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Identifying Priorities for Adaptation Planning: An Integrated Vulnerability Assessment for the Town of Oxford and Talbot County, Maryland

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Abstract

The ecology of the Chesapeake Bay and its watershed is deeply intertwined in the history, culture, and economy of the communities in this region, and provides people with valuable ecosystem services. Due to the connectivity between communities and the environment, the risks associated with flooding, coastal storms, erosion, and sea level rise are heightened. Understanding the vulnerabilities of communities along the Bay to climate and coastal hazard impacts requires integrated science techniques and methods. This project aims to provide coastal communities with the information needed 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 designing and 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, as well as novel approaches to indicator development and application for coastal communities, a set of appropriate metrics were identified and/or developed for the assessment. Both environmental and social vulnerability were examined using data collected on population demographics, economic characteristics, distribution of natural resources, and characteristics of commercial and residential structures. These vulnerabilities are then investigated alongside various flood hazard risks, including stormwater flooding, storm surge, and sea level rise. This work builds upon a range of NOAA methods and products. Further, the project seeks to advance analytic techniques for integrating measures of vulnerability with measures of risk in a spatial assessment.

This study was conducted for the Town of Oxford and Talbot County, Maryland. Talbot County is located on the Eastern Shore of the Chesapeake Bay and its climate is significantly influenced by both the Bay and the Atlantic Ocean. The Town of Oxford, located in the Lower Choptank Watershed of the Chesapeake Bay, is intersected by Town Creek. Because the Town is low-lying, it is frequently exposed to flooding events. With changing climate conditions like sea level rise and increased frequency and intensity of heavy precipitation events, Oxford's flooding issues are expected to worsen. While the initial vulnerability assessment tool development and data collection is focused on a single community of the Chesapeake Bay, the methodological approach is being tailored for maximum applicability across coastal communities in all regions.

Introduction

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. The ecology of the Chesapeake Bay and its watershed is deeply intertwined in the history, culture, and economy of the communities in this region, and provides people with valuable ecosystem services. Due to the connectivity between communities and the environment, the risks associated with flooding, coastal storms, erosion, and sea level rise are heightened. Understanding the vulnerabilities of communities along the Bay to climate and coastal hazard impacts requires integrated science techniques and methods. This project aims to provide coastal communities with the information needed 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 designing and 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 (Cutter, Boruff, and Shirley 2003), as well as novel approaches to indicator development and application for coastal communities (Dillard et al. 2013, Jepson and Colburn 2013), a set of appropriate metrics were identified and/or developed for the assessment. Both environmental and social vulnerability were examined using data collected on population demographics, economic characteristics, distribution of natural resources, and characteristics of commercial and residential structures. These vulnerabilities are then investigated alongside various flood hazard risks, including stormwater flooding, storm surge, and sea level rise. This work builds upon a range of NOAA methods and products (e.g., CSC's Digital Coast, National Marine Fisheries Service Social Indicators, National Centers for Coastal Ocean Science (NCCOS) Community Well-being Indicators, NCCOS Hydrologic Modeling, and NCCOS Biogeographic Assessment Framework). Further, the project seeks to advance analytic techniques for integrating measures of vulnerability with measures of risk in a spatial assessment.

The overarching goal of this project was to evaluate a coastal community's vulnerability to the localized impacts of climate variability and change. 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 community to address risk and identify adaptation strategies moving forward. Ultimately, the results of the vulnerability assessment will be used to inform community-led adaptation planning and corresponding management actions.

This project represents strong collaboration across the social and natural sciences, as well as across federal, state and local partners. While the initial vulnerability assessment framework development, data collection, and analysis are focused on the Town of Oxford and Talbot County, Maryland, the methodological approach has been tailored for maximum applicability across coastal communities of various sizes and in all 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.

Background

Preparing for the potential impacts of climate change requires an understanding of the populations, economies, and the built and natural environments that may be affected. This understanding includes assessing the existing vulnerabilities in relation to specific risks that may become stressors. The project objectives included:

- the development of indicators for an integrated vulnerability assessment;
- the collection and analysis of data for a vulnerability assessment of a selected community; and
- the development of information products from the resulting data that can be used to inform community-led adaptation planning and corresponding management actions.

In order to achieve these objectives, the science team sought out existing literature on the concept of vulnerability as well as previous vulnerability assessments.

During the last decade vulnerability has become a pivotal concept in understanding a community's predisposition to damage by hazards. Many studies have examined the concept of vulnerability and have attempted to determine the best way in which it may be defined and measured. As it stands, vulnerability is not a simple concept and no consensus exists regarding its precise definition (Yung 2014). Contributions to the theory of vulnerability are multi-disciplinary in nature and include input from those within the fields of emergency management (Pearce 2003), planning (Lee 2014), coastal science (Özyurt and Ergin 2010), and social science (Cutter, Boruff et al. 2003). While there is no agreed upon definition, many of these studies treat vulnerability as a function of exposure, sensitivity, and/or adaptive capacity. Therefore, this review adheres to the concept of vulnerability as defined by the Intergovernmental Panel on Climate Change (IPCC) in their Third Assessment Report: Climate Change (2001, Annex B), which states:

> "Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity."

Study Area

The Chesapeake Bay is deeply intertwined in the history, culture and economy of the communities in this region. For over a century, the Chesapeake Bay and its watershed have provided people with valuable ecosystem services. Furthermore, the Chesapeake Bay contains many special ecological places aimed at conserving this value (e.g., NERRS sites, NOAA Sentinel Site, NOAA Habitat Blueprint Choptank Habitat Focus Area). This concentration of social and ecological value was a driver of the project being selected for the Chesapeake Bay region.

Site Selection

Chesapeake Bay communities are at various stages of understanding, identifying, and planning for climate change, therefore this project was identified as a means of helping move one community along the path to risk reduction. The community of focus was selected during the first phase of the project with the assistance of the project partners. The aim was to identify a community (county or city) that was planning an assessment and/or would benefit from an assessment tool and synthesized data to inform management actions related to climate variability, climate change, and other coastal hazards. Maryland's CoastSmart Communities Grant Program[1], along with input from state partners, facilitated this selection.

The first step in the site selection process was to develop a suite of criteria that could be used to evaluate potential sites, with the geographic scale of the site serving as the first criterion. The team allowed the site to be a county and/or a municipality and preferred a site that included multiple watersheds. The remaining criteria included:

- Community need
- Community interest in using science to inform management action
- Time commitment from community representative(s) to engage in project team meetings
- Community that has not had much prior work/investment of resources
- Diversity of what is happening on the landscape including variation in land uses and hazard areas
- Mix of heavy and light development
- Moderate to large population size
- Data availability
- Data recency (collected in past 10 years)

[1] The CoastSmart Communities Grant provides financial assistance to local governments to encourage the incorporation of coastal hazards, sea level rise, and/or related coastal management issues into local long-term strategic planning, new or modified codes and ordinances, permitting processes, education and outreach campaigns, and other relevant programs (Maryland Department of Natural Resources 2014).

- Proximity to a NERRS site
- Overlap with a Habitat Blueprint Habitat Focus Area
- Overlap with a Sentinel Site

In order to allow for an open selection process, communities were invited to apply for free technical assistance. The CoastSmart Communities Program managed the application process, and the project team (Science Team and state partners) collectively evaluated the applications based on the criteria listed above using an evaluation matrix. Upon selection of a community, the state partners informed all applicants of the selection of the Town of Oxford (Figures 1-2). For analytical reasons, the project team made a decision to expand data collection and analysis to the Talbot County boundary, therefore the study site came to include the entirety of Talbot County as well. Given the spatial and economic connections between the Town of Oxford and Talbot County, as well the Town's reliance on critical services (e.g., healthcare and sheltering) provided by the County, it was important to evaluate the vulnerability of both geographies. By collecting data and conducting analyses for the Town and County, a more holistic assessment of vulnerability to flood risks was achieved. As a result of the broader geographic scope, the project will provide benefits for the County in addition to the selected study community, including the sharing of all relevant data, analysis/modeling outputs, and information products upon completion; an opportunity to connect with NCCOS scientists with expertise in a variety of areas, including hazard mitigation planning, stormwater modeling, geospatial analysis, socioeconomic and biogeographic assessments, social valuation, and natural resource economics; and opportunities to leverage this work for future CoastSmart grant funds.

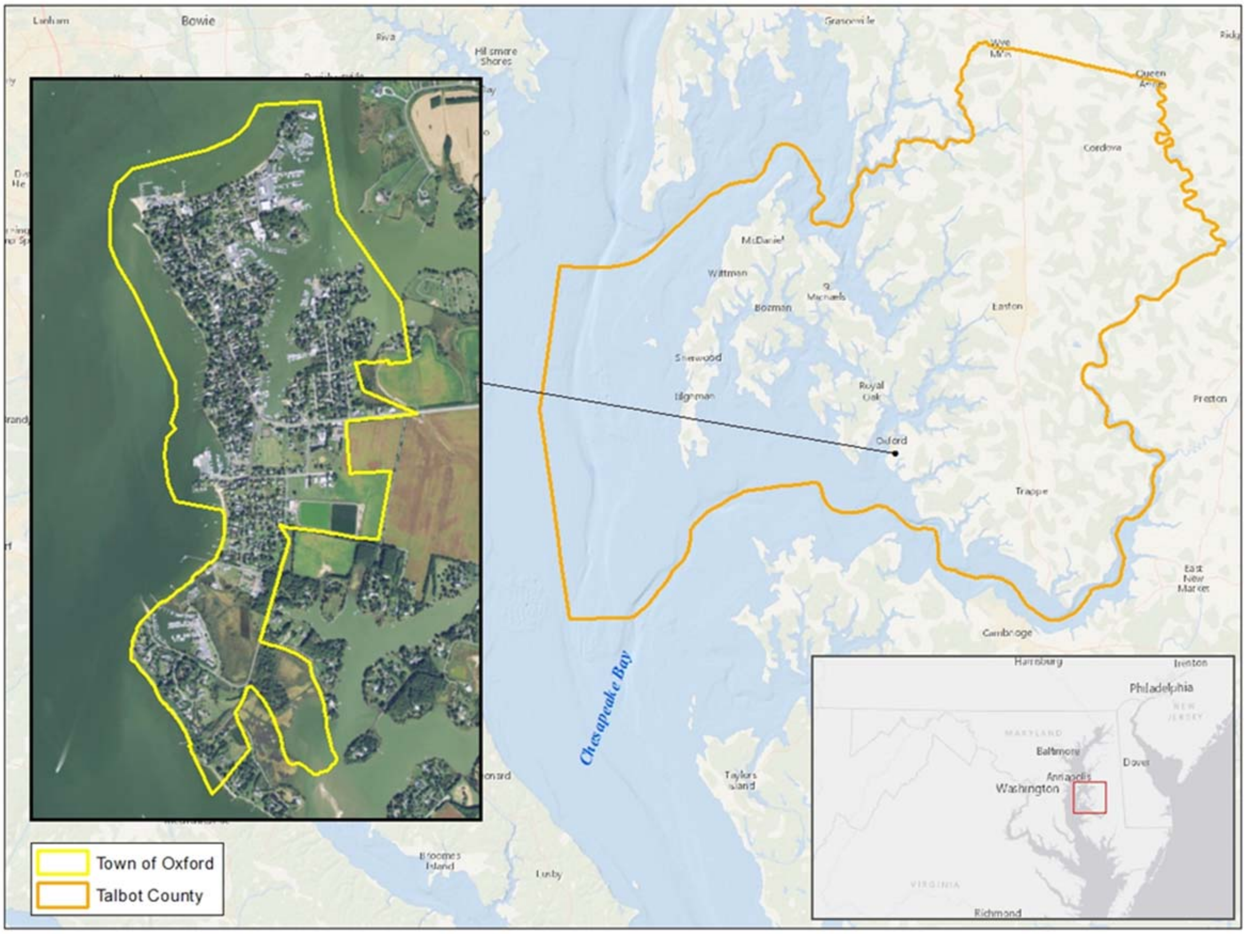

Figure 1. Map of Study Area.

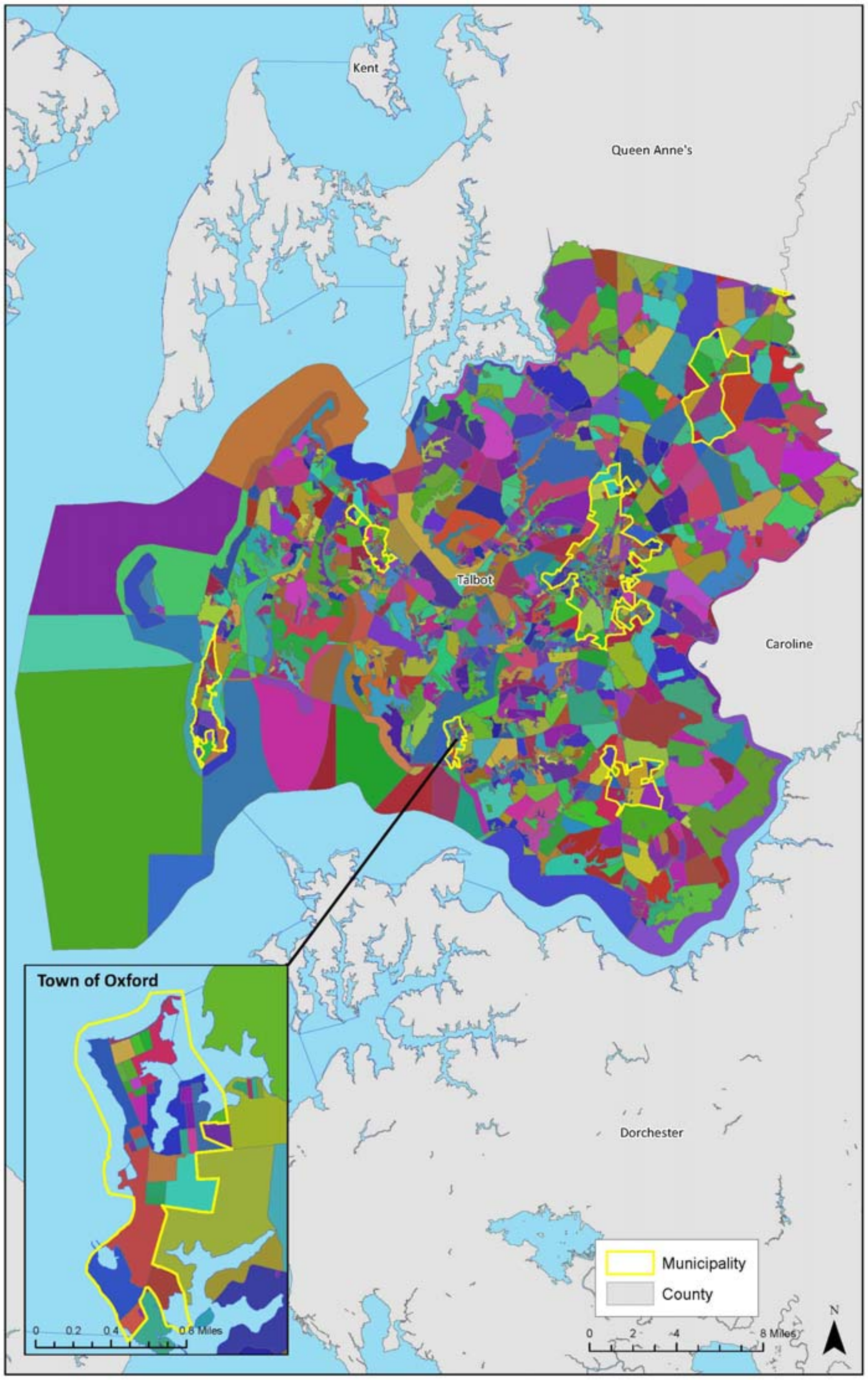

Figure 2. Map of Census Blocks for Study Area.

Site Background

Preliminary information was collected and analyzed for the Town of Oxford, Maryland, as well as Talbot County, Maryland. This included the development of demographic, economic, and climate profiles for the Town of Oxford and Talbot County. These profiles were used to guide the science team in initial decisions about the vulnerability assessment. Additionally, the trend data provides important historical knowledge of the site.

Demographic Profile: Talbot County and Town of Oxford

Talbot County

According to the 2010 U.S. Census, Talbot County has a population of 37,782 people, which constitutes an 11.7% increase from the figure reported in the 2000 U.S. Census. The largest proportion of this increase was observed in the 60-64 year age group (a 5.3% increase). The age group with the largest decrease in population from 2000 to 2010 was the 30-34 age group (a 10.6% decrease). The population density is 141 persons per square mile, and 47.7% of the 2010 population of Talbot County is male. Talbot County, Maryland has a total area of approximately 473 square miles.

The racial composition of Talbot County is as follows: 81.4% white, 12.8% black/African American, 0.2% American Indian/Alaskan Native, 1.2% Asian, and 0.1% Native Hawaiian/other Pacific Islander (Figure 3). Additionally, 5.5% of the population indicated that they were of a Hispanic or Latino ethnic origin. The racial composition of Talbot County as a whole is more diverse than the Town of Oxford; however, the proportion of white people is still about 9% greater than the national average of 72.4% reported in the 2010 U.S. Census.

The median age in Talbot County is 47 years old, about 10 years older than the national average of 37 and 9 years older than the Maryland average of 38. Just over 82% of Talbot County's 16,157 housing units are occupied, with 72.1% of the occupied housing units being owner-occupied. The average household size in Talbot County is 2.31 persons, and 23% of households have children less than 18 years of age residing in the household.

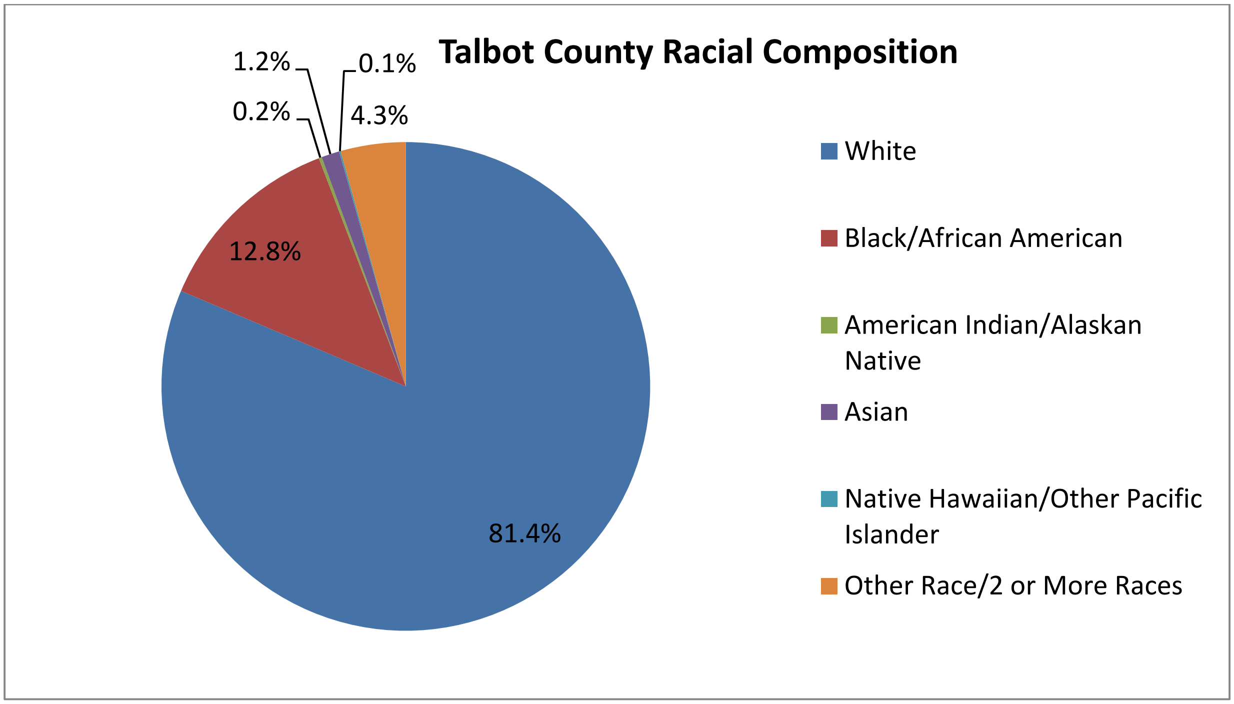

Figure 3. Racial Composition of Talbot County, Maryland

Town of Oxford

According to the 2010 U.S. Census, the Town of Oxford has a population of 651 people, which constitutes a 15.6% decrease from the figure reported in the 2000 U.S. Census.[2] The largest decrease in the population was observed in the 35-39 year age group (a 14.9% decrease), while the 65 and over age group population increased by 8.4%. The population density is 1,205.6 persons per square mile, and 49.8% of the 2010 population of Oxford is male. The Town of Oxford, Maryland has a total area of six tenths of a square mile.

The racial composition of Oxford is as follows: 91.9% white, 5.4% black/African American, and 0.6% Asian (Figure 4). Additionally, 0.5% of the population indicated that they were of Hispanic or Latino ethnicity. The above figure indicates that the Town of Oxford is not racially diverse, as it is dominated by a large proportion of one particular race.

The median age for the Town is 61 years old, reflecting a relatively older population. Nearly 59% of Oxford's 338 housing units are occupied, with 81.4% of the occupied housing units being owner-

[2] It is important to note that there are data limitations for the Town of Oxford, particularly with respect to the U.S. Census Bureau and other existing sources. These limitations are likely a function of Oxford's small population size coupled with the high number of partial year residents. Because of the small population, the impact of any sampling error is likely greater.

occupied. The average household size in Oxford is 1.93 persons, and 8.6% of households have children less than 18 years of age residing in the household. This is again indicative of an older population, as older people tend to be among those with smaller household sizes due to the lack of dependents residing in their respective households.

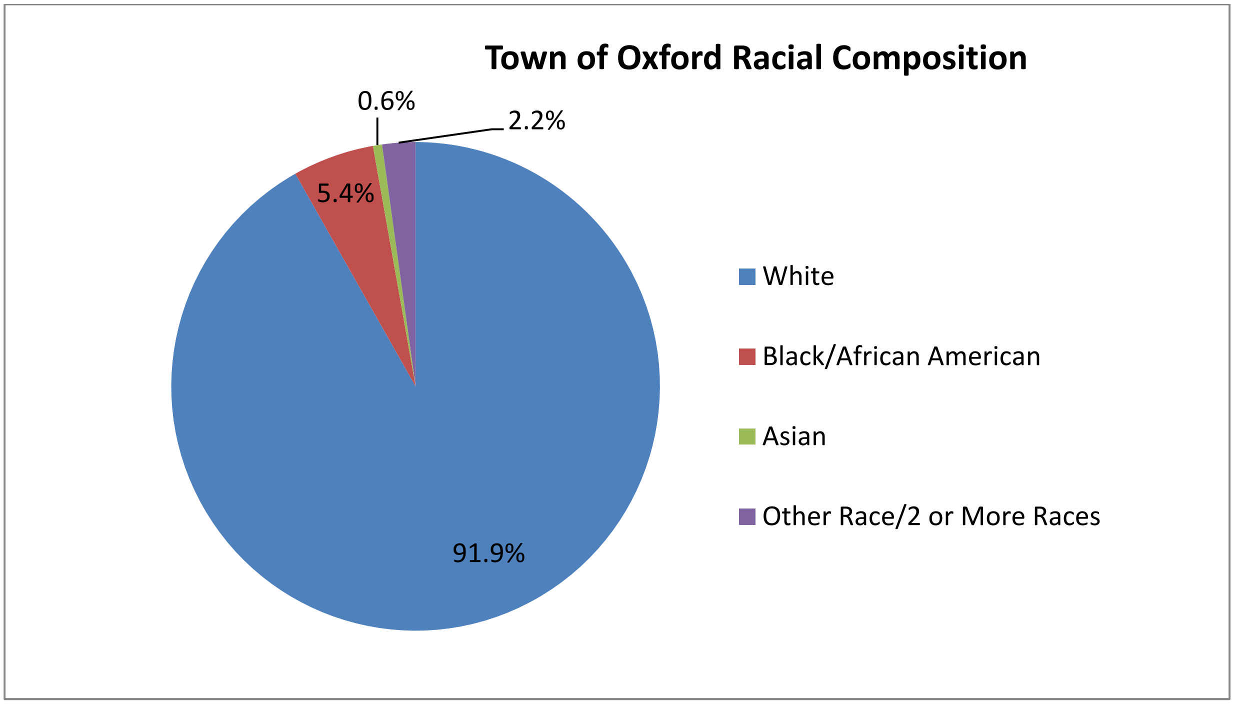

Figure 4. Racial Composition of Town of Oxford, Maryland

Economic Profile: Talbot County and Town of Oxford

Talbot County

Talbot County holds approximately 0.5% of Maryland's total population and has an average population growth rate and unemployment rate slightly higher than the rest of Maryland. Per capita income in Talbot County is $1,500 higher than the Maryland average and although poverty rates are increasing, they are still roughly 10% less than in Maryland as a whole. Nevertheless, Talbot County demonstrates certain coastal socioeconomic vulnerabilities in that the proportion of total gross domestic product (GDP) obtained through the sectors of marine construction, marine living resources, and coastal tourism and recreation is nearly three times higher, at 8.5%, than at the state level, which stands at 3%. The County's dependence on these sectors, known as the ocean economy, is important when considering impacts of a changing climate on the population and the environment. Drivers commute an average of

24.5 minutes to work, and although this is roughly 6 minutes less than other Maryland counties, this commute could be affected by coastal storm events. Within the County, the professional, scientific and technical services sector and the health care and social assistance sector are among the highest employing and highest paying sectors, and also the sectors with highest new hire numbers. Accommodation and food services, and retail trade also employ a large share of people.

Figure 5. Brewer Oxford Boatyard & Marina

Town of Oxford

Founded in 1683, Oxford's economy was historically built on its access to the water, which was essential for industries like shipping of agricultural goods, fishing, crabbing, and boat building (EFC 2013). These industries have decreased over the years. Regarding fishing and crabbing specifically, Oxford, like nearby St. Michaels, does not exhibit a high degree of fishing engagement and reliance[3] across commercial and recreational sectors when compared to other fishing communities in the northeast (Jepson and Colburn 2013). Presently, the Town's major economic stimulus is tourism and leisure activities centered on maritime recreation, which represents a shift from traditional commercial fishing and shipping activities. The Town of Oxford has a relatively high median household income and a relatively low poverty rate.

Climate Profile: Talbot County and Town of Oxford

Talbot County

Talbot County is located within the Eastern Shore of Maryland and its climate is significantly influenced by both the Chesapeake Bay and the Atlantic Ocean (Figure 6). The average temperature is 51 degrees Fahrenheit, with temperatures below 32 degrees Fahrenheit for 80 days of the average year and temperatures 90 degrees Fahrenheit or higher for 15-20 days of the average year. Precipitation in Talbot

[3] Commercial fishing engagement is measured by the presence of commercial fishing through fishing activity as shown through permits and vessel landings, while recreational fishing engagement relies on estimates provided through NOAA's Marine Recreational Information Program (MRIP). Reliance is measured by the presence of commercial or recreational fishing activity in relation to the overall population (Jepson and Colburn 2013).

County averages 43.2 inches annually, with daily rainfall events that could cause flooding (≥ 1 inch) occurring most commonly in October (17 events from 2005-2014). Winds in this area are typically from the south in summer and from the west and northwest in winter, with an average velocity of 8-10 mph (Town of Oxford 2010).

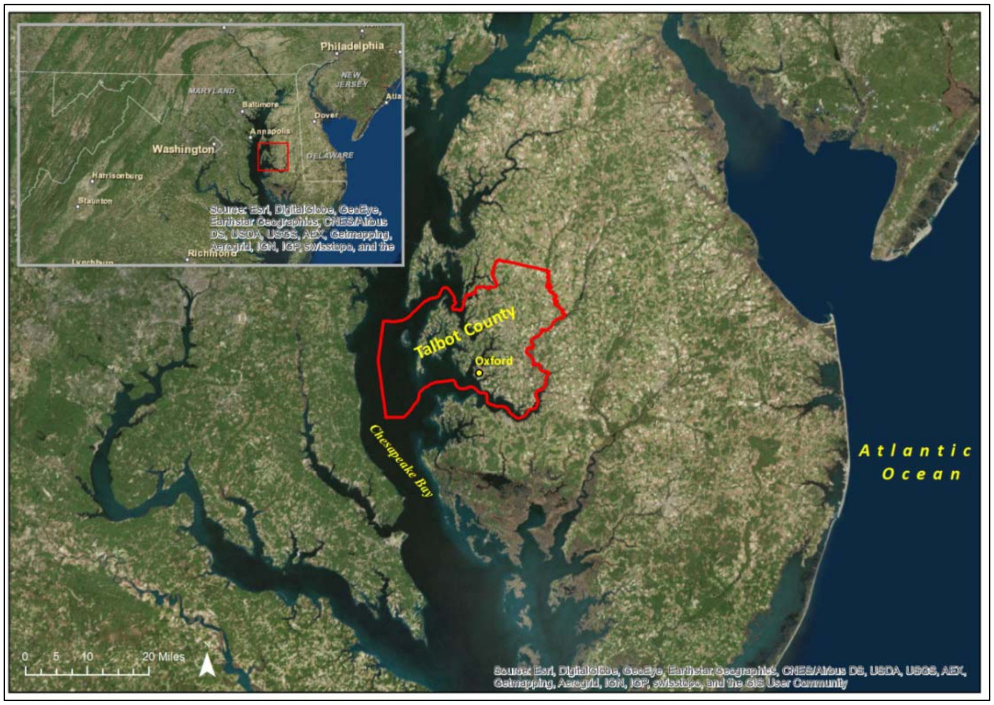

Figure 6. Talbot County, Maryland

Town of Oxford

The Town of Oxford, located in the Lower Choptank Watershed of the Chesapeake Bay is intersected by Town Creek (Figure 7). While the Town's climate mirrors some of what is described for Talbot County as a whole, Oxford's location creates special conditions. "Oxford's low-lying land is frequently exposed to flooding from tidal, wind-driven or precipitation events" (EFC 2013: 15). The flooding in Oxford may occur as a result of a single event or combination of events with differing impacts around town. Similarly, retreat of floodwaters varies by area and is dependent on tide, wind, temperature, and local topography (EFC 2013). With changing climate conditions like sea level rise and increased frequency and intensity of heavy precipitation events, Oxford's flooding issues are expected to worsen.

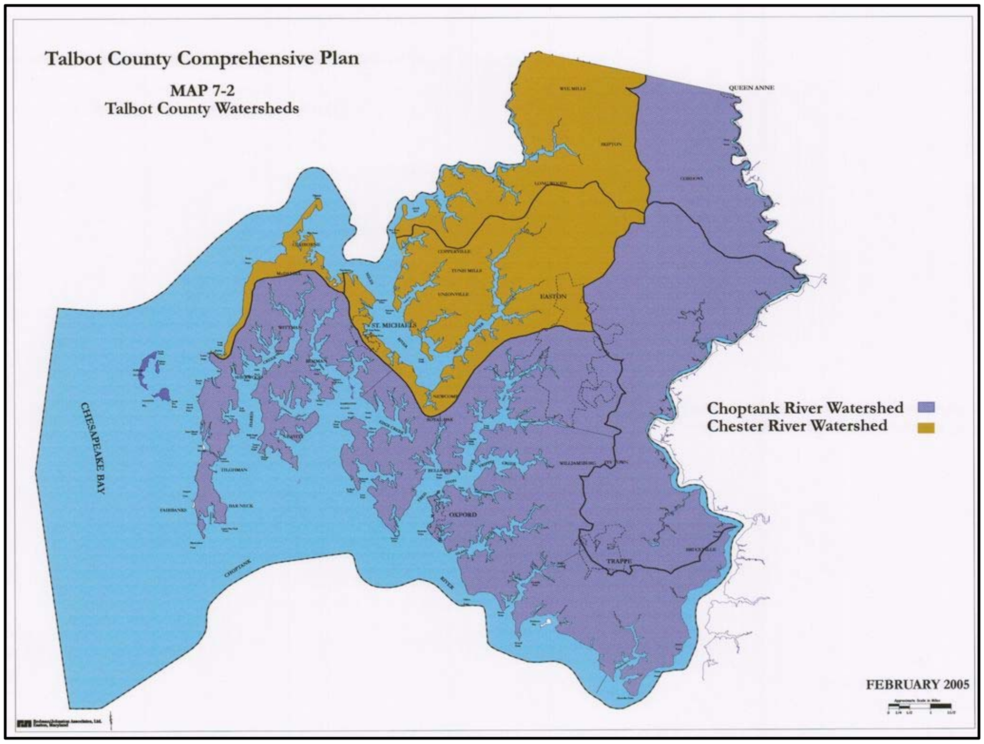

Figure 7. Watersheds of Talbot County, Maryland

Methodology for an Integrated Vulnerability Assessment

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 the assessment of vulnerability. The methodology involved first defining the climate impacts of most concern for the Town of Oxford, followed by the process of indicator selection and development, and then data collection. The analyses spanned from the indicator development to the examination of integrated vulnerability and risk. Analyses included assessing the existing vulnerabilities before a climate stressor, assessing vulnerabilities in relation to specific risks that may become stressors, and finally, assessing integrated vulnerabilities and risks.

Identifying Climate Impacts of Most Concern

Providing a framework for analysis relied upon determining the types of coastal flood hazards that most commonly pose a threat to the Town of Oxford. These hazards were identified through a series of planning meetings with town officials where past, present, and recurring problems were discussed in order to paint a picture of hazards with which Oxford commonly contends. The planning meetings resulted in four “focus areas” which described common hazards in Oxford. These focus areas consisted of: stormwater flooding, severe storm events, shoreline erosion, and land subsidence. The representatives of the Town of Oxford were asked to rank these focus areas to provide the project team with a better understanding of which areas to focus on during the data collection and analysis phases (See Appendix B for Ranking Form). The resulting rankings are shown below in Table 1.

Table 1. Rankings of Climate Issues for Oxford, MD.

Focus Area	Why?	Rank*
Stormwater & Flooding	Town has issues that originate from stormwater and tidal flooding. Frequent flooding of roadways following high tide events, precipitation, and severe storms is experienced. The new stormwater utility makes this area an important one for demonstrating progress.	1
Severe Storm Events	Limited in-town capacity for shelter in place, lack of elevated parking areas, one way in and out, limited access to critical facilities during a storm event (e.g., medical).	2
Shoreline Erosion	Areas of shoreline are experiencing erosion, living shorelines need to be added along more sections of shoreline; other shoreline protection needs to be repaired.	3
Subsidence	The Town of Oxford (along with the broader region) is experiencing a decrease in elevation, or sinking. The impact of subsidence on current flooding issues is also of concern.	4

Note: *The ranking is ordered such that 1 = highest priority and 4 = lowest priority.

The results of the ranking exercise indicated that Oxford representatives prioritize stormwater flooding and severe storm events highly. Given the scope of the project, it was concluded that while shoreline erosion and land subsidence are major issues, the vulnerability analysis would focus upon: 1) problem areas ranked most highly; 2) problem areas that could be analyzed and mapped in terms of impacts to socioeconomics, infrastructure, and natural resources; and 3) problem areas with readily available secondary data[4]. To address stormwater and flooding, the analysis focused on the specific risks of stormwater flooding and sea level rise. Then, to address severe storm events, the analysis focused on storm surge risk. Community input was also collected to aid the selection of the specific sea level rise and storm surge scenarios.

[4] Secondary data is defined as data collected by someone other than the secondary user. In most cases, the original purpose of the collection differs from that of the secondary use (Schutt 2001). Secondary data includes collections such as the U.S. Census of Population and Housing, Uniform Crime Reporting Statistics, and county vital records.

Using Indicators

Indicators serve as an aid in describing changing conditions and can have either an explanatory or a theoretical function. Indicators are useful for science, forecasting, and advising, though their use is often linked with the idea of monitoring change in order to introduce a policy intervention (Duncan 1974; Sheldon and Freeman 1970; Bauer 1966). Figure 8 below depicts the process of using indicators in the decision-making process (Spiegel and Yassi 1997). In this project, indicators are being used to advise the community on its vulnerabilities and risks with respect to different flooding hazards. In order to understand the relationship between different types of vulnerabilities and risks, indicators of both are being analyzed. Ultimately, the results of this project will provide the necessary science to inform community decisions about adaptation activities.

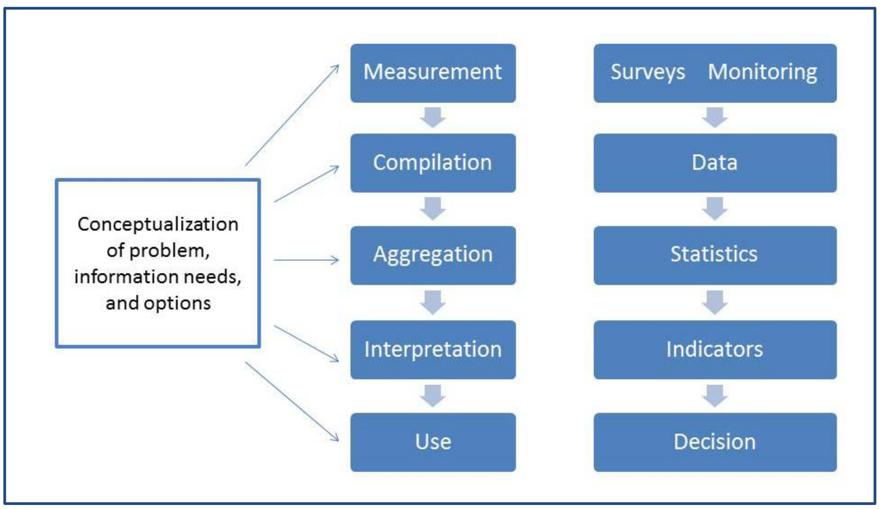

Figure 8. Using indicators for decision making (adapted from Spiegel and Yassi 1997).

Review of Indicators

Alongside scientific expertise provided by the science team[5], this literature review sought to provide a foundation for the selection of multiple indicators that were used in the vulnerability assessment for the coastal community of Oxford, Maryland. More than 50 studies were included for review in identifying potential indicators of vulnerability for the assessment. Selected studies focus on coastal communities and coastal hazards such as sea-level rise, storm surge, flooding, and erosion. For purposes of data

[5] The NCCOS Science Team included scientists with expertise in a variety of areas, including hazard mitigation planning, stormwater modeling, geospatial analysis, socioeconomic and biogeographic assessments, social valuation, natural resource economics, and ecology.

organization, each potential indicator was placed into one of five broad categories: socioeconomic, physical and infrastructure, environmental/ecological, hazard mitigation, and stakeholder participation. Table 2 demonstrates how each of these categories relates to vulnerability by providing examples of indicators included in each category.

Table 2. Indicator Categories and Their Relationship to Vulnerability.

Category and Indicator	Relationship to Vulnerability	Literature Cited
Socioeconomic • Median age • Median income	In relation to median age, very old and very young populations are considered more socially vulnerable. In terms of median income, areas with lower income are considered more socially vulnerable.	Dunning et al, 2011.
Physical and Infrastructure • Critical facilities • Property value	Critical facilities are relevant to assessing vulnerability due to the nature of their operations. Examples of critical facilities include: hospitals, police stations, and shelters. Property value helps identify vulnerable populations and estimate potential economic damages during a storm event.	Johnston et al, 2014. Nelson et al. 2015.
Environmental/Ecological • Wetlands	Wetlands provide unique ecosystem services that are important for the environment, wildlife, and humans. Loss of wetlands might make populations that rely on the wetland's ecosystem services more vulnerable.	Brody et al, 2012.
Hazard Mitigation • Best management practices	Best management practices, such as culverts, bioswales, living shorelines, and rain gardens represent a community's adaptive capacity. These practices are a positive step in reducing vulnerability to flood related hazards.	Environmental Finance Center, 2013
Stakeholder Participation • Public spaces for interaction	These areas are important because they are locations in which public meetings, policy discussion, and other stakeholder participation activities can publicly occur. Community involvement is an integral component to increasing adaptive capacity, thus decreasing vulnerability.	Wongbusarakum and Loper, 2011.

Appendix A provides a brief overview of the selected indicators derived via a literature review process, as well as from input from the NCCOS science team. The studies reviewed often contain overlapping indicators of vulnerability, which speak to the effectiveness of each indicator at measuring vulnerability.

Vulnerability assessments are an important first step in helping communities to identify populations, infrastructure, and natural resources that might be vulnerable to natural disasters. Identifying vulnerabilities in a community allows for the development of adaptation planning and the creation of mitigation strategies. In order to measure vulnerability, indicators can be utilized to provide important insights into the composition of a community. As previously described, indicators typically serve an explanatory or theoretical function. In the case of a vulnerability assessment, indicators help explain and quantify social, physical, and ecological aspects of a community that might not be evident otherwise. While generally very useful, it should be noted that indicators represent simplifications of observations (Meadows 1998). That is, they cannot be expected to describe all aspects of every environment; even the most robust index, utilizing dozens of separate indicators, cannot account for all real world processes.

Many of the indicators were taken directly from the literature. In some cases, literature was used as a basis for the development of new indicators. For example, indicators related to natural resources are often focused on resource dependence of a population (e.g., Combest-Friedman et al. 2012; Huang et al. 2012; Maldondo and Sanchez 2014). Instead, this team was interested in the potential vulnerability of the natural resources themselves to the risks associated with climate change and variability. As a result, an indicator related to the distribution of natural resources that are likely to be impacted by sea level rise was developed and utilized. Other indicators, such as community or stakeholder participation (e.g., Wongbusarakum and Loper 2011), which are critical for measuring adaptive capacity, could not be utilized because these indicators were not available at the selected scale and were reliant on primary data collection. As a result, the assessment of some indicators took a narrative form, allowing for qualitative or quantitative non-spatial data to be used. Relevant studies and practical considerations (e.g., data were available through an existing source, indicators were measureable at the study scale) were used to guide the science team in determining indicators that were most appropriate for the assessment.

Multiple indicators utilized for this project were inspired by the 2011 Talbot County Hazard Mitigation Plan (S&S Planning and Design 2011), which is similar to the hazard mitigation plan created and adopted by the Maryland Emergency Management Agency (2011). Given that a primary goal of this project is to provide a vulnerability assessment that enables the Town of Oxford to move forward with adaptation planning, it seemed prudent to take county-level hazard mitigation plans into account, particularly as the majority of these plans include existing vulnerability assessments. This consideration is evident throughout the indicators, but especially so in the physical and infrastructure category. County-level vulnerability assessments tend to emphasize impacts to infrastructure in terms of damage and economic cost, thus the need to include indicators relating to critical facilities, public facilities, residential and commercial structures, roads, and communication.

Indicators of vulnerability were considered for inclusion if they met any of the following screening criteria:

- Indicator had literature support and/or was used in prior vulnerability assessments;
- Indicator was included in hazard mitigation planning documents;
- Or the indicator was determined important by scientific experts.

By vetting each indicator prior to inclusion, the science team insured that each of the indicators met the screening criteria. As the scope of this project did not include creating new indicators where validated indicators already existed, the science team utilized the frequency of the indicators appearance within the literature (i.e., in multiple peer reviewed studies) as a measure that those indicators are in some way foundational. Where existing literature lacked suitable indicators, the science team drew on its indicator expertise to develop the appropriate measurement tools for the assessment.

Indicator Selection and Development

There are many different ways to select indicators. For this analysis, expert opinion and a review of the literature were used to develop an initial list of indicators that were then evaluated according to the following criteria. The indicators were evaluated for their ability to be:

- Policy relevant
- Amenable to management tools at our disposal
- Quantifiable
- Spatially explicit
- Meaningful, valid and reliable
- Comparable (across space and time)
- Appropriate to scale
- Responsive to change (leading or lagging)
- Easily found or collected using existing data
- Easy to understand and communicate

The preliminary list of indicators took the form of an "indicator menu," a compilation of all the indicators selected and organized by the broad categories to which they belonged: socioeconomic, physical and infrastructure, environmental, hazard mitigation, and stakeholder participation. The process of narrowing this larger list down involved evaluating the indicators on the criteria above with the assistance of the science team. The merits of each indicator as well as the appropriateness of each indicator for the study area were reviewed. All indicators were operationalized or measured by breaking down the indicator into the necessary components and then identifying measures for these components, as in the example shown in Figure 9.

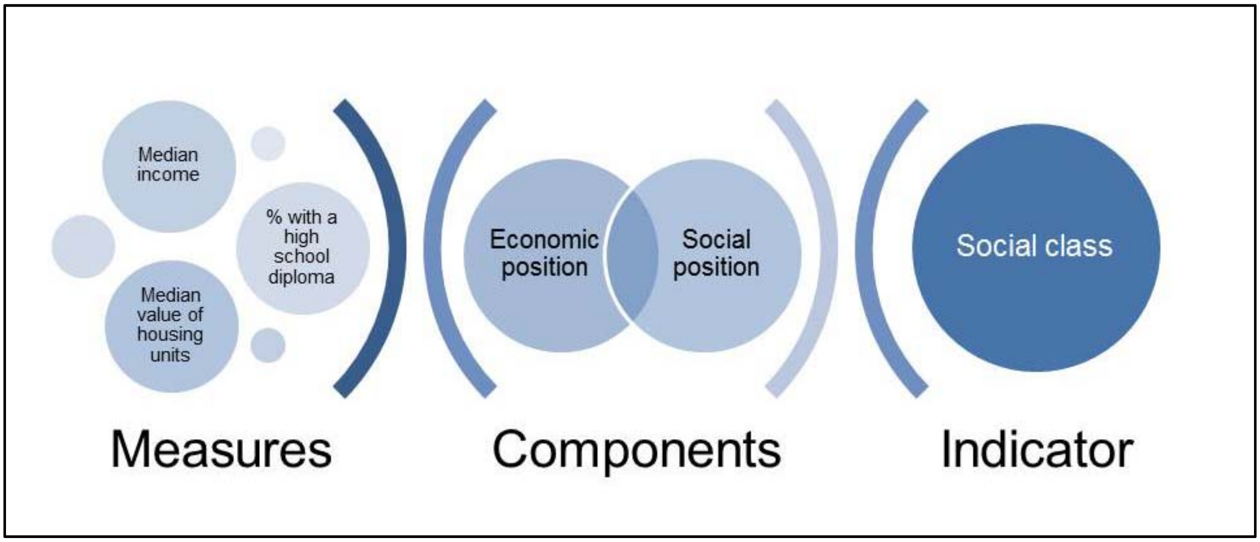

Figure 9. Operationalizing Indicators: An Example Using Social Class

Several iterations of the data indicator menu existed throughout the life of the project. The final indicator list contains all the measures utilized in the analyses for socioeconomic, infrastructure, and environmental vulnerability, as well as flood hazard risks. Included in this list is information for each indicator and measure, including a description, data source, the year the data were created, and supporting citations from relevant literature. The final indicators can be found in Appendix C.

