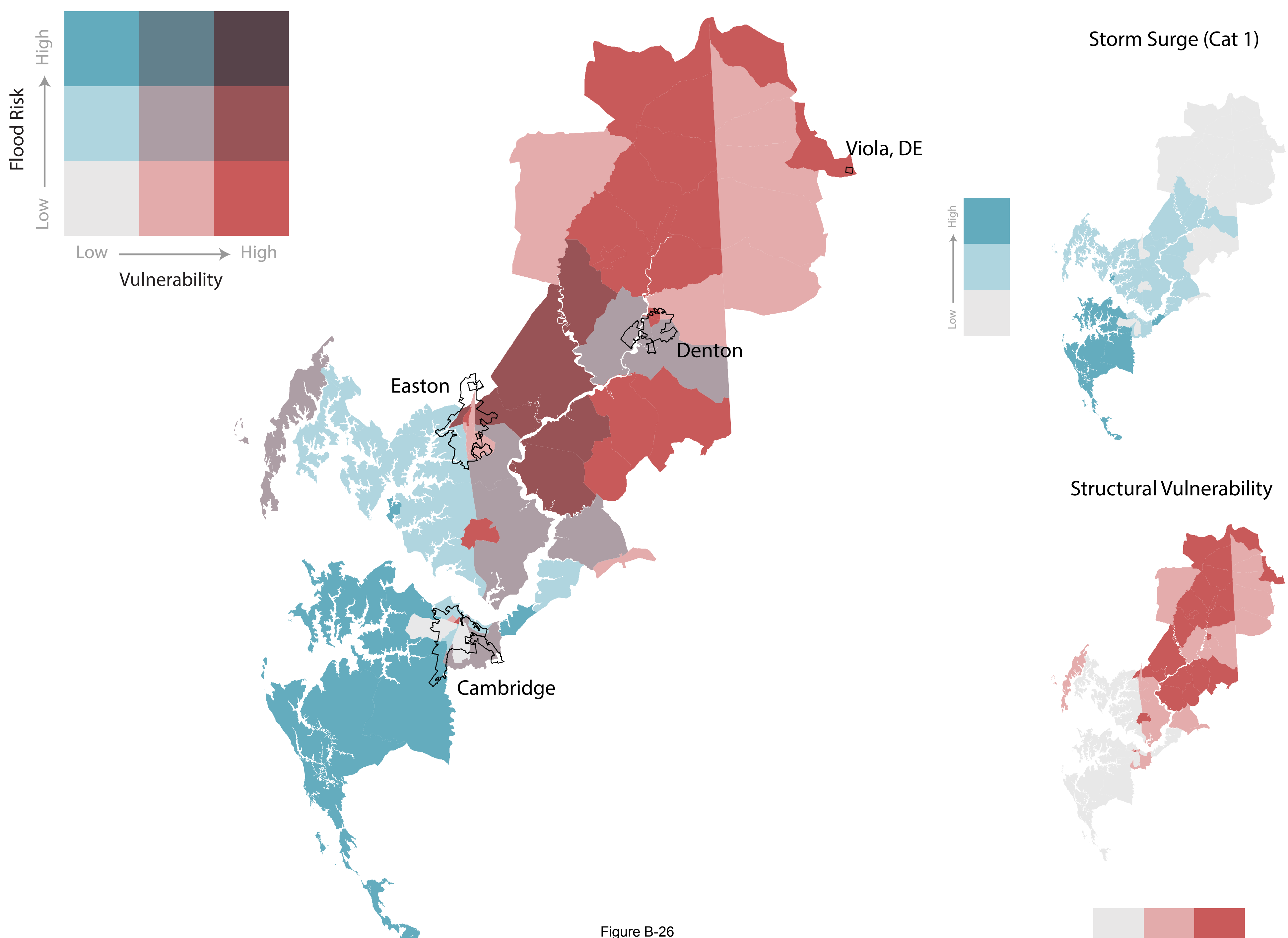

Figure B-26

Structural Vulnerability and Category 2 Storm Surge Risk

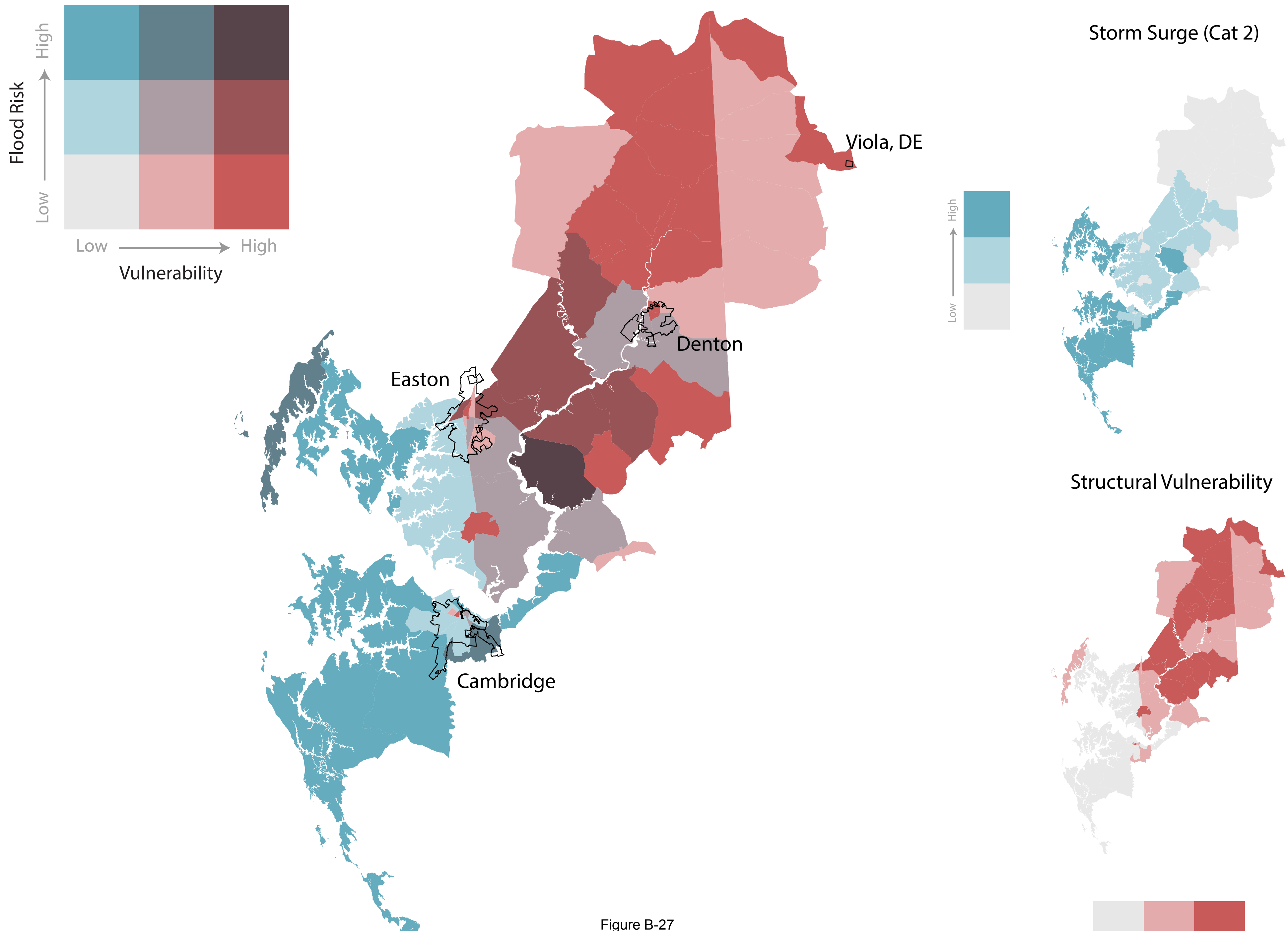

Figure B-27

