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A SPATIAL ANALYSIS OF THE IMPACTS OF CLIMATE CHANGE ON COASTAL ARCHEOLOGICAL SITES IN MARYLAND

by

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THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Jennifer L. Chadwick-Moore, entitled A SPATIAL ANALYSIS OF THE IMPACTS OF CLIMATE CHANGE ON ARCHEOLOGICAL SITES IN MARYLAND has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Master of Arts.

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ABSTRACT

A SPATIAL ANALYSIS OF THE IMPACTS OF CLIMATE CHANGE ON ARCHEOLOGICAL SITES IN MARYLAND

Jennifer L. Chadwick-Moore

Maryland is currently losing valuable archeological resources at an alarming rate. Members of the archeology community, both local and national, need to be aware of the immediate need for action against the already-active threat of climate change to our history and culture. Archeological resources are at risk from factors including sea-level rise, erosion, and storm surge. A vulnerability assessment was completed to prioritize high-risk archeological sites for management, protection and documentation purposes. Spatial analysis tools were used to develop a GIS model to overlay statewide datasets, including erosion rates, shoreline, inundation and proximity to shoreline data, with archeological resources to assess future impacts. With over 3,100 miles of shoreline in Maryland and relative sea-level rise projections for the Chesapeake Bay region as high as one meter by the year 2100, the findings revealed that thirty-three percent of recorded archeological sites in the project area are at high risk from climate change.

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KEY TO ABBREVIATIONS

CVI	Coastal Vulnerability Index
EVA	Erosion Vulnerability Assessment
IPCC	Intergovernmental Panel on Climate Change
LUBC	Land Use Bank Cover
MCAP	Maryland Climate Action Plan
MCCC	Maryland Climate Change Commission
MDE	Maryland Department of the Environment
MDNR	Maryland Department of Natural Resources
MDP	Maryland Department of Planning
MGS	Maryland Geological Service
MHT	Maryland Historical Trust
SHL	Shoreline
SHPO	State Historic Preservation Office
SLAMM	Sea Level Affecting Marshes Model
SLR	Sea-Level Rise

KEY TERMS

Climate

Climate in a narrow sense is usually defined as the ‘average weather’, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years.

Climate change

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity.

Risk

The combination of the probability of an event and its negative consequences.

Vulnerability

Vulnerability is the degree to which a system is susceptible to, and 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.

CHAPTER 1

INTRODUCTION

Climate change has many impacts on the world around us including archeological sites. Archeological sites tell us the history of past human culture, but many of them are at risk due to climate change as manifested by global warming and frequent extreme weather events. For example, two-thousand-year-old Thule culture sites in Greenland are being washed away because the sea ice belt that buffered the coast has mostly disappeared (Curry 2009, Blankholm 2009). Archeological sites in coastal Peruvian deserts are deteriorating and eroding due to torrential rains and floods during severe El Niño seasons. In the Altai Mountains, Scythian tombs that have remained frozen for 3,000 years are in danger of thawing and rotting away (Curry 2009). In fact, many archeological sites in the coastal regions are under direct threat from sea-level rise (SLR), shoreline erosion, and storm surges as a result of climate change (Erlandson 2008). It is therefore necessary to identify, assess, and prioritize these at-risk sites in order to mitigate potential impacts of climate change and protect archeological resources.

Problem Statement

Climate change is the long-term variation of the earth's climate. Scientists believe with increased certainty that such change has not only occurred over the past century but also been accelerating over recent decades as evidenced by global warming, glacial melting, sea-level rising, and weather abnormalities (IPCC 2013). Most of the environmental changes listed in the evidence are troublesome because they have broad and direct impacts detrimental to both natural systems and human systems. The dominant factors may vary with the location. In coastal regions, archeologists are more concerned with three main factors including sea-level rise, coastal erosion, and storm surge.

In the United States, sea-level rise (SLR) threatens coastal areas at alarming rates with substantial spatial variation. A new report from the Intergovernmental Panel on Climate Change (IPCC, 2013) shows that the global mean SLR is 1.8 [1.3 to 2.3] mm per year over the period between from 1901 to 2010 (IPCC 2013), but a recent study (Sallenger, Doran and Howd 2012) indicates that the acceleration rate of sea-level rise in the Northeast Atlantic coast is three to four times higher than the global average. Maryland's Chesapeake Bay region is the third most vulnerable coastline to sea-level rise after Louisiana and Florida (Department of Natural Resources 2007). It is among the SLR hotspots due to both local land subsidence and eustatic sea-level rise. Although we do not know for sure what undiscovered archeological resources have been inundated in the past, it is certain that many existing archeological sites will be immersed under water as the sea level expectedly continues to rise.