Data Collection Process

An overarching goal of this project was to develop a method that would be transferrable to multiple geographies. In terms of data collection, this meant a preference towards collecting data from national and state-level sources. Collecting as much data as possible at these levels helps to ensure that the project method can be replicated in different geographic locations without experiencing the limitations caused by a lack of available secondary data. As an example, much of the data collected for the socioeconomic vulnerability analysis comes from the U.S. Census Bureau. Census datasets are easily accessible for a wide range of geographic scales and for all mainland U.S. locations.

Data collection was conducted by the project science team and each member was assigned certain data sets. Assignments were based on individual expertise and access to the data. Progress was tracked in a spreadsheet which included the name of the indicator, the data category it belonged to (socioeconomic, physical and infrastructure, environmental, hazard mitigation, and stakeholder participation), the collector, the year of the data, the data source, and notes. Science team members were provided their assignments with detailed instructions regarding the type of data to be collected, geographic scale, time period, and data format. The geographic scale of the collection was focused on county, place (Oxford), and census block[6] (see Figure 2). The size, pattern, and shape of census blocks varies within and between areas and is influenced by a range of factors including "topography, the size and spacing of water features, the land survey system, and the extent, age, type, and density of urban and rural development" (United States Bureau of the Census, Geography Division. 1994:11-10). For environmental data, a 30 meter resolution was determined to be ideal. The time period for the data collected was limited to the most recently available data. The vast majority of the data collected was created or updated within the last ten years, and a large majority of that was created within the last five years. Collecting data from a similar and recent time period helps to reduce temporal disconnects within the indicators that might occur if data was collected from vastly different time periods. Data format was generally limited to a data file (e.g., .xls, .txt, .csv), shapefile, or geodatabase. All data collection 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.

Data used in this study had to meet several criteria related to accessibility, quality, documentation, geographic coverage, and scale. First, datasets were evaluated for accessibility. In some cases, data were online and available for download in standard data file formats, and in other cases, data were provided by state or county officials. With respect to quality, the team determined that the datasets were subject to a quality assurance and quality control process upon original collection. The quality criterion also ensured that the science team was able to obtain documentation of methods used in the collection and metadata. Finally, geographic coverage and scale of the datasets were evaluated. Data ideally represented broad geographic coverage both within the study area and beyond. Of great importance for this study was the criterion of scale; all data had to be scalable to the census block level.

Measurement and Analysis

This study utilized a "vulnerability of places" framework (e.g., Cutter 1996, Cutter et al. 2000) 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 interest and concern to local managers. 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 any stressor. Socioeconomic vulnerability indicators were used to create an index to measure the vulnerability of the population to climate stressors. Structural vulnerability indicators were used to

[6] Census blocks are the smallest geographic units used by the U.S. Census Bureau for the collection and tabulation of data. These units are formed by transportation infrastructure (e.g., streets, roads, and railroads), natural features (e.g., streams and other bodies of water), other physical and cultural features, and legal boundaries (United States Bureau of the Census, Geography Division. 1994).

create an index to measure vulnerability of the built environment to climate stressors. Finally, natural resource distribution indicators were used to create an index to measure vulnerability of the natural environment to climate stressors. For an example of the development of an index using indicators from the previous selection and development process, see Figure 10.

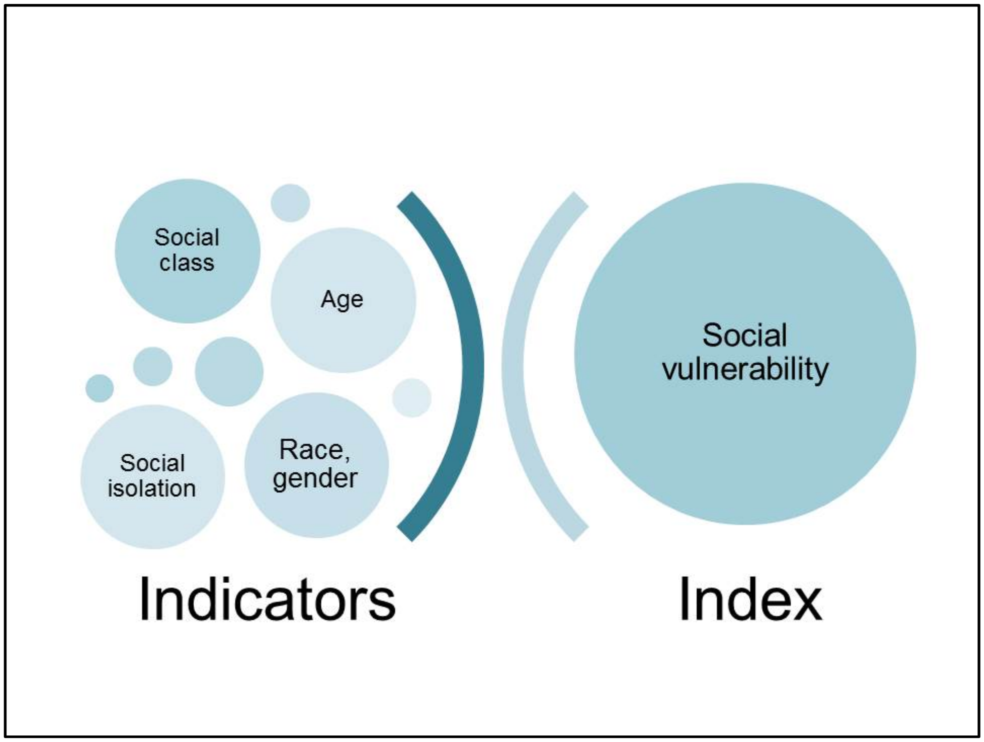

Figure 10. From Index to Measures: An Example Using Social Vulnerability

Similar to the approach used by Wu et al. (2002), indicators of social vulnerability, structural vulnerability, and natural resource distribution were employed alongside indicators of risk to short term (i.e., category 1 storm surge and stormwater flooding) and long term (i.e., sea level rise) flood hazards. The first phase of analysis included examination of the spatial distribution of both short term and long term flood hazard risk within Talbot County and the Town of Oxford, Maryland. The next phase of analysis involved intersecting each type of vulnerability with each type of risk in order to define areas where vulnerabilities and risks overlapped, spatially. In the final phase of analysis, all vulnerabilities were integrated and intersected with either short term or long term flood hazard risk. Short term risk was defined as category 1 storm surge and stormwater flooding, while long term risk was defined as the loss of land and natural resources to sea level rise. By combining measures of risk with measures of vulnerability, overall measures of priority for adaptation activities for the Town of Oxford and Talbot County were developed.

Social Vulnerability

To develop the social vulnerability measure for census blocks in Talbot County, Maryland, secondary data from the 2010 U.S. Decennial Census was utilized alongside estimates produced by the science team. The census block scale limited the data available from the 2010 U.S. Decennial Census, specifically with respect to measures of wealth, employment status, and educational attainment. These data are not provided by the U.S. Census Bureau because of small population counts in census blocks. For critical variables that were not available at this scale, estimates were derived using MERLIN, a geographic scaling method developed by a member of the science team (Buck 2016).

Because there is a rich base of literature for social vulnerability and many previous quantifications of this concept, the approach to deriving the social vulnerability value for this project was closely modeled after existing work. With modifications for scale and data availability, the Social Vulnerability Index (SoVI) methodology developed by Susan Cutter and colleagues (2003) was employed. SoVI is generally calculated at the county scale and includes 29 variables in the latest iteration, SoVI 2006-10. The data sources for SoVI 2006-10 are the 2010 U.S. Decennial Census and the 2006-2010 American Community Survey five-year estimates (HVRI 2013). In this analysis, the variables were modified due to the change of scale from county to census block.

In this approach, in order to create a single index for measuring block-level social vulnerability, each variable was normalized as a percentage (or per capita value) and then standardized using z-scores. Factor analysis, specifically principle components analysis (PCA), was used to determine the factors and variables to include in the final index. PCA is a variable reduction technique that is often used in indicator and index development. PCA is designed to reduce the number of variables to the smallest number of components that explain the most variance (Thompson 2008). Here, PCA analysis used 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 .711 and the Bartlett's Test of Sphericity was significant (11368.794, $p \leq .01$), both indicating that a factor analysis was suitable for the selected variables.

This social vulnerability index is made up of six factors: 1) age, 2) social class, 3) social isolation, 4) race, gender, and household characteristics, 5) economic condition, and 6) labor force, and is comprised of a total of 17 variables. Together, these factors explain 70.42% of the variance in the data for Talbot County. Details about the factors and loadings are in Table 3. These factors closely align with those typically included in other social vulnerability assessments (e.g., Cutter et al 2003, Dunning et al 2011, and Chakraborty et al 2005).

The resulting factors were adjusted for directionality and then placed in an additive model. The sum of the model is the single social vulnerability index score. The social vulnerability index score for each

Census block is presented as a relative ranking of less to more with those on the higher end of the scale being more socially vulnerable in relation to the rest of the blocks in the County or Town. The scores are mapped using four quantiles for Talbot County and the Town of Oxford. The use of quantiles reflects the scores as relative rankings (See Figures E-1 through E7).

Table 3. Social Vulnerability Index Components.

Factor Name	Cardinality	% Variance Explained	Variables	Loading
Age	+	25.942	Median age	.892
			Population over 65 yrs	.863
			Households with persons over 60 yrs	.841
			Household size	-.757
Social class	-	13.507	Population 25 years or older with no high school diploma	-.873
			Median value of housing unit	.841
			Median income	.818
			Urban population	-.558
Social isolation	+	10.125	Households with no vehicle	.867
			Non-English speaking	.769
Race, gender, household characteristics	+	7.579	Female-headed households with no spouse present	.744
			Race/ethnicity other than white	.595
			Female population	.580
			Renter-occupied housing units	.462
Economic condition	+	6.954	Vacant housing units	.724
			Unemployed population	.693
Labor force	+	6.313	Labor force size	.864

Structural Vulnerability

In order to arrive at a structural vulnerability measure for the Census blocks in Talbot County, Maryland, an approach was used that involved an initial collection of secondary data from county parcel records to determine structural vulnerability. There were three criteria used in the assessment of structural vulnerability of residential and commercial buildings in the study area. The first criterion utilized was the construction material of the primary building. 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 (FEMA 2013; Li and Ellingwood 2006). The second criterion was age of the structure as buildings constructed prior to 2003 were not subject to the same elevation requirements as those in the post-2003 era. All post-2003 construction is mandated to have a two foot elevation in place, providing increased protection against flood waters (Maryland Department of Housing and Community Development 2010). The final criterion was the grade of the primary structure. The parcel data contained a numerical grade to each property based on a visual inspection of its condition by a tax assessor (Maryland Department of Planning 2015). The range was from 0 to 9, with 0 being extremely poor and 9 being perfect. These values provide some insight into the upkeep of a building and its potential to withstand floods or storms.

In order to create a single index for measuring block-level structural vulnerability, each variable was scaled where higher numbers are representative of higher vulnerability. For construction material assessment, the proportion of wood structures per block was used, with 0 representing no wood structures in the block and 1 representing a block composed of wood structures only. Construction date was scaled similarly, with the proportions of buildings constructed before 2003 used as the measurement. With this variable, 0 represents no buildings constructed prior to 2003 in the block and 1 represents a block comprised of only buildings constructed prior to 2003. The final variable, grade of current structure, was scaled in a slightly different manner. For each block, the average grade of parcels was calculated and then scaled using min-max normalization.[7] In this case, 0 represents the highest average building grade while 1 represents the lowest average building grade.

Through scaling it becomes possible to create an unbiased additive index of structural vulnerability where each variable is equally weighted and exerts the same influence on the total score. The potential score range, from lowest to highest structural vulnerability, is from 0 to 3. In this analysis, the final score was then scaled to fit a 0-1 range. As with social vulnerability, the scores are displayed as quantiles. The final ranking applies to the entire block and represents assessment of both commercial and residential structures (See Figure E-8).

Natural Resource Vulnerability

The purpose of the natural resource richness analysis is twofold: to determine the spatial extent and concentrations of important natural resources within Talbot County, and to assess their vulnerability to climate and coastal hazards, such as projected sea level rise and hurricane storm surge. Natural resource richness refers to locations where multiple different natural resources share the same spatial location or are within close proximity. Natural resource richness was used for two main reasons. First, there are few examples of vulnerability assessments that take the environment into account in the way this project

[7] Min-max normalization scaling is when the normalized value of x_i for variable X in the ith row is calculated as:
Normalized $(x_i) = x_i - X_{min} / (X_{max} - X_{min})$
Where: Xmin = the minimum value for variable X; Xmax = the maximum value for variable X (Salzman 2003).

aimed to; therefore, existing indicators of vulnerability that focused on the environment were not available. Second, 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 experienced by the 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 resources analysis by considering which resources were important (in terms of ecosystem services provided and economic value) to Talbot County, which resources would conceivably be adversely impacted by the selected hazards, 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 hazards. Resources such as natural shoreline are included through the measurement of wetlands and beaches. Economic valuation studies existed for many of the variables selected for the analysis, and these studies helped to solidify each variable's inclusion in the analysis by providing quantitative data as to its importance. The results of these economic valuation studies are included below in Table 4. These values are derived though use of the benefit transfer method, which in this case is used to estimate economic values for natural resources and ecosystem services by transferring 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.

Table 4. Economic Valuation of Select Natural Resources

Natural Resource	Description
Wetlands	Weber (2007) found that in Cecil County, MD, the economic value (measured through ecosystem services benefits provided) of non-riparian wetlands is $51,510 per acre per year in 2014 dollars. The ecosystem services that were evaluated in this calculation were carbon sequestration, clean air, soil/peat formation, stormwater management/flood control, water supply, clean water, erosion/sediment control, water temperature regulation, pest control, pollination, wood products, fish/wildlife habitat, biological diversity, recreation, savings in community services, and increase in property values. The values for most of these ecosystem services are primarily based on benefit transfers from previous studies. It is believed that this value is transferrable to Talbot County due its close proximity to Cecil County and the fact that both counties are positioned on the Eastern Shore of Maryland.
Submerged Aquatic Vegetation (SAV)	Guignet et al. (2014) found that SAV provides between $1,944 and $2,374 ($2014) per acre in property value gains for the eleven Maryland counties adjacent to the Chesapeake Bay. The method utilized was a hedonic shadow pricing regression model to calculate SAV's effect on property price. Data from Talbot County is incorporated into this analysis as well.

Natural Resource	Description
Oyster sanctuaries	Grabowski et al. (2012) found that restored and protected oyster reefs provide anywhere from $26,852 to $258,558 ($2014) per year depending on where the oyster reef is located. The ecosystem services that were evaluated in this calculation were commercial fishing value, nitrogen removal, submerged aquatic vegetation enhancement, and shoreline protection. These values were taken from previous studies centered around the mid to south U.S. Atlantic coast, so it is believed that these variables are transferrable to Maryland.
Green infrastructure	Weber (2007) found that in Cecil County, MD, the economic value (measured through ecosystem services benefits provided) of green infrastructure hubs and corridors is $24,458 ($2014) per acre per year. This per acre estimate is based on a green infrastructure area of 81,619 acres reported in 2002. It is believed that this value is transferrable to Talbot County due to its close proximity to Cecil County and the fact that both counties are positioned on the Eastern Shore of Maryland.
Forested areas	Weber (2007) found that in Cecil County, MD, the economic value (measured through ecosystem services benefits provided) of upland and riparian forests is $76,091 ($2014). The ecosystem services that were evaluated in this calculation were the same as those described in the wetlands ecosystem service section. It is believed that this value is transferrable to Talbot County due to its close proximity to Cecil County and the fact that both counties are positioned on the Eastern Shore of Maryland.
Sensitive species locations	Loomis and White (1996) found that households were willing to pay an average of $92 ($2014) per year to protect sensitive species. The methods used included contingent valuation, benefit transfer, and meta-regression. The study analyzed a wide array of sensitive species but only the values of species that are found in Maryland, red-cockaded woodpeckers, bald eagles, sea turtles, and striped shiner, were transferred. Since only these four sensitive species were analyzed, this figure of $92 per household can be considered a conservative estimate because several more sensitive species exist in Maryland that were not valued in this particular study. Multiplying this figure of $92 by the number of households in Talbot County as reported in the 2010 U.S. Census (16,157) yields an economic value of $1,486,444 ($2014) per year.
Beaches	The Maryland Department of Natural Resources reports that for coastal bays in Maryland there was $295,295,853 in direct spending (recreational activities besides boating, boating recreation, lodging, food, travel, boat rental, commercial fishing, and government spending) and $246,303,049 additional non-market value (sightseeing, wildlife observation, fishing/shellfishing, swimming, camping, hunting, and boating) for a total value of $541,598,902 for the coastal bays in year 2014 dollars. These values were discerned through surveys, benefit transfers, and input-output analysis. 48.5% of the 4,376,482 person trips to the eastern shore of Maryland in 1998 were to beaches, so applying this percentage to the value of $541,598,902 yields an estimate of $262,675,467, which provides a rough economic value of beaches. It is believed that these values can be transferred to Talbot County due to its close proximity to Worcester County and the fact

Natural Resource	Description
	that both counties are positioned on the Eastern Shore of Maryland.
Marsh Buffer	Weber (2007) found that in Cecil County, MD, the economic value (measured through ecosystem services benefits provided) of tidal marshes is $33,051 ($2014) per acre per year. The ecosystem services that were evaluated were the same as those described in the wetlands ecosystem service section. It is believed that this value is transferrable to Talbot County due its close proximity to Cecil County and the fact that both counties are positioned on the Eastern Shore of Maryland.

To perform the natural resources richness analysis in ArcMap 10.3, a 30x30 meter grid cell was created for Talbot County using the fishnet tool. This cell size was selected primarily to reduce computational time as a result of the size of the study area. The selected coordinate system for this grid, as well as all layers for this analysis, was NAD 1983 (2011) StatePlane Maryland FIPS 1900 (US ft). Each grid cell serves as the primary means of determining the total amount of natural resources in a given area. Here, amount refers both to the number of different resources, as well as the spatial extent of resources within a cell.

Second, the data selected to be included in the analysis was added to ArcMap and converted to raster format with a 30x30m cell size. During the conversion process it was necessary to make sure all raster files were converted within the appropriate extent and coordinate system. This made it possible for the raster cells of all data layers to completely align with the analysis grid cells.

Third, the raster layers were converted to point layers. This conversion was necessary to initiate a spatial join process, a process that does not work with raster layers. The separate point layers were merged so that a spatial join could be performed with the analysis grid. The spatial join process determines how many points fall within each grid cell. This spatial join produced an estimate of the number of different natural resources within each grid cell. Only cells with at least one natural resource were included in the analysis (See Figure E-8).

Sea Level Rise and Storm Surge

The sea level rise layer selected for this study is a product of the NOAA Office of Coastal Management/Digital Coast. Sea level rise of 1 foot is used to assess risk in the socioeconomic, environmental, and infrastructure analyses via intersection with Talbot County census blocks in ArcMap. Detailed information regarding the creation and appropriate use of this data is provided within a PDF document called "Frequent Questions: Digital Coast Sea Level Rise and Coastal Flooding Impacts Viewer." This document is available online at the Digital Coast website (coast.noaa.gov/slr/).

Key information about this data:

- The digital elevation model (DEM) for this dataset utilized the best available lidar data known to exist at the time of the DEM'S creation. Lidar data for Talbot County was collected in 2003 by the Maryland Department of Natural Resources.
- The DEM is referenced vertically to the North American Vertical Datum of 1988 (NAVD88) with vertical units of meters, and horizontally to the North American Datum of 1983 (NAD83). The resolution of the DEM is approximately 10 meters. These datasets are publicly available via the NOAA Coastal Services Center Digital Coast at: http://www.csc.noaa.gov/lidar
- Represents inland extent and relative depth of inundation at 1 foot above mean higher high water (MHHW)
- Does not consider natural processes such as erosion, subsidence, or future construction
- By design, does not include specific timing of inundation depths (e.g., 1 foot by 2100)
- The process used to map sea level inundation at 1 foot or more is described as a modified bathtub approach or linear superposition method, taking into account local tidal variability using the NOAA VDATUM model
- Should only be used as a screening-level tool

The storm surge data selected for this study was created by the Army Corp of Engineers, Philadelphia District, and utilizes the Sea, Lake and Overland Surges from Hurricanes (SLOSH) Model. SLOSH[8] 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 locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, and other physical features (U.S. National Weather Service 2015). Figures E-11 and E-12 reflect these flood hazard risks.

Stormwater Flooding

One of the primary concerns for the Town of Oxford is flooding caused by stormwater runoff. Stormwater flooding poses a significant and increasingly regular challenge to the Town's residents and visitors. The stormwater flood prone areas layer was created in order to better analyze and prepare for

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

this issue. This layer considers conditions which contribute to or are favorable for stormwater flooding and identifies these locations throughout Oxford and Talbot County.

Literature relating to stormwater flooding suggests many conditions which make this type of flooding more likely with the most impactful 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 5 below.

Table 5. 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

The process for creating the stormwater flood prone areas layer is similar to that of the natural resources richness layer. The analysis was conducted in ArcMap 10.3 and utilized a grid cell approach. First, a 30x30 meter grid cell was created for Talbot County using the fishnet tool. The grid cell serves as the primary means of determining the total amount of flood prone characteristics present in a given grid cell. Again, the cell size was selected primarily to reduce computational time due to the size of the Talbot County study area. The selected coordinate system for this grid, as well as all layers for this analysis, was NAD 1983 (2011) StatePlane Maryland FIPS 1900 (US ft).

Second, the data selected to be included in the analysis were added to ArcMap and the soil shapefile as well as the DEM were converted to raster format with a 30x30m cell size. During the conversion process it was necessary to make sure all raster files were converted within the appropriate extent and coordinate system. This made it possible for the raster cells of all data layers to completely align with the analysis grid cells.

Last, the newly converted raster layers were converted to point layers. The separate point layers were merged so that a spatial join could be performed with the analysis grid. This spatial join process determines how many points fall within each grid cell. The output of the spatial join is a shapefile with a column containing counts. These counts represent how many points (flood prone conditions) fall within each 30x30 meter cell. Figure E-13 reflects the stormwater flood hazard risk.

Methods for Intersecting Vulnerability with Risk

The creation of the socioeconomic vulnerability, structural vulnerability, and natural resource richness layers was only the first step of the analysis to determine where populations, structures, and clusters of resources are most at risk from flood hazards. The second component of the analysis involved assessing the risk in relation to vulnerability based on potential sea level rise of 1 foot, storm surge for a category 1 storm, and stormwater flooding scenarios.

Part of the goal for the overall project was to have each analysis (socioeconomic, infrastructure, and natural resources) comparable to the next, which meant the resulting layers from the previous intersection needed to be scaled at the block level for the entirety of Talbot County. Creating a score for each block provided a means for comparison between the analyses, and helped display the complicated relationship between natural resources, infrastructure, and socioeconomic values in terms of vulnerability to climate related flood hazards.

For social or structural vulnerability, 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, intersected in one map (See Figures E-15 through E-26). 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.

For natural resources, the intersection of flood hazard risks was limited to sea level rise (1 ft) and storm surge (category 1). These flood hazard scenarios were selected because they are more likely to have a negative impact on natural resources than stormwater flooding. Natural resources vulnerable to the impacts of sea level rise and storm surge were determined by intersecting the natural resource richness layer with each flood hazard layer (See Figures E-27 and E-28).

Scores for each block were calculated as a percentage of the total land area of natural resources potentially impacted by storm surge or sea level rise per block. First, the outputs resulting from the intersection of hazard layers and natural resources were assigned to a block via matching the Census designated FIPS code, or block number. Utilizing the spatial join tool in ArcMap, natural resources were assigned to a block using the match option “have their center within.” This match options insures that any given 30x30 meter grid cell is not matched to more than one block, which eliminates double counting. The resulting output included the total area for each 30x30m grid cell (or remnant thereof) and the block to which it was assigned. The summarize tool then allowed for the total area of natural resources to be calculated for each block and generateed a table as an output. This table could then be joined to a block shapefile by joining the block number fields in each. Once joined, the total area of each block could be determined by adding a new field and using the calculate geometry command. Finally, the percentage of impacted natural resources per block could be calculated with the field calculator by dividing total area of natural resources by the total area of each block and multiplying by one hundred. From here it proved useful to export the block shapefile (with the join) into a new shapefile for both storm surge and sea level rise. The result was two shapefiles, one for each flood hazard, which can then be symbolized to represent the percentage of impacted natural resources per block in a multitude of ways.

Methods for Mapping Adaptation Priorities

Maps were created in order to identify especially vulnerable blocks within Oxford and Talbot County so that those blocks may be prioritized for adaptation activities. These maps address two major types of flood risk – short term and long term. Adaptation actions ideally address both types of risk, but there may be greater support in taking action related to the immediate, short term risks. This may be a result of the impacts from short term risks, such as flooding caused by storm surge or a heavy rain event, being more readily observed and experienced by the average citizen. In the case of stormwater flooding, the Town of Oxford experiences this flood hazard frequently and therefore it is more familiar to the community. On the other hand, impacts from long term risks such as sea level rise are more difficult to observe because sea level rise is a slow process and projections indicate that substantial rises will take place over many decades. It is important, however, to plan and prepare for sea level rise not only because of the problems it creates on its own (e.g., loss of land, property, and habitat), but also because rising seas are likely to exacerbate impacts caused by short term hazards like storm surge and stormwater flooding.

Priority Mapping for Short Term Risks

Priority mapping for short term risks was completed for both Oxford and Talbot County (See Figures E-29 through E-32). The block level adaptation prioritization scores were determined through a combination of risk and vulnerability analyses. The risk components utilized in these maps include category 1 storm surge and stormwater flooding impact per block. In terms of vulnerability, block scores calculated from the socioeconomic and infrastructure analyses were combined. Each census block was scored as an index value from 0 to 1. Index values are a summation of the block scores from four separate analyses: social vulnerability, structural vulnerability, storm surge, and stormwater flooding. In terms of mapping the index scores, the data were classified into quartiles so that priority adaptation tiers could be created. The blocks range from Tier 1 to 4, where Tier 1 blocks are associated with the highest overall vulnerability and risk. Blocks designated as Tier 1 should be highly prioritized when considering adaptation measures that address short term hazards within the Town of Oxford and Talbot County.

Priority Mapping for Long Term Risks

Priority mapping for long term risks was completed for both Oxford and Talbot County. The block level adaptation prioritization scores were determined through a combination of risk and vulnerability analyses. The risk component utilized in these maps includes the loss of land and natural resources to sea level rise (1 ft.). In terms of vulnerability, block scores calculated from the social vulnerability, structural vulnerability, and natural resource richness analyses were combined. Each census block was scored as an index value from 0 to 1. Index values are a summation of the block scores from four separate analyses: social vulnerability, structural vulnerability, natural resource vulnerability, and sea level rise. In terms of mapping the index scores, the data were classified into quartiles so that priority adaptation tiers could be created. The blocks range from Tier 1 to 4, where Tier 1 blocks are associated with the highest overall vulnerability and risk. Blocks designated as Tier 1 should be highly prioritized when considering adaptation measures that address long term hazards within the Town of Oxford and Talbot County.

Results

In this section, the results of the analyses are discussed. The corresponding maps for the results of the vulnerability assessment for the Town of Oxford and Talbot County are included as Appendix E. 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 intersection of single vulnerabilities and risks for the Town of Oxford and Talbot County. The next series of maps combine multiple vulnerabilities and risks in order to prioritize geographic areas of the Town of Oxford and Talbot County for adaptation activities. Example results from the maps are explained for each type of vulnerability, with particular attention to the legend and scaling.

What are the Vulnerabilities and Flood Hazard Risks?

Using the Bivariate Choropleth Mapping

The bivariate choropleth maps created for the social and structural 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 to have one of nine scoring combinations. The diagram below (Figure 11), a slightly more detailed version of the matrix found on each map, uses structural vulnerability and sea level rise risk as an example. Structural vulnerability increases from left to right and sea level risk increases from bottom to top. Structural vulnerability is characterized by shades of reds, while sea level rise risk is characterized by shades of grey. Additionally, each corner of the matrix represents a different extreme in terms of variable scoring. Perhaps the two most important scorings in terms of adaptation prioritization are within the top-right (dark red) and bottom-left (light grey) corners. Dark red blocks on the maps indicate areas with both high risk and high vulnerability, while light grey blocks indicate the opposite.

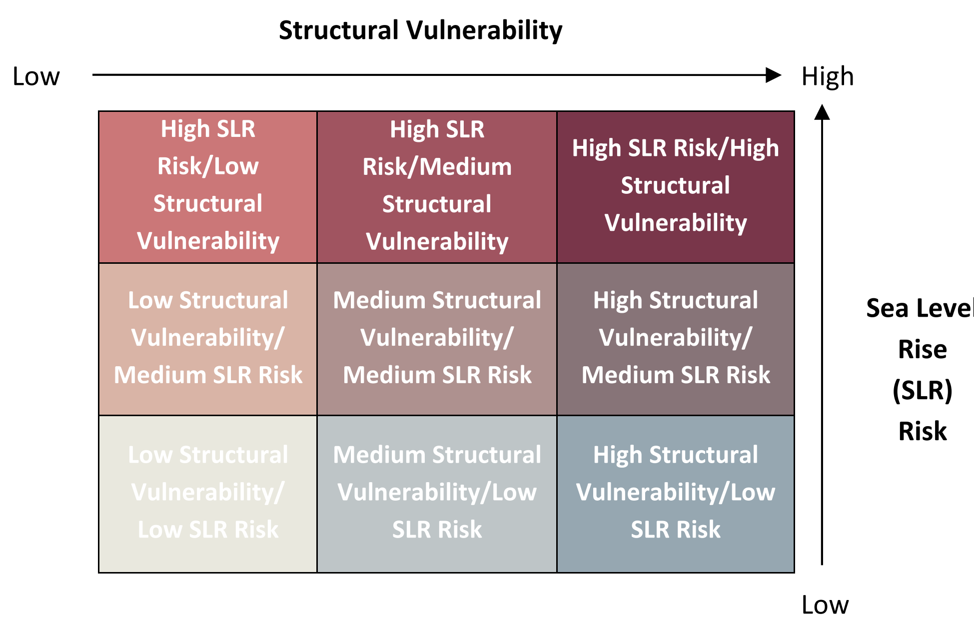

Figure 11. Matrix for the Bivariate Choropleth Maps

Social Vulnerability and Flood Hazard Risks

Social vulnerability by block in Talbot County is highly variable, but there are some important patterns. Social vulnerability tends to be low in rural areas of the eastern portion of the county and high in western portions of the county, particularly in coastal regions. Social vulnerability is also fairly high in and around the municipal boundaries of Easton, St. Michaels, and Oxford.

Projected Sea level Rise

Locations within Talbot County that have both high social vulnerability and high sea level rise risk are situated along coastal areas in western portions of the County. Large blocks adjacent to the Chesapeake Bay, Choptank River, Tilghman Island, and Neavitt (a town located on a peninsula southwest of St. Michaels) exhibit a combination of high vulnerability and high risk With the exception of Cordova and Trappe, the majority of incorporated areas within the County face at least some amount of risk to sea level rise.

Oxford exhibits various combinations of vulnerability and risk, but predominantly falls within the moderate range for social vulnerability and the low range for sea level rise risk. Blocks within the core of the Town which are not adjacent to water have medium to high social vulnerability but tend to have low sea level rise risk. Locations of highest concern are adjacent to Town Creek, as well as the block which comprises the Strand beach. Half of the critical facilities within the Town are in areas with low sea level rise risk and the rest are in areas with medium sea level rise risk.

Storm Surge

The majority of Talbot County has low combined social vulnerability and storm surge risk. Areas of high vulnerability and high risk are observed along the coasts of the eastern and central portions of the County. In particular, Tilghman Island, Oxford, Neavitt, and areas surrounding St. Michaels have blocks which have both high social vulnerability and high storm surge risk.

Figure 12. Roadway flooding along the main entrance of town caused by a combination of high tide and rain.

Oxford is very much at risk for category 1 storm surge: Nearly three quarters (73%) of the Town's blocks are scored as highly at risk to storm surge. Blocks between Town Creek and Oxford Road (entrance of town), Strand Road, and Oxford Road (in town) have the greatest combined vulnerability and risk. Nearly half of Oxford's critical facilities are within these areas, including two churches, a police station, and a post office.

Stormwater Flood Prone Areas

Highly stormwater flood prone areas are most prominent in incorporated areas of Talbot County, such as Easton, Oxford, and St. Michaels. Areas of high social vulnerability and high stormwater flood risk are also common in these areas. Additionally, due to lower coastal elevations and poorly drained soils, large amounts of rural blocks in western portions of the County are moderately at risk for stormwater flooding.

Stormwater flood risk is mostly moderate for Oxford. Instances of high social vulnerability and high stormwater flood risk exist in three blocks within the Town. Areas for consideration consist of the neighborhood to the right of Oxford Road at the entrance of town (north on the map), blocks along Banks Street, and blocks along Tilghman Street.

Structural Vulnerability and Flood Hazard Risks

Structural vulnerability by block in Talbot County is largely within the medium to high range with slight differences based upon geography. Blocks within the northeastern portion of the County are overwhelmingly scored as having high structural vulnerability.

Projected Sea level Rise

Locations within Talbot County that have both high structural vulnerability and high sea level rise risk are situated along coastal areas at the western and eastern extremes of the County. Large blocks adjacent to the Choptank River and Tuckahoe Creek exhibit a combination of high vulnerability and high risk. The same is true for areas adjacent to the Chesapeake Bay, including Tilghman Island and Neavitt. With the exception of Tilghman Island and Oxford, the majority of incorporated areas within the County face little risk from one foot of sea level rise.

Oxford exhibits various combinations of vulnerability and risk, but predominantly falls within the moderate range for both structural vulnerability and sea level rise risk. Blocks within the core of the Town which are not adjacent to water have medium to high structural vulnerability but tend to have low sea level rise risk. Locations of highest concern are adjacent to Town Creek, particularly the northernmost block. The majority of critical facilities within the Town are in areas with low sea level rise risk.

Figure 13. Street sign along The Strand with the Tred Avon River in the background.

Storm Surge

The majority of Talbot County has low to medium storm surge risk. High storm surge risk is observed along the coasts of the eastern and central portions of Talbot County. In particular, Tilghman Island, Oxford, Neavitt, and areas surrounding St. Michaels have blocks which have both high structural vulnerability and high storm surge risk.

Oxford is very much at risk for category 1 storm surge: Nearly three quarters (73%) of the Town's blocks are scored as highly at risk to storm surge. Table 6 below breaks this percentage down by structural vulnerability score. Blocks between Town Creek and Oxford Road (entrance of town), Strand Road, and Oxford Road (in town) have the greatest combined vulnerability and risk. Half of Oxford's critical facilities are within these areas, including two churches, a police station, and a post office.

Table 6. Total number of blocks by structural vulnerability score

Structural Vulnerability Score	Number of Blocks (33 total)	Percentage
Low	7	21.2
Medium	9	27.3
High	8	24.2

Stormwater Flood Prone Areas

Highly stormwater flood prone areas are most prominent in incorporated areas of Talbot County, such as Easton, Oxford, and St. Michaels. Additionally, due to lower coastal elevations and poorly drained soils, large amounts of rural blocks in western portions of the County are moderately at risk for stormwater flooding.

Stormwater flood risk is mostly moderate for Oxford. Instances of high structural vulnerability and high stormwater flood risk exist in four blocks within the Town. Areas for consideration consist of the neighborhood to the right of Oxford Road at the entrance of town (north on the map), as well as the block behind the police station, which contains a church and a post office.

Natural Resource Vulnerability and Flood Hazard Risks

Vulnerability of natural resources to flood hazards was determined for Oxford and Talbot County at the block level. This vulnerability is expressed as a percentage of the total land area of the block covered by natural resources that would be exposed to flood hazard impacts. Further, blocks are scored as low, medium, or high based upon this percentage. Scores ranging from 0-13% fall into the low category, 14-44% are within the medium category and 45-100% in the high category. Vulnerability score ranges were created by slightly modifying the "natural breaks" classification system utilized by ArcMap. The basis of this scoring system is primarily focused on how much land area with natural resources is potentially exposed to flood hazards per block. For example, natural resources within a block are highly vulnerable if 45% or more of the total land area within the block is covered by natural resources that could be exposed to flood hazard impacts, such as storm surge.

Projected Sea level Rise

The percentage of the total land area covered by natural resources at risk to projected 1 foot sea level rise ranges from 1% to 99% among Talbot County blocks. The average percentage of total land area for all blocks having any amount of natural resources which are at risk to sea level rise is 5%. The median value is 2.6%. The majority of blocks with a medium to high rating are concentrated along the Choptank River. Only nine blocks, 1.5% of the total, are classified as high, the largest of which is Poplar Island. The analysis determined that roughly 68% of the island's area contains natural resources which are at risk to this sea level rise scenario. This is explained by the fact that the entire island is classified as a wetland which means it would likely disappear under this scenario, assuming no mitigation measures were put into place.

Oxford's natural resources fare pretty well under this scenario, with all but one block containing natural resources being placed into the low category. The most vulnerable block within the low range is the beach, locally referred to as "The Strand," located in northern Oxford; 11.1% of the total area of this block consists of natural resources exposed to 1 foot sea level rise. The most vulnerable block, which falls within the medium range due to its 19.8% score, is located in southern Oxford and is entirely comprised of wetlands. Overall, nine blocks, 27% of the total, within Oxford contain natural resources which may be at risk to this sea level rise scenario. These blocks total 162 acres (out of 344) but only 7.3 acres are composed of at-risk natural resources, or 4.5% of the total acreage.

Storm Surge

The percentage of the total land area covered by natural resources at risk to a present category 1 storm surge scenario ranges from 1% to 100% among Talbot County blocks. The average percentage of total land area for all blocks having any amount of natural resources which are at risk to category 1 storm surge is nearly 11%. The median value is 5.7%. The majority of blocks with a medium to high rating are concentrated along the Choptank River and Tuckahoe Creek. Only 26 blocks, 4% of the total, are classified as high. Poplar Island is the largest block to be classified as high, and nearly 67% of its land area is covered by natural resources at risk to storm surge. This is explained by the fact that the entire island is classified as a wetland and that the island exists at a low elevation.

The majority of Oxford falls within the low range but there are a few exceptions. The most vulnerable block within the low range is the block which wraps around Town Creek towards the entrance of town: 9.14% of the total area of this block consists of natural resources exposed to storm surge. The most vulnerable block within the medium range comprises most of western South Morris Street, including

NOAA's Cooperative Oxford Laboratory: Nearly 30% of this block consists of natural resources exposed to storm surge. The most vulnerable block, which falls within the high range due to its 88.2% score, is located in southern Oxford and is entirely comprised of wetlands. Overall, eleven blocks, 33% of the total, within Oxford contain natural resources which may be impacted under this storm surge scenario. These blocks total 229 acres (out of 344) but only 45 acres are composed of at risk natural resources, or 19.7% of the total acreage.

Stormwater Flood Prone Areas

The percentage of the total land area covered by natural resources within stormwater flood prone areas ranges from 1% to 100% among Talbot County blocks. The average percentage of total land area for all blocks having any amount of natural resources which are within stormwater flood prone areas is 13%. The median value is 6.0%. The majority of blocks with a medium to high rating are concentrated along the Choptank River, Tuckahoe Creek, and Tilghman Island. Only 65 blocks, 6.9% of the total, are classified as high. The largest block to be classified as high has an area of 79 acres and just over 50% of its land area is covered by natural resources within stormwater flood prone areas. This area is adjacent to the Choptank River where many different natural resources intersect. Another area ranked as high is a block in Easton which contains the Walmart and Giant shopping centers. This area is considered by the State of Maryland to contain sensitive species, and 70% of this block is comprised of stormwater flood prone areas. The most obvious reason for this is the large amount of impervious surface contained within the developed block.

The majority of Oxford falls within the low range, but there are a few exceptions. The most vulnerable block within the low range is the block which wraps around Town Creek towards the entrance of town: 9.5% of the total area of this block consists of natural resources within stormwater flood prone areas. The most vulnerable block within the medium range comprises most of western South Morris Street, including the Cooperative Oxford Lab: Nearly 31% of the total area of this block consists of natural resources within stormwater flood prone areas. The most vulnerable block, which falls within the high range due to its 98.6% score, is located in southern Oxford and is entirely comprised of wetlands. Overall, twelve blocks, 36% of the total, within Oxford contain natural resources which are within stormwater flood prone areas. These blocks total 234 acres (out of 344), but only 48 acres are composed of impacted natural resources, or 20.5% of the total acreage.

What are the Priorities for Adaptation?

Short Term Risks

Adaptation priority scores for short term flood hazards were determined through a combination of risk analysis (surge and stormwater flooding impact per block) and vulnerability analysis (social and structural scores per block).

Talbot County

In Talbot County the majority of blocks are classified as Tier 3 which means most areas within the County are of medium-low adaptation priority. Blocks determined to be of Tier 1 (highest) priority level are primarily located along coastal areas in the western portion of the County. While the highest priority blocks are located within coastal areas, there are many Tier 2 blocks within the Town of Easton. This is likely a result of the amount of development in Easton which contributes to an increased risk of stormwater flooding. Table 7 includes information regarding the total number of blocks per tier.

Table 7. Total number of blocks in Talbot County per short term adaptation priority tier

Priority Level	Number of Blocks (2,975 total)	Percentage
Tier 1	193	6.5
Tier 2	706	23.7
Tier 3	1422	47.8
Tier 4	654	22.0

Town of Oxford

Oxford has eight blocks which are categorized as highest priority for short term flood hazard adaptation activities. These blocks are located along Oxford Road, Strand Road, Tilghman Street, Banks Street, Market Street, and Bonfield Avenue. Over half of the blocks in the Town have a Tier 2 or Tier 1 score. Table 8 includes information regarding the total number of blocks per tier.

Table 8. Total number of blocks in Oxford per short term adaptation priority tier

Priority Level	Number of Blocks (33 total)	Percentage
Tier 1	8	24.2
Tier 2	9	27.3
Tier 3	9	27.3
Tier 4	7	21.2

Long Term Risks

Adaptation priority scores for long term flood hazards were determined through a combination of risk analysis (sea level rise and natural resource impact per block) and vulnerability analysis (social and structural scores per block).

Talbot County

Most blocks in Talbot County are classified as Tier 3 which indicates that they are of medium-low adaptation priority. Blocks of Tier 1 priority are almost exclusively found along the Choptank River and Tuckahoe Creek. The concentration of Tier 1 and Tier 2 blocks along coastal areas is likely explained by the increased concentrations of natural resources in these areas, as well as the presence of sea level rise risk. Table 9 includes information regarding the total number of blocks per tier.

Table 9. Total number of blocks in Talbot County per long term adaptation priority tier

Priority Level	Number of Blocks (2,975 total)	Percentage
Tier 1	14	0.5
Tier 2	443	14.9
Tier 3	1328	44.6
Tier 4	1190	40.0

Town of Oxford

The majority of blocks within Oxford are classified as Tier 1 or Tier 2. Oxford has seven blocks which are categorized as highest priority for long term flood hazard adaptation activities. These blocks are located along Oxford Road, Strand Road, Tilghman Street, Banks Street, Market Street, and Bachelor's Point Road. Table 10 includes information regarding the total number of blocks per tier.

Table 10. Total number of blocks in Oxford per long term adaptation priority tier

Priority Level	Number of Blocks (33 total)	Percentage
Tier 1	7	21.2
Tier 2	11	33.3
Tier 3	9	27.3
Tier 4	6	18.2

What is the Adaptive Capacity?

Following the analyses of the vulnerabilities and risks for the Town of Oxford and Talbot County, it is important to examine the positive conditions that have and will continue to mediate the negative effects of climate variability and change. Many of the items assessed in this section represent capacities that can be strengthened or otherwise enhanced. Understanding what has been done to plan for and respond to changing climate conditions in the Town of Oxford and Talbot County is necessary for developing strategies and plans for the future.

Hazard Mitigation in a Changing Climate

Several significant challenges are posed by climate change which includes events such as "more intense storms, frequent heavy precipitation, heat waves, drought, extreme flooding, and higher sea levels" (FEMA 2012: 1). Climate-induced changes in disaster risk areas will potentially cause a need for increased emergency response capacities and improved resiliency of critical infrastructure and emergency assets (FEMA 2012) as these changes can exacerbate other stressors typical to an area (IPCC 2014). Managing for these changes has "implications for future generations, economies, and environments" (IPCC 2014: 25). State mitigation plans are important for the reduction of disaster losses as well as the current and future resiliency of local communities (Burke et al. 2012). Incorporating efforts to protect citizens from current climate conditions into such mitigation planning is a first step toward adaptation to climate change scenarios projected for the future (IPCC 2014). Implementation of plans in the form of structural hazard mitigation efforts further protects residents from natural and climate-induced hazards. These different types of efforts come together in the form of management systems aimed at mitigating the effects of these phenomena.

Stormwater Management Practices

Stormwater management systems are designed to reduce the volume and rate of runoff from impervious surfaces as well as the concentration of pollutants found in the runoff (USEPA 2014). When left unchecked, these components affect the hydrology and water quality of urban areas, which is known to result in a range of detrimental impacts such as "habitat modification and loss, increased flooding, decreased aquatic biological diversity, and increased sedimentation and erosion" (USEPA 2014: 1). With rainfall events expected to intensify in the future due to climate change, existing drainage systems alone will likely not be able to handle the amount of stormwater runoff occurring in the future (NOAA 2010). The drainage system in the Town of Oxford is already overburdened during excessive rainfall events (Town of Oxford 2010), which necessitates the implementation of a variety of stormwater runoff management practices known as Best Management Practices (BMPs).