Structural Vulnerability and Stormwater Flooding Risk

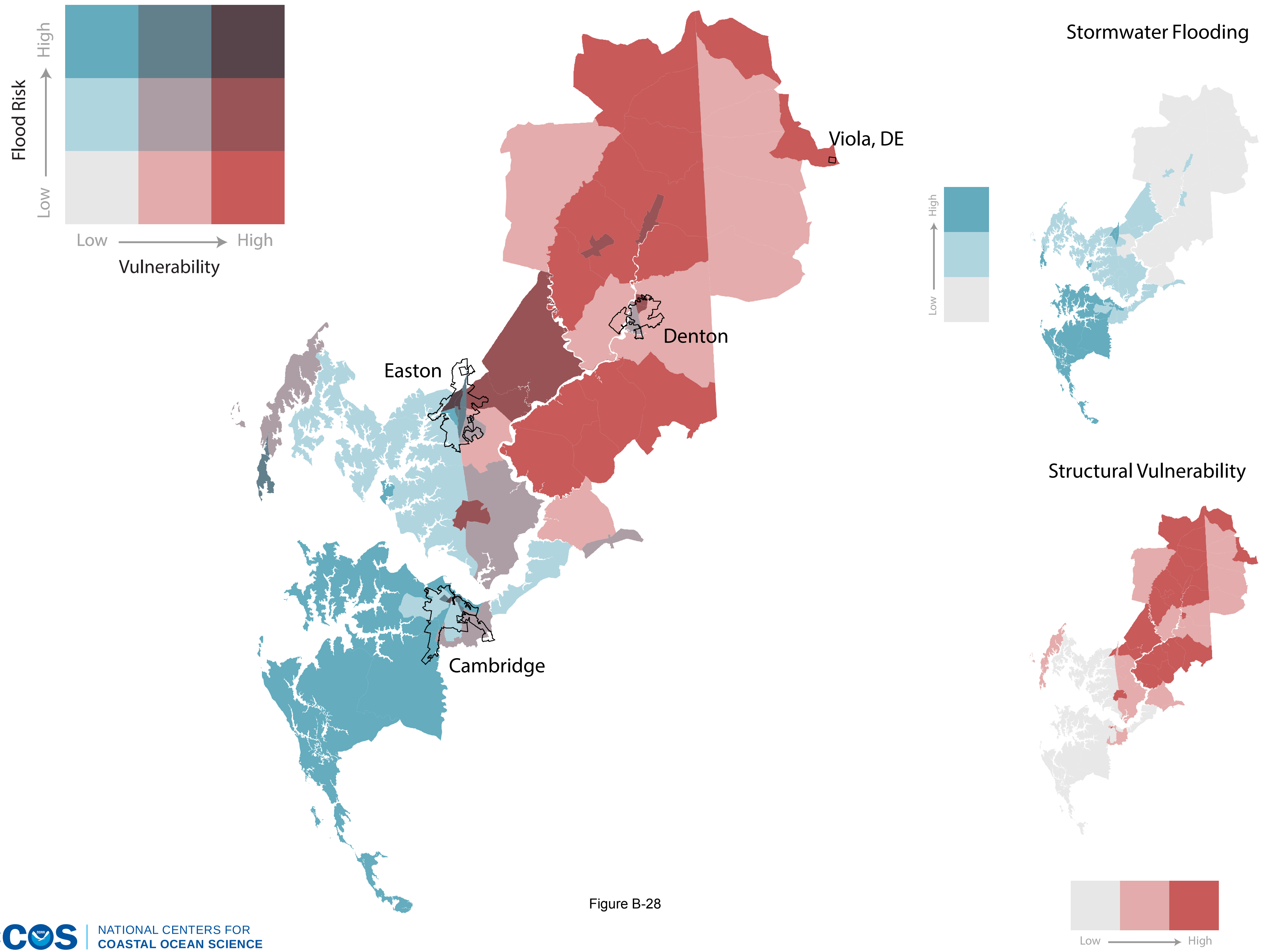

Figure B-28

Block groups that are **darkest** are areas where both natural resource valuation and flood risk are high