About 31% of Maryland's coastline is eroding and approximately 580 acres of land are lost annually to shore erosion (Department of Natural Resources 2007). Sperling, Schiszik and Cox (2010) found that archeological sites in Anne Arundel County are not only at risk from sea-level rise but from coastal erosion. Unlike SLR whose impact may occur at a large scale in space with a long temporal cycle if not permanently, coastal erosion may be local and take place on a daily basis due to tides and wave action. Both erosion and aforementioned factors appear unrelated to climate change, but shoreline retreat due to sea-level rise and severe erosion induced by intensifying storms and floods certainly belong to the domain of climate change. Therefore, erosion has conventionally been considered one of the main factors in literature when assessing the impact of climate change or environmental change on archeological resources (Reeder, Rick and Erlandson 2010, Robinson et al. 2010). While inundation due to SLR may preserve sub-surface sites forever, erosion could damage or destroy the material remains both above and under the ground.

With climate change, scientists (Emanuel 2005 and Webster et al. 2005) have revealed a trend of increasing intensity, frequency and destructiveness of tropical storms over the past three decades. Storms that track on the west side of the Chesapeake Bay create the strongest storm surge and heavy flooding. South winds from the storms drive water up the Bay and along Western shore rivers causing flooding in cities like Annapolis, Baltimore and Washington, D.C. Hurricane Isabel in 2003 was the most recent example of a western-tracking storm. The hurricane destroyed many archeological sites across the Chesapeake Bay region (Ridout 2004). Other record storms of this type were Hurricane Hazel in 1954 and the August Hurricane of 1933 (Fincham 2010). As global temperatures increase, glaciers melt causing a rise in the sea level. Global warming is very likely due to an increase in greenhouse gases that trap the sun’s energy in the atmosphere. Rainfall and wind speeds will likely increase with global warming producing greater storm surge (Boesch 2008).

Maryland hosts many archeological sites of national significance simply due to its unique location and history, particularly those related to the Chesapeake Bay. Among them are prehistoric Paleoindian sites dating back to 10,000 BC. Unfortunately, more than one-third of all archeological sites located in the low-lying coastal plain and eastern shore regions of Maryland are vulnerable to accelerating sea-level rise and intensifying storm surge. On the other hand, there is little surviving documentation for prehistoric people in Maryland prior to European contact as many archeological sites have been destroyed. If these remaining archeological sites are allowed to be obliterated before data are collected from the material remains and sub-surface features, we will lose valuable information about past cultures. Erlandson (2008) therefore calls upon archeologists for action. "In coastal regions around the world, we need to accelerate our own efforts to inventory, investigate, and interpret the history of endangered coastal sites before it is lost forever."

Research Questions

There are many questions to resolve at the state level before any action plan is formed. Which archeological sites in Maryland are most at risk from climate change? How do archeologists begin to identify high-risk sites? Where are the most vulnerable coastal areas in Maryland? Can a system be developed to prioritize documentation and survey efforts across the state?

The goal of this research is to identify high-risk areas and archeological resources that are most threatened by climate change. This goal can be achieved by developing and applying a multi-criteria ranking system that allows archeologists to differentiate the effects of climate related factors, delineate the vulnerable areas by different sea-level rise scenarios, and prioritize specific resources for immediate documentation and salvage.

It should be pointed out that this research is not intended to test any hypothesis or theory. This delimitation, however, should not depreciate the value of the research designed with strong policy orientation. Although the rating and ranking methods to be used are considered deterministic, they can be used for assessing the impacts of climate change on other environmental systems or human activities in the coastal regions.

It is expected that findings of this research will help us understand how climate change affects archeological resources, particularly in the Chesapeake Bay region. The resulting list of at-risk sites can be targeted for future fieldwork. More importantly, the information generated will aid in the development of a comprehensive plan for monitoring, documenting, preserving, and salvaging threatened historical and cultural resources.

CHAPTER 2

LITERATURE REVIEW

Climate change is currently affecting archeological sites around the world. This chapter provides a brief review of the literature on the effects of climate change on archeological sites and efforts of archeologists to document, assess, and prioritize archeological sites before they disappear. Literature exclusively on climate change was purposefully left out because it is available elsewhere (see IPCC Report, 2013). Maryland was included because it serves as both requirement and motivation of the research. Special attention is paid to vulnerability and risk assessments done either at the state level or closely related coastal environments that help to understand and address the climate change issues in both the state of Maryland and the Chesapeake Bay Region.