BMPs are among the means of mitigating the harmful effects of stormwater runoff and can be of two primary types: nonstructural practices and structural practices. Nonstructural practices can come in the form of stakeholder participation as well as land use and hazard mitigation planning, each of which has the ability to modify individuals' behaviors to reduce harmful runoff at the source (USEPA 2005). Structural BMPs, on the other hand, "are engineered to manage or alter the flow, velocity, duration, and other characteristics of runoff by physical means" (USEPA 2005: 0.36). The term "best" in "Best

Management Practices" is subjective, because it depends on the location of the area, necessitating that a unique approach to stormwater management be taken by each area (USEPA 2005). BMPs of both varieties currently in place in the Town of Oxford are discussed in the following subsections; however, a comprehensive list of such practices can be found at the United States Environmental Protection Agency's National Menu of Stormwater Best Management Practices (http://water.epa.gov/polwaste/npdes/swbmp/).

Figure 13. Oxford Town Park on Morris Street. This location provides an ideal space for stakeholder participation and other public events.

Nonstructural Practices

Stakeholder Participation

Stakeholder participation involves the participation of interest groups in a planning or decision-making process. Interest groups can include community representatives, local government authorities, civil organizations, and businesses. In the context of an assessment of vulnerability to climate change and coastal hazards, stakeholder participation allows for more meaningful identification of vulnerable areas or assets within the community, particularly because the community is able to define priorities in relation to its value for particular areas and assets. Stakeholder participation in the Town of Oxford ranges from low (~5 individuals) to high (~25-40 individuals) depending on the meeting topic, with stormwater public meetings having generally higher attendance levels. Due to the Town's relatively high vulnerability to flooding and large storm events, the topic of climate change hazard mitigation provides fertile ground for incorporating engaged stakeholders into the decision making process. Doing so generates multiple benefits including access to stakeholder knowledge, increased buy-in to decisions made by legislators, and stakeholder education and subsequent behavioral change. Figure 14, below, is a map of the areas available for engagement of the community in adaptation planning and other critical activities for the Town of Oxford.

Figure 14: Spaces available in the Town of Oxford to hold public participation events

Land Use and Hazard Mitigation Planning

The Town of Oxford lies mostly within the 100 year flood plain designated by FEMA (Town of Oxford 2010), which makes it susceptible to damage from relatively minor storms, and highly vulnerable to storms of severe intensity. In order to address the risks posed by flooding hazards, the State of Maryland, Talbot County, and the Town of Oxford have implemented various hazard mitigation efforts aimed at reducing these risks to their citizens as well as the area's critical infrastructure and natural habitat (Table 11). The plans and strategies being implemented at the township level are vital steps toward mitigating the risks associated with climate change to this sensitive area; however, additional steps should be taken to strengthen the resiliency of the Town to current and future scenarios of flooding occurrence along the Chesapeake Bay.

Table 11: Hazard Mitigation Planning Types. 'Y' indicates jurisdiction has planning type in place, 'N' indicates jurisdiction does not.

Planning Style	Planning Type	Talbot	Oxford
Plan	Comprehensive Plan	Y	Y
	Hazard Mitigation Plan	Y	N
	Emergency Operations Plan	Y	Y
	Disaster Recovery Plan	N	N
Strategy	Continuity of Operations	Y	N
	Sensitive area development restrictions	Y	Y
	Coastal Setbacks	Y	Y
Other	Community Rating System Participation	Y*	N

* Effective October 1, 2014, Talbot County's unincorporated areas were confirmed as Class 8 in the National Flood Insurance Program's Community Rating System (CRS)

Both Talbot County and the Town of Oxford have comprehensive plans in place (Talbot County is in the final stages of review for its most recent plan). These plans lay out the area's policies for a range of issues including land use planning for the Town of Oxford (Town of Oxford 2010; Talbot County, Maryland 2015). The land use plans in these documents establish significant oversight over new development within the Town due to its location within the 100-year flood plain (Town of Oxford 2010; Talbot County, Maryland 2015). Under these guidelines, all new construction within the Town is built in compliance with federal flood elevation requirements (Town of Oxford, 2010), and new buildings on existing lots in Talbot County should be located outside of "lands threatened by flooding or shoreline change" (Talbot County, Maryland 2015: 2.12).

Additionally, the State of Maryland has designated that critical area buffers must be established around sensitive wildlife areas for the purpose of conserving these resources (Maryland DNR 2011). The Critical Area Program adopted by the Town designates all land within 1,000 feet of tidal shorelines as critical areas (Town of Oxford 2010). While not directly intended to affect hazard mitigation initiatives (Maryland DNR 2011), the Town's Critical Area Program has established development planning concordant with flood mitigation recommendations (Town of Oxford 2010). Although much of the Town's structures had already been established in the critical area prior to its designation, this action resulted in the annexation of land along the southern edges of the Town which had been previously undeveloped. These lands have been classified under the most restrictive categories of critical area and town zoning designations to protect them from future development (Town of Oxford 2010). In addition to protecting critical wildlife areas, this measure established a buffer between the tidal shoreline and town structures in that area of town, while also providing a space for drainage of water from the Town (Town of Oxford 2010).

In 2011, Talbot County developed a Hazard Mitigation Plan with guidance from FEMA (2009) as a "long-term strategy to reduce disaster losses and break the cycle of disaster damage, reconstruction, and repeated damage" (Talbot County, Maryland 2011: 2). The plan enacts policies aimed at increasing the resiliency of the locality to natural hazards such as floods, winter storms, hurricanes, tornadoes, erosion, wildfire, and drought. Alongside other major towns in Talbot County, the Town of Oxford adopted the County's plan as their own in May 2011 (Talbot County, Maryland, 2011). This planning document not only includes the actions needed to make the Town more resilient, but also allows the Town to apply for federal funding assistance for hazard mitigation efforts (FEMA 2009). With many of the components of the current stormwater infrastructure of the Town thought to be approaching the end of their useful lifetime (EFC 2013), funding for the replacement and strengthening of this system will be necessary in the face of climate change.

Structural Practices

The stormwater infrastructure system currently in place in the Town of Oxford "consists of pipes, culverts, swales, rain gardens, rain barrels, outfalls, biobags, and tide gates that work together to convey or store stormwater and minimize pollution loading" (EFC 2013: 5). Most of these structures, many of which are shown in Figure 15, are in place to handle the persistent flooding events that occur in the Town of Oxford on a regular basis, as opposed to medium to large-scale events that occur less frequently (EFC 2013). Tide gates installed near the entrance of the Town are capable of reducing flooding during small-scale flooding events up to 10 and 20-year storm events (Town of Oxford 2010). Even with these measures in place, the Town continues to deal with constant flooding that often lasts for days (EFC 2013). Climate-induced sea level rise in the Chesapeake Bay, which potentially reaches 2.6-4.3 feet by 2100 (EFC 2013), coupled with an observed increase in storm intensity and duration (Trenberth et al. 2007; FEMA 2012) makes the town even more susceptible to natural hazards. Coping with these changes will continue to be a priority for the Town of Oxford and its residents.

Figure 15. A bioswale, located in Causeway Park, filled with stormwater following a rain event.

Figure 16. Gauges such as this one can be found throughout Oxford in order to help residents estimate flood inundation levels during a storm event. Located at the corner of Banks and Wilson Street.

Additional Steps for Enhancing Adaptive Capacity

A recent study of the financial feasibility of stormwater management in the Town of Oxford concluded that high water events can be mitigated through the development of a comprehensive stormwater management program along with related capital improvement projects (EFC 2013). The report recommended that stormwater management be included as a regularly financed program in order to establish optimal functionality of the Town's stormwater infrastructure system (EFC 2013). Education and outreach to the general public were the final recommendations, so that private residents could better contribute to the stormwater management of the Town (EFC 2013). Resiliency can be additionally increased by participating in more of the hazard mitigation planning measures not currently in place (Table 11).

Figure 17: Location of Structural Stormwater BMPs in the Town of Oxford

Discussion

The Adaptation Process

Though this project identifies numerous vulnerabilities and risks for the Town of Oxford, there are many actions that can be taken. Oxford has demonstrated a proactive approach in many past and present initiatives. The Town can continue to move forward with strategic mitigation, especially with the right information to support the process. NOAA (2010) suggests four primary steps and corresponding activities for climate change adaptation planning (Figure 18). These steps are: 1) establish the planning process, 2) assess vulnerability, 3) create an adaptation strategy, and 4) design a plan implementation and maintenance process. Step 1 activities have been accomplished through the work that Oxford has done in the area of stormwater management, including the *Stormwater and Flood Management Financing Study in Oxford, Maryland* (2013). This project has addressed the activities of Step 2: Assess Vulnerability. Immediate next steps for the Town would include setting goals and identifying actions. This would lead to a process of evaluating, selecting and prioritizing actions.

The final series of maps created for this project feature integrated vulnerabilities with short and long term risks as a means for prioritizing areas for adaptation (Appendix E). These maps are designed as tools for decision makers and community members to use collectively to evaluate next steps, and are tiered such that Tier 1 is reflective of a high priority area for adaptation. In actuality, the tiers represent multiple options for prioritization, depending on the needs and values of the community. The community may decide that they should focus on Tiers 2 and 3 as the vulnerabilities and flood hazard risks are somewhat lower and adaptation may consequently have a more significant impact. This flexibility is an intentional component of the project design and makes a community-driven process of selecting adaptation activities possible. The completion of these activities, followed by the development of the action plans under Step 3: Create an Adaptation Strategy, would enable the Town to begin implementing adaptations. The outcomes of this project provide necessary data and tools to support decision making regarding adaptation.

Step 1: Establish the Planning Process

- Step 1.1: Scope out Level of Effort and Responsibility
- Step 1.2: Assess Resource Needs and Availability
- Step 1.3: Assemble Planning Team and Establish Responsibilities
- Step 1.4: Educate, Engage, and Involve Stakeholders

Step 2: Assess Vulnerability

- Step 2.1: Identify Climate Change Phenomena
- Step 2.2: Identify Climate Change Impacts and Consequences
- Step 2.3: Assess Physical Characteristics and Exposure
- Step 2.4: Consider Adaptive Capacities
- Step 2.5: Develop Scenarios and Simulate Change
- Step 2.6: Summarize Vulnerability and Identify Focus Areas

Step 3: Create an Adaptation Strategy

- Step 3.1: Set Goals
- Step 3.2: Identify Actions
- Step 3.3: Evaluate, Select, and Prioritize Actions
- Step 3.4: Write Action Plans

Step 4: Design a Plan Implementation and Maintenance Process

- Step 4.1: Adopt the Plan
- Step 4.2: Implement the Plan
- Step 4.3: Integrate Plan Findings into Other State Planning Efforts and Programs
- Step 4.4: Track, Evaluate, and Communicate Plan Progress
- Step 4.5: Update the Plan

Figure 18. Adaptation Planning Process

Understanding the Results

Significance

One of the most significant outcomes of this study is that areas of the Town and the County can be prioritized differently based on the outcomes of this assessment and on the specific flood risks being planned for. 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.

When compared to other vulnerability assessments, this framework has many similarities and a few key differences. Among the similarities, this vulnerability assessment examines vulnerability in relation to a hazard or hazards and aims to aid in the prioritization of areas for management action. Also, this vulnerability assessment follows other approaches in its intention to inform management action or plan development.

This assessment diverges from other vulnerability assessment approaches in several critical ways. This framework included a more narrow focus on coastal flooding hazards as opposed to some vulnerability assessments which take into account a range of hazards. Other vulnerability assessment approaches tend to favor either the society or the environment, but not both, as is the case with this approach. Other vulnerability assessments tend to be more descriptive and largely focus on where hazards intersect with space. Alternately, this approach examines the spatial intersection of individual risks and vulnerabilities, and then combines various risks and vulnerabilities together to understand the most critical geographic spaces for action. Most importantly, this framework was meant to integrate the vulnerabilities of social and environmental systems within a community. As a result, the value is in the combined results (e.g. adaptation priority maps) as opposed to the single layers (e.g. social vulnerability map) of the assessment. On a block by block basis, this assessment considered vulnerability of the society, its infrastructure, and its natural resources, as well as the distribution of flood risks. Despite the emphasis, the individual components of the assessment may also be useful in certain contexts and for other management and planning purposes.

Data Limitations

The project team notes that there are data limitations associated with the use of secondary data sources, particularly in terms of assessment of a small geographic unit such as the Town of Oxford. In this case, the limitations came into play most noticeably with the assessment of social vulnerability. Because the Town of Oxford has a high proportion of seasonal residents and these residents may not be included in the data collected by the U.S. Census Bureau, the final values are only applicable to primary residents captured by the U.S. Census of Population and Housing. The already small population size for the town increases the impact of any missing data. The results can only be used to assess the potential social vulnerability of primary residents as opposed to the potential social vulnerability of all residents.

Furthermore, the scale of analysis led to a variety of measures, which are routinely included in social vulnerability assessments, being unavailable. These include educational attainment, income and poverty measures, and employment status. These measures were estimated using a geographic scaling method (Buck 2016). As a result of the use of any estimation procedure, there is error associated with the derived values.

Unfortunately, alternatives to the use of U.S. Census Bureau data are limited. There are no known existing sources that capture the same level of social information for both primary and seasonal residents at this scale of analysis. Therefore, other options include engaging in a primary data collection to obtain the information for a full census of the Town of Oxford's residents or severely limiting the measurement of social dimensions to only those items that could be obtained from existing sources. Both alternatives have significant drawbacks and may still lead to data that fails to represent all portions of the population.

For the Town of Oxford, the factors that dominate social vulnerability are age, labor force size, and economic conditions. This is unsurprising, given the large retired population and the small amount of economic activity within the town boundaries. Despite this, the Town scores relatively low in comparison to the rest of the County on factors such as race, gender, household characteristics and social class. This suggests that the overall social vulnerability of the town is rather low when compared to a larger geographic area like the County or the State.

In order to be able to prioritize some areas of the Town over others for adaptation, the analysis needed to be able to identify and highlight differences in underlying vulnerability and risk. Though variation was known to be present, to be able to showcase this variation, the results needed to be mapped for just the blocks of the Town. This is because the differences are of such a fine scale that they do not appear when scores are mapped for the blocks of the entire County. As a result, the "more vulnerable" to "less vulnerable" scales are different for the County and Town maps; however, both maps are based on the same underlying scores to assess potential vulnerability.

Using the Results in Decision Making

For ideas about how to use the results of this assessment for a variety of management needs, see Appendix D: Guide to Using Data for Decision Making. The diagrams provide instructions for further applications of the individual components of this assessment, such as the structural vulnerability analysis or the social vulnerability plus storm surge flood risk analysis. Additionally, the following notes about use of the results in decision making are important to consider:

- Results are a start to the process of planning for specific adaptation actions. The results should not be applied to implementing specific adaptation actions without further investigation both to ground-truth the specifics of the findings and to ensure the necessary technical specifications are met.
- The results are best used to answer the questions: "What areas should we investigate further?" and "What areas might be prioritized for action?"
- Results can be used to prioritize actions for Talbot County and/or the Town of Oxford.
- Results should not be used to prioritize actions at the state level. This would require analysis for all blocks in the state, which would then mean that scores for each block would be relative to the rest of the state.

The final series of maps that depict long and short term flood risks and the relevant vulnerabilities were developed as the primary resource for climate adaptation planning, particularly when focused on impacts of coastal flooding and sea level rise.

Conclusions

The purpose of this work was two-fold. First, the aim was to assess the vulnerability of the social and environmental systems to climate variability and change for a specific coastal community of the Chesapeake Bay. Second, the aim was to develop a framework for integrated vulnerability assessments that could be transferred to other scales and geographies to support other coastal communities in planning for and adapting to the impacts of climate change. As a result, it is important to evaluate the outcomes of this project in relation to both purposes.

Several features of the project approach proved to be extremely advantageous. These included the federal-state-local partnership; the flood risks selected for the assessment; the community focus; the results and intended applications; and the overarching framework for the integrated vulnerability assessment. These features are discussed in more detail below.

- Partnership: The partnership of federal, state, and local agencies was a highly successful attribute of this project that will help ensure the application of the results to management decisions and actions. Additionally, through the partnership this project was able to draw on an existing network of programming and investment dedicated to assisting Maryland's coastal communities to address short and long term coastal hazards including sea level rise and coastal flooding. The partnership enhanced the NOAA investment and contributed added value.

- Flood risks: The selection of Category 1 storm surge, 1 foot sea level rise, and stormwater flooding represented a strength of the project design. State and local partners, climate extension agents, and community managers agree that the flood risks selected for this assessment will transfer well to other geographies and scales of analysis. This stems from the use of both short and long term flood risks, which provide applicable information for a broader range of management needs, time horizons, and available resources.
- Community Focus: Taking the community and associated social dimensions into consideration is critical for balanced policies and decisions about coastal resource management, climate adaptation, and habitat restoration. This method includes the people, the economy, and the structures people live and work in, while also taking into account the environment and the resources upon which people depend. By focusing the assessment on the community, this project emphasized the importance of planning for climate impacts to our coastal communities in a way that integrates the functions and services of the natural environment.
- Science to Inform Management: The primary result of this project was science to inform climate adaptation. Adaptation will require many steps beyond this work, but the results position the Town of Oxford to obtain funding to develop plans and take actions necessary for ongoing protection.
- Framework: The integrated vulnerability assessment framework proved to be an effective way of analyzing the complex interface of vulnerabilities and risks within a single geography. By including both social and environmental dimensions, this assessment provides a more holistic understanding of what is vulnerable and at risk to the long and short term impacts of climate variability and change.

Future Applications

This project included the development of a framework for integrated vulnerability assessments with the intention of specific application to coastal communities facing the impacts of climate variability and change. The success of this initial application of the approach provides support for continued work to build upon the method while expanding the application to new geographies and scales. Future applications of this work are already planned and will encompass assessment for the purpose of supporting the siting of wetland restoration projects. Other potential uses include the application of the framework for the assessment of vulnerability to other hazards (e.g. severe weather events) and the assessment of vulnerability in relation to coastal protection (e.g., siting areas for investment in green/gray/hybrid shoreline protection). Also, with some modifications, the method could be used to assess vulnerability to risks like ocean acidification. Ultimately, the integrated vulnerability assessment framework lends itself well to many applications in various coastal geographies of the U.S. and beyond.

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Appendix A: Indicators Literature Review

Socioeconomic				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
Wealth and Poverty	• Poverty status in the last 12 months • Median income in the last 12 months	Social Vulnerability for Evacuation Assistance Index (SVEAI)	(1) Population and structure (total pop, # of housing units, # of mobile homes), (2) Differential access to resources (pop below poverty level, occupied housing units w/ no telephones, occupied housing units w/ no vehicles), and (3) Populations with special evacuation needs (institutionalized population in group quarters, pop age 5 years or under, pop age over 85 years, pop over age of 5 with disabilities)	Chakraborty et al, 2005
		Social Vulnerability Index (SoVI)	Personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, and infrastructure dependence	Cutter et al, 2003
		Principal Component Analysis	Age, income/poverty, minority status, disabled, employment, mobile homes/renters, gender, education, density/rural status, density/urban status	Dunning et al, 2011
				Brody et al, 2012 Felsenstein and Lichter, 2013
	• Car ownership			Felsenstein and Lichter, 2013

Socioeconomic				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
	• Value of land parcels			NOAA/NCCOS science team expertise
Age Structure	• Population of children 5 years old and younger • Population of adults 65 years and older			Chakraborty et al, 2005 Cutter et al, 2003 Brody et al, 2012 Dunning et al, 2011 Felsenstein and Lichter, 2013
Single Sector Economic Reliance	• Industry by class of worker for the civilian employed population 16 years and over: percent of workers working within Agriculture, forestry, fishing, and hunting			UNC Institute for the Environment, 2009 Sherrieb et al, 2009 Dunning et al, 2011
	• NMFS social indicators - fishing dependence and reliance			NOAA/NCCOS science team expertise
Housing Stock/Tenancy	• Tenure by year structure built: percent of renters • Occupancy characteristics • Tenure by household size • Female head of house, no husband present			Cutter et al, 2003 Wu et al, 2002 Wongbusarakum and Loper, 2011
Race and Ethnicity	• Percent non-white populations			Wu et al, 2002

Socioeconomic				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
	• Percent immigrant populations	Social Vulnerability Index (SoVI)	Social vulnerability indicators were measured with census data compiled into 3 main categories: poverty, immigrants, and old age/disabilities data.	Kleinosky et al. , 2005
	• Percent populations who speaks English < "very well"			Y-J, Lee, 2013
Sex	• Sex by age: percent female population			Wu et al, 2002
Occupation	• Selected economic characteristics	Wealth Index	Meteorological data: rainfall, temperature, and wind speed for a 30 year period. Dependent variables measuring household asset risk, livelihood risk and climate change perception were analyzed relative to four categories of explanatory variables: resource dependency, social standing, economic status, and spatial location of households.	Combest-Friedman et al, 2012
	•			Cutter et al, 2010
	•	Index of Adaptive Capacity (IAC)	Socioeconomic: poverty, infrastructure, occupational characteristics. Socio-political and institutional: structural social capital, cognitive social capital, perception about MPAs. Socio-ecological: resource-use dependence,	Maldondo and Sanchez, 2014

Socioeconomic				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
			awareness about ecological processes and functions, ability to anticipate disturbances.	
	• Job supported by marine environment • Length of employment for marine jobs			NOAA/NCCOS science team expertise
Disability Status	• Disability characteristics: hearing, vision, cognitive, ambulatory, self-care, independent living difficulties			Y-J, Lee, 2013
Level of Education	• Educational attainment: population with < high school diploma aged < 25	Sensitivity Index (SI), Adaptive Capacity Index (ACI),	SI Indicators: people considering environmental degradation (%), people without stable jobs (%), households losing their agricultural lands (%), household lack of secure water (%), households losing traditional houses (%). ACI Indicators: people with high school education or above (%), people with living space more than 20 m^2 (%), people with higher income, people satisfied with environmental management (%), people optimistic about the future (%).	Huang et al, 2012
Casualties	• Total injuries per recorded storm event			NOAA/NCCOS science team expertise

Socioeconomic				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
	• Total deaths per recorded storm event			Talbot County Hazard Mitigation Plan 2011
Property Loss/Damage	• Estimated property damage per storm event • Estimated crop damage per storm event			NOAA/NCCOS science team expertise Talbot County Hazard Mitigation Plan 2011
Population	• Density	Dimension Index (DI) Environmental Vulnerability Index (EVI)	Exposure values: inundation and pollution. Sensitivity values: population density, slum population, managed systems and unmanaged systems. Adaptive capacity values : awareness, policy foundation, and GRDP.	G. Yoo et al, 2014 Dunning et al, 2011 NOAA/NCCOS science team expertise

Physical and Infrastructure				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
Critical Facilities	• Police station • Fire station • Healthcare (Hospital beds, location of hospitals) • EOC • Property value			Kleinosky et al, 2005 Talbot County Hazard Mitigation Plan, 2011
Public Facilities	• Shelter locations • Property value			Talbot County Hazard Mitigation Plan, 2011

Physical and Infrastructure				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
	• Wastewater treatment facility			
Structures	• Residential • Commercial • Repetitive Loss Properties • Property value • Median age of housing units • Housing units built prior to 1960 • Hazardous material stations			Talbot County Hazard Mitigation Plan, 2011
Roads	• Street shapefile • Centerlines • Total impervious surfaces	Multi-criteria Analysis Matrix	Three climate change scenarios presented: highest astronomical tide, highest astronomical tide plus 0.6 m, and 1978 storm elevation plus 0.6 m. Infrastructure included: roads, sewer, water supply, Stormwater, communications, natural gas pipelines, and "other community" emergency response facilities.	Johnston et al, 2014
				Talbot County Hazard Mitigation Plan, 2011
Pipelines	• Sewer • Water • Stormwater			Johnston et al, 2014 Talbot County Hazard Mitigation Plan, 2011

Physical and Infrastructure				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
	Natural gas			
Communications	Tower locations			Johnston et al, 2014 Lam et al, 2014
Marinas	• Locations • Property value • Number of boat slips Boating access locations (ramps, piers, marinas, etc)			NOAA/NCCOS science team expertise

Environmental				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
Topography/Boundaries	• Watershed boundaries • 100-year & 500-year flood zones			NOAA/NCCOS science team expertise
	• Storm surge inundation zones • Hydrological characteristics (soil type, permeability)			Brody et al, 2012 Werner et al, 2012
	• Land cover			NOAA/NCCOS science team expertise
	• Elevation • Coastline slope	Coastal Vulnerability Index (CVI)	Seven physical and geologic risk variables characterizing the vulnerability	Kunte et al, 2014

Environmental				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
			of the coast: historical shoreline change, rate of relative sea-level change, coastal regional elevation, coastal slope, mean tidal range, significant wave height, and geomorphology using conventional and remotely sensed data. In addition two socioeconomic parameters are utilized: population and tourist density data.	
Critical Habitat	• Location and area of living shoreline			NOAA/NCCOS science team expertise
	• Wetland locations • Seagrass habitat location			Brody et al, 2012 Martinez et al, 2011
	• Shoreline habitat and sensitive biological resources • Oyster reef locations • Blue infrastructure and nearshore habitat priority areas			NOAA/NCCOS science team expertise
Ecosystem Services	• Number of access points, including fishing docks and boat launches (as a measure of recreational opportunity) • Percent of shoreline that is protected by buffers			NOAA/NCCOS science team expertise

Environmental				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
	• Pounds of fish landed in Oxford			
	• Number of local educational programs that are focused on marine/environmental science			Wongbusarakum and Loper, 2011
Sea-level Change	• Tidal measurements			Kunte et al, 2014
	•	Coastal Vulnerability Matrix/Index	Basic information on coastal geomorphology, rate of sea-level rise, past shoreline evolution, coastal slope, mean tidal range, and mean wave height.	Ozyurt and Aysen, 2008
	• IPCC projected sea-level rise • Long term monitoring data for Oxford and surrounding area • MD projected sea-level rise			NOAA/NCCOS science team expertise
Water Quality	• Sediment quality • Salinity • Average temperature • Average dissolved oxygen • Average dissolved solids • Water quality (data for			NOAA/NCCOS science team expertise

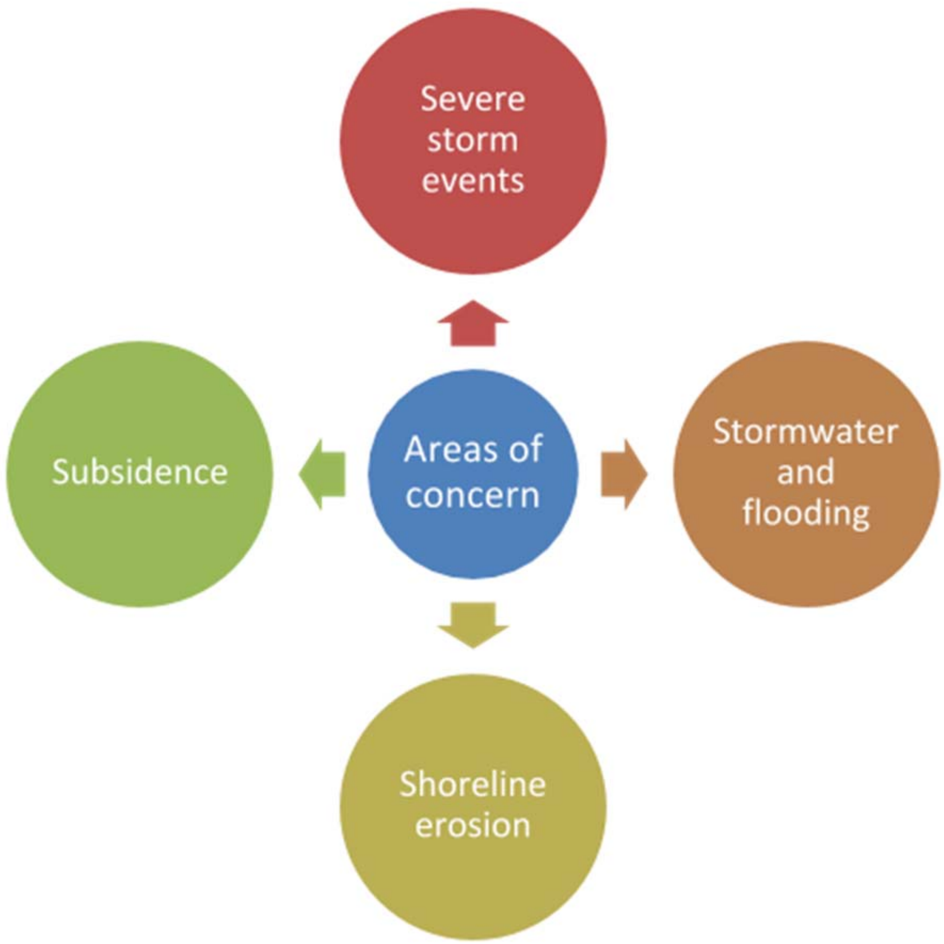
Environmental				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
	mouth of Town Creek, sewage outfall in Oxford) • Historical shellfish closures			
Erosion & Subsidence	• Coastal subsidence rate per year			NOAA/NCCOS science team expertise
	• Erosion rates per year	Beach Vulnerability Index (BVI)	Long-shore sediment transport, cross-shore sediment transport, riverine sediment inputs, the effect of sea level change, erosion of associated coastal landforms, wave run up, and aeolian transport.	Alexandrakis et al, 2014
	•			Talbot County Hazard Mitigation Plan, 2011
Climate Change/Weather	• Annual rainfall amount • Change in intensity of storms • Change in frequency of storms • Average wind speed			Combest-Friedman et al, 2012 Talbot County Hazard Mitigation Plan, 2011

Hazard Mitigation				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
Planning Documents	• Emergency Response • Hazard Mitigation Plan • Comprehensive Plan • Continuity of Operations • Disaster Recovery • Inclusion of ecosystem service valuation in MD coastal zone management plan			NOAA/NCCOS science team expertise
Policy	• Building codes • Zoning ordinances • NFIP participation • Coastal setbacks • Sensitive area development restrictions • CRS participation • Utility taxes			NOAA/NCCOS science team expertise Talbot County Hazard Mitigation Plan, 2011 Brody et al, 2012
Built Structures	• Living shorelines • Bulkheads • Stormwater retention ponds			NOAA/NCCOS science team expertise
Practices	• BMPs • Disaster resilience funding at state and county level • Vulnerability assessments completed			NOAA/NCCOS science team expertise

Hazard Mitigation				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
	• Adaptation activities			Hurlimann, Anna et al, 2013

Stakeholder Participation				
Data Categories	Indicators	Indices Utilized	Combined Metrics	Source
Community Involvement	• Town meeting attendance • Public meeting attendance • Voting activity (total amount of recent voters) • Number of community service organizations • Church memberships • Number of opportunities for public participation (town mtgs, volunteer beach clean ups, etc) • Number of public spaces for interaction (library, town hall, parks, etc)			Wongbusarakum and Loper, 2011 NOAA/NCCOS science team expertise
Perception of Coastal Hazard Risk	• Total number of active flood insurance policies			Marshall et al, 2013

Appendix B: Determining the Focus Areas and Potential Outcomes for Town of Oxford



Expanded Breakdown of Focus Areas with Potential Outcomes

Stormwater/flooding

- Evaluate current mitigation measures (e.g. stormwater retention areas, flood levels in streets)
- Evaluate suitable parcels for future mitigation
- Assess change over time in precipitation and coastal flooding
- Analyze physical infrastructure, housing units, and populations that are vulnerable to impacts of stormwater and flooding
- Analyze ecosystems and associated services that are vulnerable to impacts of stormwater and flooding
- Assess roadways prone to flooding
- Identify/map vulnerable populations within the flood plain
- Create stormwater runoff models that predict change associated with increased development, precipitation rates, etc.

Shoreline erosion

- Evaluate current mitigation measures (e.g. living shoreline, bulkheads, and other)
- Analyze populations, housing units, and physical infrastructure being protected by current mitigation measures
- Assess change over time in erosion (historical rate of shoreline change)
- Analyze highly vulnerable shoreline areas
- Analyze physical infrastructure and housing units that are vulnerable to impacts of shoreline erosion
- Analyze ecosystems and associated services that are vulnerable to impacts of shoreline erosion

Subsidence

- Assess historical rate of coastal subsidence for the town
- Assess areas most susceptible to impacts from land subsidence
- Assess vulnerability of sensitive habitats to land loss (e.g. marsh)
- Assess vulnerability of ecosystem services to land loss (e.g. marsh)

Severe coastal storm events

- Identify/map vulnerable populations within the flood plain
- Evaluate vulnerable physical infrastructure
- Evaluate vulnerable economic industries
- Map high elevation points in town (e.g. for shelter in place and protected parking)
- Assess current shelter capabilities
- Analyze change over time in severe storm events
- Estimate economic loss associated with storm events

Ranking Exercise

First, please review the list of focus areas related to coastal hazard and climate adaptation that has been developed based upon the input we collected from the Town of Oxford. **Is there a focus area that we missed?** If so, please add that to the list.

Then, please **rank each focus area from 1 to 5** based upon its priority of importance to the town. A score of five (1) indicates the focus area is of highest importance and a score of one (5) indicates that the focus area is of least importance.

Focus Area	Why?	Rank	Notes
Stormwater & Flooding	Town has issues that originate from stormwater and tidal flooding. Frequent flooding of roadways following high tide events, precipitation, and severe storms is experienced. The new stormwater utility makes this area an important one for demonstrating progress.		
Severe Storm Events	Limited in-town capacity for shelter in place, lack of elevated parking area, one way in and out, limited access to critical facilities during a storm event (e.g., medical).		
Shoreline Erosion	Areas of shoreline are experiencing erosion, living shorelines need to be added along more sections of shoreline; other shoreline protection needs to be repaired.		
Subsidence	The Town of Oxford (along with the broader region) is experiencing a decrease in elevation, or sinking. The impact of subsidence on current flooding issues is also of concern.		
Other:			
Other:			
Other:			

Appendix C: Final Indicators for NCCOS Integrated Community Vulnerability Assessment

Part I: Indicators Employed in Vulnerability Analysis
Part II: Indicators Employed in Flood Risk Analysis

Part I: Indicators Employed In Vulnerability Analysis

Socioeconomic				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Median Age	This measure divides the age distribution into two equal parts: one-half of the cases falling below the median value and one-half above the value. Median age is computed on the basis of a single year-of-age distribution using a linear interpolation method.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Chakraborty et al, 2005. Cutter et al, 2003. Dunning et al, 2011. Kleinosky et al, 2005. Wongbusarakum and Loper, 2011.
Median income*	Median income is the amount which divides the income distribution into two equal groups, half having income above that amount, and half having income below that amount.	Estimate produced by project team	2010	Brody et al, 2012. Cutter et al, 2003. Dunning et al, 201.1 Felsenstein and Lichter, 2013. Sherrieb et al, 2009.
% race/ethnicity other than white	The race of all persons in the population is recorded in the Decennial Census. Here, all categories of race that are not white are summed as a percentage of the total population. These include: Black or African American, American Indian and Alaska Native, Asian, Native Hawaiian and Other Pacific Islander, and Some Other Race. The concept of race as used by the Census Bureau does not denote a clear-cut scientific definition of biological stock.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Cutter et al, 2003. Wu et al, 2002.
% of pop over 65 years old	The percentage of persons in the population that are 65 years of age and older.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Cutter et al, 2003. Chakraborty et al, 2005.

Socioeconomic				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Average number of people per household	Average household size is a measure obtained by dividing the number of people in households by the number of households. Average household size is rounded to the nearest hundredth.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Cutter et al, 2003. Wongbusarakum and Loper, 2011.
% renter-occupied housing units	All occupied housing units which are not owner-occupied, whether they are rented or occupied without payment of rent, are classified as renter-occupied.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Cutter et al, 2003. Wongbusarakum and Loper, 2011.
% vacant housing units	A housing unit is classified as vacant if no one is living in it on Census Day, unless its occupant or occupants are only temporarily absent—such as away on vacation, in the hospital for a short stay, or on a business trip—and will be returning.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Cutter et al, 2010.
% of pop 25 years or older with no high school diploma*	The percentage of persons in the population that are 25 years of age and older that did not complete high school or an equivalent.	Estimate produced by project team	2010	Cutter et al, 2003. Huang et al, 2012.
% of pop participating in labor force*	The percentage of persons in the population that are non-institutionalized and are 16 years of age and older that are participating in the civilian labor force.	Estimate produced by project team	2010	Cutter et al, 2010.
% of pop unemployed*	The percentage of persons in the population that are non-institutionalized and are 16 years of age and older that are not employed. Persons are classified as unemployed if they do not have a job, have actively looked for work in the prior 4 weeks, and are currently available for work. Persons who were not working and were waiting to be recalled to a job from which they had been temporarily laid off are also	Estimate produced by project team	2010	Dunning et al, 2011.

Socioeconomic				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
	included as unemployed. Receiving benefits from the Unemployment Insurance (UI) program has no bearing on whether a person is classified as unemployed.			
% urban population	In this case, urban is defined as an urban cluster, which consists of densely developed territory that has at least 2,500 people but fewer than 50,000 people.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Cutter et al, 2003. Dunning et al, 2011.
% females	The percentage of persons in the population that is female.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Cutter et al, 2003. Wu et al, 2002.
% female-headed households, no spouse present	A household consists of all people who occupy a particular housing unit as their usual residence, or who live there at the time of the interview and have no usual residence elsewhere. The usual residence is the place where the person lives and sleeps most of the time. This place is not necessarily the same as a legal residence, voting residence, or domicile. Here, household composition is measured as the percentage of all households that are female-headed with no spouse present.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Cutter et al, 2003. Wu et al, 2002.
% HHs with people over 60	Household composition by age category is measured here as the percentage of all households that include members over 60 years of age.	US Census Bureau, 2010 Decennial Census of Population and Housing	2010	Wu et al, 2002
% non-English speaking*	The percentage of persons in the population that is non-English speaking.	Estimate produced by project team	2010	Cutter et al, 2003. Y-J, Lee, 2013.
% with no vehicle*	The percentage of households in the population that do not have access to at least one vehicle.	Estimate produced by project team	2010	Chakraborty et al, 2005.

Socioeconomic				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Median value of housing unit*	Median income is the amount which divides the housing unit value distribution into two equal groups, half of all occupied housing units with value above that amount, and half having a value below that amount.	Estimate produced by project team	2010	Cutter et al, 2003. Wu et al, 2002.

NOTE: **The MERLIN Estimation Procedure was used to derive the values for this variable at the Census block level.*

Physical Infrastructure				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Critical facilities (police, fire, healthcare, EOC, shelters, wastewater treatment)	Critical facilities are structures that serve an important/unique function for communities, often safety and/or health related. **Why included:** Impacts to these facilities via natural hazards have the potential to cause serious bodily harm, extensive property damage, or disruption of vital socioeconomic activities if they are destroyed, damaged, or impaired.	Talbot County GIS	2014	Johnston et al, 2014. Kleinosky et al, 2005
Residential and Commercial structures	Residential and commercial property owners are the most at risk populations in the face of coastal hazards such as SLR and storm surge. It is important to know where these structures are in order to better protect lives, property, and economic stability.	Maryland Department of Planning, MdProperty View	2013	Talbot County Hazard Mitigation Plan, 2011
Property value	Property value allows for the identification of vulnerable populations as well as an estimate of potential economic damages that may occur due to a hazard event.	Maryland Department of Planning, MdProperty View	2013	NOAA/NCCOS science team expertise. Shi et al, 2010 Nelson et al. 2015
Structure grade	A measure of a structure's overall quality of construction based on a 1-9 scale, where 1 is the worst and 9 is the best. Why included: This serves as a measure of a structure's vulnerability to flood hazards and storm events. Structure's with a higher quality of construction would be less vulnerable and vice versa.	Maryland Department of Planning, MdProperty View	2013	NOAA/NCCOS science team expertise. Rabieifar et al, 2014. FEMA 2012. Kappes et al. 2012.

Physical Infrastructure				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Built after 2003	Structures built after 2003 are included as a measure of lower flood vulnerability due to increases in structure elevation standards during this time.	Maryland Department of Planning, MdProperty View	2013	NOAA/NCCOS science team expertise. FEMA NFIP.
Wood-based structures	According to FEMA, structures that are wood-based on the bottom story are considered less resilient to water exposure than other materials such as concrete, brick, or stone. Therefore, wood-based structures are utilized as an indicator of increased vulnerability to flood hazards.	Maryland Department of Planning, MdProperty View	2013	NOAA/NCCOS science team expertise. FEMA NFIP. FEMA 2012. Kappes et al, 2012. Messner and Meyer, 2006. Godfrey et al, 2015.
Centerlines	Roadways are a crucial component of infrastructure both economically and socially. It is important to identify segments that could be adversely impacted by hazard events, such as roadways within a flood hazard area.	Talbot County GIS	2004-2014	Johnston et al, 2014

Ecological				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Wetland locations	Wetlands provide unique ecosystem services that are important for the environment, wildlife, and humans. Wetland locations and their spatial extent are included in the natural resources richness & vulnerability analysis; all wetland classifications included in the data were considered in this analysis.	Maryland DNR Wetlands Inventory http://www.dnr.state.md.us/gis/	2005	Brody et al, 2012 Martinez et al, 2011
Submerged aquatic vegetation (SAV)	SAV beds filter polluted runoff, provide food for waterfowl, and provide habitat for blue crabs, juvenile rockfish, and other aquatic species. The location and spatial extent of SAV beds are included in the natural resources richness & vulnerability analysis.	Virginia Institute of Marine Science http://web.vims.edu/bio/sav/	2013	Martinez et al, 2011 Godwin and Randolph 2012, pg. 61 Balica et al. 2012
Oyster sanctuaries	Oyster sanctuaries are locations where shellfish harvesting is prohibited. The location and spatial extent of these sanctuaries are included in the natural resources richness & vulnerability analysis.	Maryland DNR http://www.dnr.state.md.us/gis/	2013	Balica et al. 2012
Green infrastructure (hubs/corridors)	Green infrastructure consists of a network of undeveloped land that provides the bulk of the State's natural support system. Ecosystem services, such as cleaning the air, filtering water, storing and cycling nutrients, conserving soils, regulating climate, and maintaining hydrologic function, are all provided by the existing expanses of forests, wetlands, and other natural lands. These ecologically valuable lands also provide marketable goods and services, like forest products, fish and wildlife, and recreation. The location and spatial extent of green infrastructure is included in the natural resources richness & vulnerability analysis. Wetlands and forests included in other layers that overlapped with the	Maryland DNR http://www.dnr.state.md.us/gis/	2005	Balica et al. 2012

Ecological				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
	green infrastructure layer were removed to prevent double counting of resources.			
Forested areas	Forests provide necessary habitat for wildlife as well as valuable economic and recreational resources for human use. The location and spatial extent of forested areas are included in the natural resources richness & vulnerability analysis.	Talbot County GIS	2010	Balica et al. 2012

Ecological				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Sensitive species locations	Sensitive species locations consist of buffered areas that primarily contain habitat for rare, threatened, and endangered species and rare natural community types. It generally includes, but does not specifically delineate, such regulated areas as Natural Heritage Areas, Wetlands of Special State Concern, Colonial Waterbird Colonies, and Habitat Protection Areas. The location and spatial extent of sensitive species are included in the natural resources richness & vulnerability analysis.	Maryland DNR http://www.dnr.state.md.us/gis/	2010	Hemming et al. 2013
Beaches	Beaches provide wildlife habitat and recreational opportunities for people which help sustain coastal economies. The location and spatial extent of beaches are included in the natural resources richness & vulnerability analysis.	NOAA Environmental Sensitivity Index (ESI) data http://response.restoration.noaa.gov/maps-and-spatial-data/download-esi-maps-and-gis-data.html	2007	Balica et al. 2012

Ecological				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Marsh buffer	Marsh buffers are designed to protect marsh environments from the potential damages of nearby development. The location and spatial extent of marsh buffers are included in the natural resources richness & vulnerability analysis.	Virginia Institute of Marine Science, Center for Coastal Resources Management http://ccrm.vims.edu/gis_data_maps/shoreline_inventories/	2005	Balica et al. 2012
Forest conservation easement	Forest conservation easements protect a forest on private land by limiting certain activities, such as the clearing of any trees, brush, or vegetation. The location and spatial extent of forest conservation easements are included in the natural resources richness & vulnerability analysis.	Maryland DNR http://www.dnr.state.md.us/gis/	2013	Balica et al. 2012

Hazard Mitigation				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Planning documents Hazard Mitigation Plan; Comprehensive Plan; Continuity of Operations Plan	The plans and strategies being implemented at the local and county levels are vital steps toward mitigating the risks associated with climate change within coastal communities.	2011 Talbot County Hazard Mitigation Plan. http://www.talbotdes.org/plan_prepare.asp?res=des_hazard_mitigation Town of Oxford 2010 Comprehensive Plan. http://www.oxfordmd.net/documents/Comp_Plan71010_County.pdf 2011 Talbot County Continuity of Operations Plan.	2010, 2011	NOAA/NCCOS science team expertise.
Policy Building codes; Zoning ordinances; Coastal setbacks; Sensitive area development restrictions; Stormwater utility tax		Town of Oxford 2012 Building Code http://www.oxfordmd.net/zoning.html Current Oxford Zoning Ordinance http://www.oxfordmd.net/zoning.html Oxford Town Code http://www.oxfordmd.net/documents/Town%20of%20Oxford%20Code.pdf	Varies	NOAA/NCCOS science team expertise. Talbot County Hazard Mitigation Plan, 2011. Brody et al, 2012.

Hazard Mitigation				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Best Management Practices Structural; Nonstructural	Structural practices utilized in Oxford include: pipes, culverts, swales, rain gardens, rain barrels, outfalls, biobags, and tide gates. These structures work together to convey or store stormwater and minimize pollution loading. Nonstructural practices can come in the form of stakeholder participation as well as land use and hazard mitigation planning, each of which has the ability to modify individual behavior and thus reduce harmful runoff at the source.	Project team collection	Varies	NOAA/NCCOS science team expertise. Hurlimann, Anna et al, 2013.