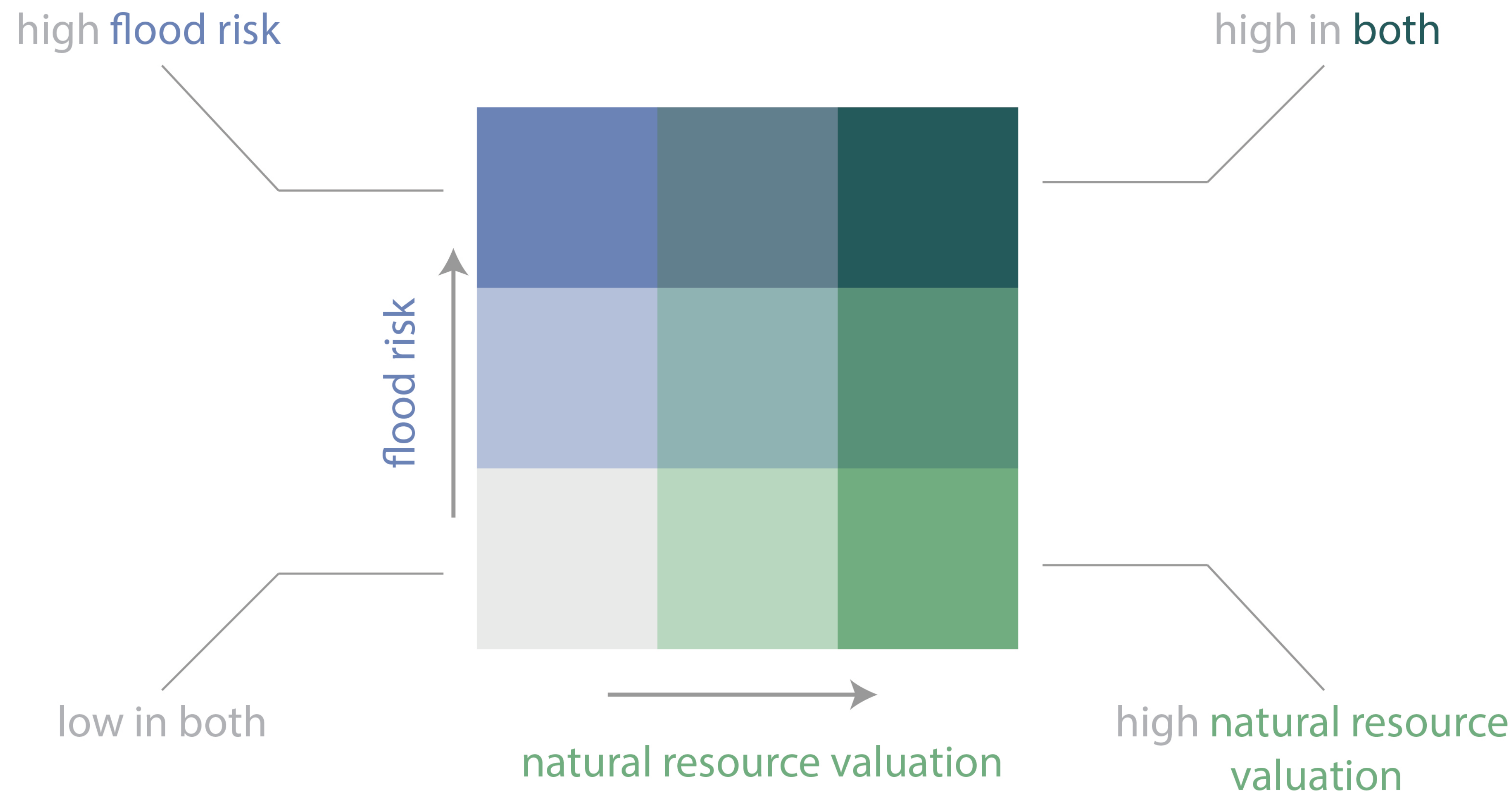

Figure B-29

Natural Resource Valuation and Sea Level Rise Risk of 1 ft

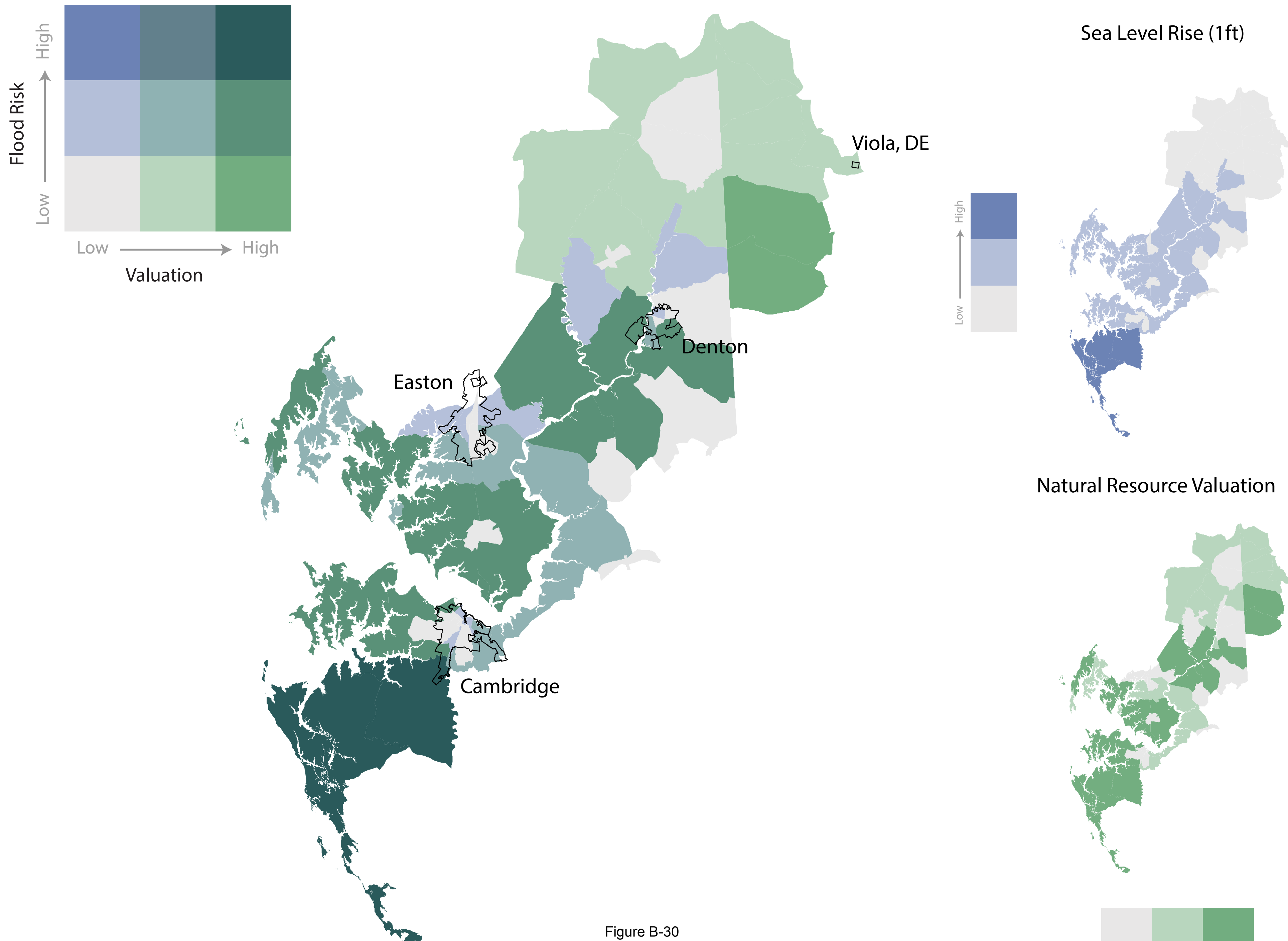

Figure B-30

Natural Resource Valuation and Sea Level Rise Risk of 2 ft

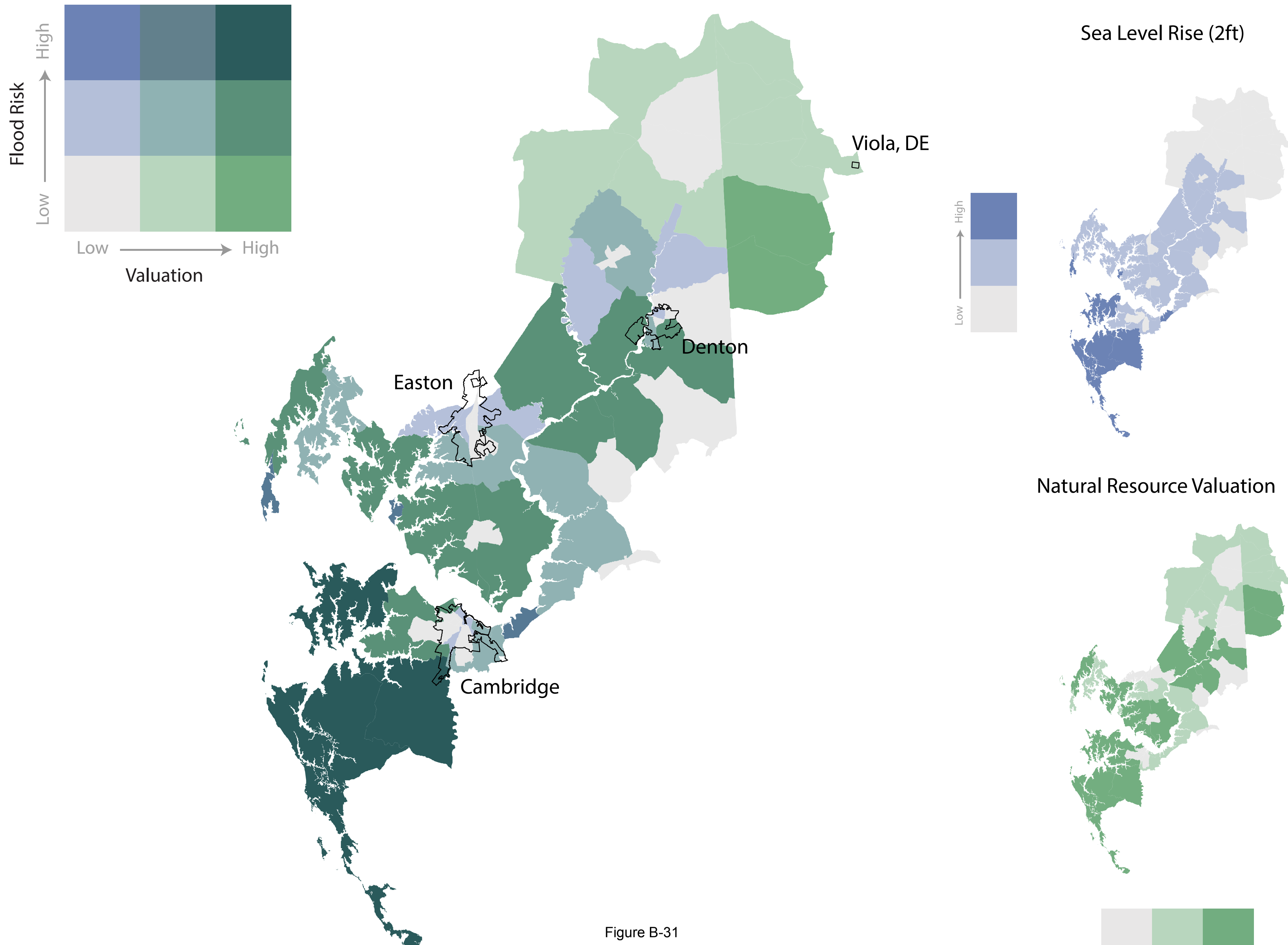

Figure B-31

Natural Resource Valuation and Category 1 Storm Surge Risk

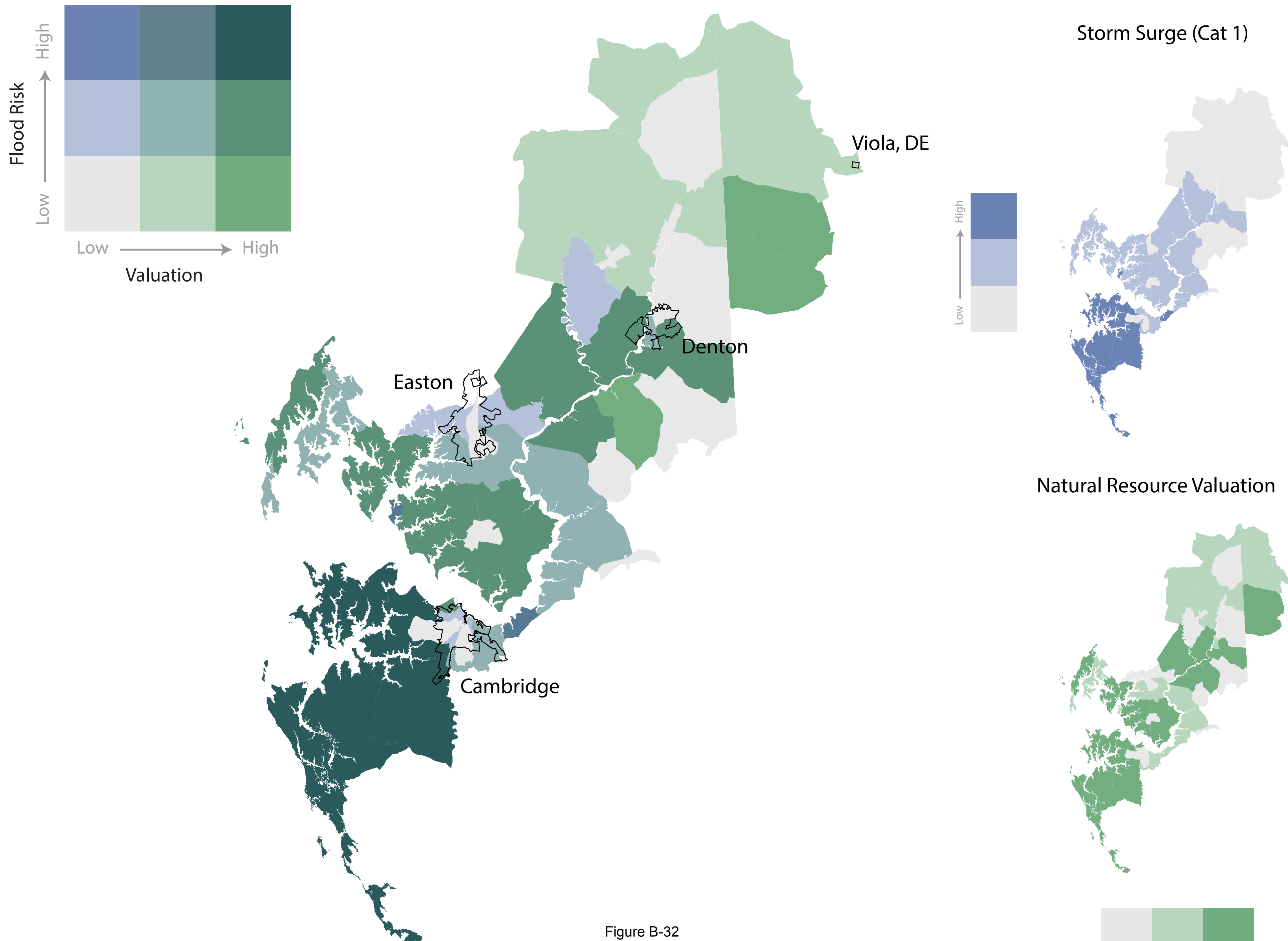

Figure B-32

Natural Resource Valuation and Category 2 Storm Surge Risk

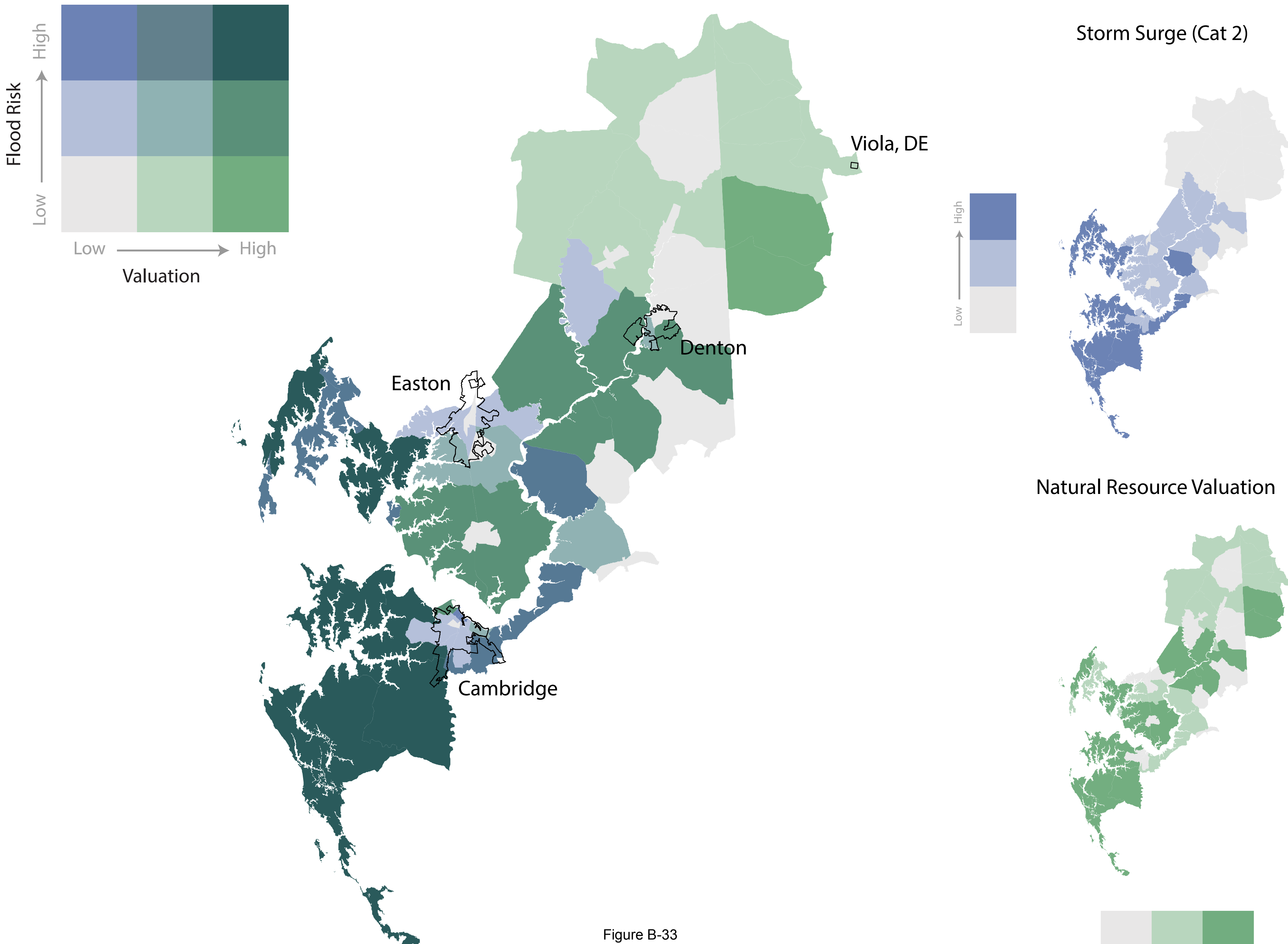

Figure B-33

Natural Resource Valuation and Stormwater Flood Risk

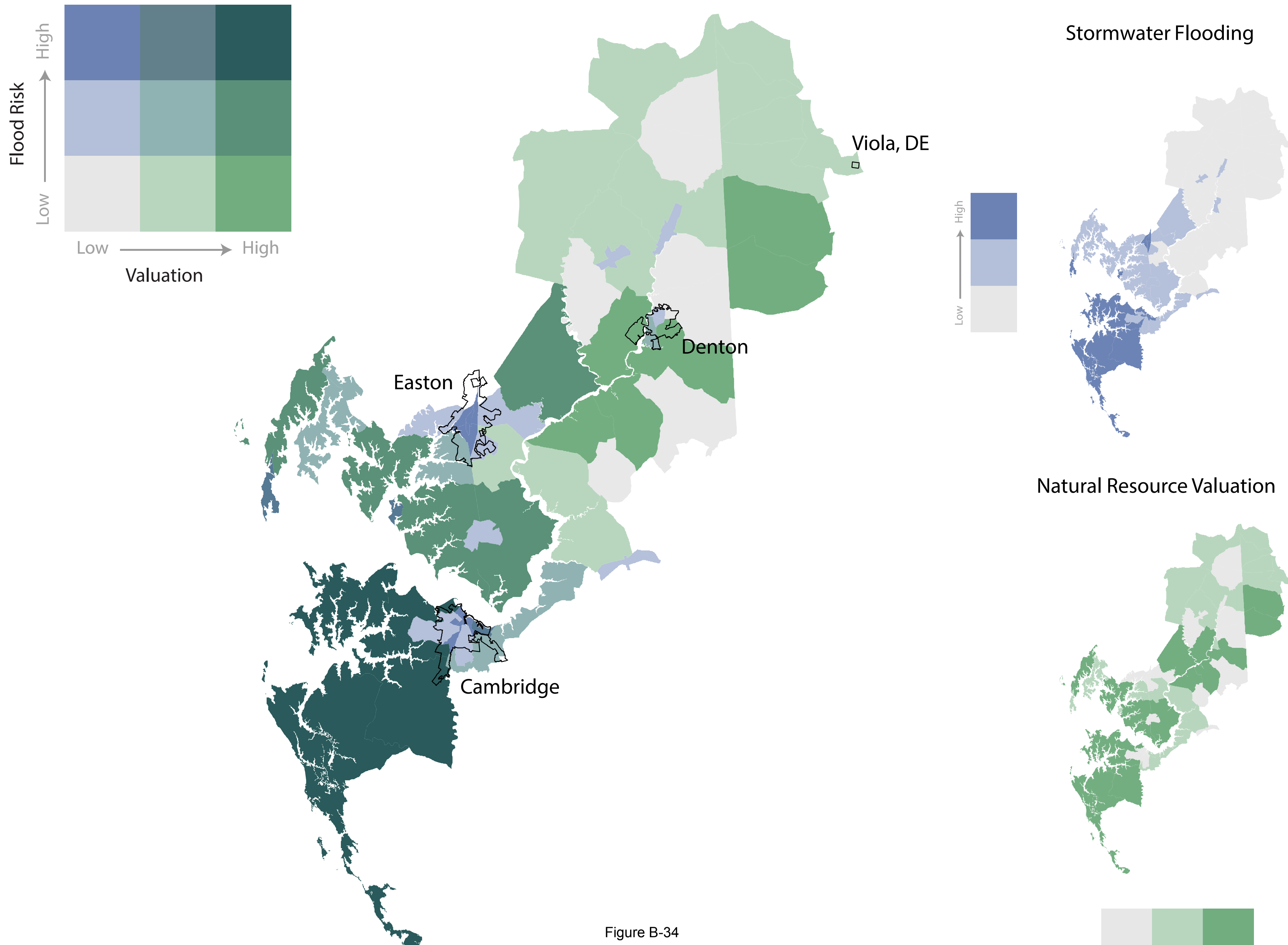

Figure B-34

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SECTION 4: ADAPTATION AREAS