Effects of Climate Change on Archeological Sites

The issue of climate change affecting archeological sites is not a new phenomenon. Archeologists have observed the effects of climate change on archeological sites and their distribution patterns along the coasts for decades. Ruppe (1979) observed that some Colonial archeological sites along the East Coast that were above the water during their occupation are currently below high tide. There are smaller numbers of older site types recorded in terrestrial settings because many of the archeological remains from early to middle Holocene periods are submerged off the coast (Lewis 2000 and Snow 1972). Sea-level rise was very low throughout the time of early occupation.

Recently there has been a surge of publications bringing awareness to archeologists (as well as the public) about climate change resulting in the destruction of archeological sites. Erlandson (2008) says to archeologists, “In coastal regions around the world, we need to accelerate our own efforts to inventory, investigate, and interpret the history of endangered coastal sites before it is lost forever.” These publications do not describe a future risk as archeological sites have been and continue to be destroyed. An estimated one thousand historical and archeological sites along the coast were destroyed by Hurricane Katrina in 2005 (Erlandson 2008). Rowland (1992) urges archeologists to focus survey work, make recording coastal sites a priority and to become more involved with other disciplines to address issues of climate change.

Assessment of Archeological Sites at Risk

An article about a case study of the Santa Barbara Channel region issues a call to action to assess sites most at risk. This study analyzed which sites were most likely to be impacted by environmental factors and urban development (Reeder, Rick and Erlandson 2010). A weighted average cultural resource vulnerability index was developed which ranked archeological sites risk level by three risk factors: 1) relative distance to coast, 2) relative coastal vulnerability index (CVI) value, and 3) relative human threat index value. The coastal vulnerability index was based on the Pacific Coast CVI by (Thieler and Hammar-Klose (2000).

The coastal vulnerability index was also generated for the U.S. Atlantic Coast by Thieler and Hammar-Klose (1999). The coastal vulnerability index assigns a risk value for each of the six physical variables used in the calculation. These variables are geomorphology, shoreline erosion rates (and accretion), coastal slope, rate of relative sea-level rise, mean tidal range, and mean wave height. The coastal vulnerability index value is the square root of the geometric mean of the variables. It showed a very high value of the coastal vulnerability index for the lower Chesapeake Bay due to the region's low coastal slope, high-risk geomorphology and high rate of relative sea-level rise (Figure 2.1). This study was completed for the entire Atlantic Coast but did not assess areas further up river in Maryland. The Chester, Choptank, Nanticoke, Wicomico, Potomac and Patuxent rivers were not assessed further inland.