Stakeholder Participation				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Town meeting attendance	Measures the general willingness/ability of the community to engage in the local decision making process.	Town of Oxford	2015	Pearce 2003
Public meeting attendance	Measures the general willingness/ability of the community to engage in the local decision making process.	Town of Oxford	2015	Pearce 2004
Number of community service organizations	Community service organizations are a metric which reveals the public's involvement within a community as well as their ability to organize and come together in response to a coastal hazard event.	Town of Oxford	2015	Dillard et al., 2013 Wongbusarakum and Loper, 2011

Stakeholder Participation				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Number of public spaces for interaction	These areas are important because they are locations in which public meetings, civil discourse, discussion of policy, and other stakeholder participation activities can publicly occur.	Project team collection	2015	Wongbusarakum and Loper, 2011
Number of opportunities for public participation	This represents how often a local government shows a willingness or ability to include the public in the decision making process for important community level decisions.	Town of Oxford	2015	Dillard et al., 2013 Wongbusarakum and Loper, 2011

Part II: Indicators Employed In Flood Risk Analysis

Hazards and Supporting Data				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Storm Surge				
Storm surge inundation zone (Cat 1)	Storm surge is defined as the abnormal rise of water generated by a storm, over and above the predicted astronomical tides. A category 1 hurricane produces storm surge 4 to 5 feet above normal. The category 1 storm surge inundation zone was selected as one of three flood hazard layers. This level of inundation most accurately reflects the type of storm that can be expected within the study area.	Army Corp of Engineers (national source). Talbot County GIS (local source).	2006	Brody et al, 2012
Stormwater Flooding				
Soil Type	Soil type plays a role in modeling stormwater runoff. Areas of poorly drained/impervious soil types are more likely to contribute to increased stormwater runoff and flooding.	USDA NRCS http://datagateway.nrcs.usda.gov/GDGOrder.aspx	2013	Blair, A. et al., 2014 Blair, A. et al., 2014 Brody et al, 2012
Land Cover	Land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types. Why included: land cover data is utilized in stormwater runoff modeling, determination of flood prone areas, and other analyses.	C-CAP Land Cover Atlas http://www.coast.noaa.gov/digitalcoast/dataregistry/#/	2010	Blair, A. et al., 2014 Blair, A. et al., 2014 Taubenbock et al. 2008 Kienberger et al. 2008

Hazards and Supporting Data				
Indicator	**Description**	**Data Source**	**Year**	**Lit Review Citation**
Elevation (DEM)	Low-lying coastal areas are especially at risk to the impacts of flooding caused by coastal hazards such as sea level rise and storm surge. Elevation data (30x30m) is utilized in the assessment of natural resource richness, flood prone areas, and stormwater runoff volume.	National Map Viewer http://viewer.nationalmap.gov/viewer/	2015	Blair, A. et al., 2014 Blair, A. et al., 2014 Kunte et al, 2014
Sea Level Rise				
MD projected sea-level rise (SLR)	Sea level rise poses a threat to multiple groups, including humans, the environment, wildlife, infrastructure, and economic systems. As such, varying levels of projected SLR (1-3 ft) are utilized as a flood hazard layer to aid in determining the level of vulnerability of the aforementioned groups. SLR is utilized as a hazard layer in analyses to determine social, infrastructure, economic, and environmental vulnerability.	NOAA Sea level rise viewer	2012	Talbot County Hazard Mitigation Plan 2011 Balica et al. 2012
Supporting Data				
Watershed boundaries	Watershed boundaries represent the areal extent of surface water drainage and serve as a unit of analysis. The Boone Creek & Town Creek drainage basins were utilized in a SWARM analysis, which models stormwater runoff within the drainage basins based upon user defined rainfall amounts and runoff conditions.	Town of Oxford 2010 Comp Plan (Boone Creek & Town Creek Drainage Basins) Maryland DNR (Talbot watershed hua14)	1998	Blair, A. et al., 2014 Blair, A. et al., 2014
Annual rainfall amount	Annual rainfall is used in determining climate trends, as a bar in developing flood prone areas, in selecting appropriate hazard severity when creating scenarios, and in stormwater runoff modeling.	NCDC - Royal Oak Station	2000-2014	Combest-Friedman et al, 2012 Talbot County Hazard Mitigation Plan, 2011 Balica et al. 2012

Appendix D: Using the Data

Oncoming coastal storm; flood watch issued for county

Where is the greatest risk of flooding?

- Stormwater flood risk analysis can provide information about where the rainfall will go.
- Storm surge + stormwater flood risk analysis can provide information about what might happen if high tide happens during the storm.

What infrastructure is most vulnerable?

- Structural vulnerability + stormwater flood risk analysis can provide information about which commercial and residential structures are most vulnerable to stormwater flooding.
- Structural vulnerability analysis can provide information about which commercial and residential structures are generally most vulnerable.

What people are most vulnerable?

- Social vulnerability + stormwater flood risk analysis can provide information about which people are most vulnerable to stormwater flooding.
- Social vulnerability analysis can provide information about which people are generally most vulnerable.

What natural resources are most vulnerable?

- Natural resource richness analysis can provide information about which areas have high concentrations of resources.

Where should adaptation activities occur?

- Integrated vulnerabilities and risk analysis for short term flood hazards can provide information about which areas should be prioritized for future mitigation activities.

Oncoming hurricane; hurricane watch issued for county

Where is the greatest risk of flooding?	• Storm surge flood risk analysis can provide information about where the water will go. • Storm surge + stormwater flood risk analysis can provide information about what might happen if there is both rain and tidal flooding during the storm.
What infrastructure is most vulnerable?	• Structural vulnerability + storm surge flood risk analysis can provide information about which commercial and residential structures are most vulnerable to storm surge flooding. • Structural vulnerability analysis can provide information about which commercial and residential structures are generally most vulnerable.
What people are most vulnerable?	• Social vulnerability + storm surge flood risk analysis can provide information about which people are most vulnerable to storm surge flooding. • Social vulnerability analysis can provide information about which people are generally most vulnerable.
What natural resources are most vulnerable?	• Natural resource + storm surge flood risk analysis can provide information about which areas have high concentrations of resources that are at risk of storm surge impacts. • Natural resource richness analysis can provide information about which areas have high concentrations of resources.
Where should adaptation activities occur?	• Integrated vulnerabilities and risk analysis for short term flood hazards can provide information about which areas should be prioritized for future mitigation activities.

Long term climate adaptation planning

Where will the greatest SLR risk be?	• SLR risk analysis can provide information about where the greatest risks are located.
What infrastructure will be most vulnerable?	• Structural vulnerability + SLR risk analysis can provide information about which commercial and residential structures are most vulnerable to SLR. • Structural vulnerability analysis can provide information about which commercial and residential structures are generally most vulnerable.
What people will be most vulnerable?	• Social vulnerability + SLR risk analysis can provide information about which people are most vulnerable to SLR. • Social vulnerability analysis can provide information about which people are generally most vulnerable.
What will things look like with more development?	• Natural resource + SLR risk analysis can provide information about which areas have high concentrations of resources that are at risk of SLR impacts. • Natural resource richness analysis can provide information about which areas have high concentrations of resources.
Where should adaptation activities be sited?	• Integrated vulnerabilities and risk analysis for long term flood hazards can provide information about which areas should be prioritized for long term climate adaptation planning.

Appendix E: Mapbook Supplement for NCCOS Integrated Community Vulnerability Assessment

Appendix E: Mapbook Supplement for NCCOS Integrated Community Vulnerability Assessment

Introduction

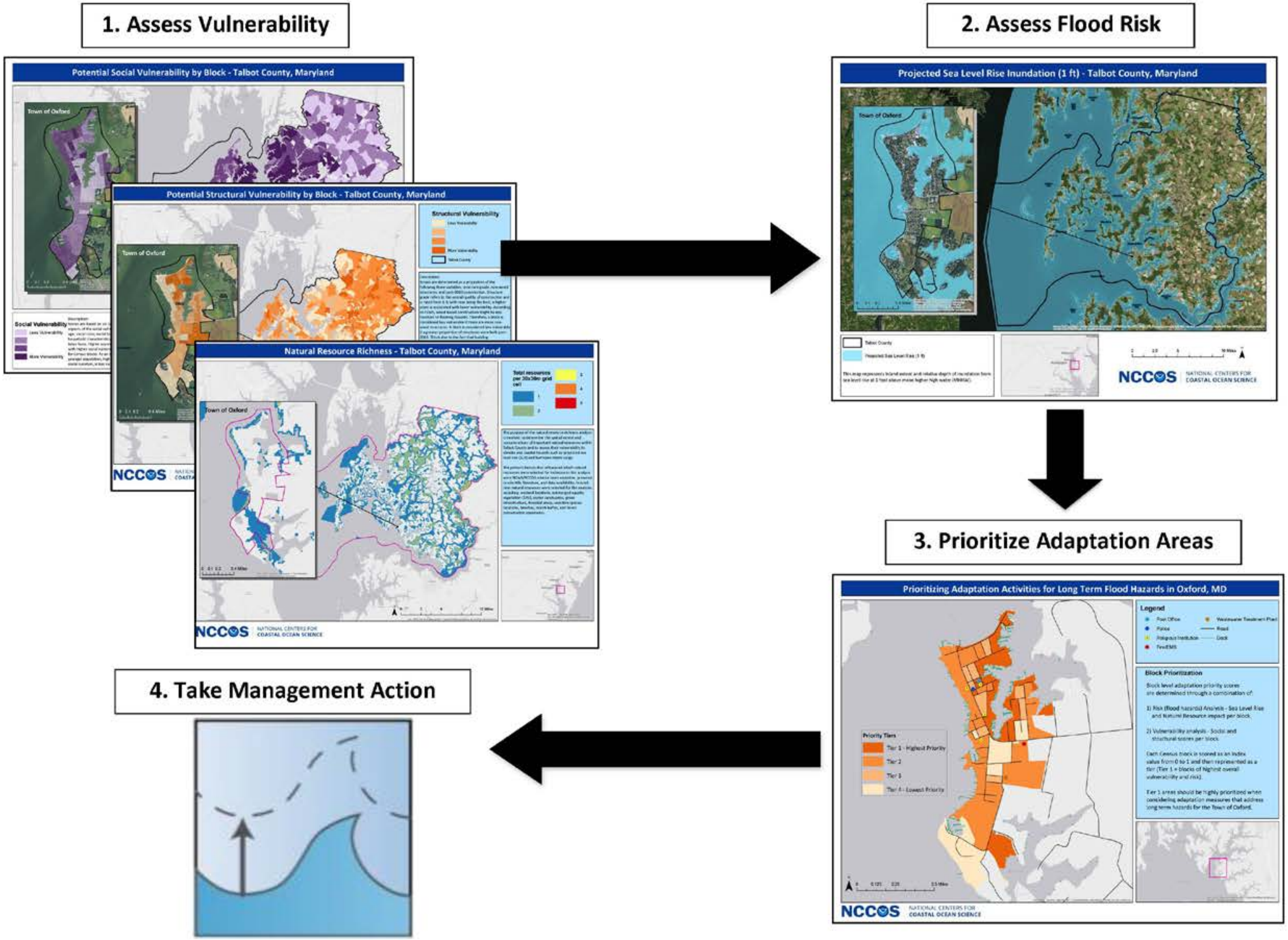
The overarching goal of this project was to evaluate a coastal community's vulnerability to the localized impacts of climate variability and change. The study utilized a "vulnerability of places" framework (e.g., Cutter 1996, Cutter et al. 2000) to examine social and environmental vulnerability to climate variability and change. 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 community to address risk and identify adaptation strategies moving forward. Ultimately, the results of the vulnerability assessment will be used to inform community-led adaptation planning and corresponding management actions. This series of maps is an integral part in achieving this project's goals by providing strong visual aid to community adaptation planners and managers.

This study was conducted for the Town of Oxford and Talbot County, MD. Talbot County is located within the Eastern Shore of Maryland and its climate is significantly influenced by both the Chesapeake Bay and the Atlantic Ocean. The Town of Oxford, located in the Lower Choptank Watershed of the Chesapeake Bay is intersected by Town Creek. Because the Town is low-lying, it is frequently exposed to flooding events. These events may occur as a result of a single event or combination of events with differing impacts around town. Similarly, retreat of floodwaters varies by area and is dependent on tide, wind, temperature, and local topography (EFC 2013). With changing climate conditions like sea level rise and increased frequency and intensity of heavy precipitation events, Oxford's flooding issues are expected to worsen.

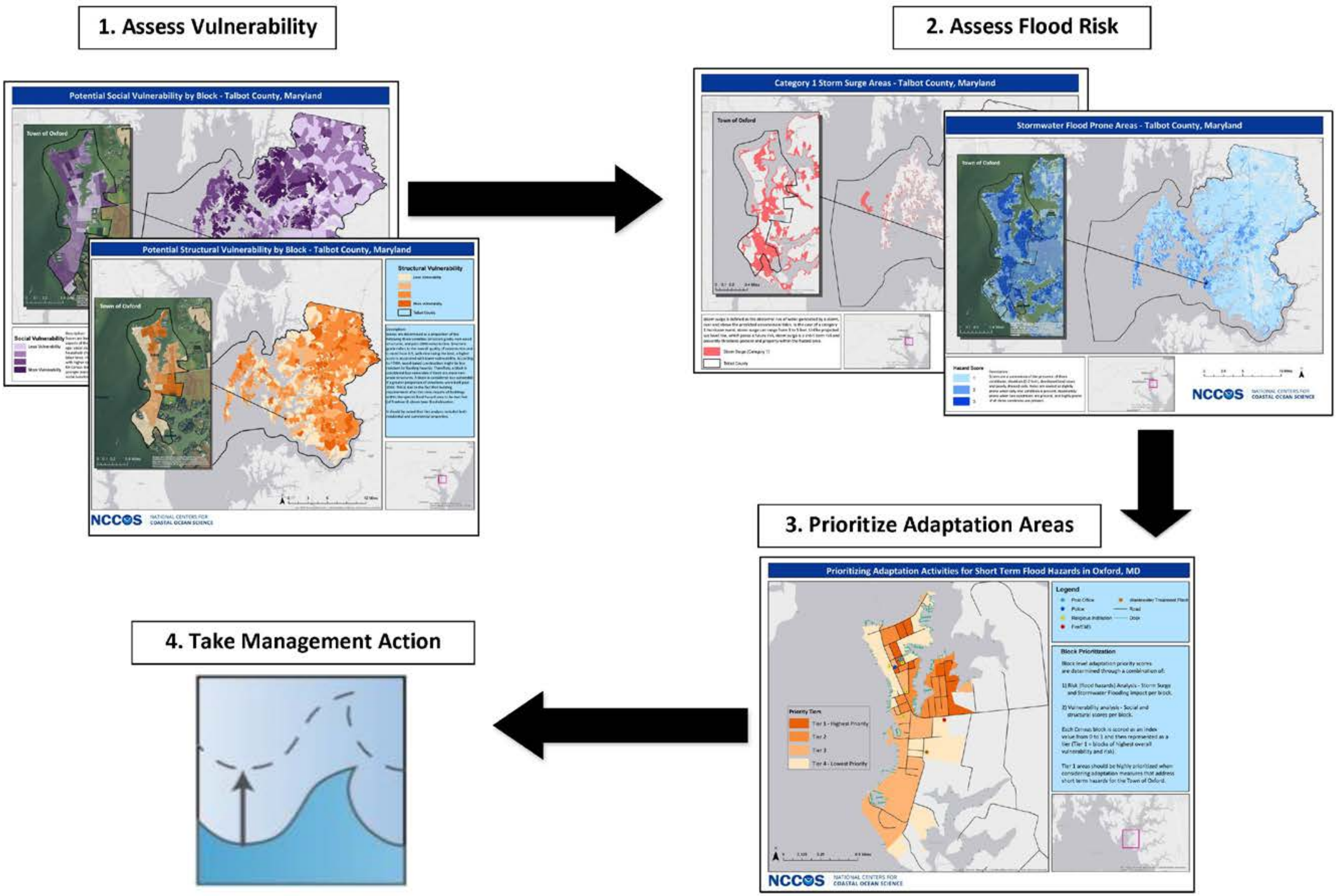
This project represents strong collaboration across the social and natural sciences, as well as across federal, state and local partners. While the initial vulnerability assessment tool development and data collection is focused on the Town of Oxford, MD, the methodological approach is being tailored for maximum applicability across coastal communities in all regions. This work 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 maps on vulnerabilities, Section 2 provides maps on flood risk hazards, Section 3 provides maps on the intersection of vulnerabilities and flood risk hazards, and Section 4 provides maps on adaptation planning.

Integrated Vulnerability Assessment Framework: Long Term Flood Risks



Integrated Vulnerability Assessment Framework: Short Term Flood Risks



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Section 1:

Vulnerabilities

Vulnerabilities

This section provides maps of social vulnerability by block, structural vulnerability by block, natural resource distribution and natural resource richness for Talbot County, MD.

The science team began by measuring the risks of flooding by climate change that were most important to local managers. The team then measured how likely these flood events were and how they would impact 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 how vulnerable their community's population is to climate stressors and flood events. Structural vulnerability indicators were used to create an index that would help managers measure how vulnerable their community's built environment and infrastructure are to climate stressors and flood events. Lastly, natural resource distribution indicators were used to create an index that would help managers measure how vulnerable their natural environment is to these stressors and flood events.

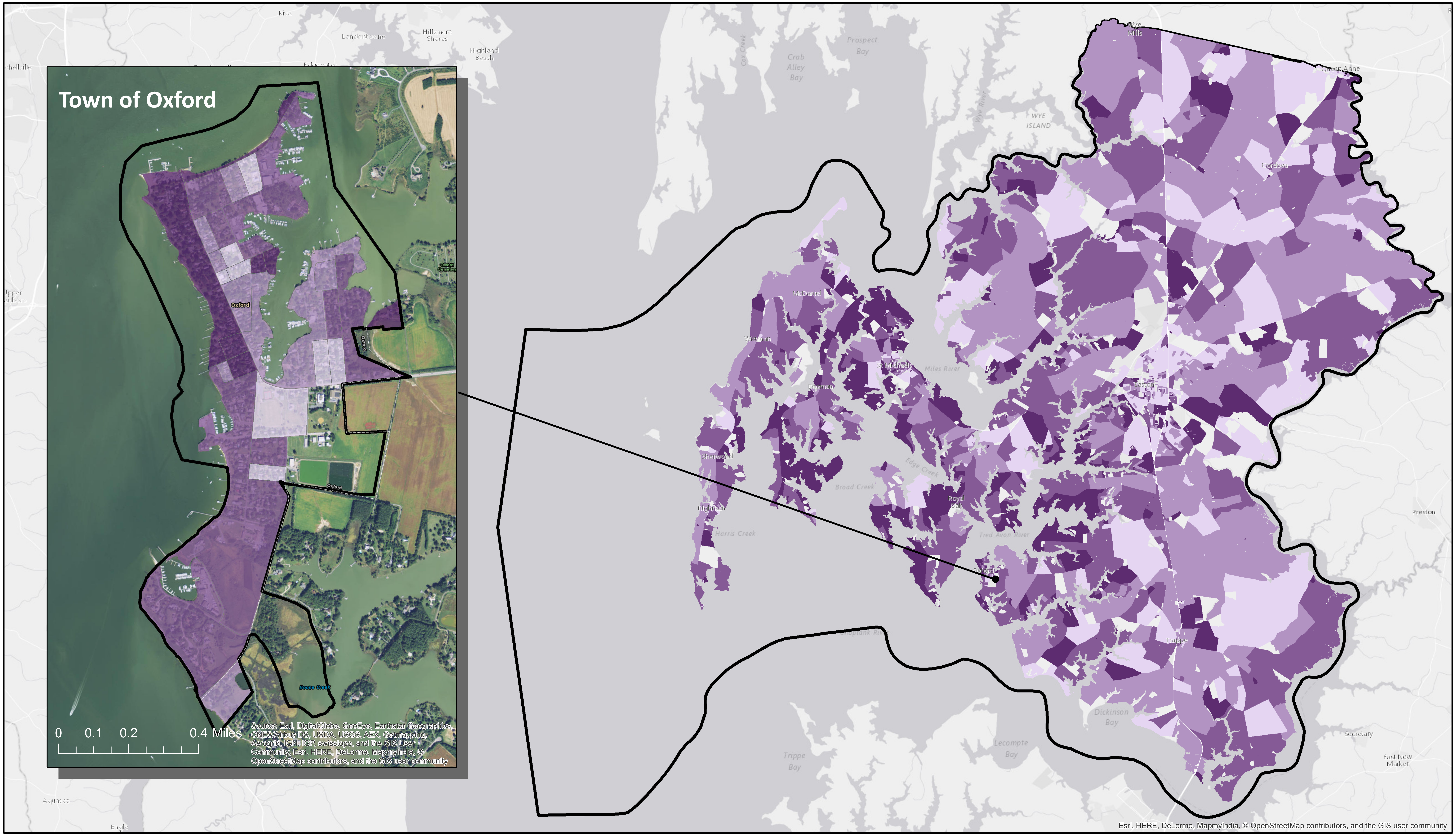
To develop the social vulnerability measure for census blocks in Talbot County, MD, secondary data from 2010 U.S. Decennial Census was utilized alongside estimates produced by the science team. For critical variables that were not available via these methods, estimates were derived using MERLIN, a geographic scaling method developed by a member of the science team (Buck 2015). 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 are comprised of 17 variables total, were: *1) age, 2) social class, 3) social isolation, 4) race, gender, and household characteristics, 5) economic condition, and 6) labor force*.

In order to arrive at a structural vulnerability measure for the Census blocks in Talbot County, MD, an approach was used that involved an initial collection of secondary data from county parcel records to determine structural vulnerability. The following indicators were used in the assessment of structural vulnerability: *1) the construction material of the primary building, 2) the age of the structure,* and *3) the grade of the primary structure.*

The purpose of the natural resource richness analysis was to determine the spatial extent and concentrations of important natural resources within Talbot County, and to assess their vulnerability to climate and coastal hazards, such as projected sea level rise and hurricane storm surge. Natural resource richness was used because there is a lack of existing environmental vulnerability indicators since few studies attempt to capture what this project aimed to, and it was important to examine the environment in relation to its social value. The science team determined which indicators were best to include in the natural resources analysis by considering which resources were important (in terms of ecosystem services provided and economic value) to Talbot County, which resources would conceivably be adversely impacted by the selected hazards, and the availability of the data. The analysis included the following resources as indicators: *1) wetlands, 2) submerged aquatic vegetation, 3) oyster sanctuaries, 4) green infrastructure, 5) forested areas, 6) sensitive species locations, 7) beaches,* and *8) marsh buffer.*

Age Component of Potential Social Vulnerability - Talbot County, Maryland

E6



Social Vulnerability

Age Factor

- Less Vulnerable
-
-
- More Vulnerable

Description:
The age factor is comprised of 4 components: median age, population over 65 years, households with persons over 60 years, and household size.

This factor is one of six which combines to determine the potential social vulnerability index score as shown on the map "Potential Social Vulnerability by Block - Talbot County, Maryland".

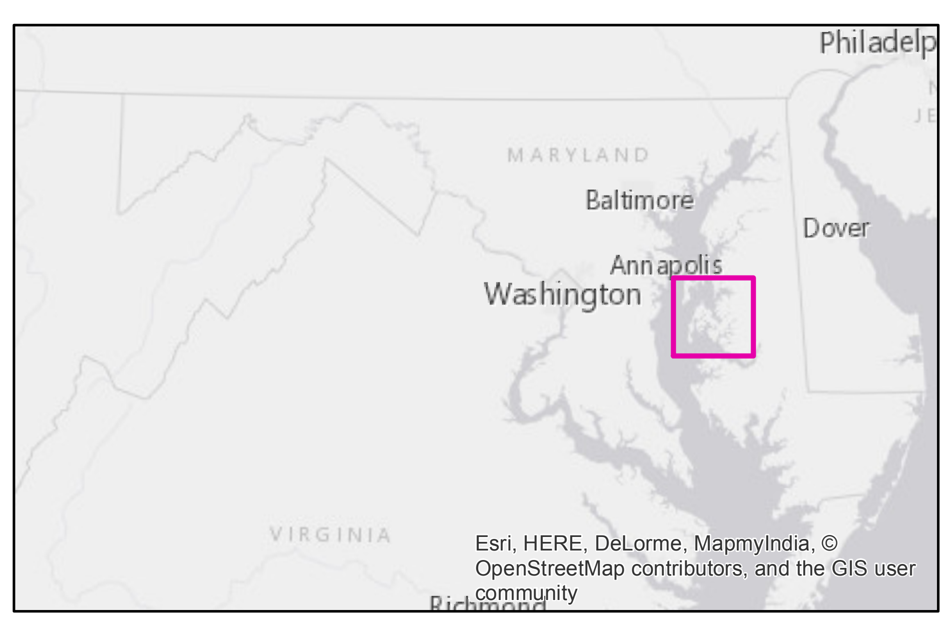


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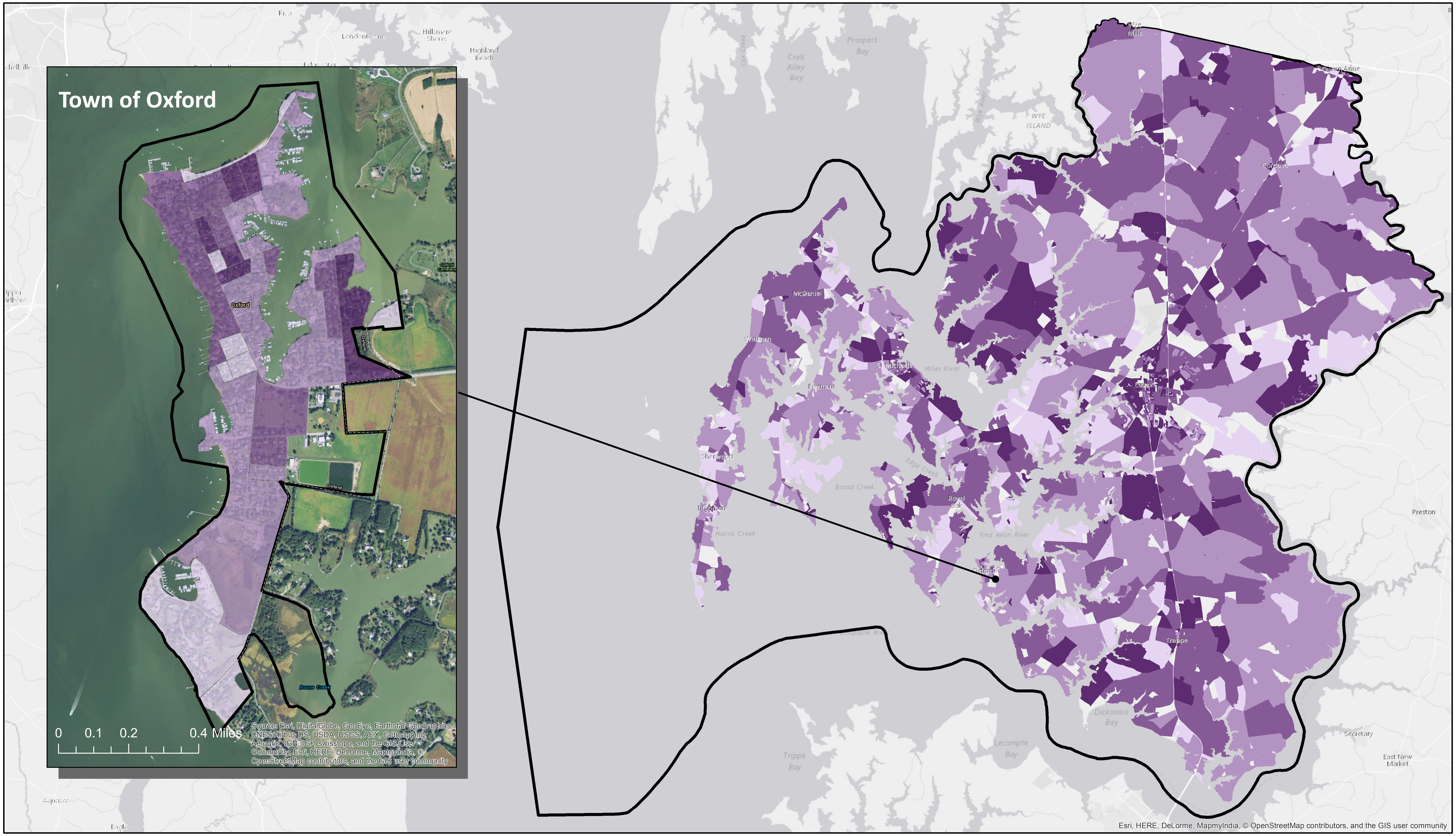
Figure E-1

Race, Gender, Household Characteristics Component of Potential Social Vulnerability - Talbot County, Maryland

E7



Social Vulnerability

Race, Gender, HH Factor

- Less Vulnerable
-
-
- More Vulnerable

Description:
The race, gender, and household characteristics factor is comprised of 4 components: female-headed households with no spouse present, race/ethnicity other than white, female population, and renter-occupied housing units.

This factor is one of six which combines to determine the potential social vulnerability index score as shown on the map "Potential Social Vulnerability by Block - Talbot County, Maryland".

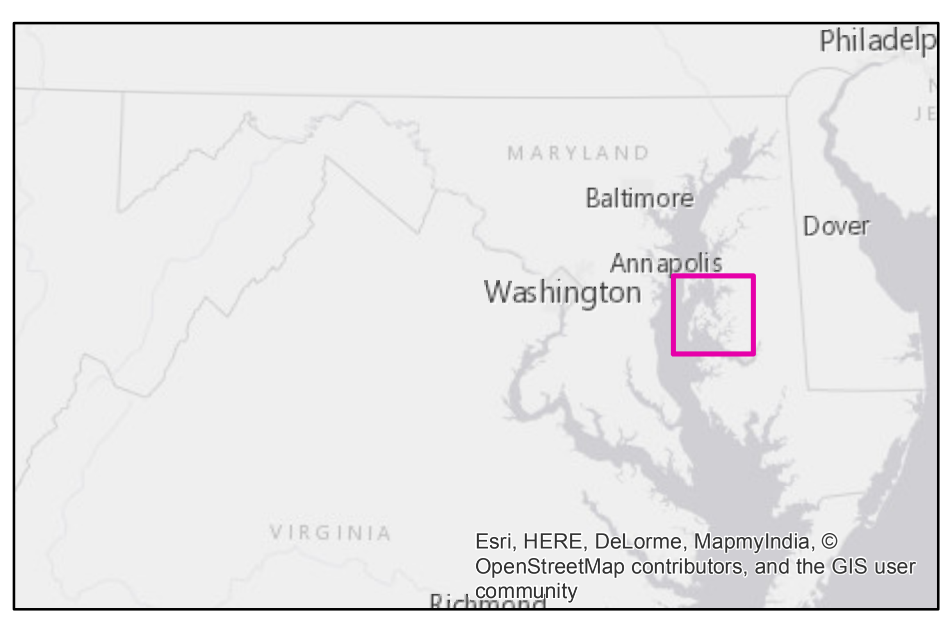


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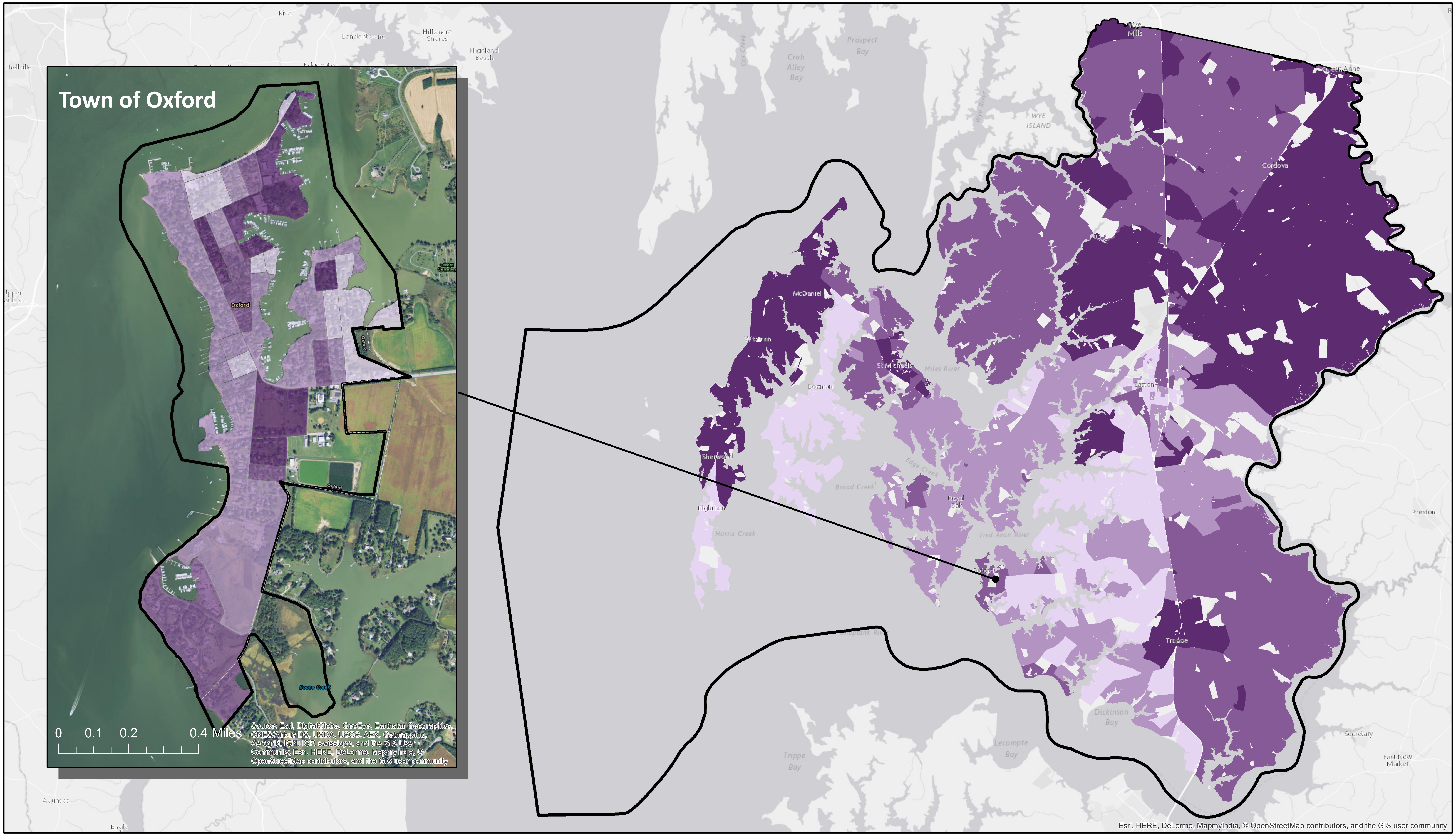
Figure E-2

Social Class Component of Potential Social Vulnerability - Talbot County, Maryland



Social Vulnerability

Social Class Factor

- Less Vulnerable
-
-
- More Vulnerable

Description:
The social class factor is comprised of 4 components: population 25 years or older with no high school diploma, median value of housing unit, median income, and urban population.

This factor is one of six which combines to determine the potential social vulnerability index score as shown on the map "Potential Social Vulnerability by Block - Talbot County, Maryland".

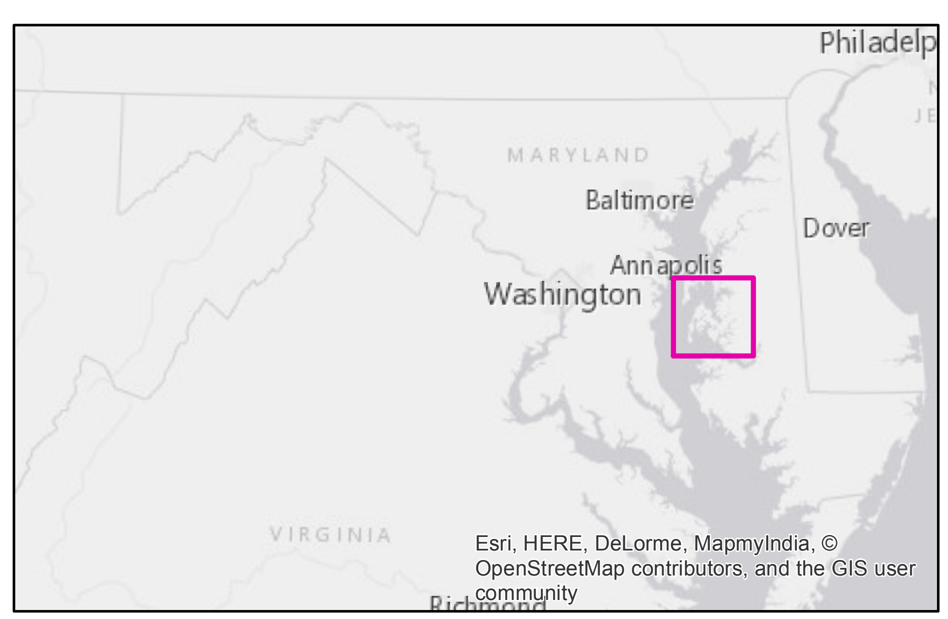


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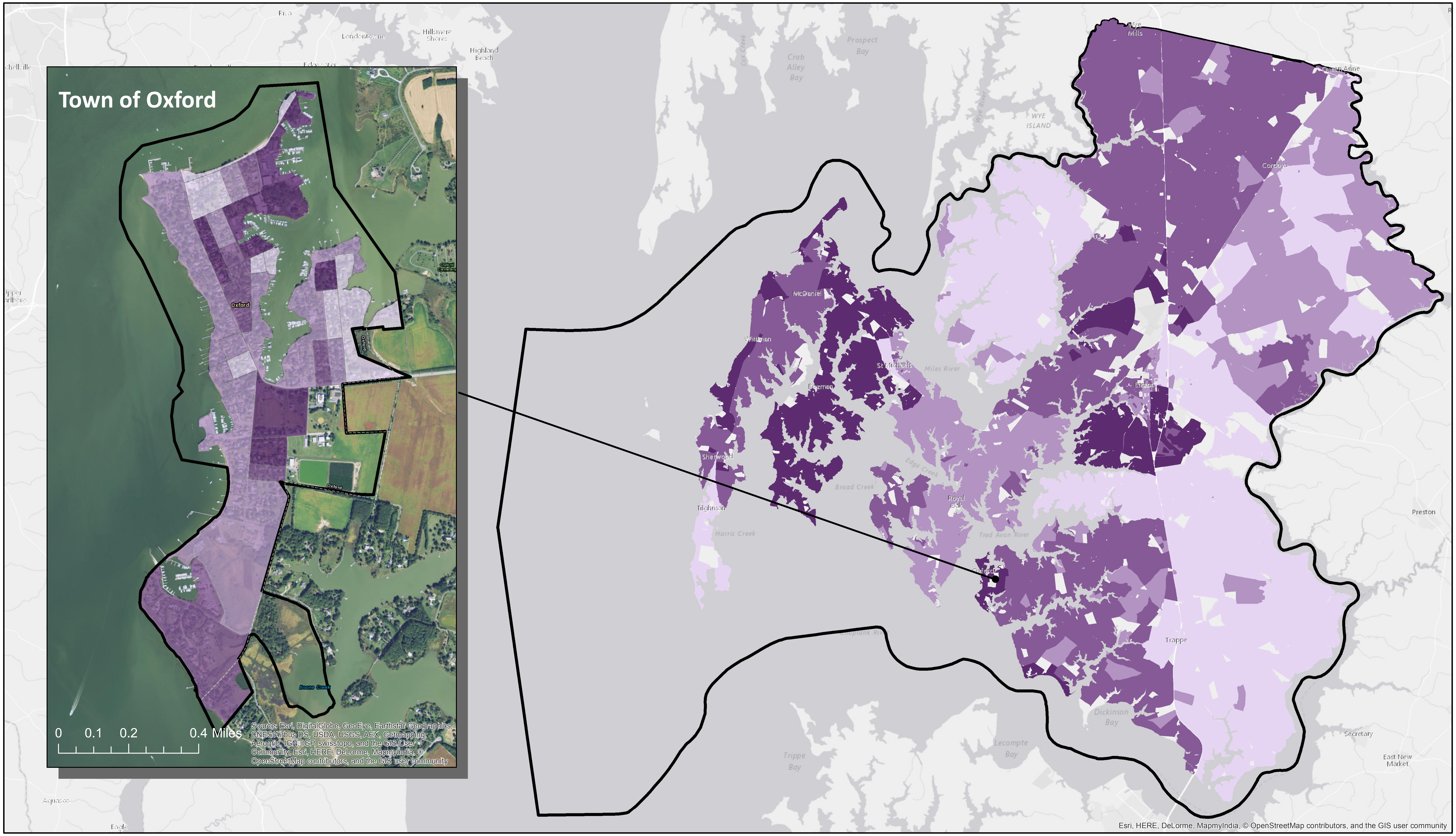
Figure E-3

Labor Force Component of Potential Social Vulnerability - Talbot County, Maryland



Social Vulnerability

Labor Force Factor

- Less Vulnerable
-
-
- More Vulnerable

Description:
The labor force factor is comprised of 1 component: labor force size.

This factor is one of six which combines to determine the potential social vulnerability index score as shown on the map "Potential Social Vulnerability by Block - Talbot County, Maryland".

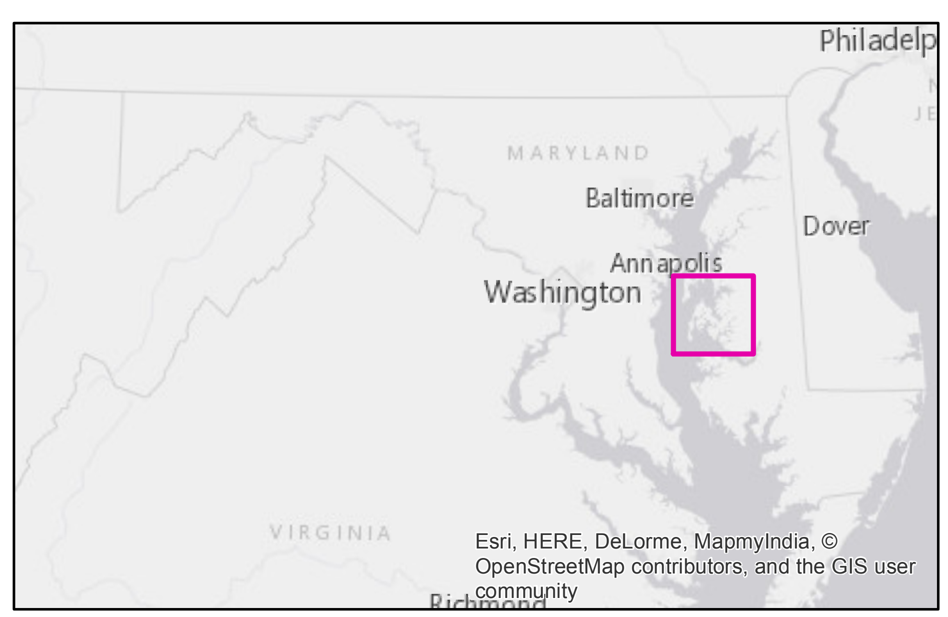


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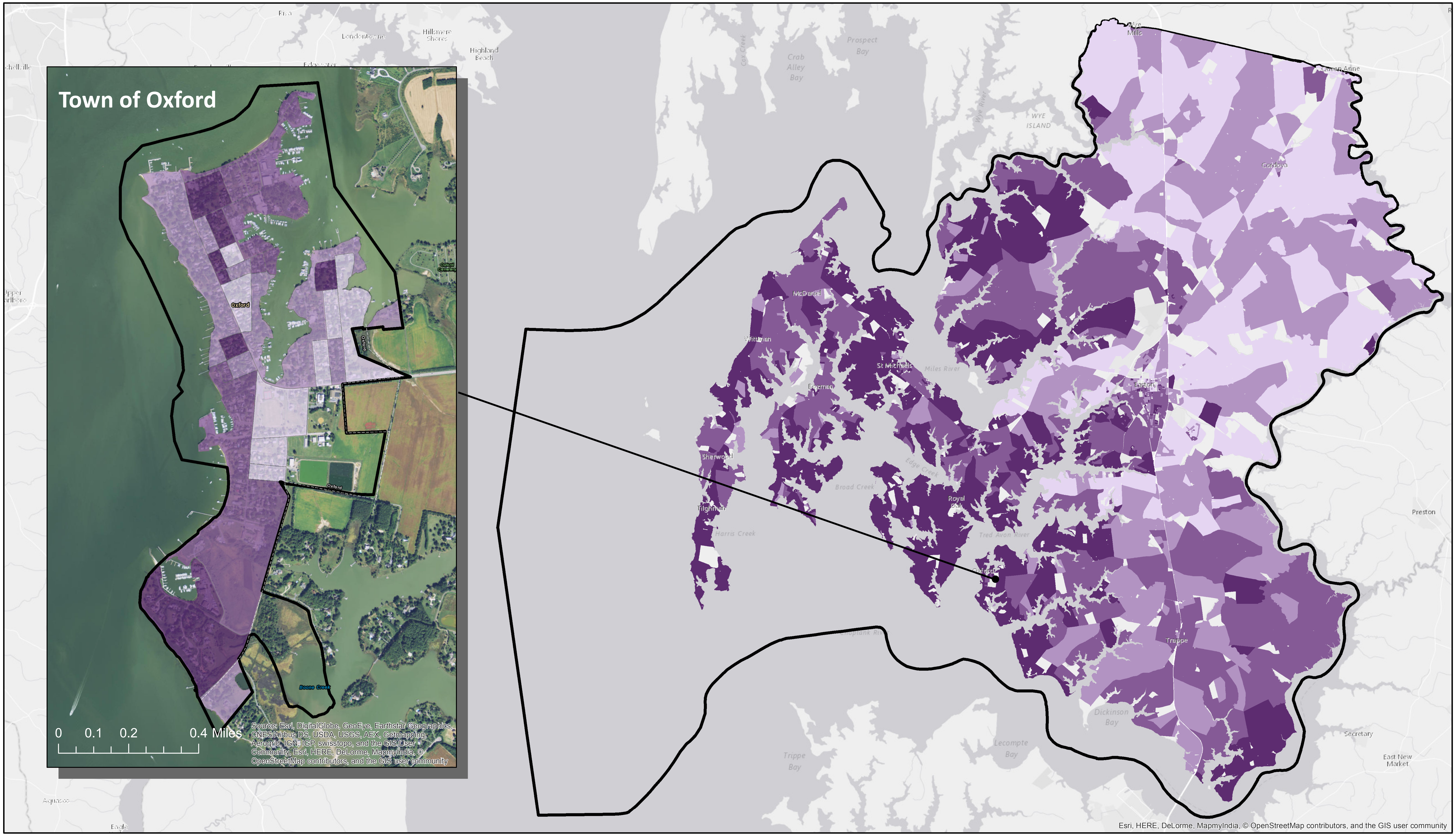
Figure E-4

Economic Condition Component of Potential Social Vulnerability - Talbot County, Maryland

E10



Social Vulnerability

Economic Condition Factor

- Less Vulnerable
-
-
- More Vulnerable

Description:
The economic condiction factor is comprised of 2 components: vacant housing units and unemployed population.