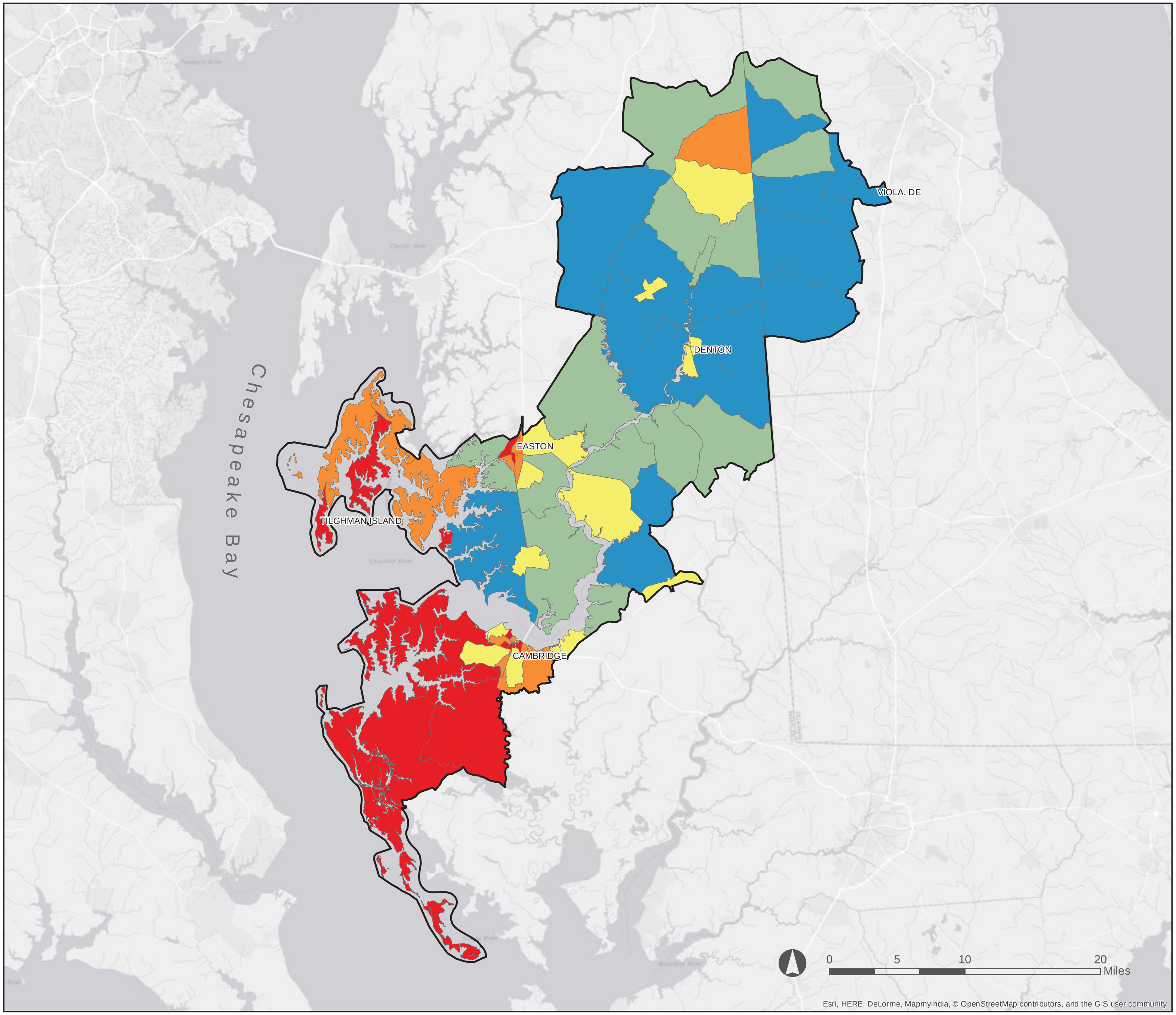
This final section provides maps of short and long term flood risk and vulnerabilities to support future prioritization for coastal flooding adaptation action. In the final phase of analysis, all vulnerabilities (social, structural, and natural resource) were intersected with either short or long term flood risks.

Short term risk was defined as category 2 storm surge and stormwater flooding impact (category 1 storm surge was inherently included with category 2 storm surge). Long term risk was defined as all short term risks and the addition of sea level rise of 2 feet (similarly to storm surge, sea level rise of 1 ft was inherently included in sea level rise of 2 ft).