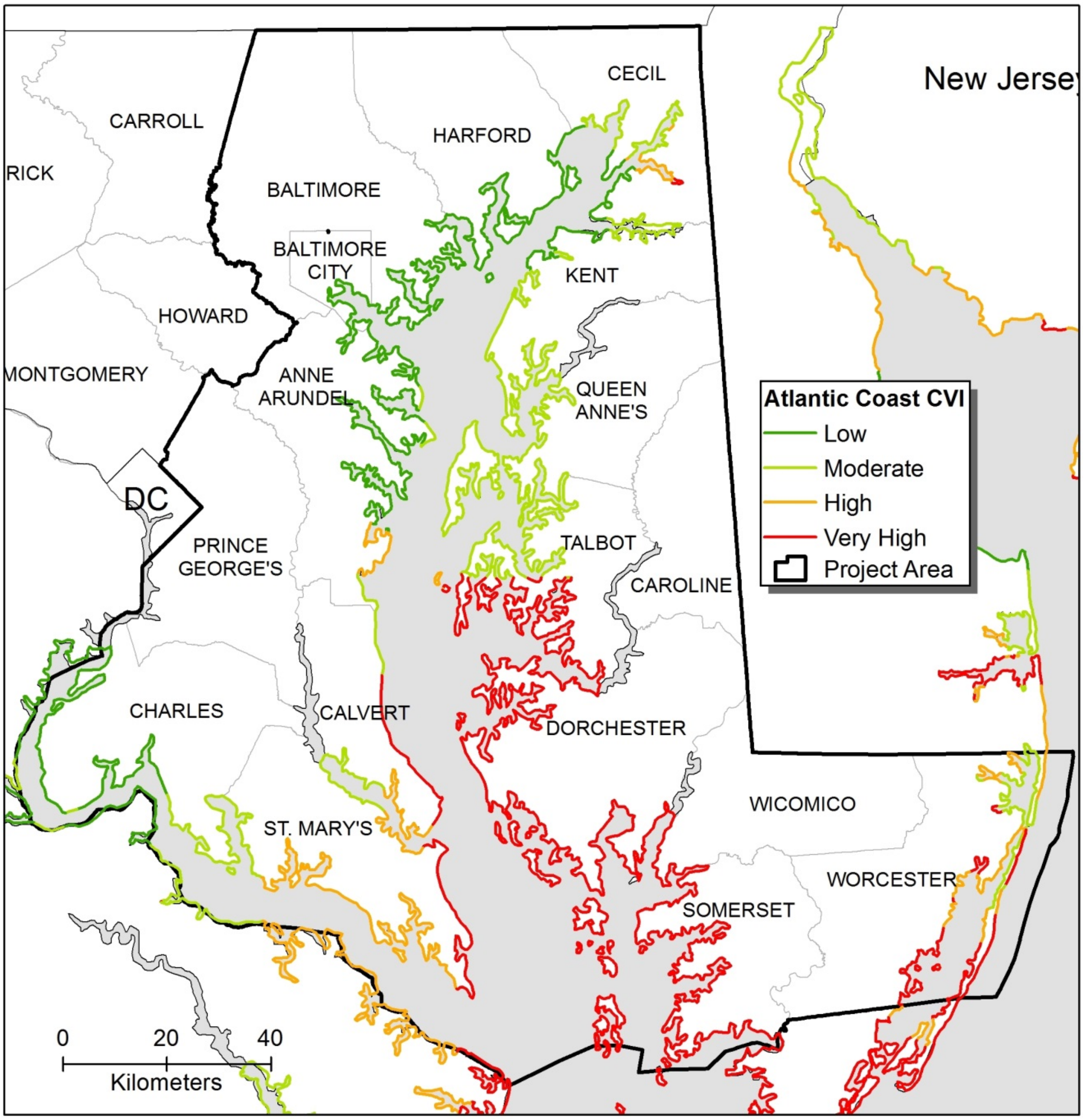

Figure 2.1. Coastal Vulnerability Index (CVI) for the Chesapeake Bay

In 2010, the Maryland Historical Trust (MHT), which serves as the State Historic Preservation Office (SHPO) under the Maryland Department of Planning (MDP), sent a request to other SHPOs to find out what has been done in other coastal states regarding the impact of climate change on their historical and cultural resources. There was correspondence with Alaska (McMahan 2010), Louisiana (McGimsey 2010), Massachusetts (Patton 2010), and North Carolina (Abbott 2010). The Alaska SHPO served on a Technical Work Group for the Governor's Panel on Climate Change. None of the other states had addressed the impacts on cultural resources in their climate action plans. SHPOs around the country are dealing with different climate change issues. Alaska is addressing problems with ocean acidification, ice melts, erosion and sea-level rise. Louisiana is largely focused on subsidence, saltwater intrusion and erosion. North Carolina is working with the North Carolina Geological Survey to convert archeological site data into a spatial dataset to use in a sea-level-rise spatial analysis. Massachusetts has published an article on coastal cultural resource management (Bell 2009). Georgia also published an article identifying and prioritizing threatened cultural resources on the Georgia coast (Robinson et al. 2010).

The study on Georgia's barrier islands identified and prioritized archeological sites that are threatened by erosion (Robinson et al. 2010). Archeological site locations (identified as X,Y points) were buffered with a 23-meter radius (representing the area potentially threatened by erosion over 50-year period using average erosion rates) and then intersected by water, channel banks and open shorelines. All 89 archeological sites that intersected these features were reviewed individually to assess data quality. Sites that contained more than just basic information were reviewed a second time to determine if they were potentially eligible for the National Register of Historic Places. Only 21 archeological sites of the original sample were potentially eligible and used for the analysis. Erosion rates for each site were determined based on the change in shoreline (comparing historical maps and aerial photography maps) and field verification of current site and shoreline positions. Of the 21 sites used in the study, results showed that for the shoreline change rates, eleven are eroding, eight are stable, and two are accreting. Even though several of the actively eroding archeological sites are eroding slowly, critical archeological information is constantly being lost.

The Maryland Climate Action Plan

In the spring of 2010, MHT began to develop an inventory of resources along Maryland's shoreline that were potentially vulnerable to climate change, including sea-level rise, worsening coastal storms, and worsening coastal erosion in response to a directive in the Maryland Climate Action Plan (MCCC 2008). The Climate Action Plan directive stated that "Department of Natural Resources (DNR) will work with other state agencies, including MDP and MHT, to identify the types of infrastructure that will be included in the inventory of potentially impacted infrastructure". The Maryland Climate Change Commission was established in April 2007 and was "charged with collectively developing an action plan to address the causes of climate change, prepare for the likely consequences and impacts of climate change to Maryland, and establish firm benchmarks and timetables for implementing the commission's recommendations." The Maryland Climate Action Plan was released in August 2008. Maryland's Climate Action Plan is to identify "vulnerable sea level rise inundation areas along Maryland's shoreline."