This factor is one of six which combines to determine the potential social vulnerability index score as shown on the map "Potential Social Vulnerability by Block - Talbot County, Maryland".

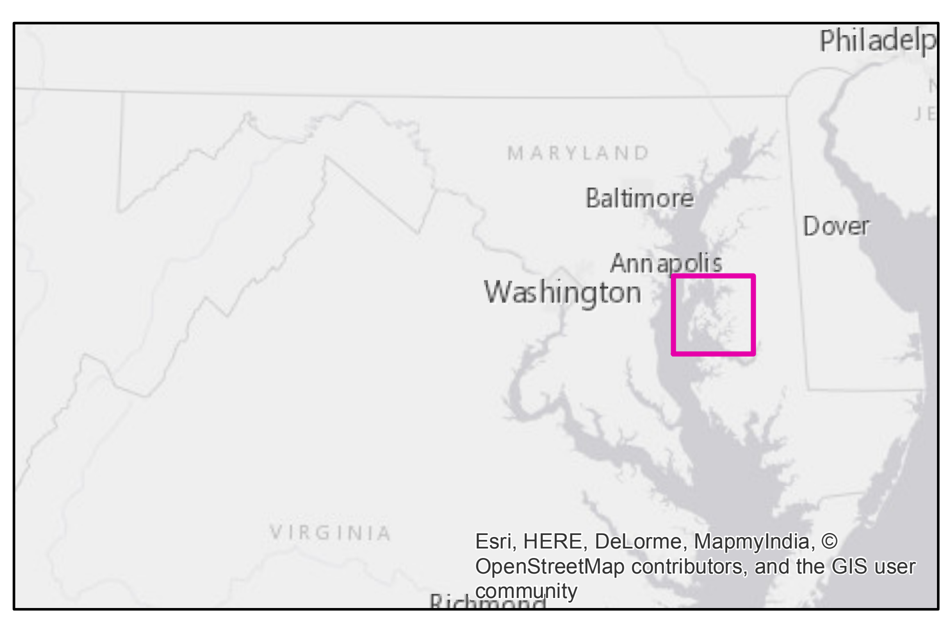


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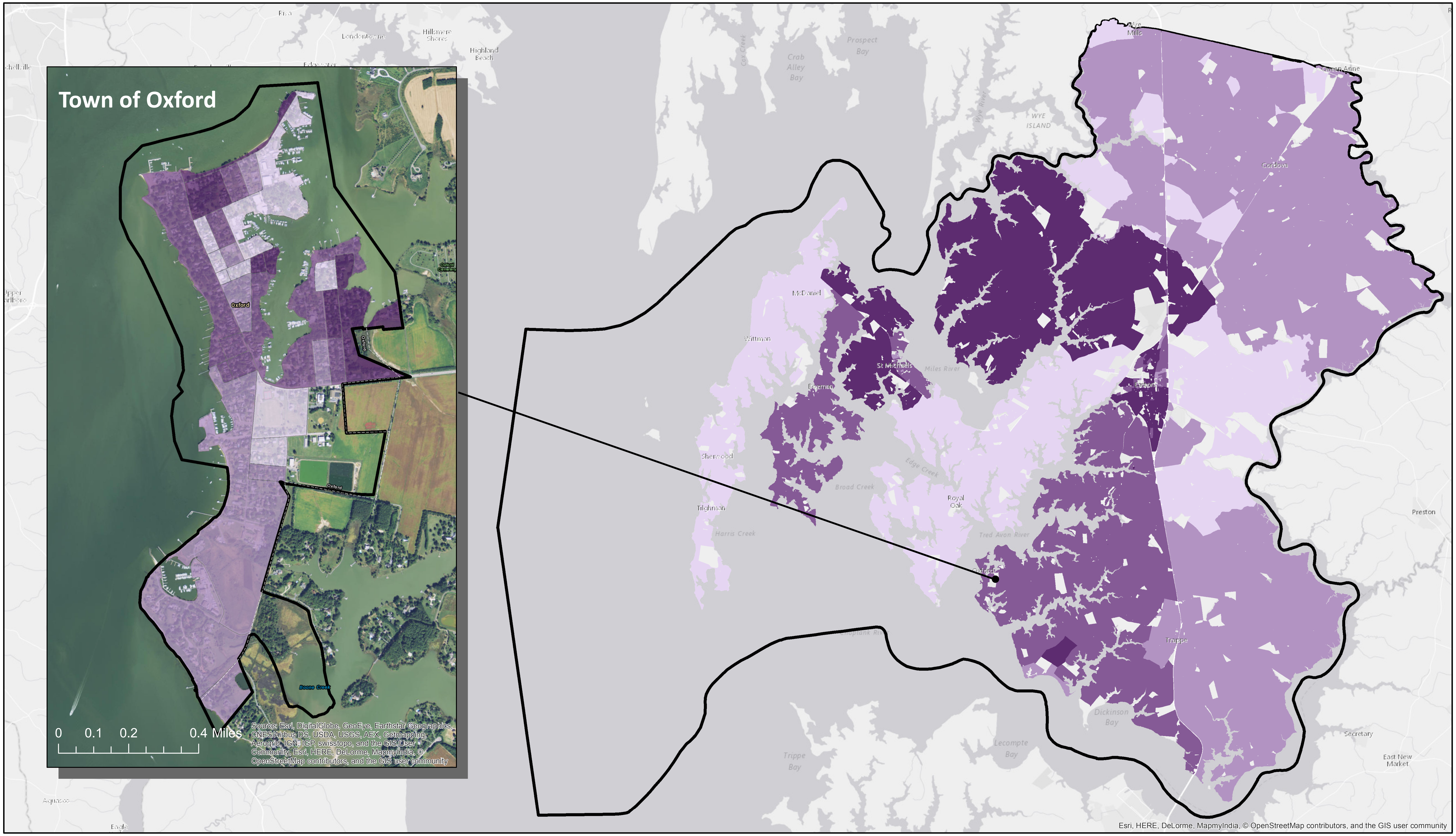
Figure E-5

Social Isolation Component of Potential Social Vulnerability - Talbot County, Maryland

E11



Social Vulnerability

Social Isolation Factor

- Less Vulnerable
-
-
- More Vulnerable

Description:
The social isolation factor is comprised of 2 components: households with no vehicle and non-english speaking.

This factor is one of six which combines to determine the potential social vulnerability index score as shown on the map "Potential Social Vulnerability by Block - Talbot County, Maryland".

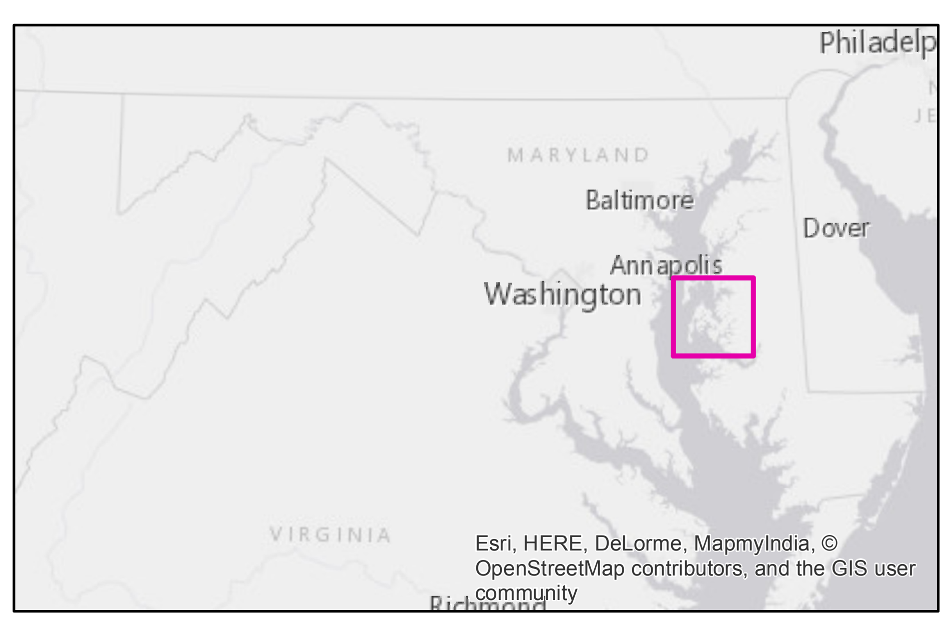


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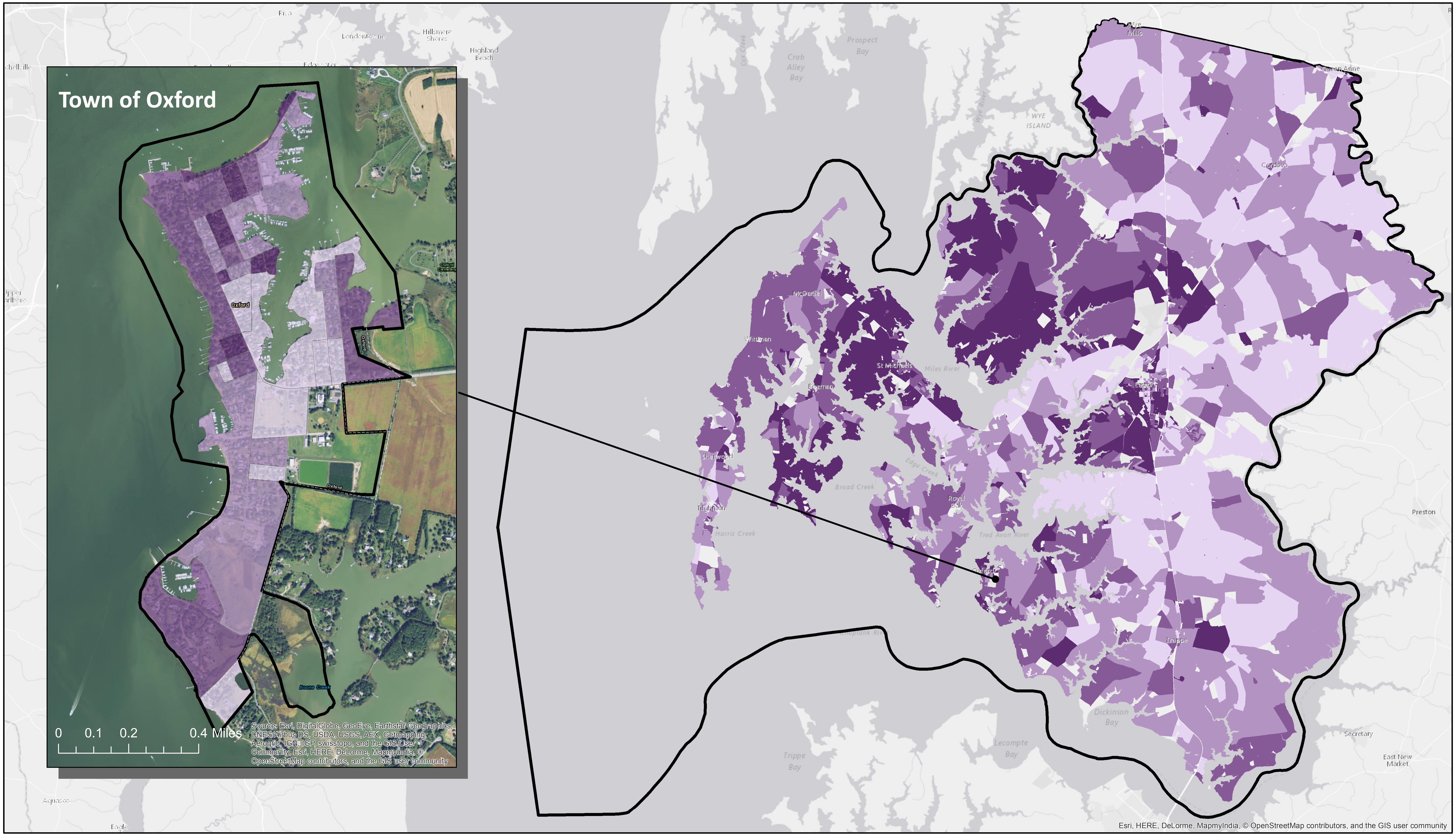
Figure E-6

E12

Potential Social Vulnerability by Block - Talbot County, Maryland



Social Vulnerability

- Less Vulnerability
-
-
- More Vulnerability

Description:
Scores are based on six components that measure aspects of the social vulnerability of the population: age; social class; social isolation; race, gender, and household characteristics; economic condition; and labor force. Higher scores of this index are associated with higher social vulnerability. Scores are calculated for Census blocks. As an example, a block with a younger population, higher social class, and low social isolation, is less vulnerable.

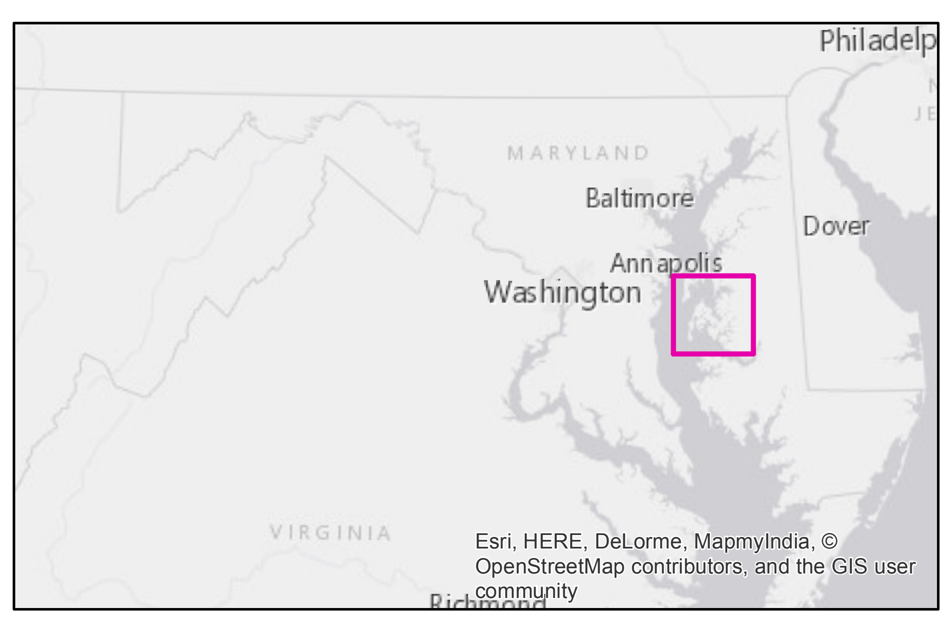


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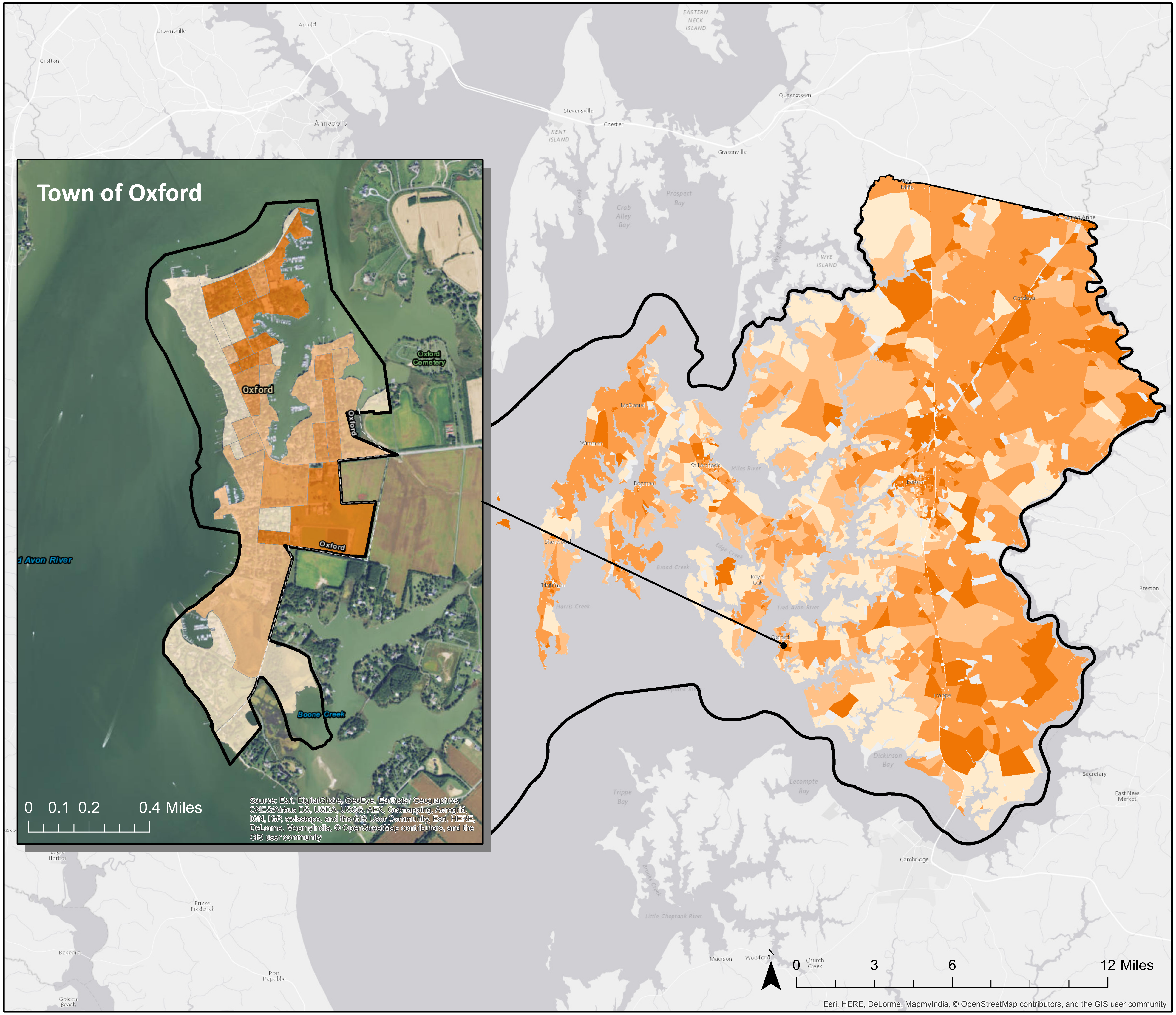
Figure E-7

Potential Structural Vulnerability by Block - Talbot County, Maryland



Structural Vulnerability

- Less Vulnerability
- More Vulnerability
- Talbot County

Description:
Scores are determined as a proportion of the following three variables: structure grade, non-wood structures, and post-2003 construction. Structure grade refers to the overall quality of construction and is rated from 1-9, with nine being the best; a higher score is associated with lower vulnerability. According to FEMA, wood-based construction might be less resistant to flooding hazards. Therefore, a block is considered less vulnerable if there are more non-wood structures. A block is considered less vulnerable if a greater proportion of structures were built post-2003. This is due to the fact that building requirements after this time require all buildings within the special flood hazard area to be two feet (of freeboard) above base flood elevation.

It should be noted that this analysis included both residential and commercial properties.

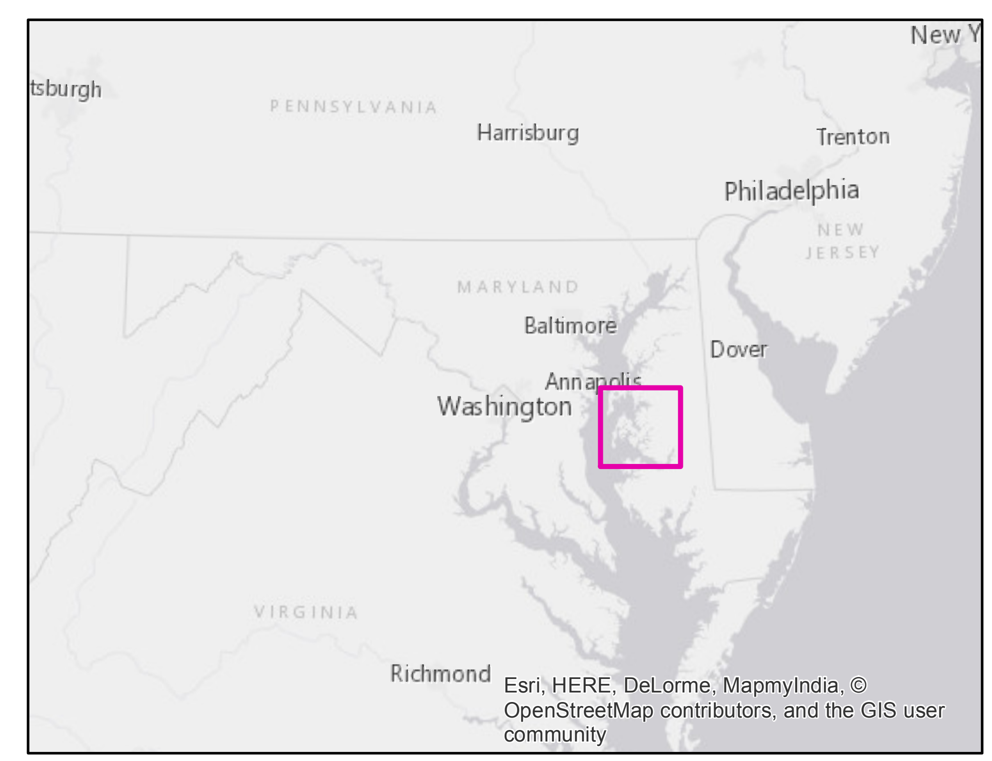


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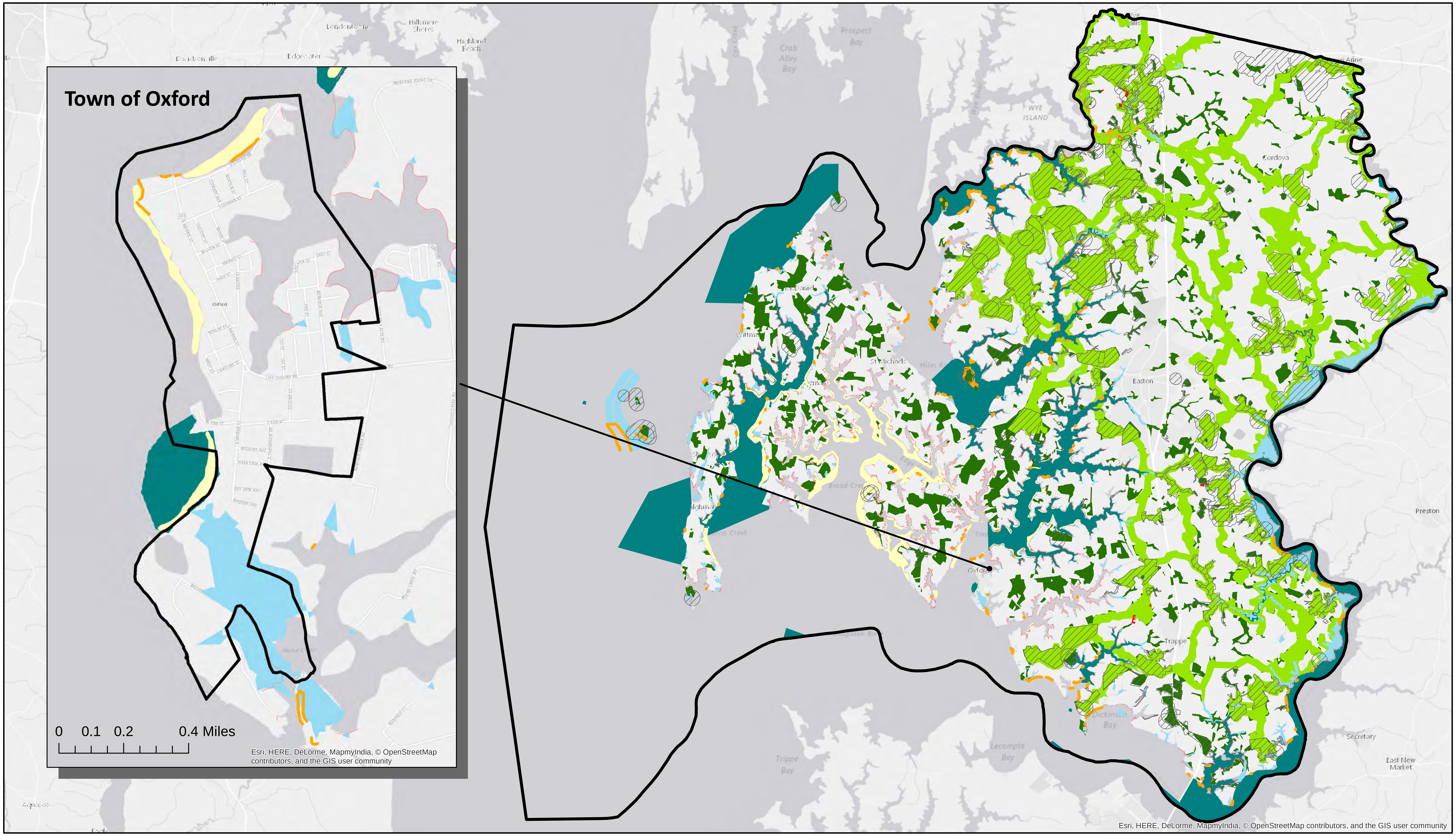
Figure E-8

E14

Natural Resource Distribution - Talbot County, Maryland



- Sensitive Species
- Marsh Buffer
- Beach
- Wetland
- Forest Easement
- Oyster Sanctuary
- Green Infrastructure
- Forest
- Submerged Aquatic Vegetation

Description: The natural resources depicted in this map are those included within the natural resource richness analysis. These natural resources were selected due to their increased likelihood of impacts from flood hazards such as storm surge and sea level rise. Additionally, these resources provide important ecosystem services to Talbot County and the Town of Oxford.

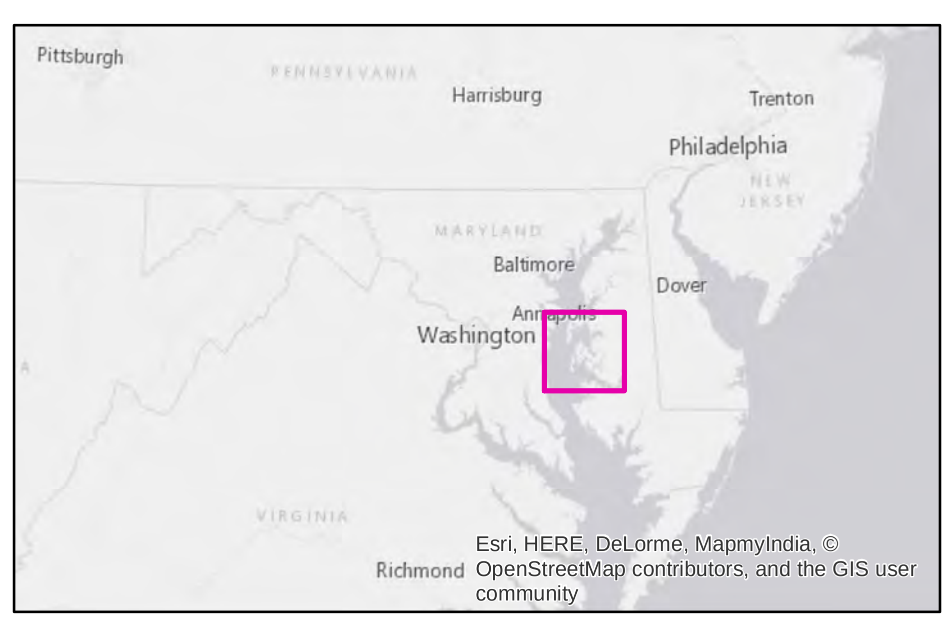


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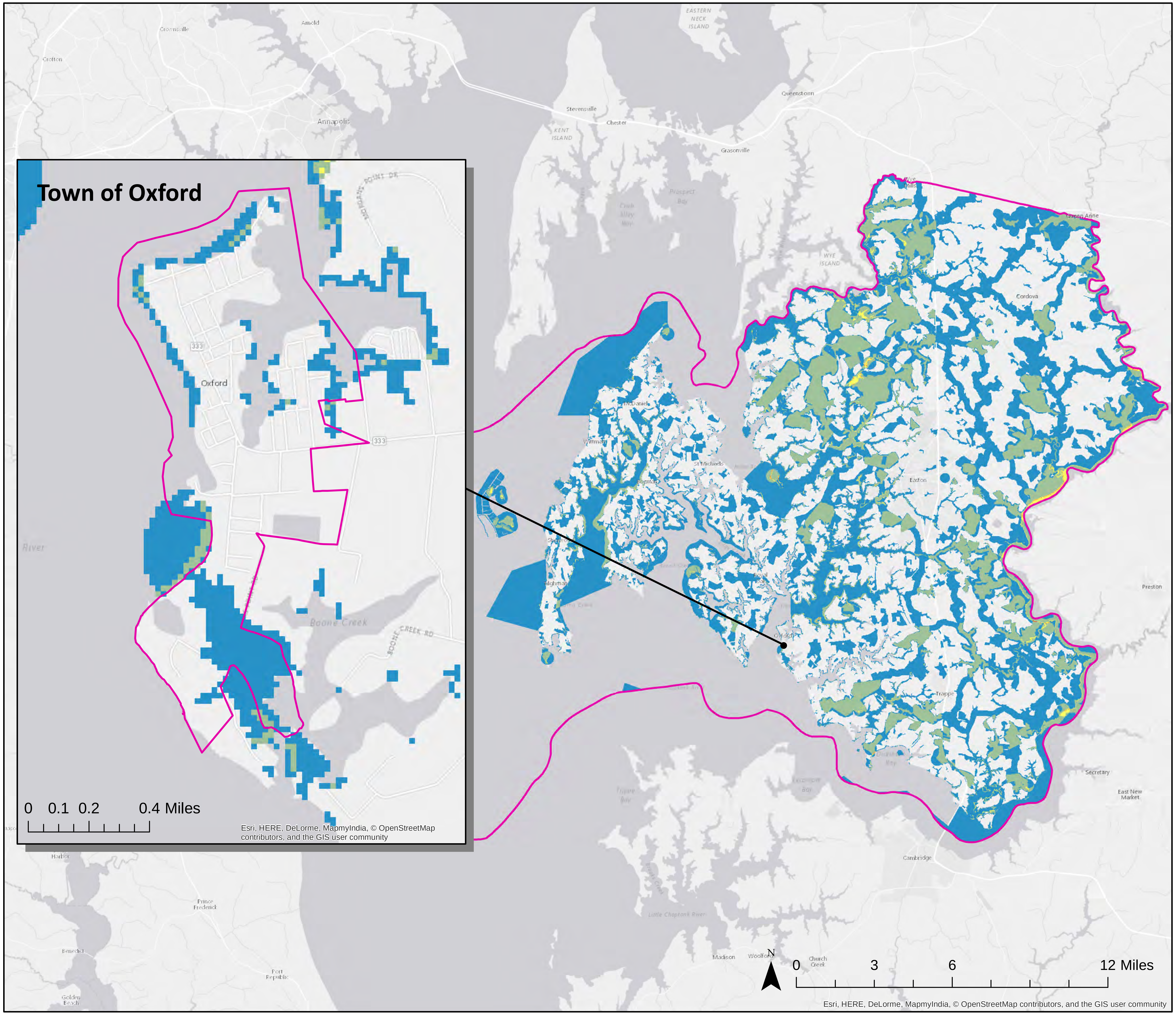
Figure E-9

Natural Resource Richness - Talbot County, Maryland



Total resources per 30x30m grid cell

- 1
- 2
- 3
- 4
- 5

The purpose of the natural resource richness analysis is twofold: to determine the spatial extent and concentrations of important natural resources within Talbot County and to assess their vulnerability to climate and coastal hazards such as projected sea level rise (SLR) and hurricane storm surge.

The primary factors that influenced which natural resources were selected for inclusion in this analysis were NOAA/NCCOS science team expertise, presence in scientific literature, and data availability. In total, nine natural resources were selected for the analysis, including: wetland locations, submerged aquatic vegetation (SAV), oyster sanctuaries, green infrastructure, forested areas, sensitive species locations, beaches, marsh buffer, and forest conservation easements.

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Figure E-10

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Section 2:

Flood Hazard Risks

Flood Hazard Risks

This section provides maps of projected sea level rise inundation, category 1 storm surge areas, stormwater flood prone areas, and the intersection of storm surge and stormwater flood prone areas for Talbot County and the Town of Oxford, MD.

Creating the socioeconomic vulnerability, structural vulnerability and natural resource richness layers discussed in Section 1 was only the first step in determining which specific populations, structures and natural resources were most at risk from flood hazards. The next step required comparing these vulnerabilities to specific flood hazard climate events, including potential sea level rise of 1 foot, storm surge for a category 1 storm, and stormwater flooding. Similar to the approach used by Wu et al. (2002), indicators of social vulnerability, structural vulnerability and natural resource distribution 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 Talbot County and the Town of Oxford, MD.

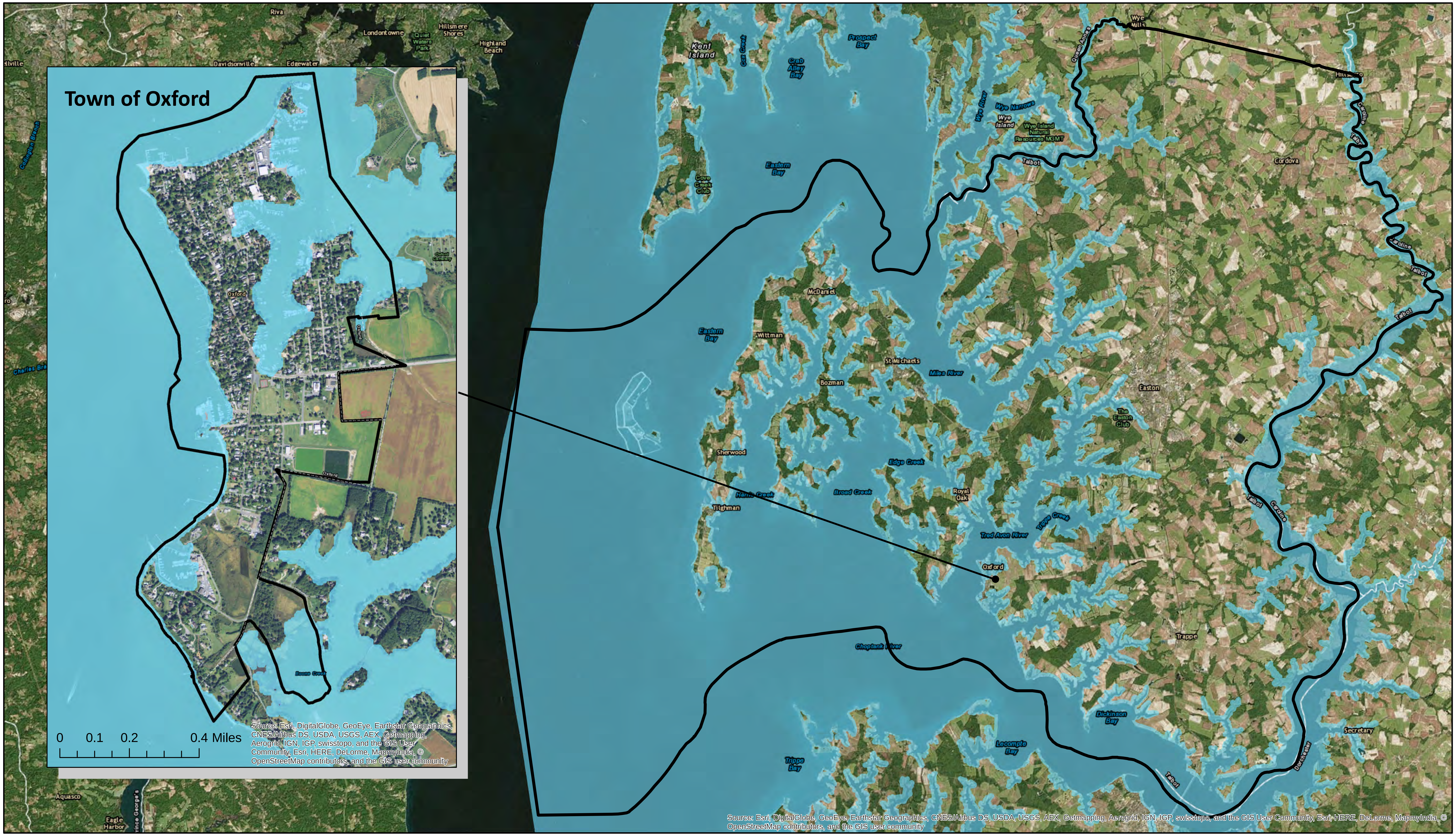
The sea level rise layer selected for this study is a product of the NOAA Office of Coastal Management/Digital Coast. Sea level rise of 1 foot is used to assess risk in the socioeconomic, environmental, and infrastructure analyses via intersection with Talbot County census blocks in ArcMap.

The storm surge data selected for this study was created by the Army Corp of Engineers, Philadelphia District, and utilizes 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. (U.S. National Weather Service, 2015).

The stormwater flood prone areas layer was created in order to help the Town of Oxford better analyze and prepare for this increasingly challenging issue. This layer considers conditions which contribute to or are favorable for stormwater flooding and identifies these locations throughout Oxford and Talbot County. 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,* 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. Developed land cover classes create an additional likelihood of stormwater flooding due to the increase in impervious surfaces, which encourages stormwater runoff. Lastly, 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.

Projected Sea Level Rise Inundation (1 ft) - Talbot County, Maryland

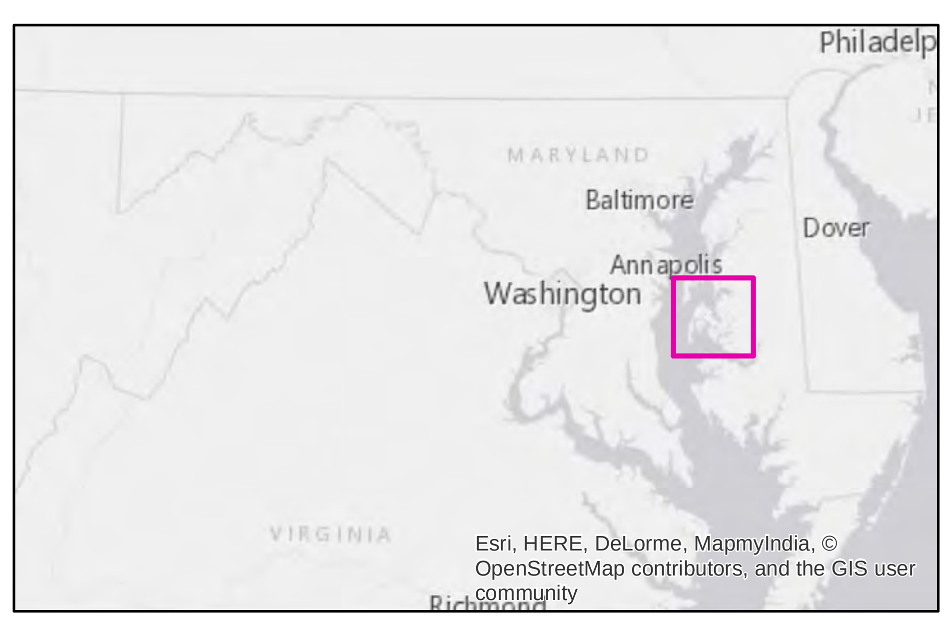
E18



Talbot County

Projected Sea Level Rise (1 ft)

This map represents inland extent and relative depth of inundation from sea level rise at 1 foot above mean higher high water (MHHW).



0 2.5 5 10 Miles

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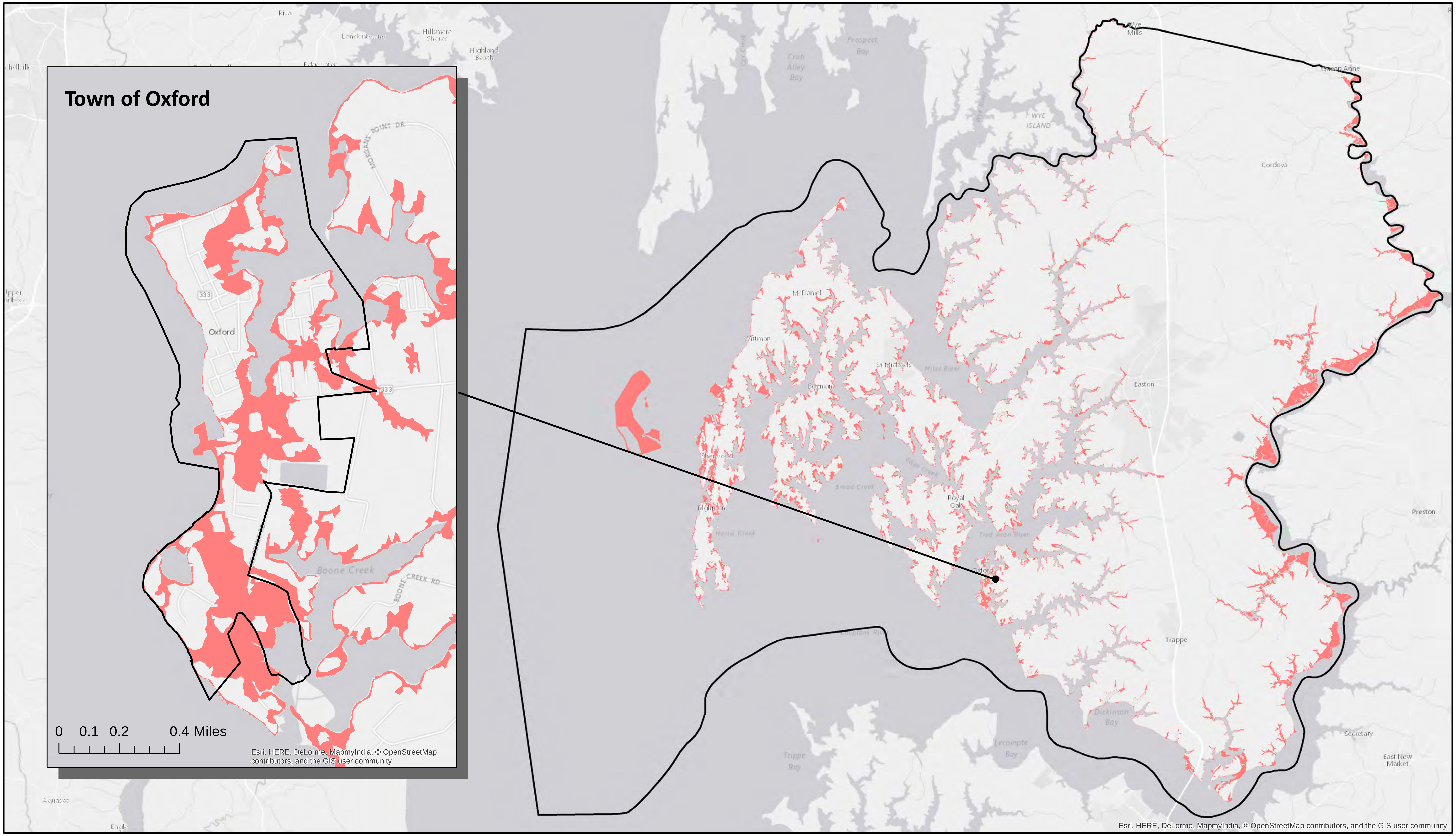
Figure E-11

E19

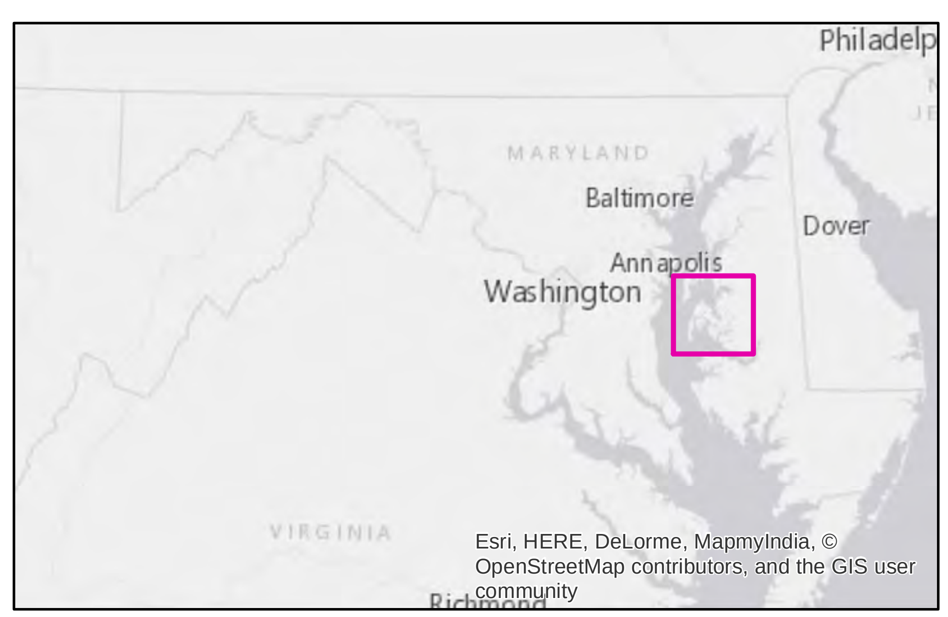
Category 1 Storm Surge Areas - Talbot County, Maryland



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.