By combining measures of risk with measures of vulnerability, the science team was able to establish adaptation areas that may be used to target priority areas for coastal flooding adaptation activities within the Choptank HFA study area. Vulnerability was calculated at the block group level, and social, infrastructure, and natural resource analyses were combined in an additive index and intersected with the risk score of the aforementioned flood risks. Block groups designated as Tier 1 should be highly prioritized when considering adaptation measures that address flood hazards within the Choptank HFA study area.

The results in this section show that Tier 1 areas (high overall vulnerability and risk) for short and long term risks are generally located closest to the coast, and are concentrated along the southwestern parts of the Choptank HFA study area. Tier 3 areas (medium overall vulnerability and risk) for short and long term risks are scattered throughout the central and northeastern regions of the study area; some of these areas increase to Tier 2 for long term risks. Lastly, Tier 5 areas (low overall vulnerability and risk) for short and long term risks are scattered throughout the central region of the study area, and also just south of the northernmost block groups; these remain fairly consistent for long term risks, but some of the central block groups increase in potential priority by moving from Tier 5 to Tier 4 when longer term risks are taken into account.

Coastal Flooding Adaptation Areas (Short Term)



Adaptation Priority Tiers

- Tier 1 - Highest
- Tier 2
- Tier 3
- Tier 4
- Tier 5 - Lowest

Short term vulnerability scores per block group are determined through a combination of risk analysis (category 1 and 2 storm surge and stormwater flooding impact) and vulnerability analysis (social, structural, and natural resource). Each census block group is scored as an index value from 0 to 1, and then represented as a tier (Tier 1 -Tier 5).

Tier 1 block groups are associated with the highest composite vulnerability and risk, and may indicate areas for prioritization of adaptation action that addresses coastal flooding within the study area.