Storm Surge (Category 1)

Talbot County



0 2.5 5 10 Miles

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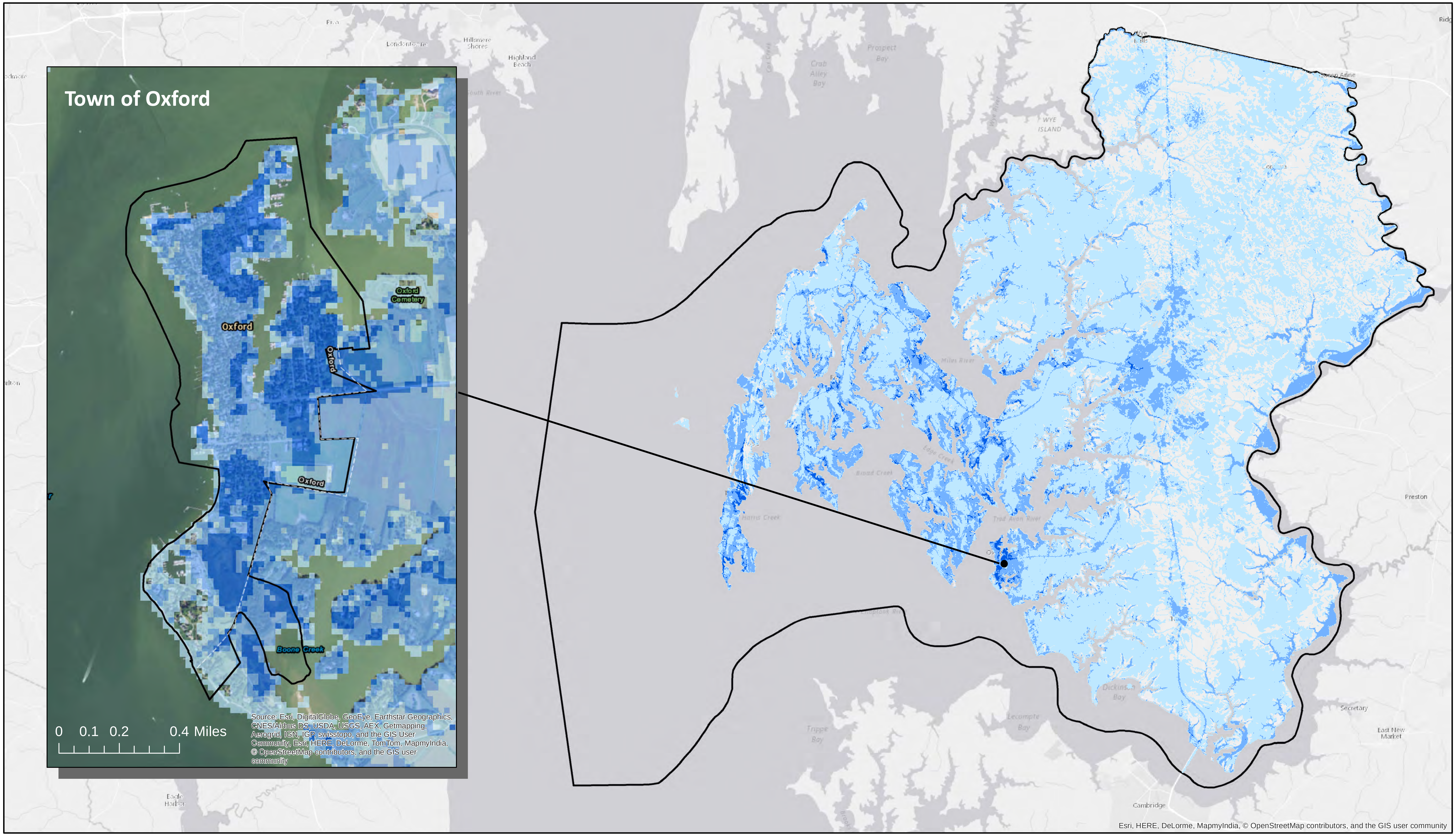
Figure E-12

E20

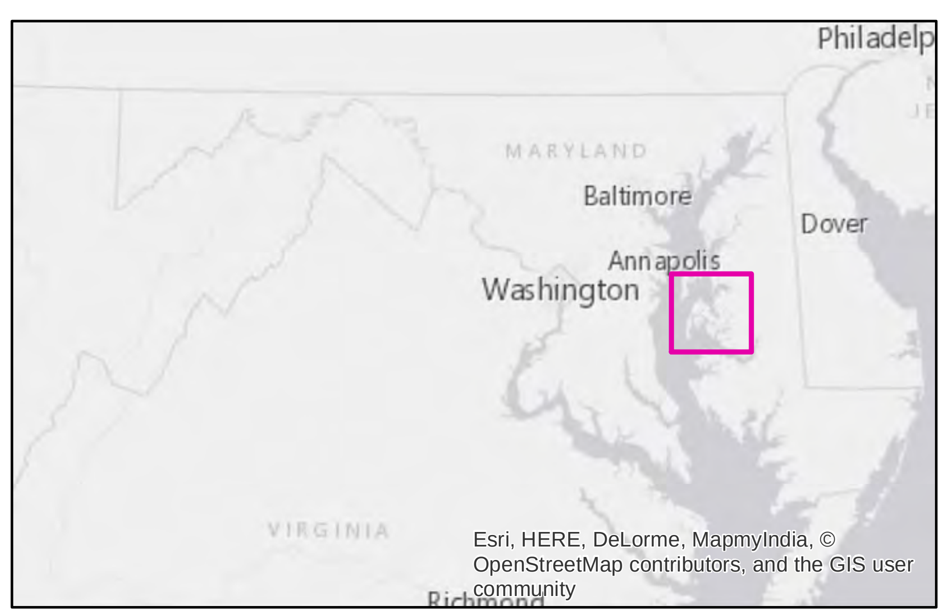
Stormwater Flood Prone Areas - Talbot County, Maryland



Hazard Score

(lightest blue)	1
(medium blue)	2
(dark blue)	3

Description:
Scores are a summation of the presence of three conditions: elevation (0-2 feet), developed land cover, and poorly drained soils. Areas are ranked as slightly prone when only one condition is present, moderately prone when two conditions are present, and highly prone if all three conditions are present.



0 2.5 5 10 Miles

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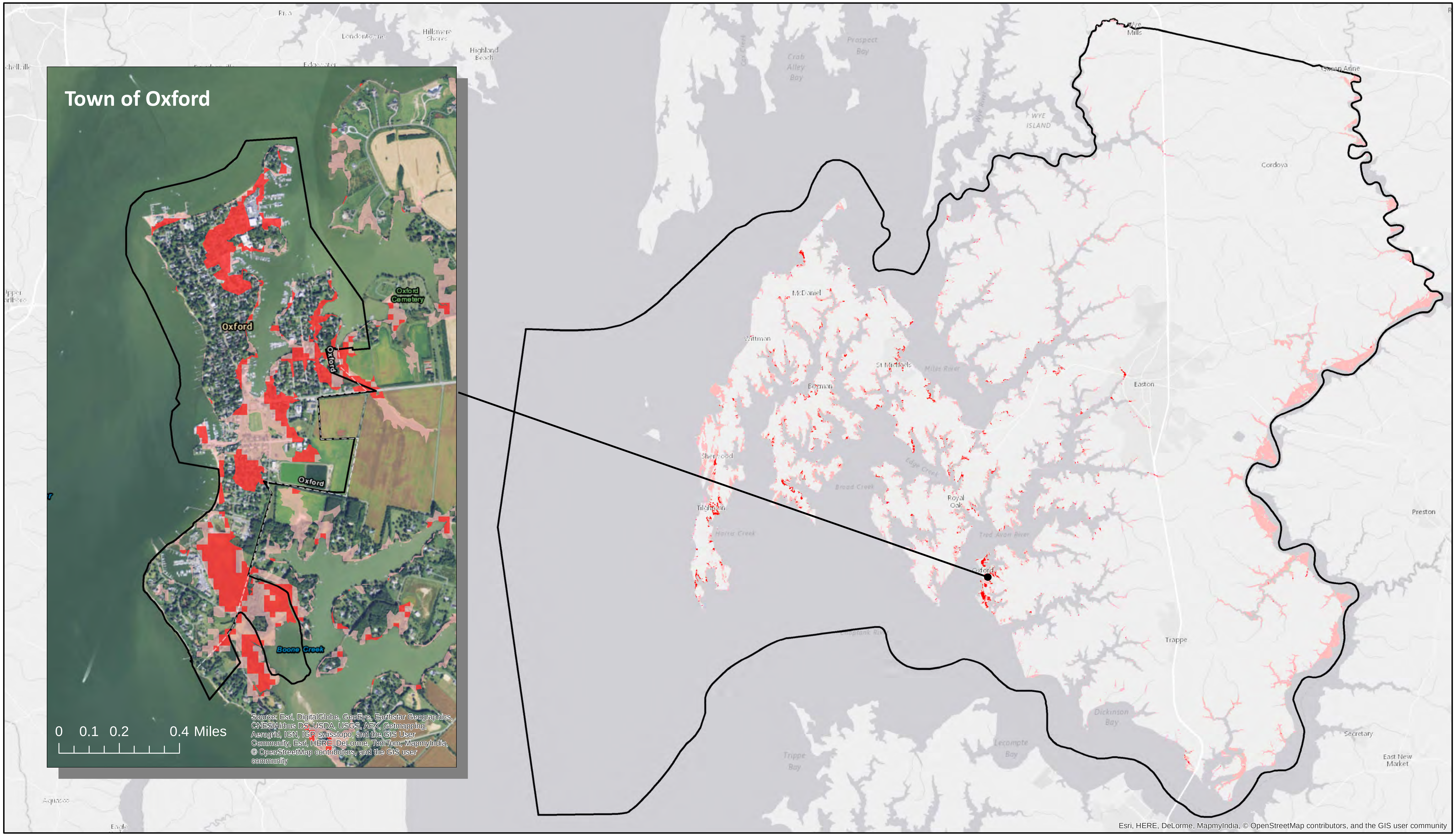
Figure E-13

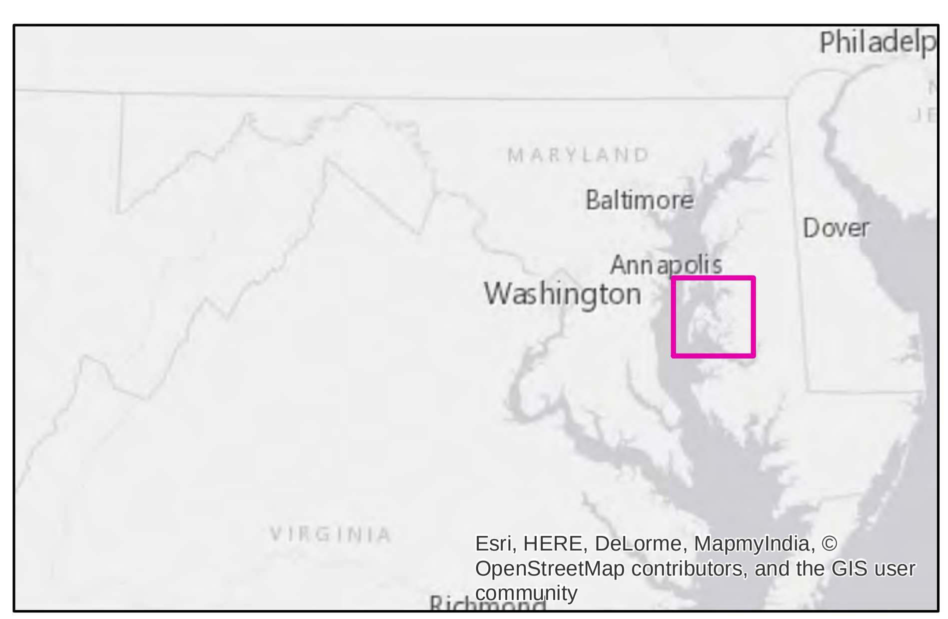
Intersection of Storm Surge and Stormwater Flood Prone Areas -Talbot County, Maryland



Highly prone stormwater areas intersected with storm surge (cat 1)

Moderately prone stormwater areas intersected with storm surge (cat 1)

Description:
This map intersects stormwater flood prone areas with category 1 storm surge areas as a means of identifying locations where conditions exist that are favorable for both types of flooding. Flooding might be more extreme in these locations due to inundation created by both stormwater and storm surge. In theory these locations are subject to influences from both tidal and non-tidal forces, which helps to create a more complete picture of flood hazard areas in Oxford.



0 2.5 5 10 Miles

N

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Figure E-14

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Section 3:

Vulnerabilities and Flood Hazard Risks

Vulnerabilities and Flood Hazard Risks

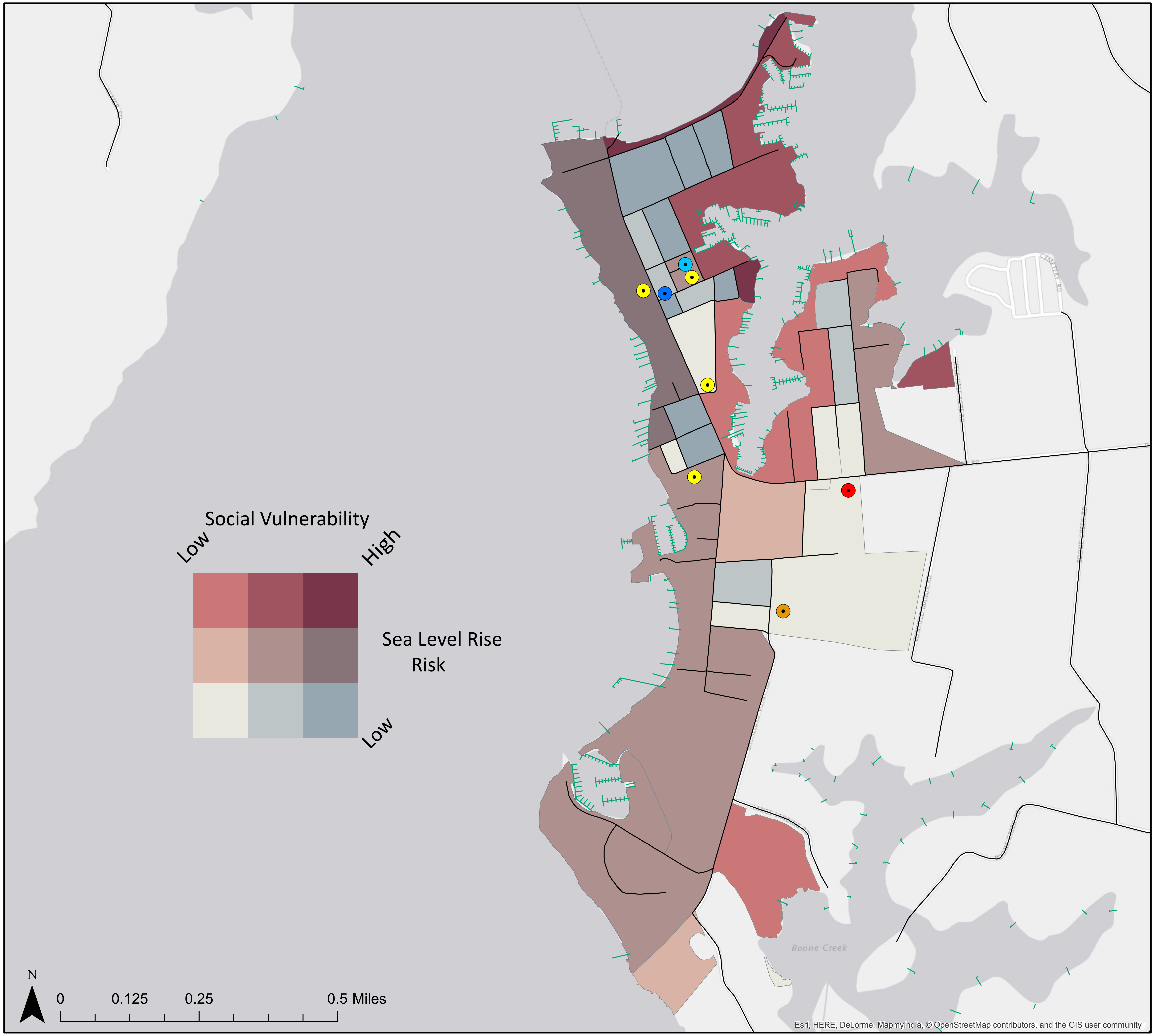
This section provides maps that intersect social and structural vulnerability with sea level rise risk, category 1 storm surge risk, and stormwater flood risk for Oxford, MD and Talbot County, MD, as well as maps that intersect projected sea level rise impacts and category 1 storm surge impacts with natural resources for Talbot County, MD.

Part of the goal for the overall project was to provide managers with analyses of different indicators (socioeconomic, infrastructure and natural resources) that they could easily compare to one another. This meant that the resulting maps and map layers from Section 2 needed to be changed to the block level for all of Talbot County. By creating a score of each block, the science team made it easier to understand the complicated relationship between the indicator values and the vulnerabilities to climate related flood hazards, and made it possible for managers to easily compare the different analyses. After this, the team intersected, or overlaid, each type of vulnerability with each type of risk to show where these vulnerabilities and risks overlapped.

For social and structural vulnerability, 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, 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.

For natural resources, the intersection of flood hazard risks was limited to sea level rise (1 ft) and storm surge (category 1). These flood hazard scenarios were selected because they are more likely to have a negative impact on natural resources than stormwater flooding. Natural resources vulnerable to the impacts of sea level rise and storm surge were determined by intersecting the natural resource richness layer with each flood hazard layer. Scores for each block were calculated as a percentage of the total land area of natural resources potentially impacted by storm surge or sea level rise per block.

Potential Social Vulnerability vs. 1 ft. Sea Level Rise Risk - Oxford, MD



Legend

- Post Office
- Police
- Religious Institution
- Fire/EMS
- Wastewater Treatment Plant
- Road
- Dock

Description

Sea Level Rise risk is measured as the percentage of land area in a block potentially inundated In the event of a rise in sea level 1 foot above current mean tide conditions.

Social Vulnerability is a comparative metric used to measure the relative ability of a population to withstand environmental stressors based on social characteristics at the block level.

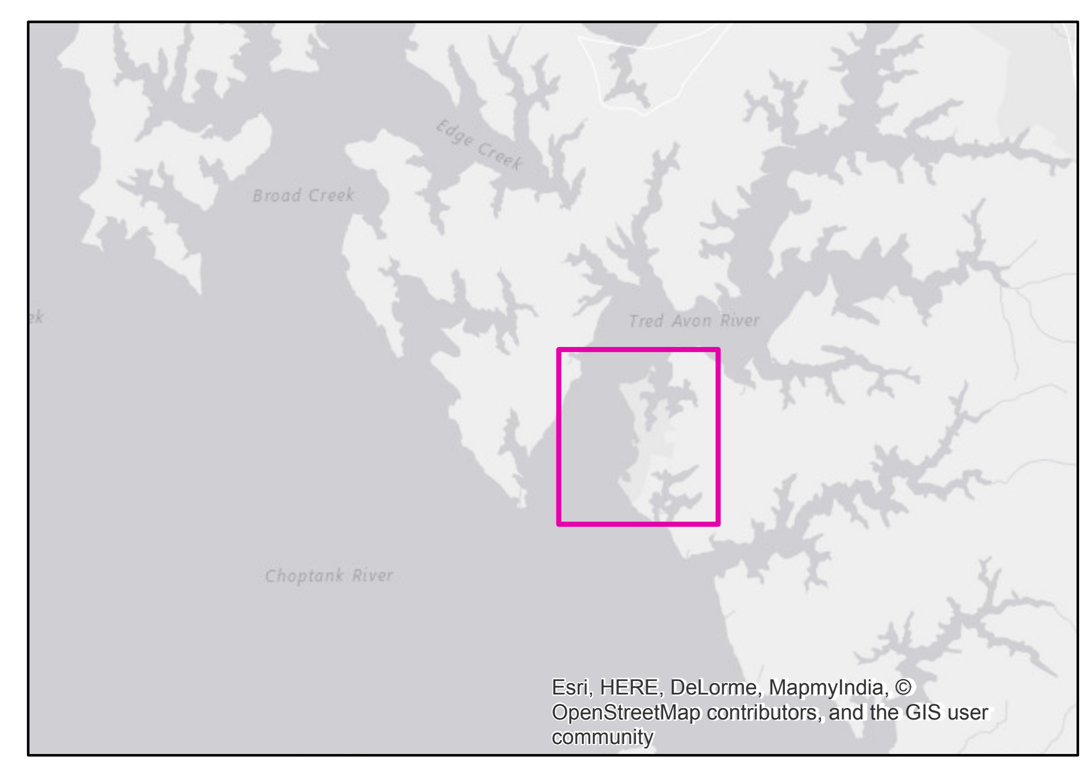


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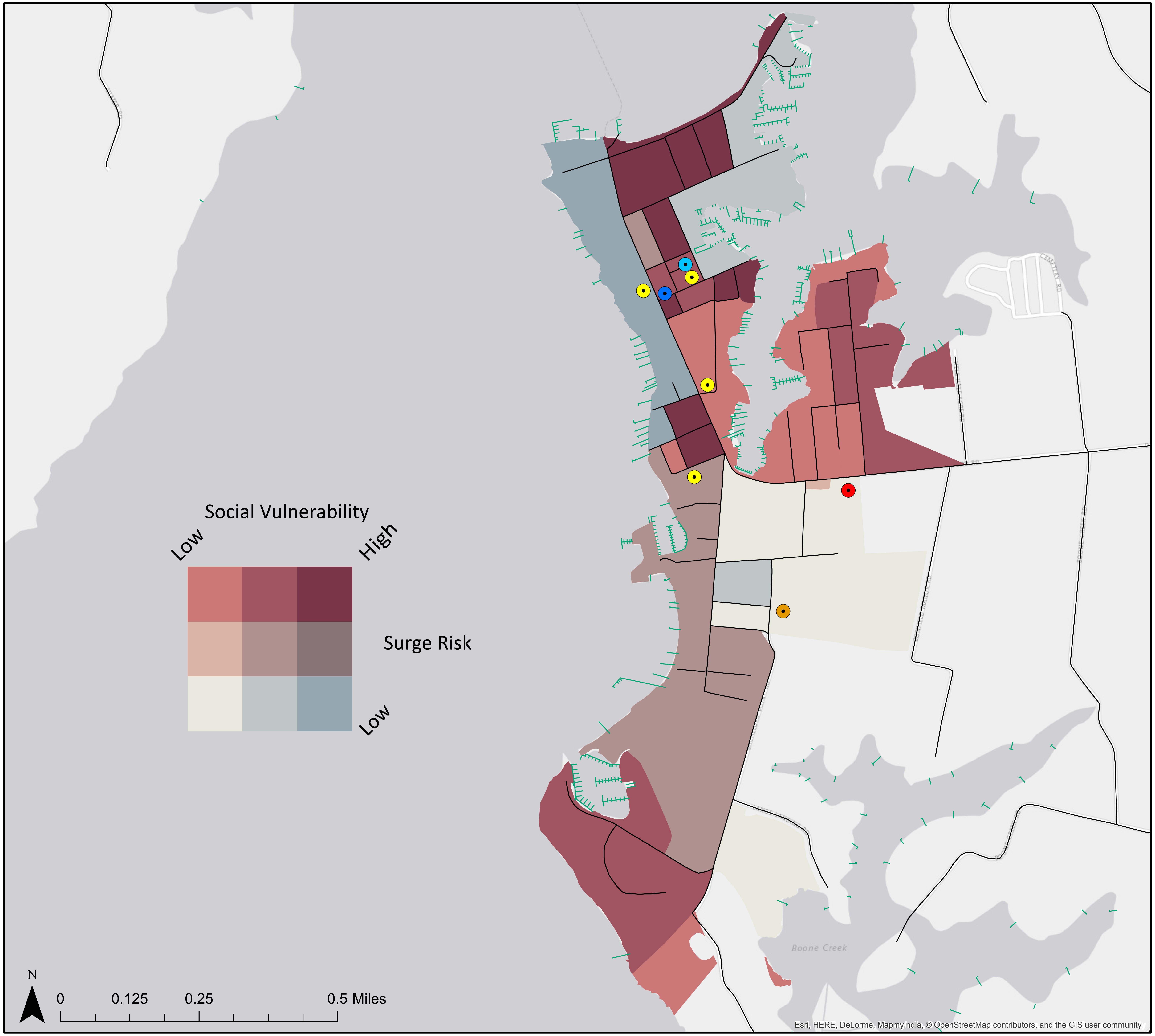
Figure E-15

Potential Social Vulnerability vs. Category 1 Storm Surge Risk - Oxford, MD



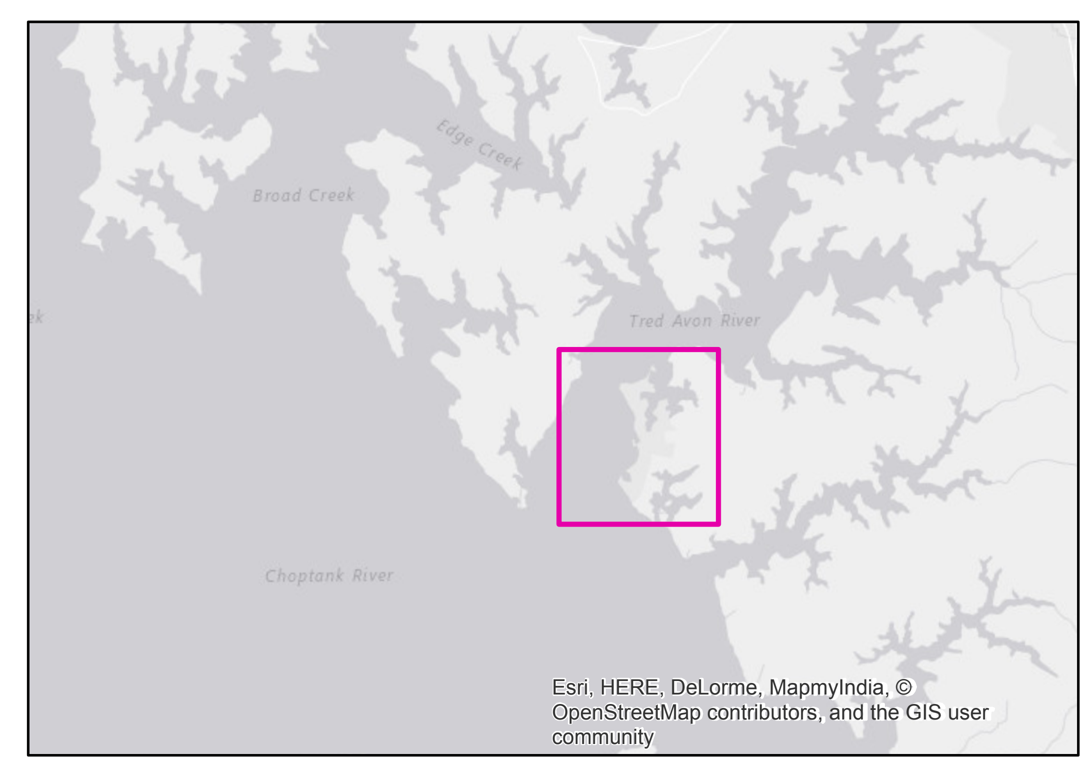
Legend

- Post Office
- Police
- Religious Institution
- Fire/EMS
- Wastewater Treatment Plant
- Road
- Dock

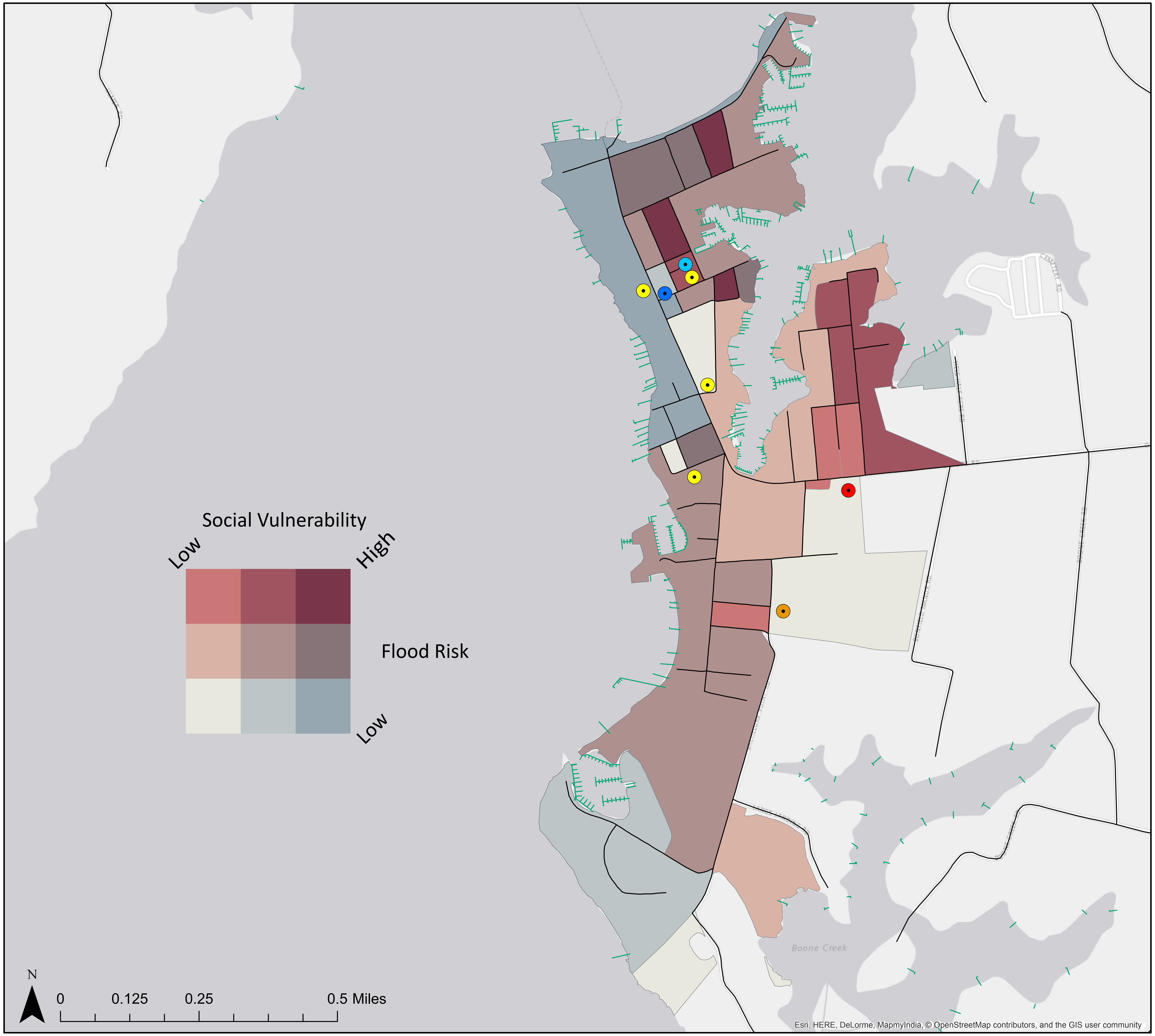
Description

Storm surge risk is measured as the percentage of land area in a block potentially inundated in the event of a category 1 hurricane with a surge of 3 to 5 feet above normal high tide.

Social Vulnerability is a comparative metric used to measure the relative ability of a population to withstand environmental stressors based on social characteristics at the block level.



Potential Social Vulnerability vs. Storm Water Flood Risk - Oxford, MD



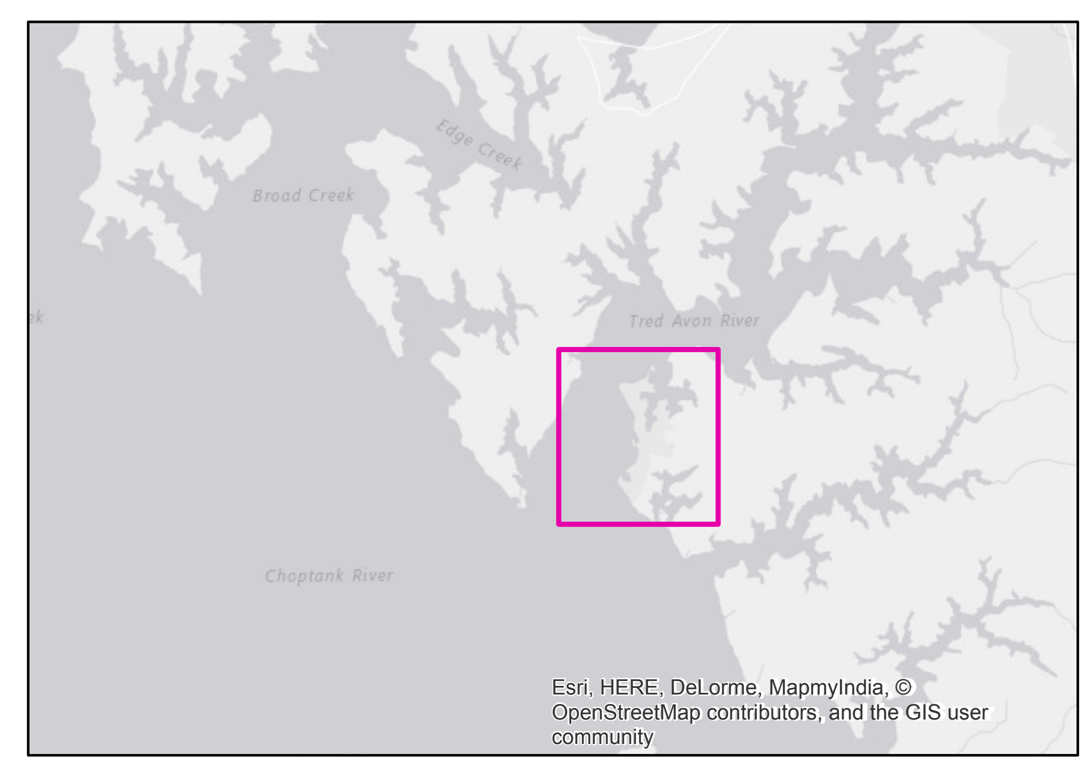
Legend

- Post Office
- Police
- Religious Institution
- Fire/EMS
- Wastewater Treatment Plant
- Road
- Dock

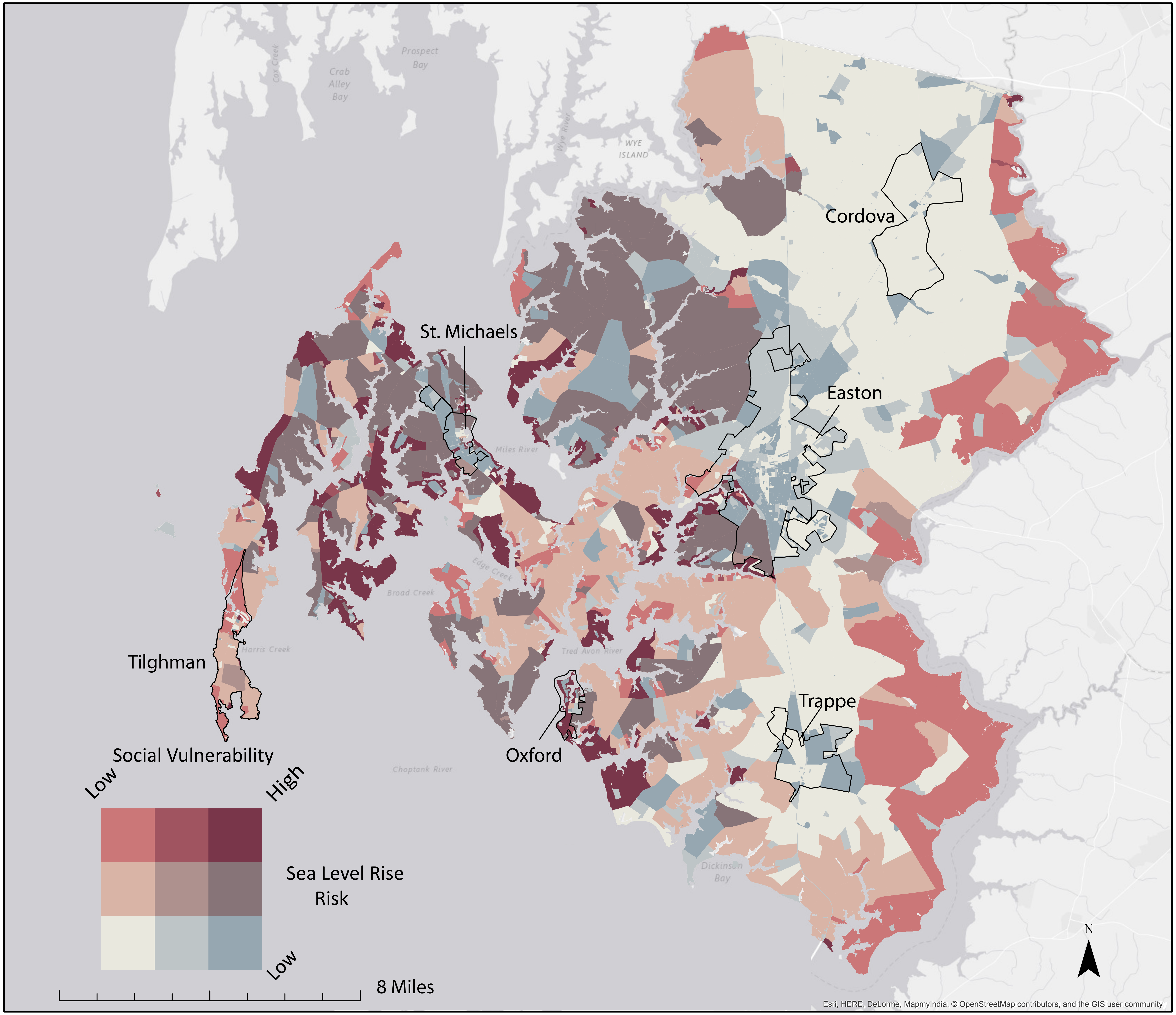
Description

Storm water flood risk represents the presence of three conditions: elevation (0-2 feet), developed land cover, and poorly drained soils.

Social Vulnerability is a comparative metric used to measure the relative ability of a population to withstand environmental stressors based on social characteristics at the block level.



Potential Social Vulnerability vs. 1 ft. Sea Level Rise Risk - Talbot County, MD



Legend

Municipality Boundaries

Description

Sea Level Rise risk is measured as the percentage of land area in a block potentially inundated In the event of a rise in sea level 1 foot above current mean tide conditions.

Social Vulnerability is a comparative metric used to measure the relative ability of a population to withstand environmental stressors based on social characteristics at the block level.

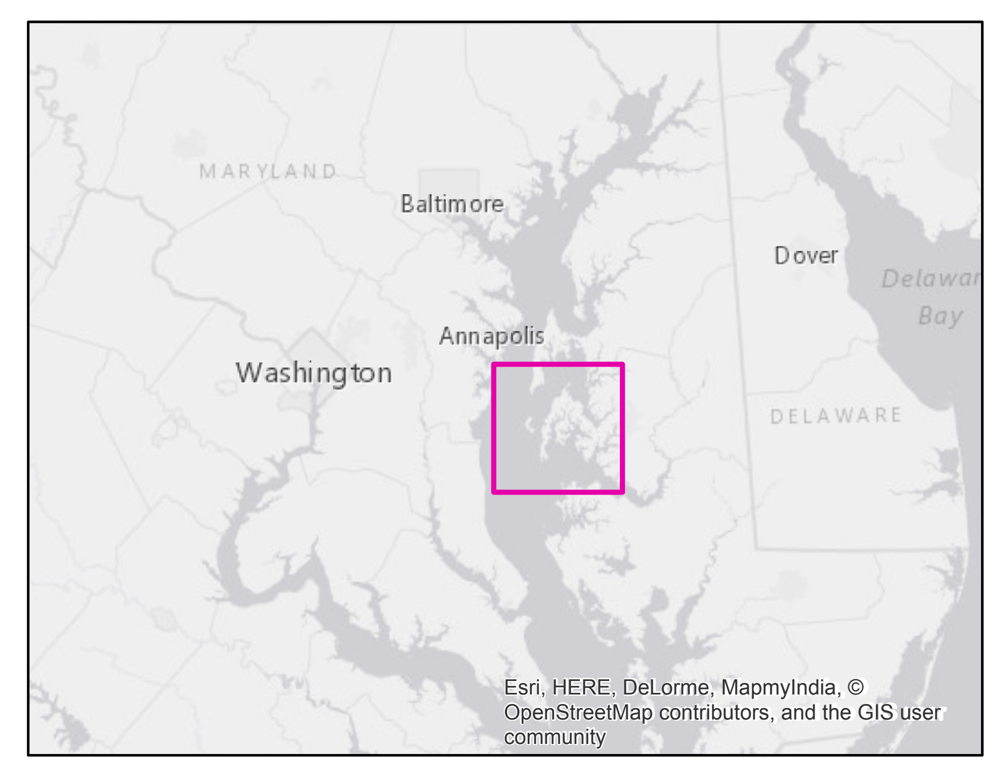


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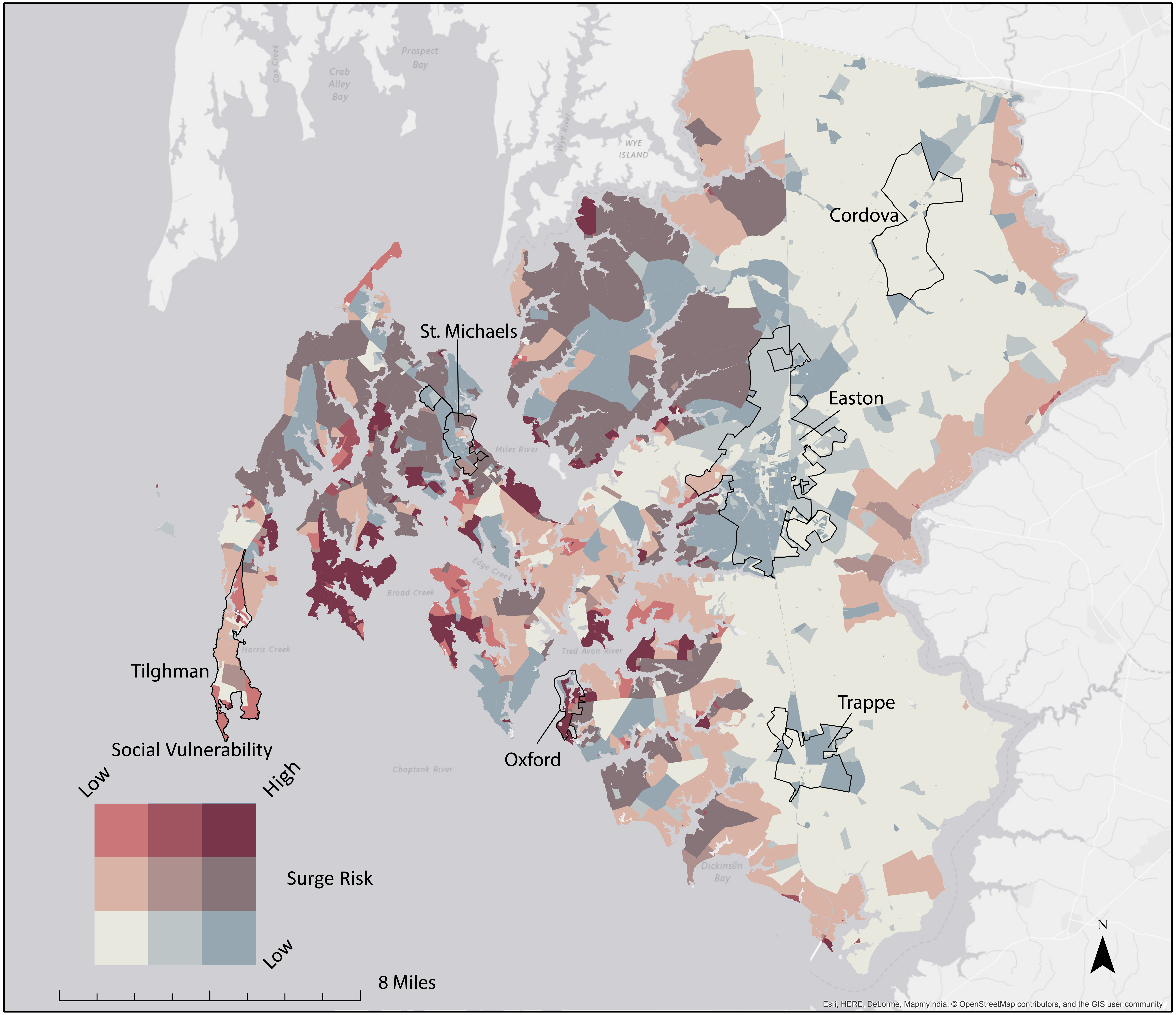
Figure E-18

Potential Social Vulnerability vs. Category 1 Storm Surge Risk - Talbot County, MD



Legend

Municipality Boundaries

Description

Storm surge risk is measured as the percentage of land area in a block potentially inundated in the event of a category 1 hurricane with a surge of 3 to 5 feet above normal high tide.

Social Vulnerability is a comparative metric used to measure the relative ability of a population to withstand environmental stressors based on social characteristics at the block level.

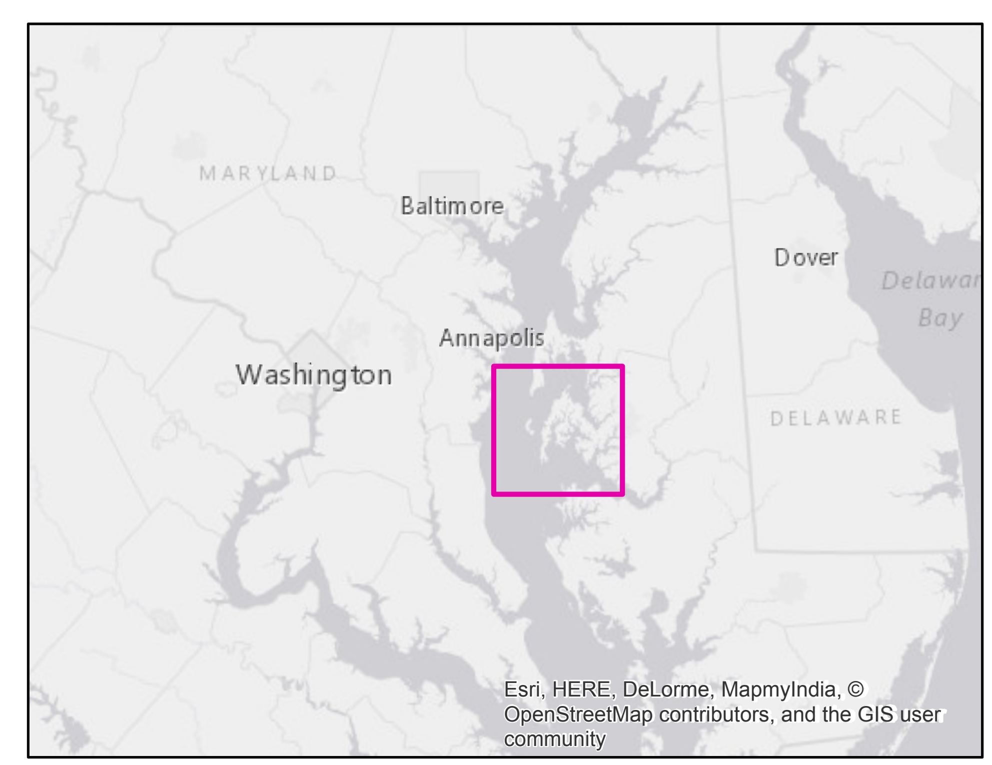


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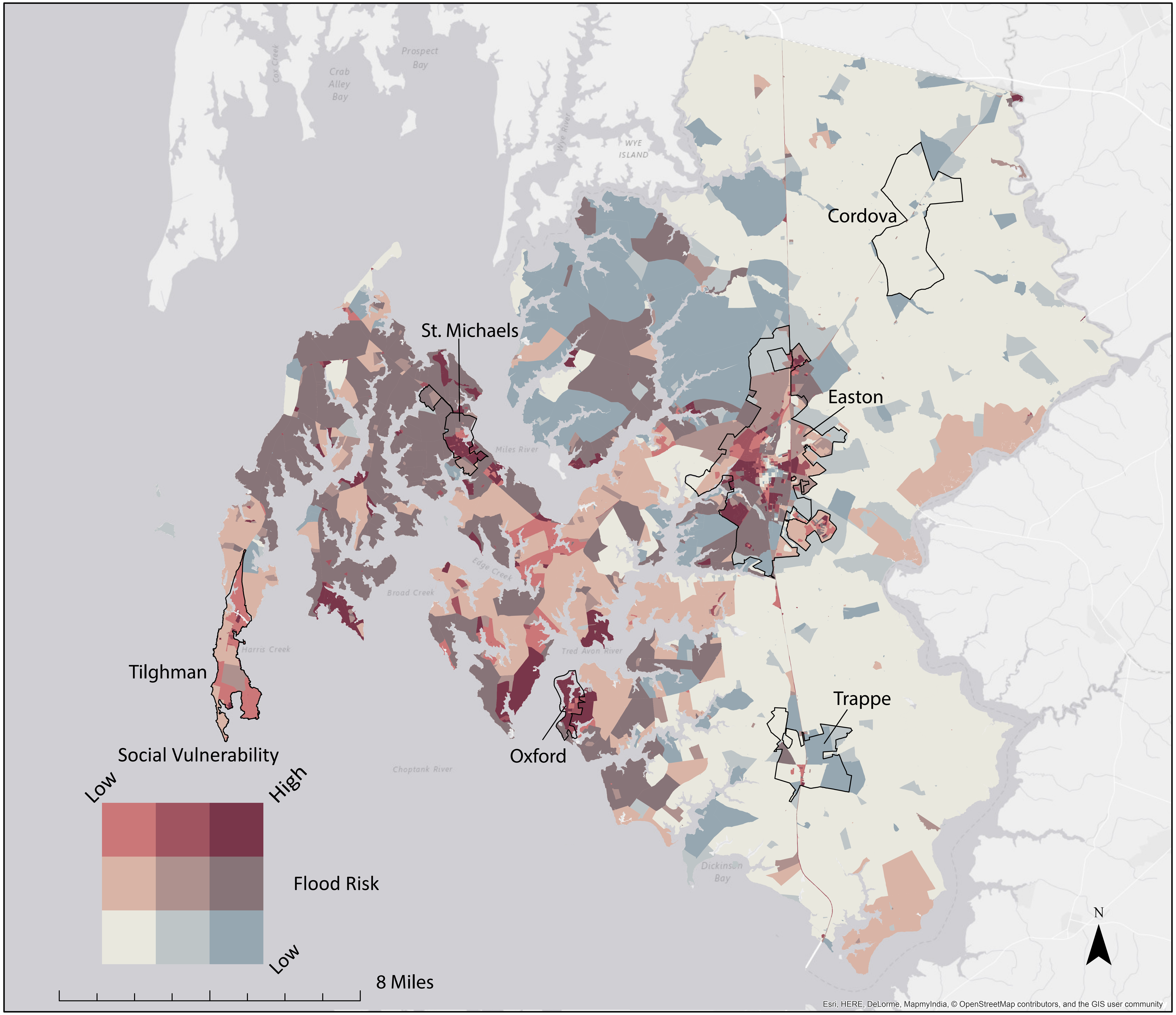
Figure E-19

Potential Social Vulnerability vs. Storm Water Flood Risk - Talbot County, MD



Legend

Municipality Boundaries

Description

Storm water flood risk represents the presence of three conditions: elevation (0-2 feet), developed land cover, and poorly drained soils.

Social Vulnerability is a comparative metric used to measure the relative ability of a population to withstand environmental stressors based on social characteristics at the block level.

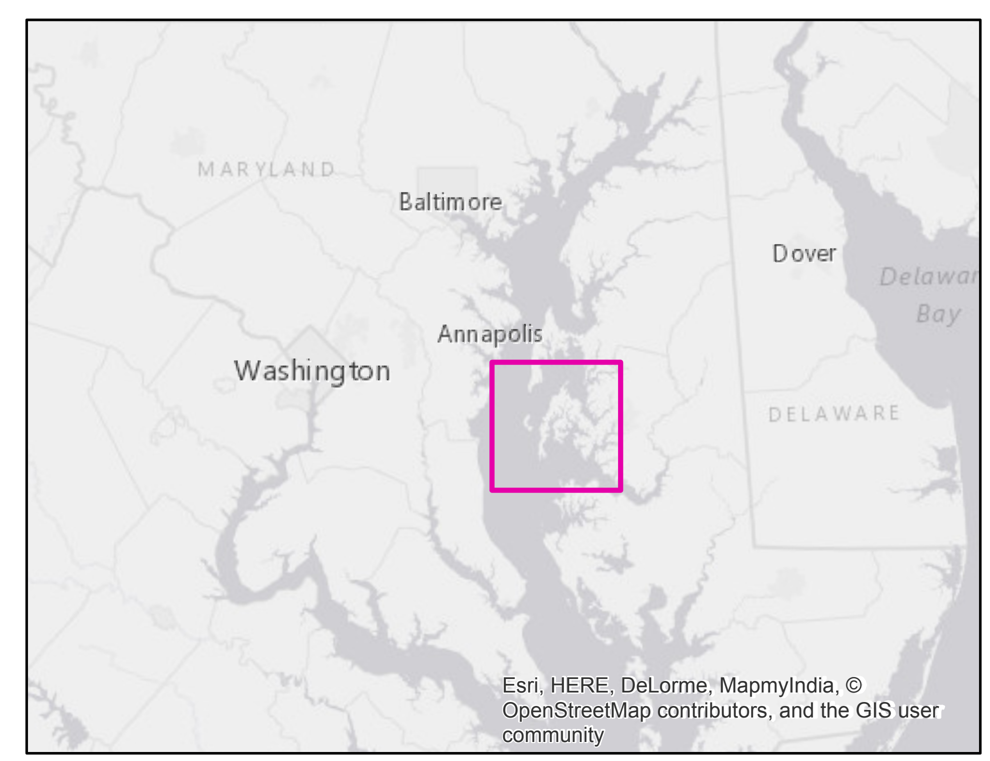


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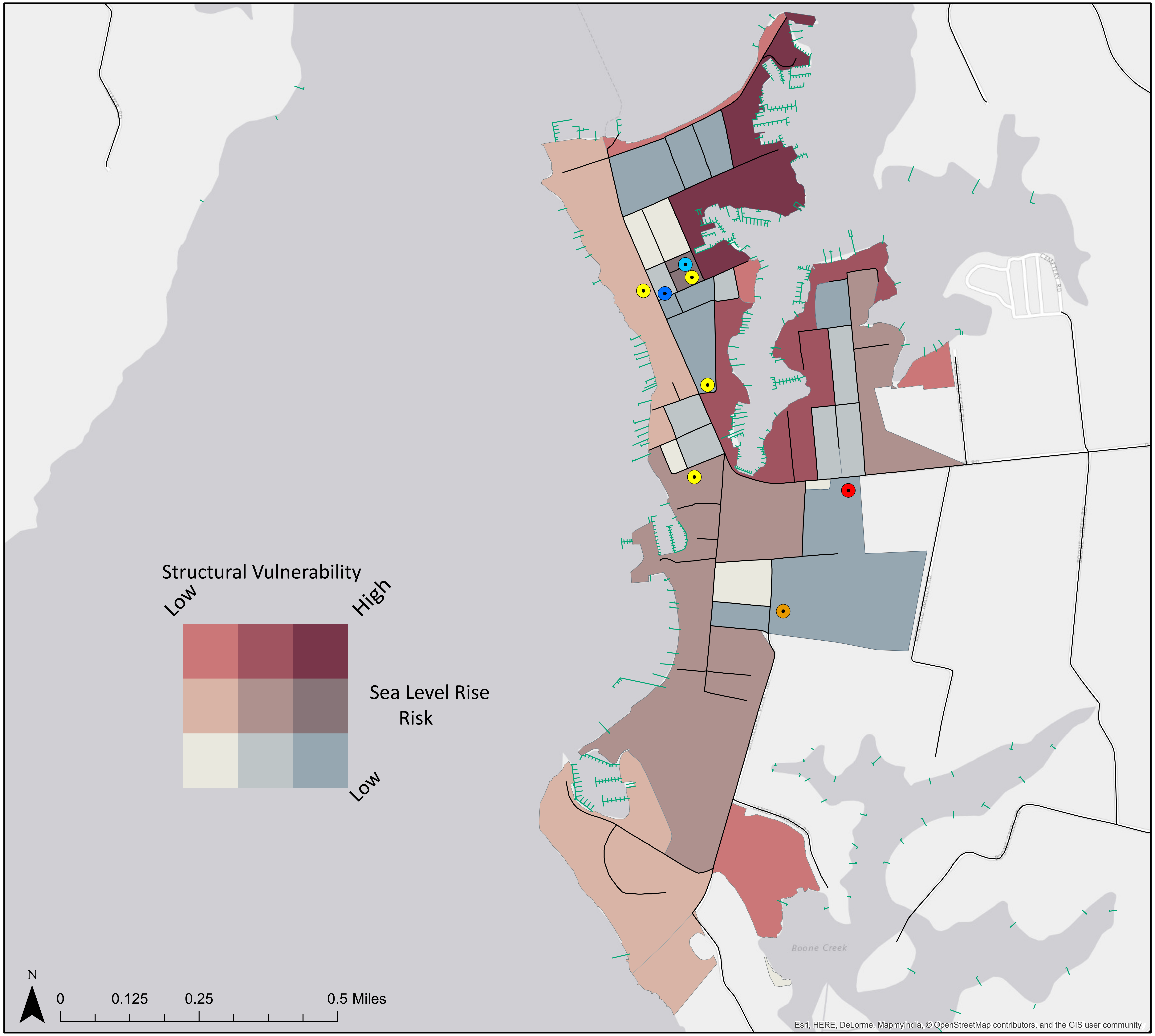
Figure E-20

Potential Structural Vulnerability vs. 1 ft. Sea Level Rise Risk - Oxford, MD



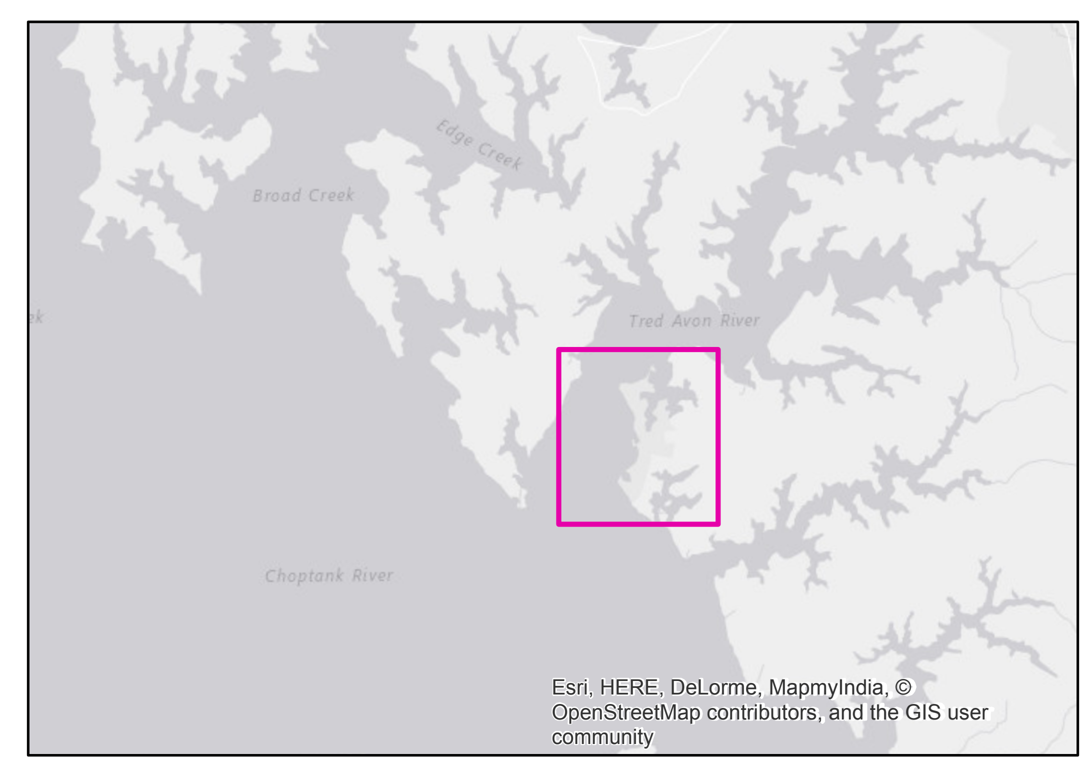
Legend

- Post Office
- Police
- Religious Institution
- Fire/EMS
- Wastewater Treatment Plant
- Road
- Dock

Description

Sea Level Rise risk is measured as the percentage of land area in a block potentially inundated In the event of a rise in sea level 1 foot above current mean tide conditions.

Structural Vulnerability is determined as a proportion of the structures per block with the presence of the following three variables: structure grade, non-wood structures, and post-2003 construction.



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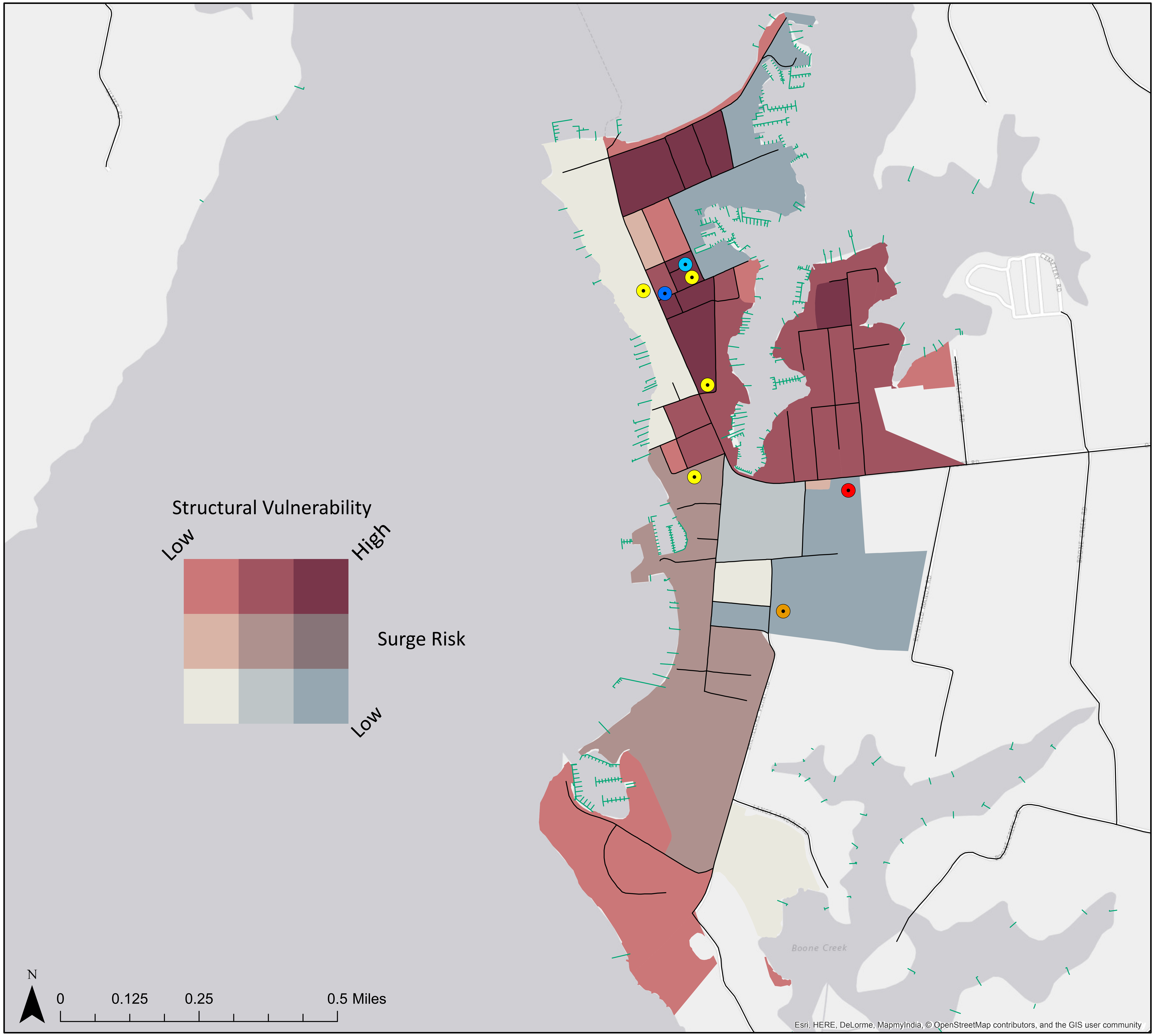
Potential Structural Vulnerability vs. Category 1 Storm Surge Risk - Oxford, MD



Legend

- Post Office
- Police
- Religious Institution
- Fire/EMS
- Wastewater Treatment Plant
- Road
- Dock

Description

Storm surge risk is measured as the percentage of land area in a block potentially inundated in the event of a category 1 hurricane with a surge of 3 to 5 feet above normal high tide.

Structural Vulnerability is determined as a proportion of the structures per block with the presence of the following three variables: structure grade, non-wood structures, and post-2003 construction.

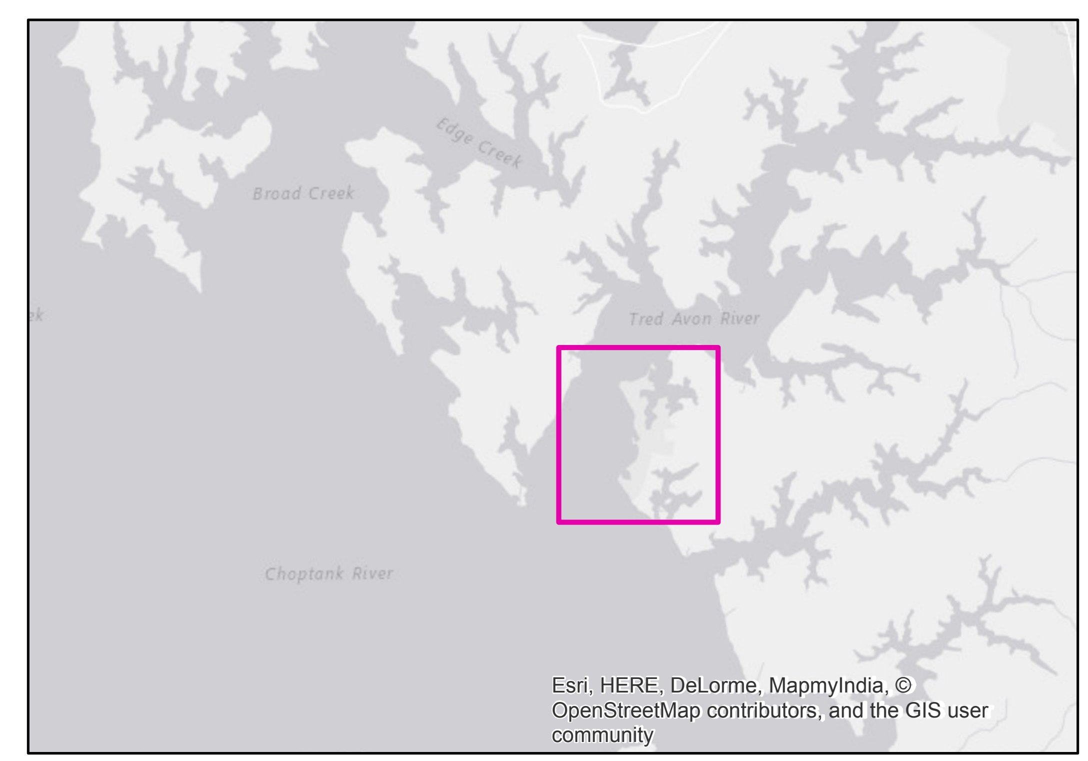


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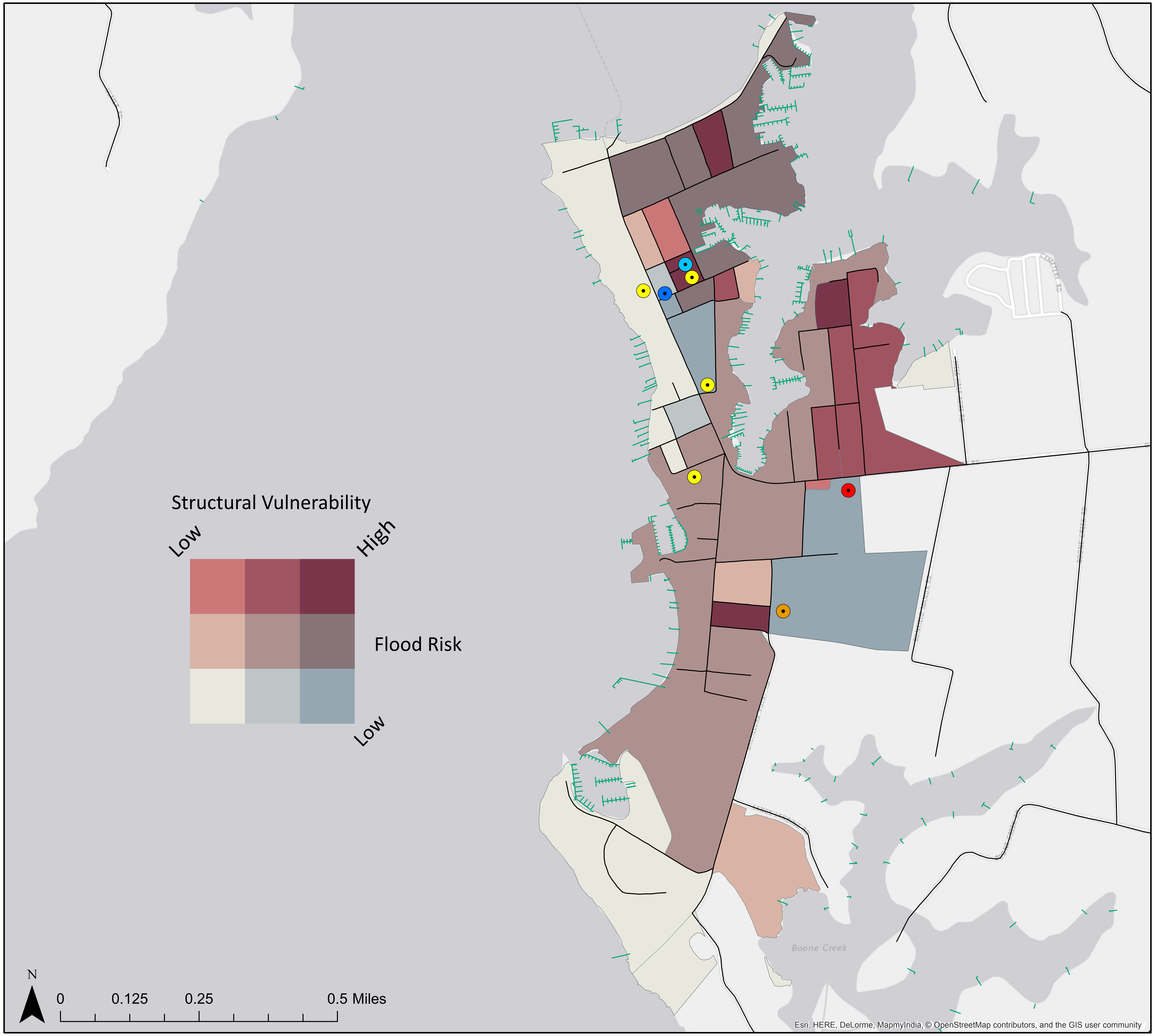
Figure E-22

Potential Structural Vulnerability vs. Storm Water Flood Risk - Oxford, MD



Legend

- Post Office
- Police
- Religious Institution
- Fire/EMS
- Wastewater Treatment Plant
- Road
- Dock

Description

Storm water flood risk represents the presence of three conditions: elevation (0-2 feet), developed land cover, and poorly drained soils.

Structural Vulnerability is determined as a proportion of the structures per block with the presence of the following three variables: structure grade, non-wood structures, and post-2003 construction.

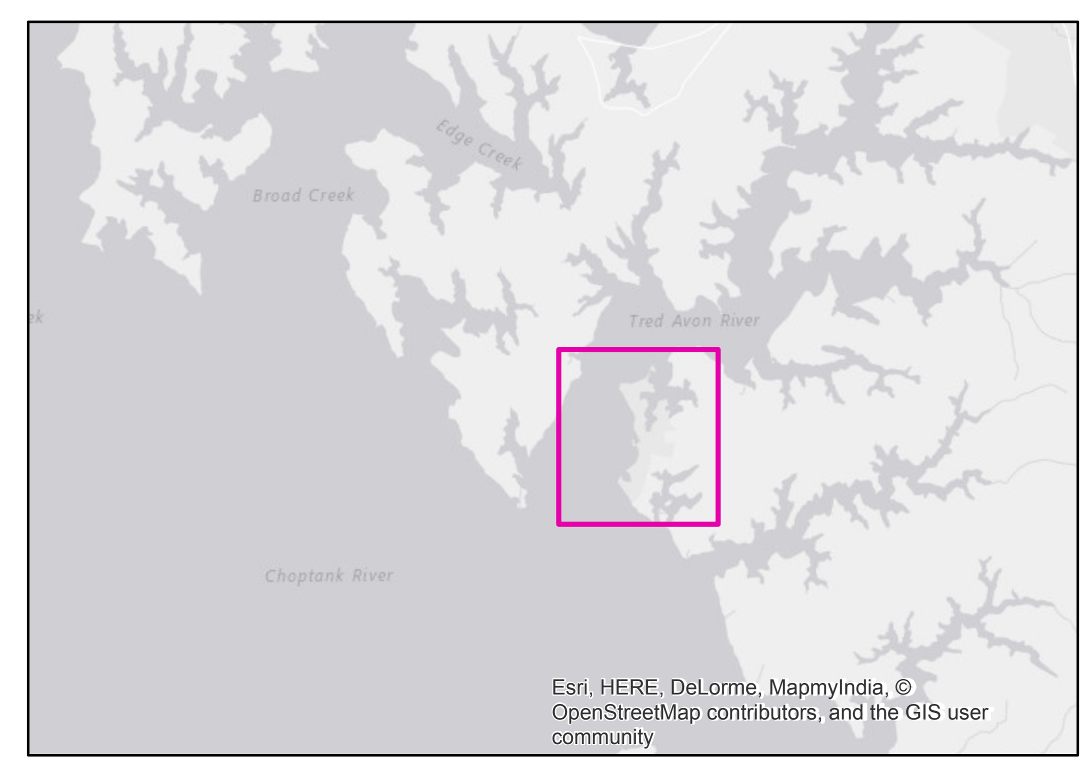


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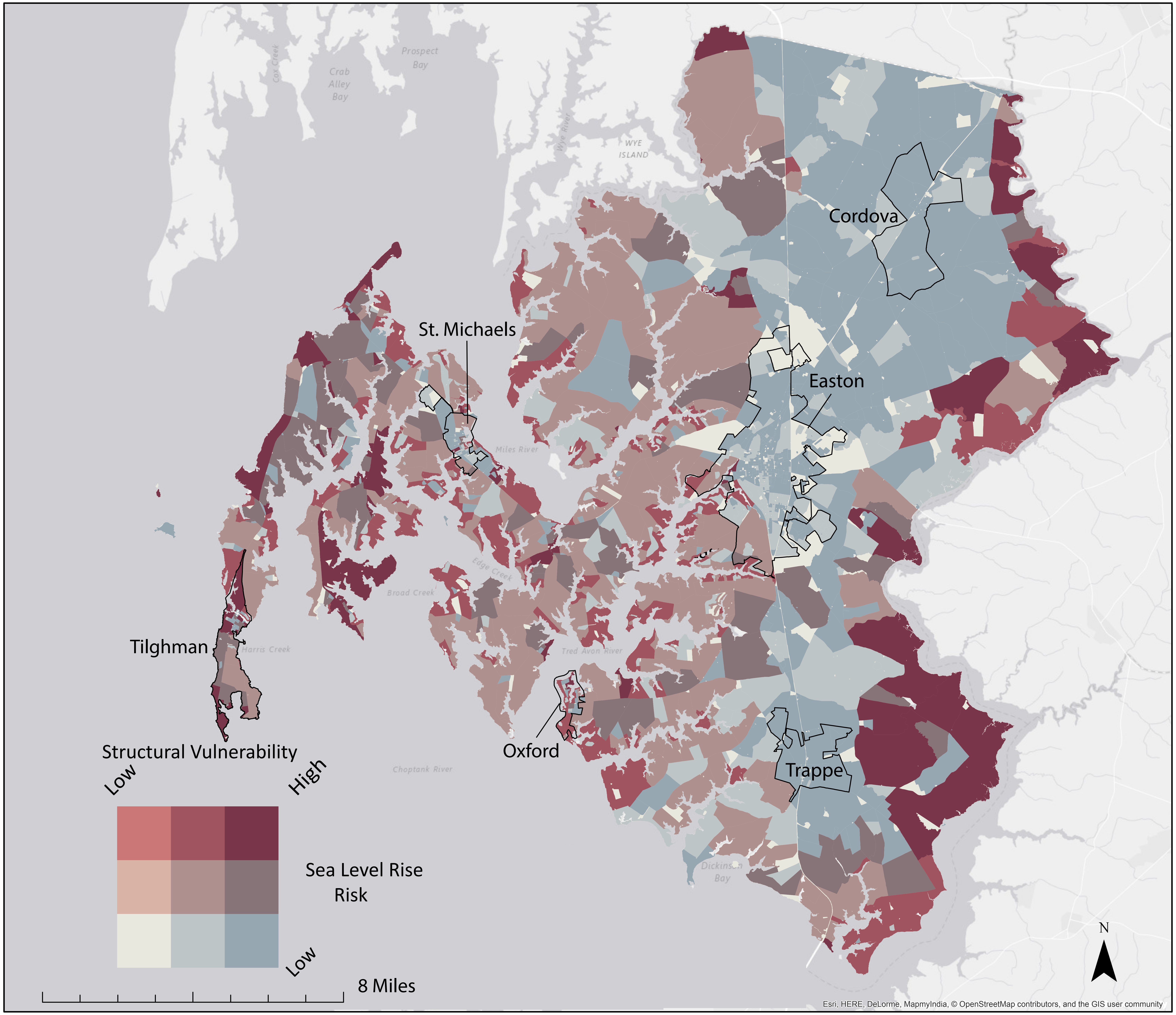
Figure E-23

Potential Structural Vulnerability vs. 1 ft. Sea Level Rise Risk - Talbot County, MD



Legend

Municipality Boundaries

Description

Sea Level Rise risk is measured as the percentage of land area in a block potentially inundated In the event of a rise in sea level 1 foot above current mean tide conditions.

Structural Vulnerability is determined as a proportion of the structures per block with the presence of the following three variables: structure grade, non-wood structures, and post-2003 construction.

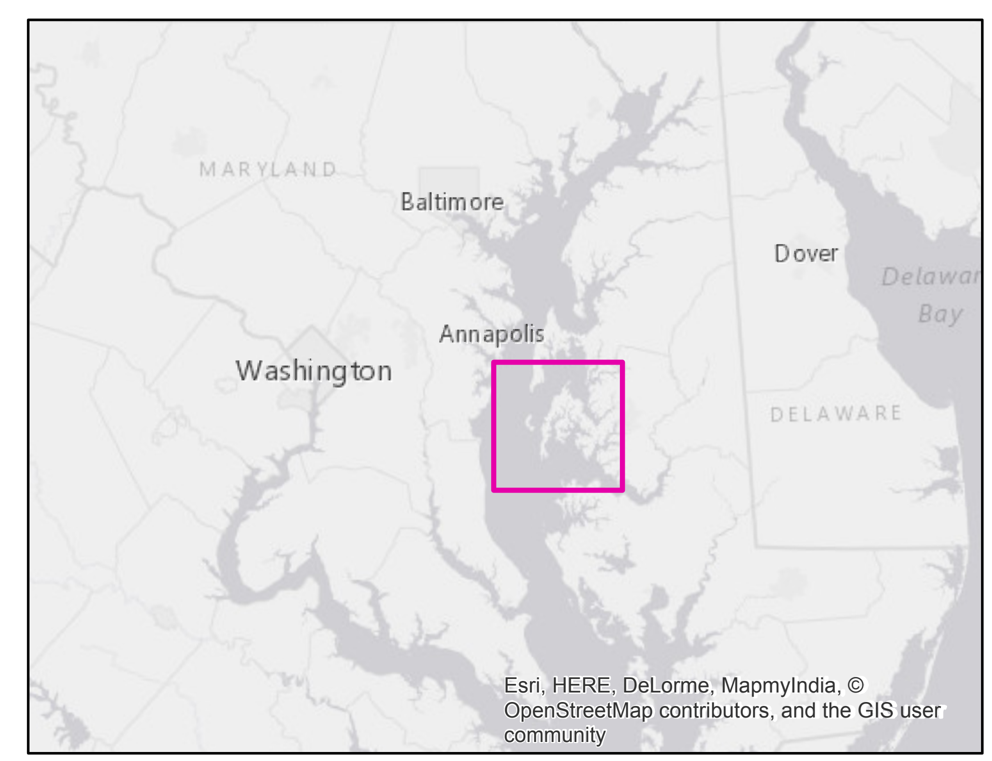


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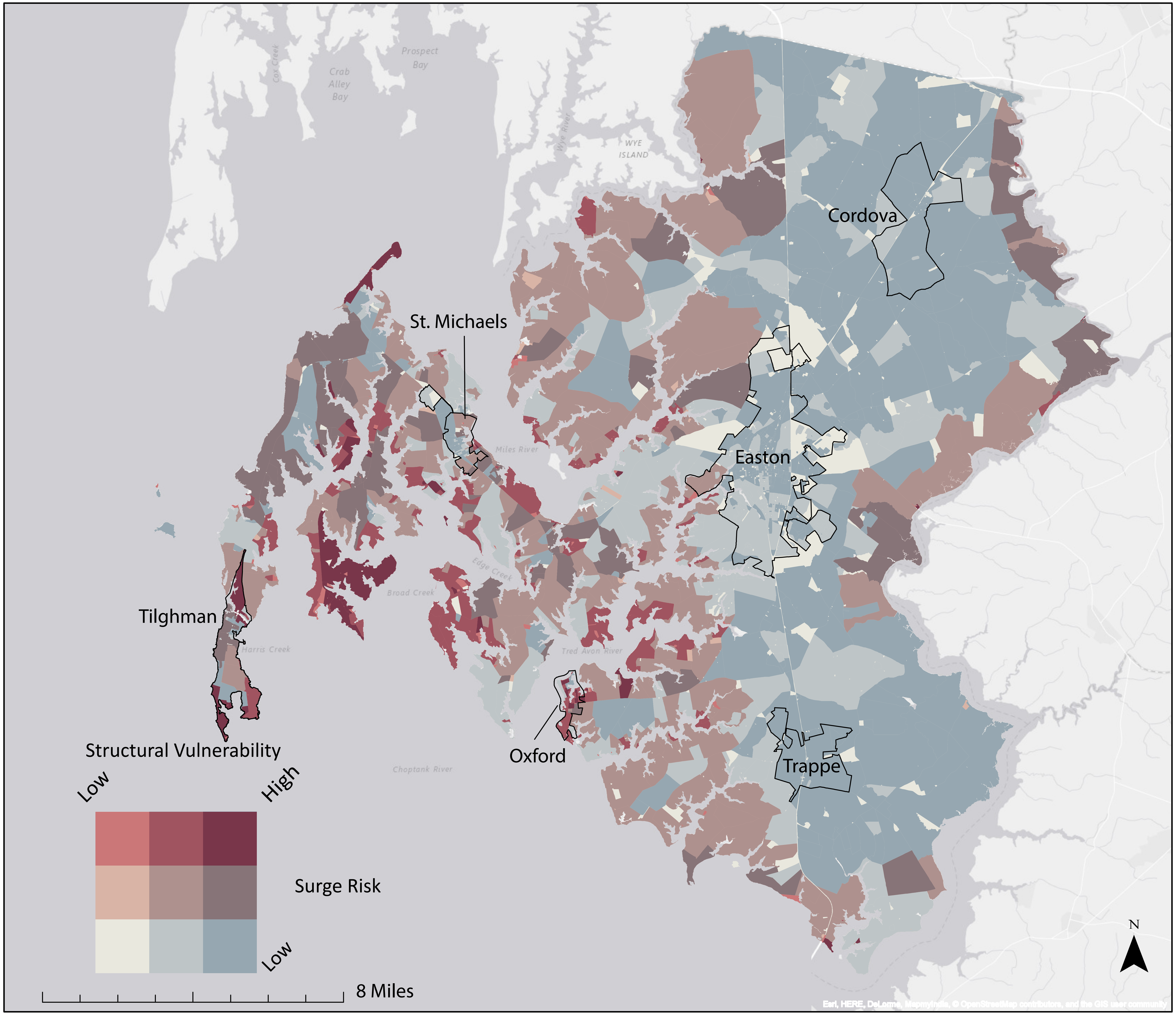
Figure E-24

Potential Structural Vulnerability vs. Category 1 Storm Surge Risk - Talbot County, MD



Legend

Municipality Boundaries

Description

Storm surge risk is measured as the percentage of land area in a block potentially inundated in the event of a category 1 hurricane with a surge of 3 to 5 feet above normal high tide.

Structural Vulnerability is determined as a proportion of the structures per block with the presence of the following three variables: structure grade, non-wood structures, and post-2003 construction.

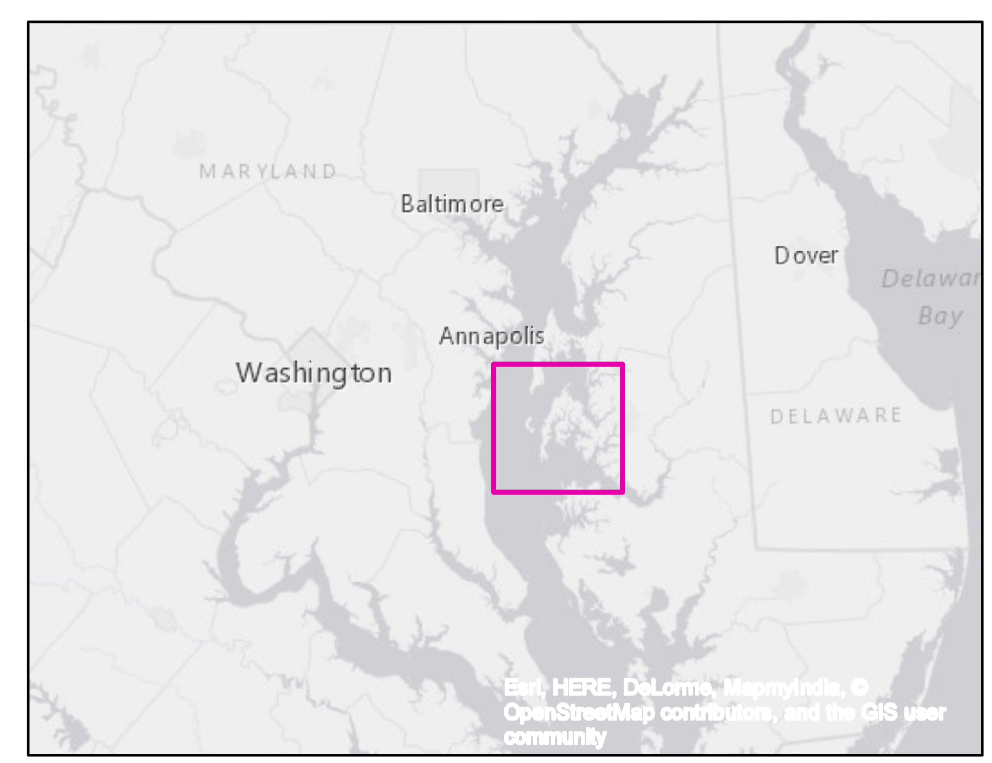


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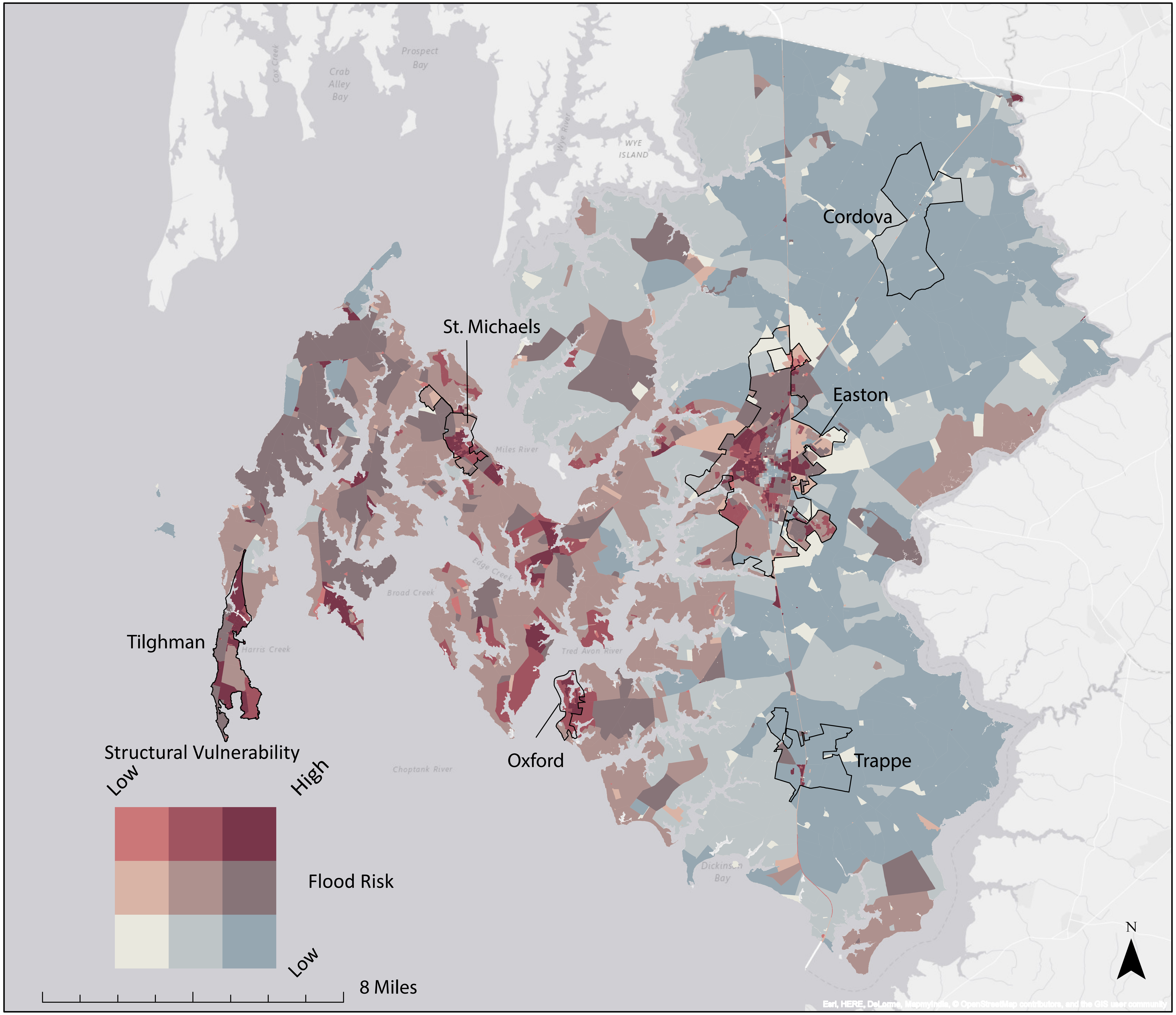
Figure E-25

Potential Structural Vulnerability vs. Storm Water Flood Risk - Talbot County, MD



Legend

Municipality Boundaries

Description

Storm water flood risk represents the presence of three conditions: elevation (0-2 feet), developed land cover, and poorly drained soils.

Structural Vulnerability is determined as a proportion of the structures per block with the presence of the following three variables: structure grade, non-wood structures, and post-2003 construction.