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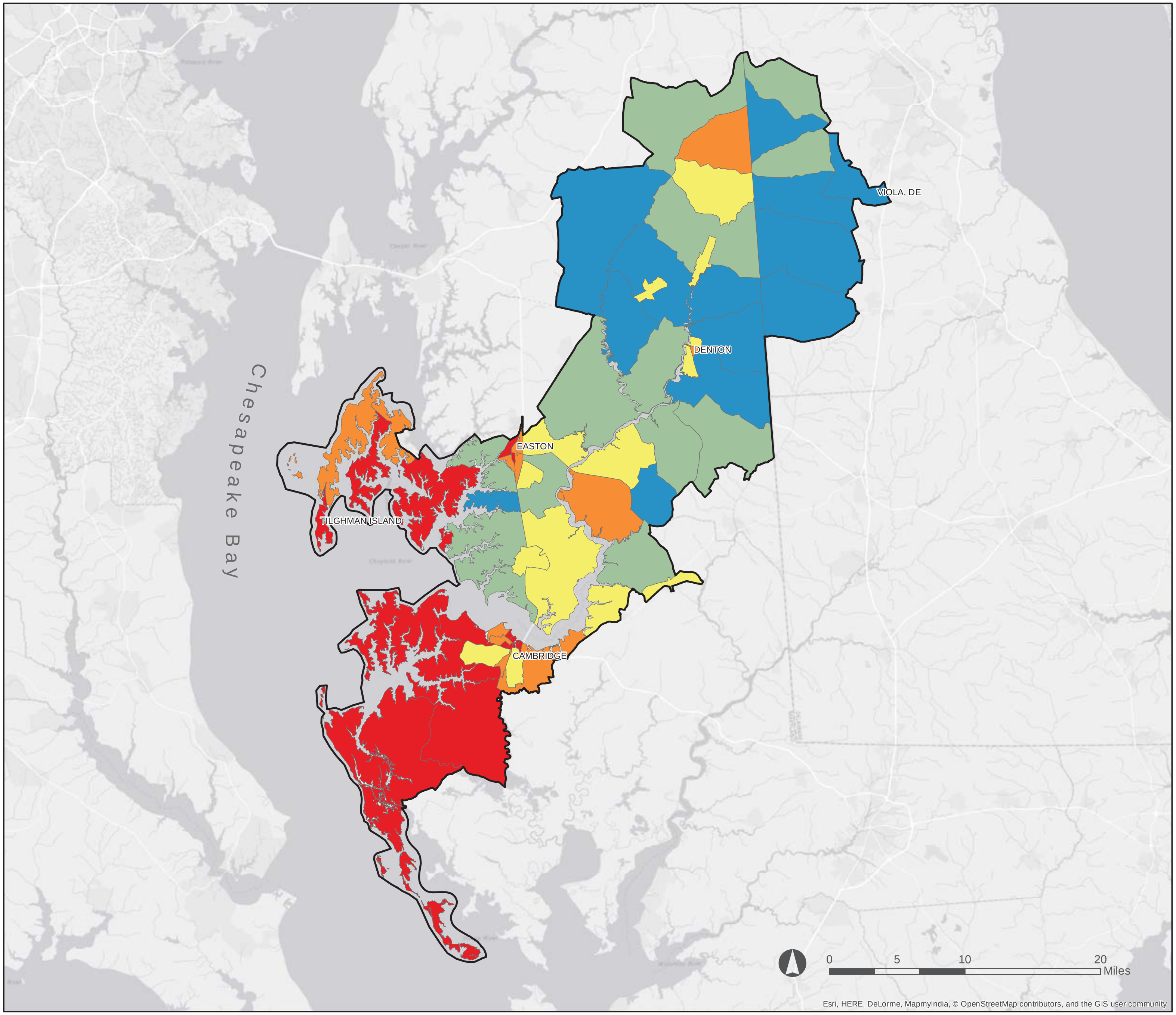
Figure B-35

Coastal Flooding Adaptation Areas (Long Term)



Long term vulnerability scores per block group are determined through a combination of risk analysis (short term risks and sea level rise of 1 and 2 ft) and vulnerability analysis (social, structural, and natural resource). Each census block group is scored as an index value from 0 to 1, and then represented as a tier (Tier 1 -Tier 5).

Tier 1 block groups are associated with the highest composite vulnerability and risk, and may indicate areas for prioritization of adaptation action that addresses coastal flooding within the study area.

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Figure B-36

References:

Cutter, S.L., B.J. Boruff, and W.L. Shirley. 2003. Social Vulnerability to Environmental Hazards. Social Science Quarterly 84(2): 242-261.

Cutter, S.L., C.T. Emrich, J.J. Webb, and D. Morath. 2009. Social Vulnerability to Climate Variability Hazards: A Review of Literature. 44 pp. Hazards and Vulnerability Research Institute, University of South Carolina. Columbia, SC.

Cutter, S.L. 2008. A Framework for Measuring Coastal Hazard Resilience in New Jersey Communities. White Paper for the Urban Coast Institute. 12 pp.

Messick, E. and M. Dillard. 2016. Identifying Priorities for Adaptation Planning: An Integrated Vulnerability Assessment for the Town of Oxford and Talbot County, Maryland. NOAA Technical Memorandum NOS NCCOS 212. 149 pp.

National Hurricane Center. 2015. Sea, Lake, and Overland Surges from Hurricanes (SLOSH). National Weather Service, National Oceanic and Atmospheric Administration. Online: http://www.nhc.noaa.gov/surge/slosh.php (Accessed 27 October 2016)

Wu, S., B. Yarnal, and A. Fisher. 2002. Vulnerability of coastal communities to sea-level rise: a case study of Cape May County, New Jersey, USA. Climate Research 22: 255-270.

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A COASTAL COMMUNITY VULNERABILITY ASSESSMENT FOR THE CHOPTANK HABITAT FOCUS AREA

NOAA Technical Memorandum NOS NCCOS 225