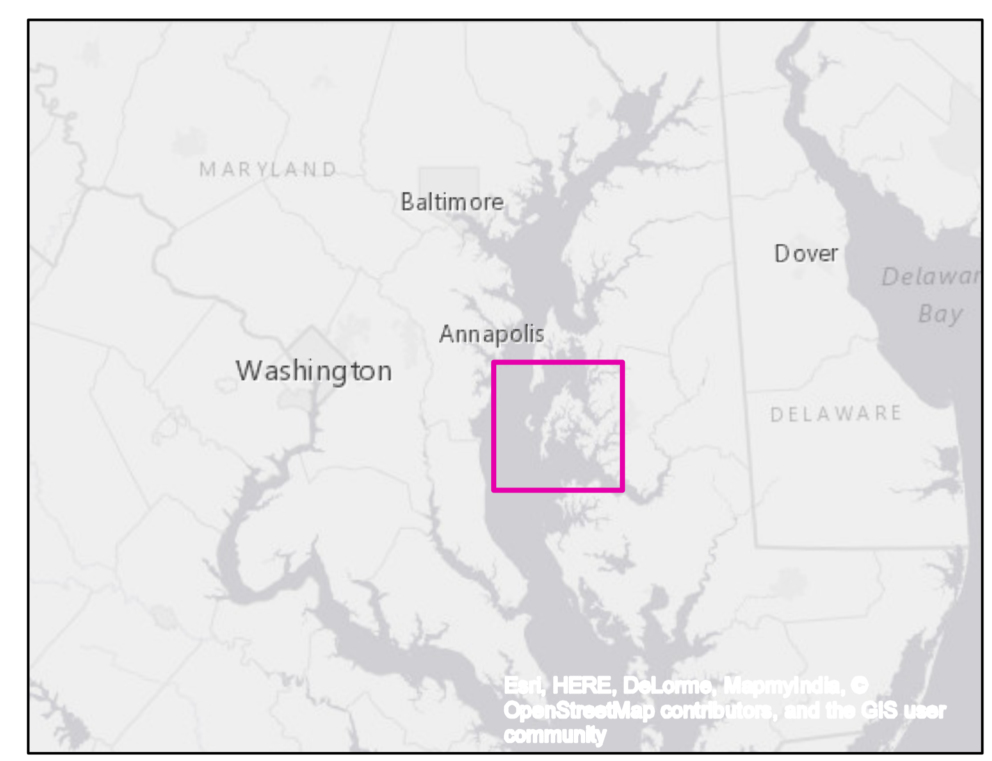


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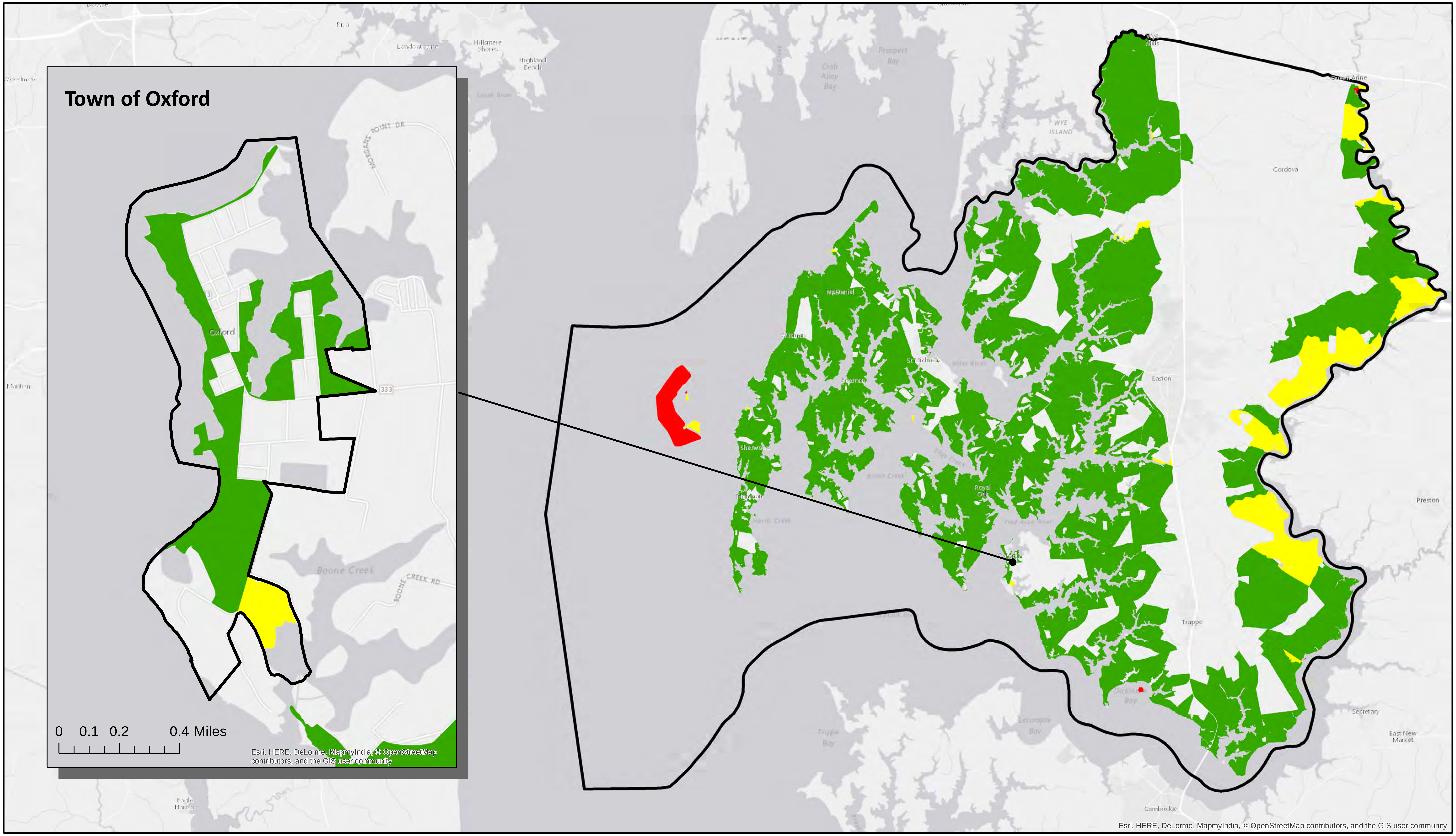
Figure E-26

Projected Sea Level Rise (1 ft) Impacts to Natural Resources by Block - Talbot County, Maryland

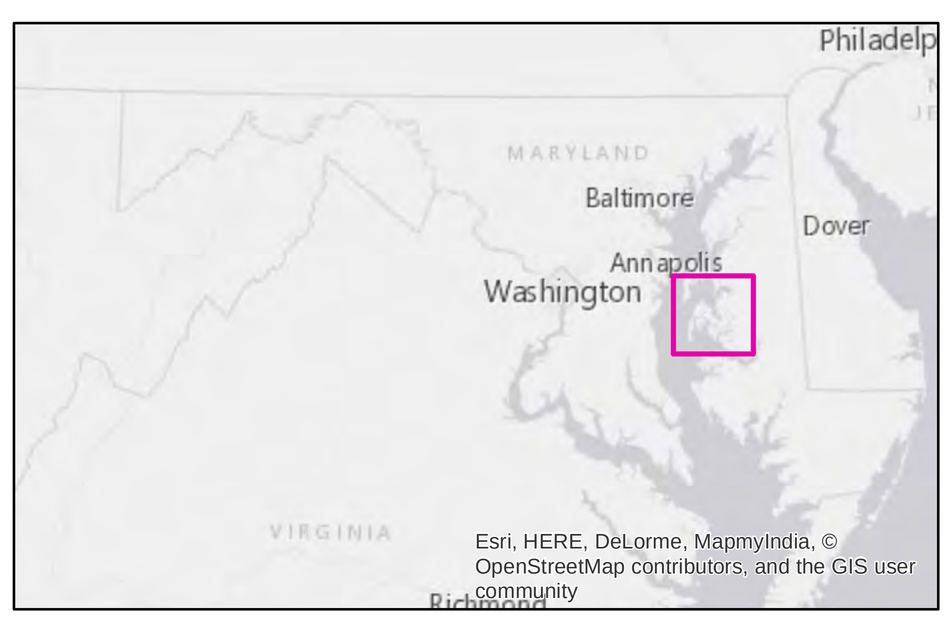
E36



Block Score

- Low
- Medium
- High

Description:
Vulnerability of natural resources to projected sea level rise is expressed as a percentage of the total land area (in acres) of the block covered by sensitive natural resources that would be exposed to inundation. Blocks are scored as low, medium, or high based upon this percentage. Scores ranging from 0-13% fall into the low category, 14-44% medium, and 45-100% are high.



0 2.5 5 10 Miles

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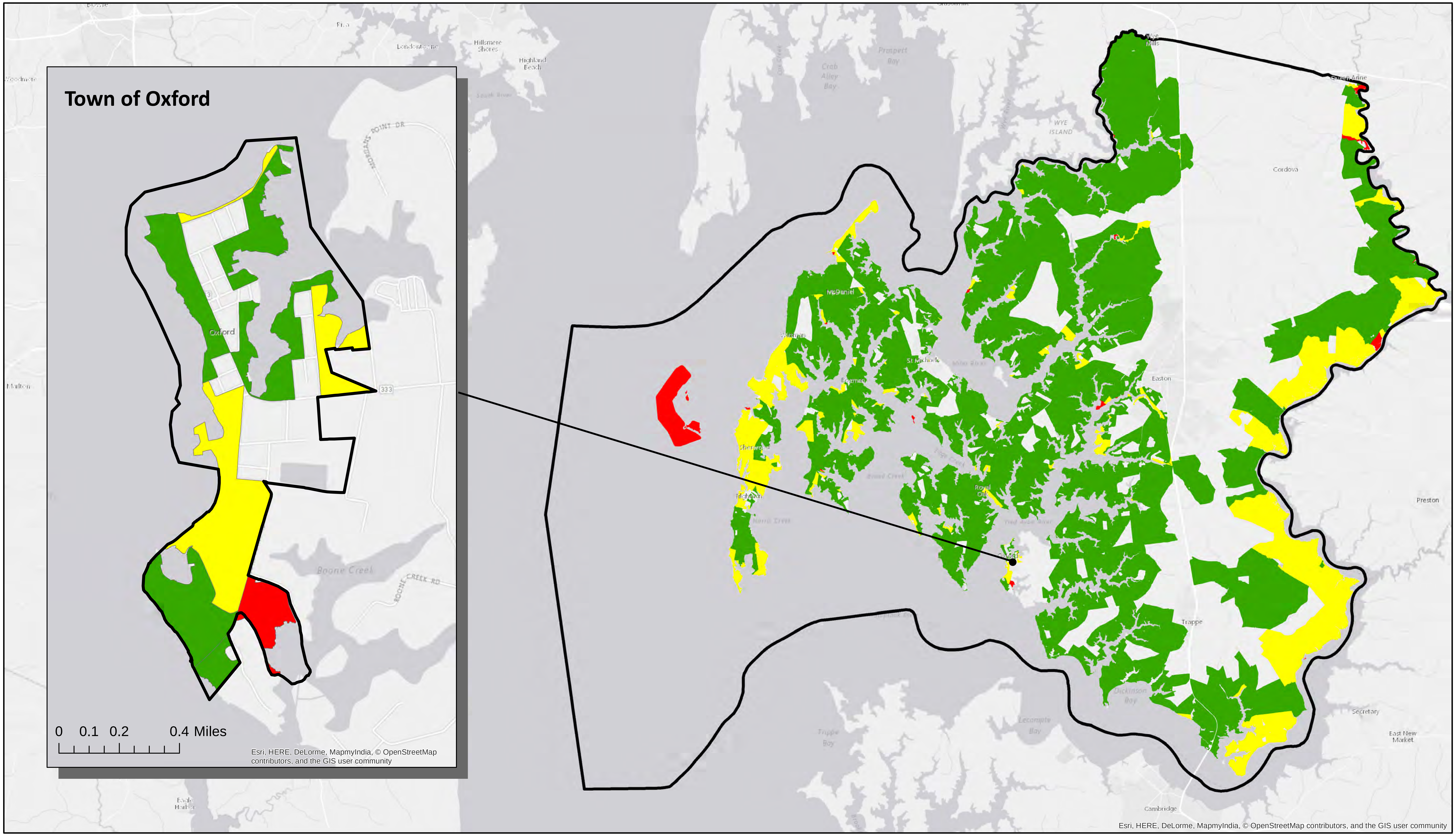
Figure E-27

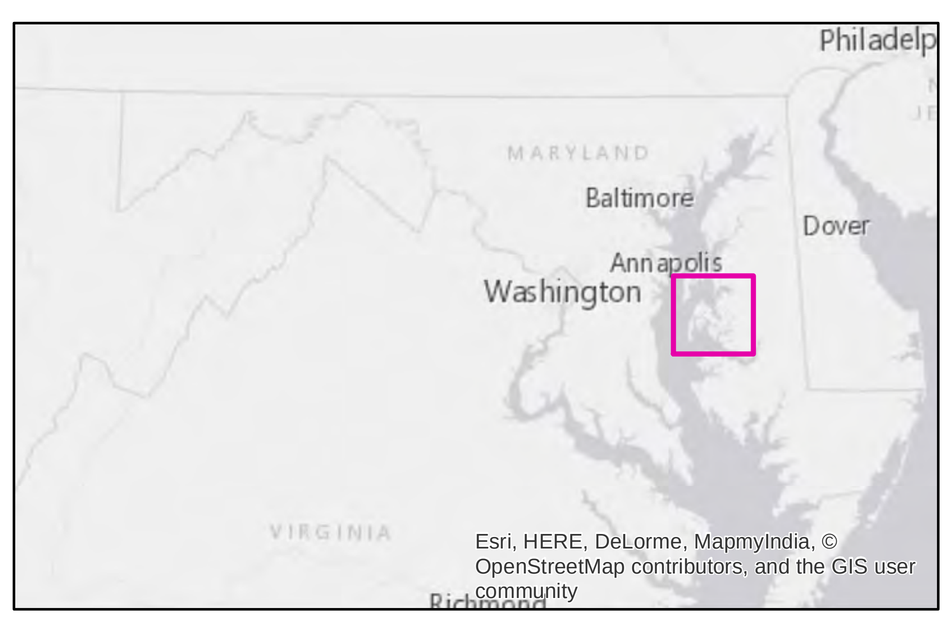
Storm Surge (Cat 1) Impacts to Natural Resources by Block - Talbot County, Maryland



Block Score

- Low
- Medium
- High

Description:
Vulnerability of natural resources to storm surge is expressed as a percentage of the total land area (in acres) of the block covered by sensitive natural resources that would be exposed to storm surge. Blocks are scored as low, medium, or high based upon this percentage. Scores ranging from 0-13% fall into the low category, 14-44% medium, and 45-100% are high.



0 2.5 5 10 Miles

N

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Figure E-28

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Section 4:

Priorities for Adaptation

Priorities for Adaptation

This final section provides maps of short and long term flood hazards and plans to prioritize adaptation activities for both Oxford, MD and Talbot County, MD.

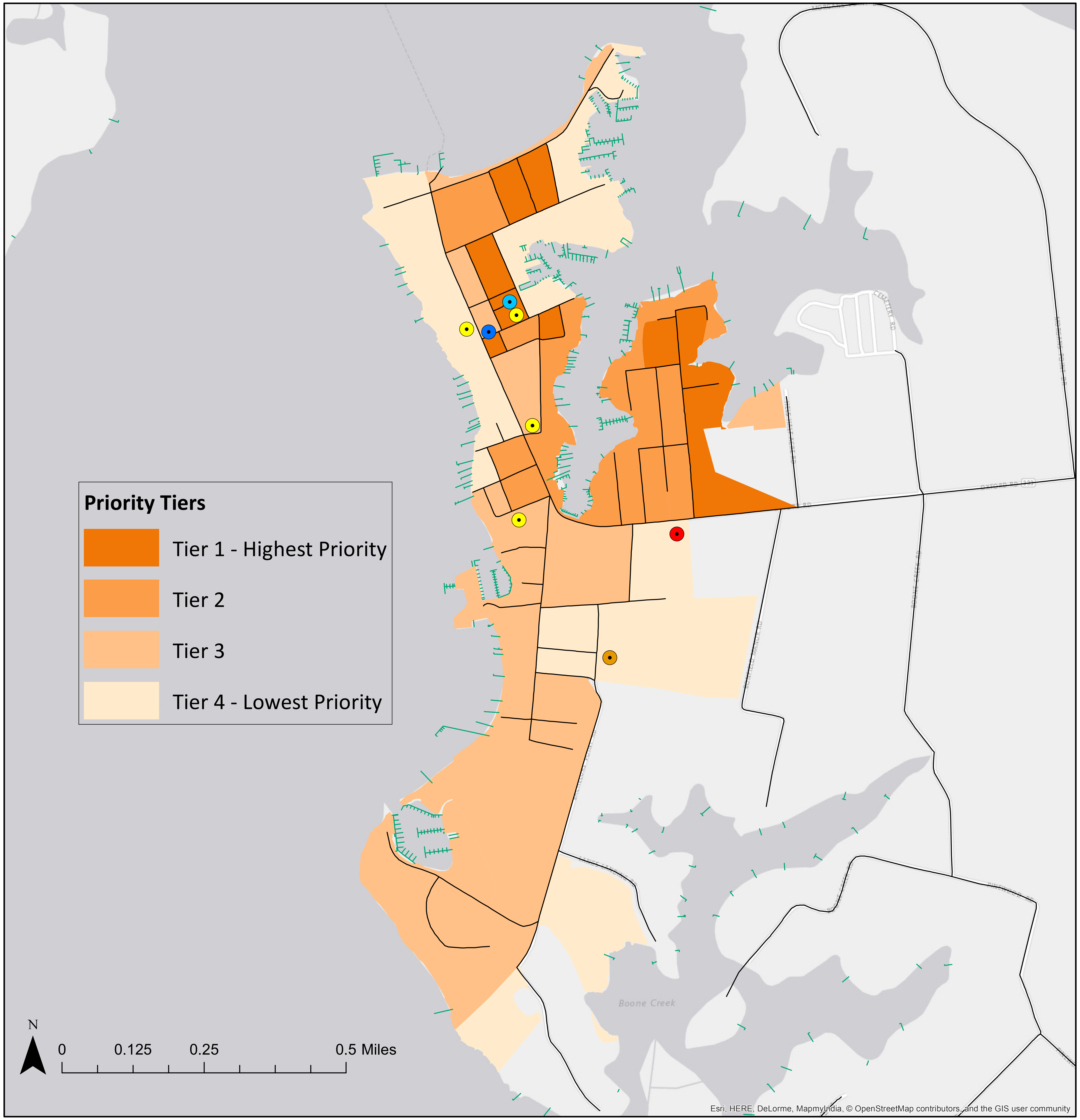
In the final phase of analysis, all vulnerabilities were interested with either short term or long term flood hazard risks. Short term risk was defined as category 1 storm surge and stormwater flooding, while long term risk was defined as the loss of land and natural resources to sea level rise. By combining measures of risk with measures of vulnerability, the science team was able to establish overall measures of priority for adaptation activities for the Town of Oxford and Talbot County. Maps were created in order to identify especially vulnerable blocks so that they may be prioritized for adaptation activities. These maps address two major types of flood risk – short term and long term. Adaptation actions ideally address both types of risk, but many communities show greater support for taking action to combat short term risks. This is likely because short term risks can cause immediate and readily observed changes, such as flash flooding from a heavy rain event. In the case of stormwater flooding, the Town of Oxford experiences this flood hazard frequently and it is more familiar to the community as a result. In comparison, impacts from long term risks such as sea level rise are more difficult to observe because sea level rise is a slow process and may take over many decades to occur. Despite the apparent lack of urgency, it is important to plan and prepare for sea level rise not only because of the problems it creates on its own (e.g., loss of land, property, and habitat) but also because rising seas are likely to exacerbate impacts caused by short term hazards like storm surge and stormwater flooding.

Priority mapping for short term risks utilized risk components that include category 1 storm surge and stormwater flooding impact per block. In terms of vulnerability, block scores calculated from the socioeconomic and infrastructure analyses were combined from four separate analyses: social vulnerability, structural vulnerability, storm surge, and stormwater flooding. Blocks designated as Tier 1 should be highly prioritized when considering adaptation measures that address short term hazards within the Town of Oxford and Talbot County.

Priority mapping for long term risks utilized risk components that include the loss of land and natural resources to sea level rise (1 ft). In terms of vulnerability, block scores calculated from the social vulnerability, structural vulnerability, and natural resource richness analyses were combined from four separate analyses: social vulnerability, structural vulnerability, natural resource vulnerability, and sea level rise. Blocks designated as Tier 1 should be highly prioritized when considering adaptation measures that address long term hazards within the Town of Oxford and Talbot County.

E40

Prioritizing Adaptation Activities for Short Term Flood Hazards in Oxford, MD



Legend

- Post Office
- Police
- Religious Institution
- Fire/EMS
- Wastewater Treatment Plant
- Road
- Dock

Block Prioritization

Block level adaptation priority scores are determined through a combination of:

1) Risk (flood hazards) Analysis - Storm Surge and Stormwater Flooding impact per block.

2) Vulnerability analysis - Social and structural scores per block.

Each Census block is scored as an index value from 0 to 1 and then represented as a tier (Tier 1 = blocks of highest overall vulnerability and risk).

Tier 1 areas should be highly prioritized when considering adaptation measures that address short term hazards for the Town of Oxford.

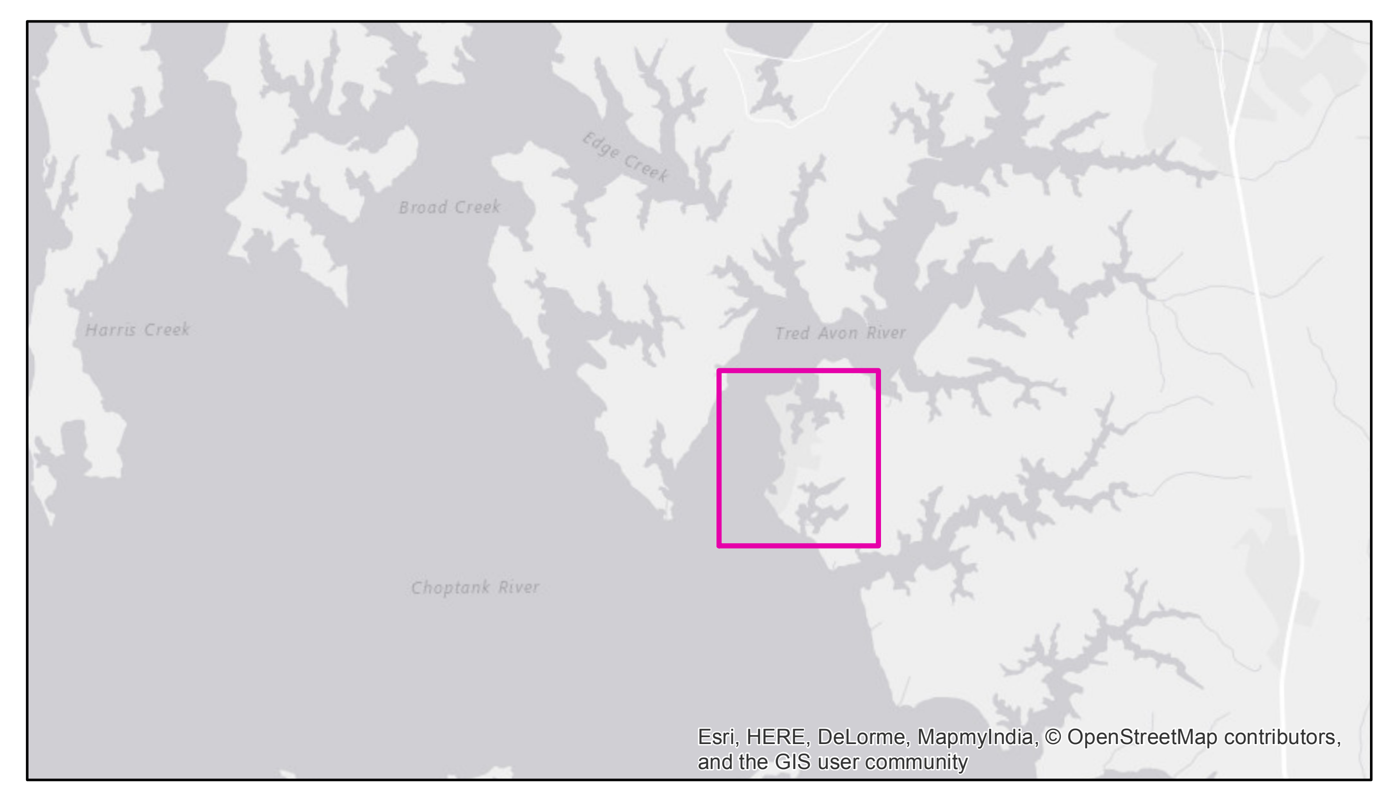


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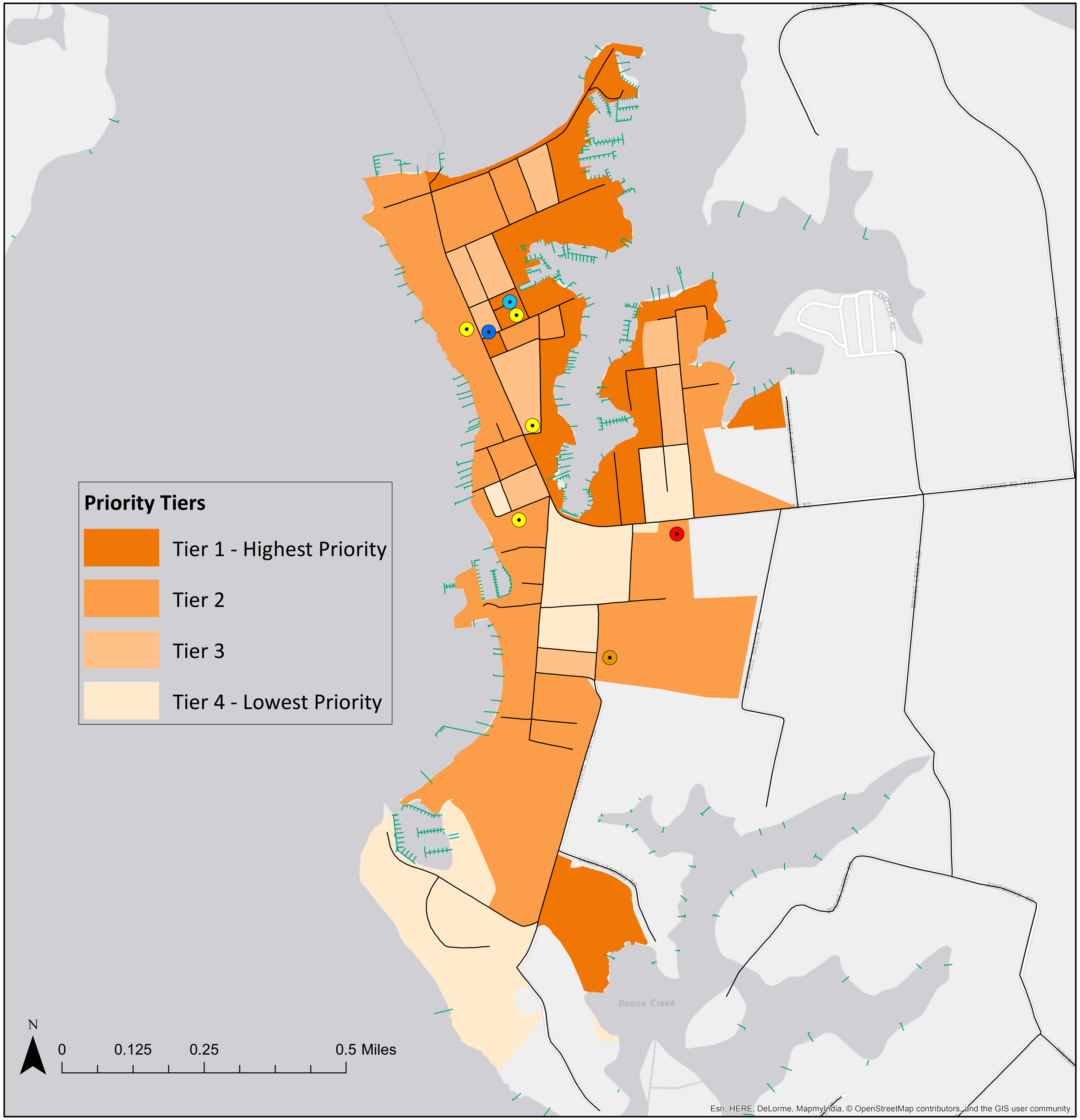
Figure E-29

Prioritizing Adaptation Activities for Long Term Flood Hazards in Oxford, MD

E41



Legend

- Post Office
- Police
- Religious Institution
- Fire/EMS
- Wastewater Treatment Plant
- Road
- Dock

Block Prioritization

Block level adaptation priority scores are determined through a combination of:

1) Risk (flood hazards) Analysis - Sea Level Rise and Natural Resource impact per block.

2) Vulnerability analysis - Social and structural scores per block.

Each Census block is scored as an index value from 0 to 1 and then represented as a tier (Tier 1 = blocks of highest overall vulnerability and risk).

Tier 1 areas should be highly prioritized when considering adaptation measures that address long term hazards for the Town of Oxford.

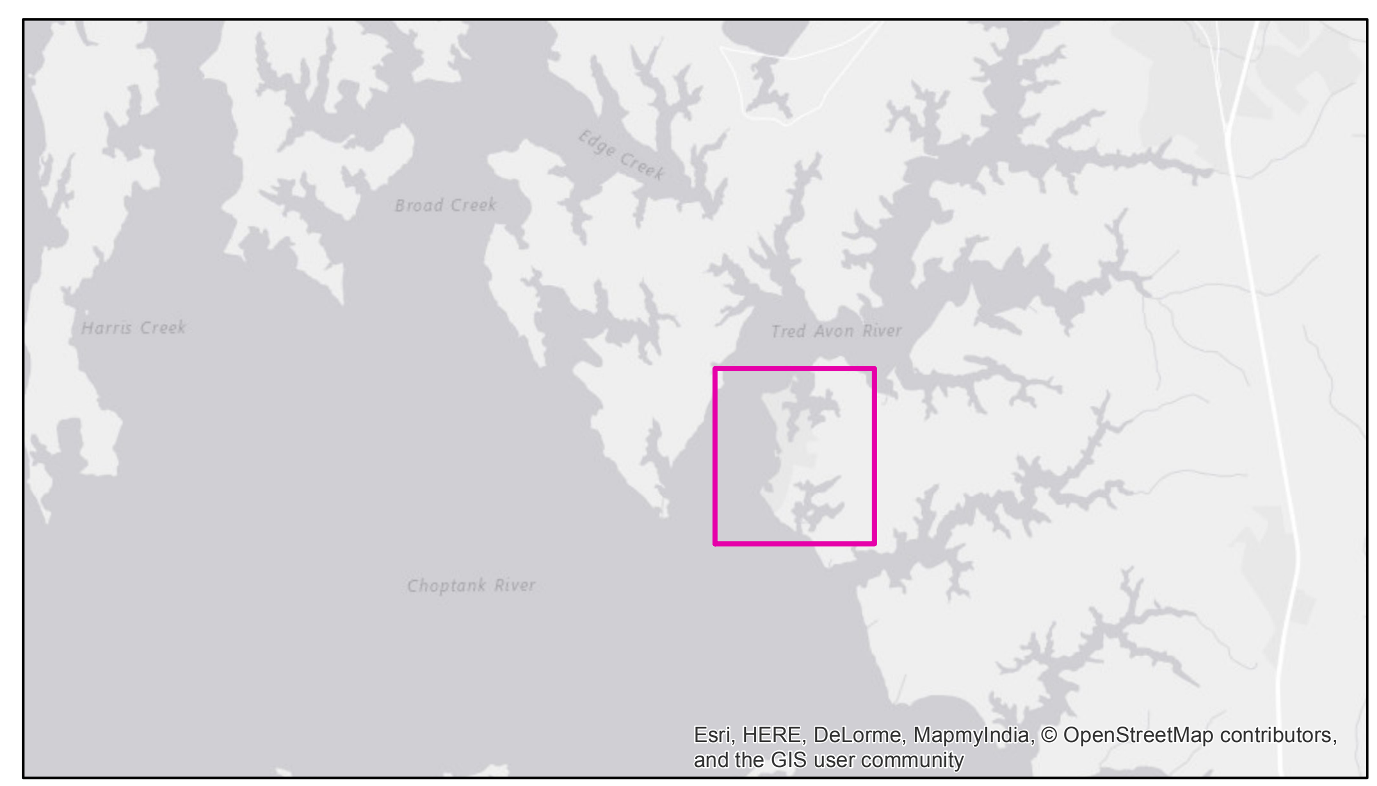


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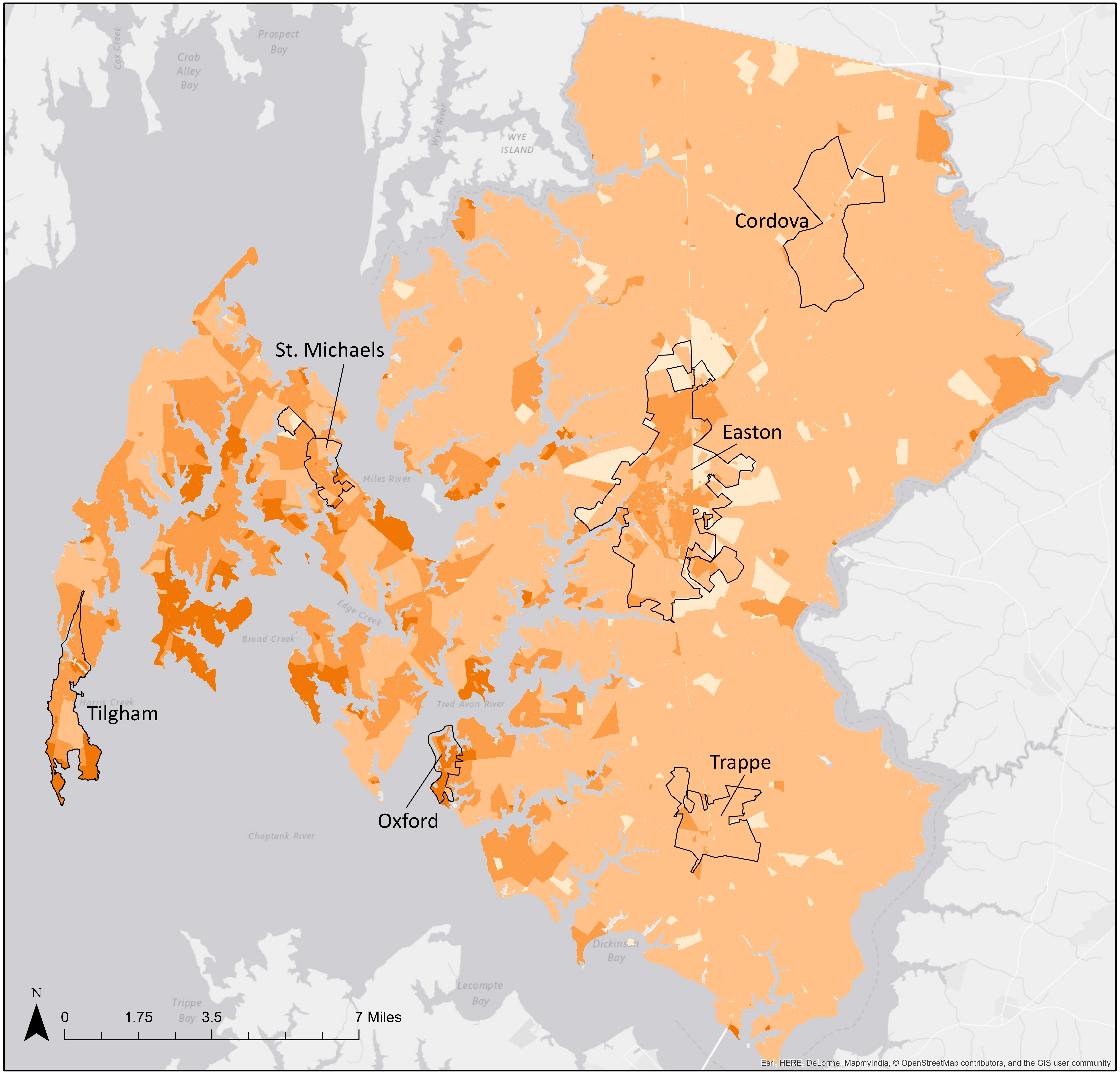
Figure E-30

Prioritizing Adaptation Activities for Short Term Flood Hazards in Talbot County, MD

E42



Legend

Priority Levels

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

Block Prioritization

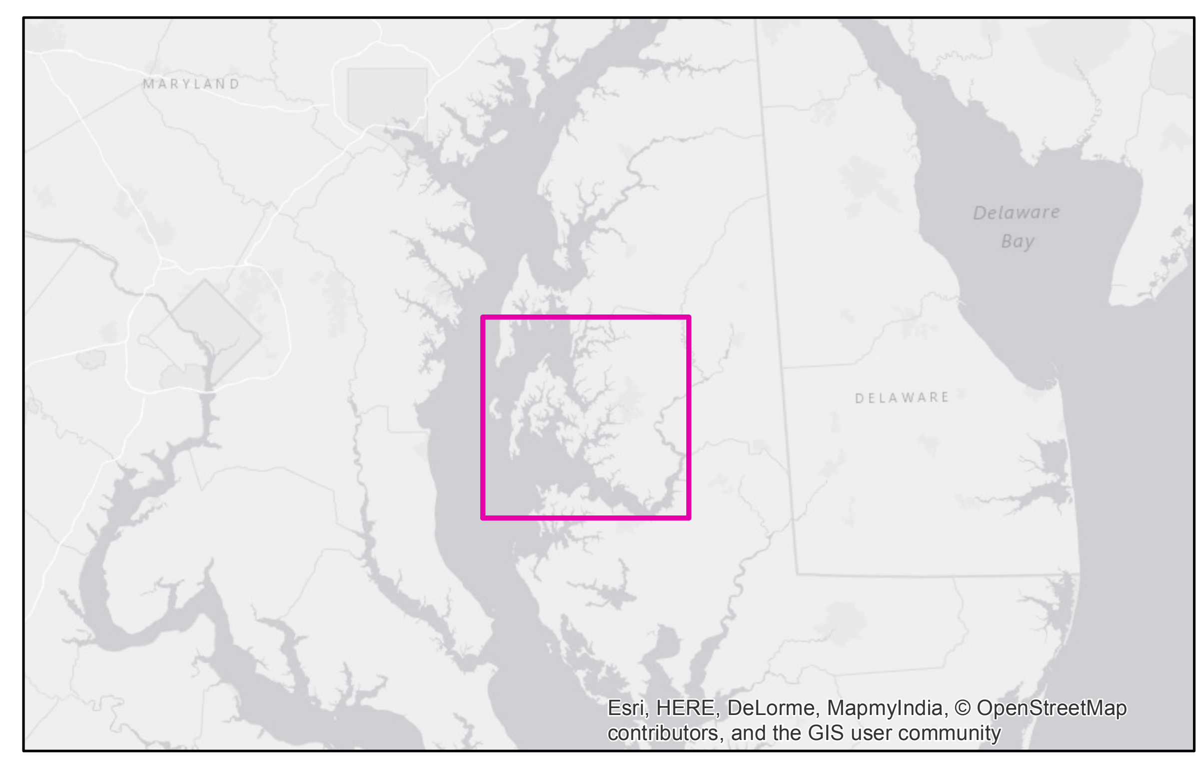
Block level adaptation priority scores are determined through a combination of:

1) Risk (flood hazards) Analysis - Storm Surge and Stormwater Flooding impact per block.

2) Vulnerability analysis - Social and structural scores per block.

Each Census block is scored as an index value from 0 to 1 and then represented as a tier (Tier 1 = blocks of highest overall vulnerability and risk).

Tier 1 areas should be highly prioritized when considering adaptation measures that address short term hazards for the Town of Oxford.



NATIONAL CENTERS FOR COASTAL OCEAN SCIENCE

Figure E-31

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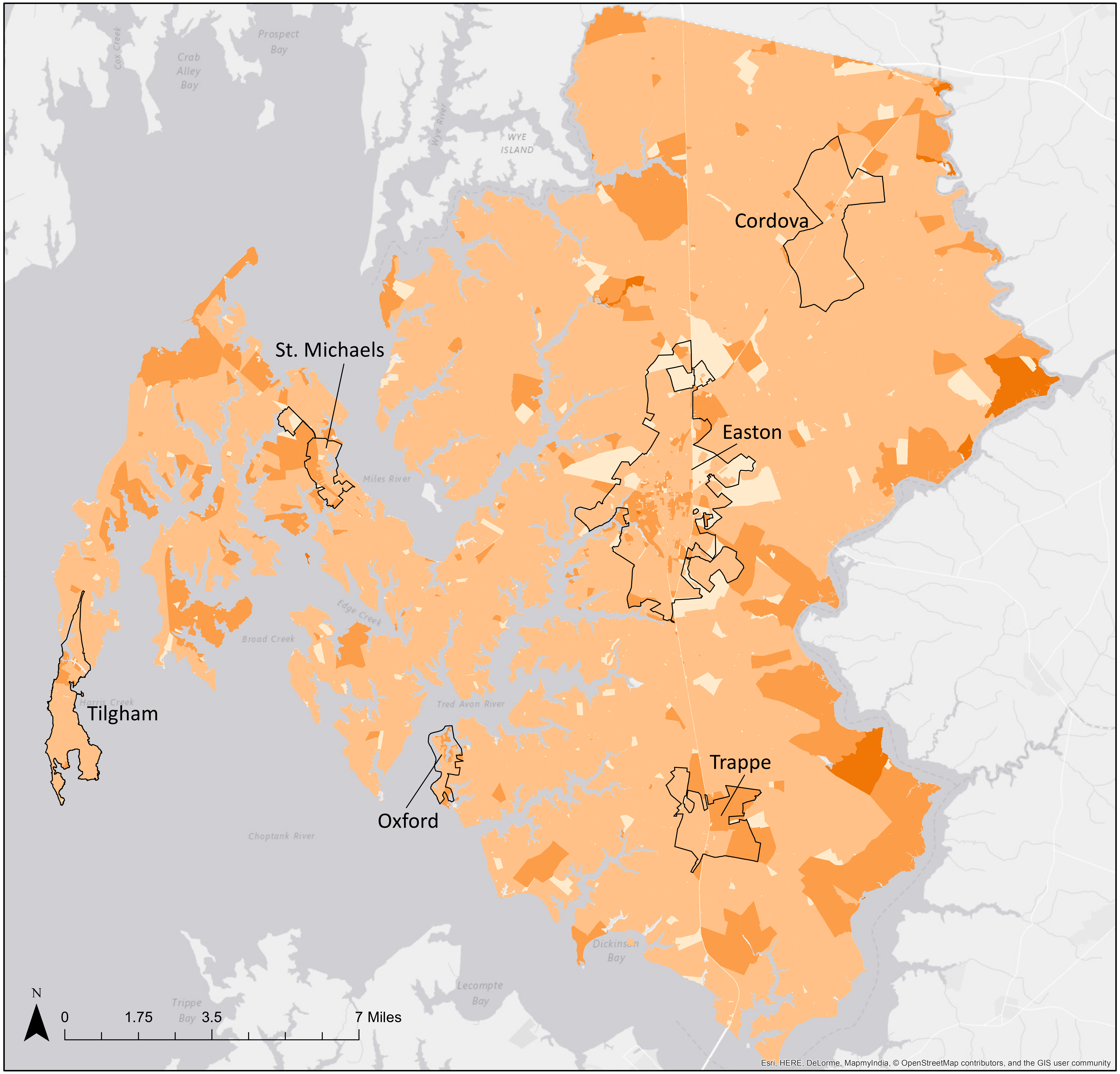
Prioritizing Adaptation Activities for Long Term Flood Hazards in Talbot County, MD



Legend

Priority Levels

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

Block Prioritization

Block level adaptation priority scores are determined through a combination of:

1) Risk (flood hazards) Analysis - Sea Level Rise and Natural Resource impact per block.

2) Vulnerability analysis - Social and structural scores per block.

Each Census block is scored as an index value from 0 to 1 and then represented as a tier (Tier 1 = blocks of highest overall vulnerability and risk).

Tier 1 areas should be highly prioritized when considering adaptation measures that address long term hazards for Talbot County.

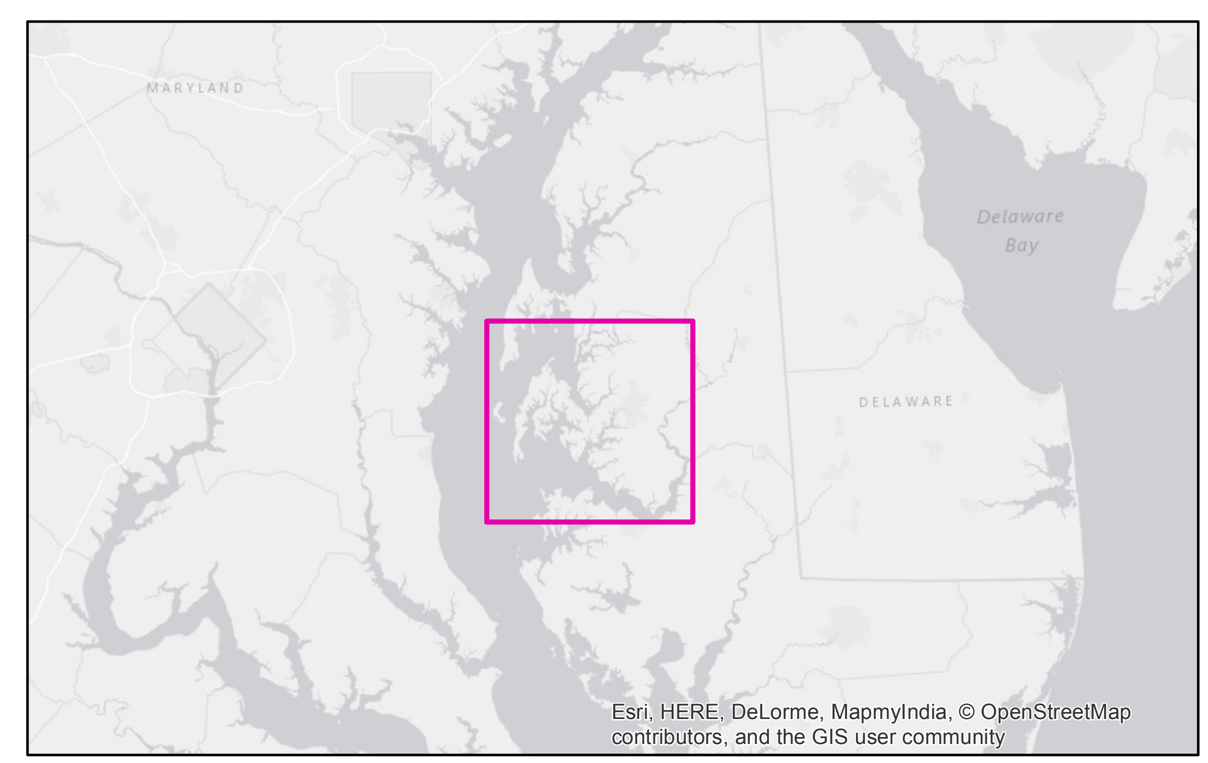


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Figure E-32

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United States Department of Commerce

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Secretary of Commerce

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