The Maryland Commission on Climate Change (2008) has estimated relative sea-level rise to be as much as 0.4 meters (1.3 ft.) by 2050 and 0.8 to 1 meters (2.7 to 3.4 ft.) by 2100 under different CO_2 emission scenarios. The Commission has recommended these numbers as a reasonable basis for impact assessment and strategic planning pertaining to climate change.

MHT completed a preliminary sea-level-rise vulnerability assessment study of historical and cultural resources in Maryland (MARCO 2010, Chadwick-Moore and Kavanagh 2011). This study identified resources that would be potentially vulnerable in the 0 - 1.5 meter inundation zone for the Chesapeake Bay region. Resource types evaluated were National Historic Landmarks, National Register of Historic Places, Maryland Historical Trust Preservation Easements, Maryland Inventory of Historic Properties and archeological sites. The results showed that archeological sites would be impacted the most compared to the other five resource types evaluated. Over 2,500 archeological sites would be impacted, which is equal to approximately 20% of all recorded sites in Maryland and 32% of all sites recorded in the coastal counties studied. The site types identified as at highest risk were Paleoindian, 17th century historic sites and Contact period Native American sites. The study also showed that resources located on the Lower Eastern Shore were the most vulnerable to sea-level rise.

While this study brought awareness to the issue of sea-level rise impacting historical and cultural resources, it was not able to address the questions about prioritizing sites for documentation or salvage. This analysis was only able to provide raw data and did not identify the true level of impact. The data used for the analysis were inundation data available from DNR in 0 – 0.6 meter and 0.6 – 1.5 meter levels. Data were not complete for all affected counties (three jurisdictions were not available) and did not address other factors impacting archeological sites. The model could only account for rising water and did not address impacts of erosion and storm surge.

While MHT was completing its preliminary statewide analysis, Anne Arundel County was developing a sea-level-rise strategic plan to assess its cultural resources (Sperling, Schiszik and Cox 2010). The first phase of the Anne Arundel study was a GIS assessment to rank site priority based on site location, site information, inundation levels and verification with aerial photography. The GIS assessment found that 422 archeological sites in Anne Arundel County (30%) are threatened by sea-level rise and that 6% of recorded sites are already submerged. In the second phase of the assessment, archeologists field checked a 20% sample of sites impacted at 0-1.5 meters based on priority level. The sites were evaluated for significance and integrity, condition and level of preservation, level of previous investigation and threat level. Based on data from their field visits, they found that 23% of sites visited were completely destroyed.

Remaining Issues

In Maryland, researchers have only been able to analyze inundation as a factor for archeological site risk. This has not allowed archeologists to determine which sites are eroding away. There is no way to predict which sites will be destroyed during future coastal storms. With over 3,300 recorded archeological sites in Maryland potentially at risk, how do you begin? Archeologists need to prioritize the documentation of sites because time and resources are limited. A proactive approach is needed in order to document sites before they are gone.

CHAPTER 3

METHODS

This research took a spatial approach to vulnerability and risk assessment. A GIS model was built by using similar methods developed by Reeder and his collegues (2010) for California but with three different sets of variables that better measure the climate change factors prevailing in the Chesapeake Bay region. These variables include inundation scenarios, coastal erosion, and shoreline proximity. This chapter will provide detailed description about the project area, variables and data used, ranking criteria, and methods used for assessing and calculating risk for archeological sites due to climate change.

Project Area

The State of Maryland is located in the Mid-Atlantic region of the United States. The study area includes areas in Maryland around the Chesapeake Bay impacted by 0 – 1.5 meters of sea-level rise. This area was selected in order to compare results from the previous Maryland study that identified cultural resources impacted by 0 – 5 feet inundation. The area contains seventeen Maryland counties (Baltimore City included) in the Coastal Plain. All of the counties in the study area are adjacent to the Chesapeake Bay or its tributaries. Archeological sites in the study area are at risk from sea-level rise, storm surge and erosion (Figure 3.1).

Archeological Data

Archeological site data were used for this analysis. Archeological sites are evidence of human activity or occupation of a location in the past. There are archeological sites across the Maryland landscape, from the Appalachian Plateau of

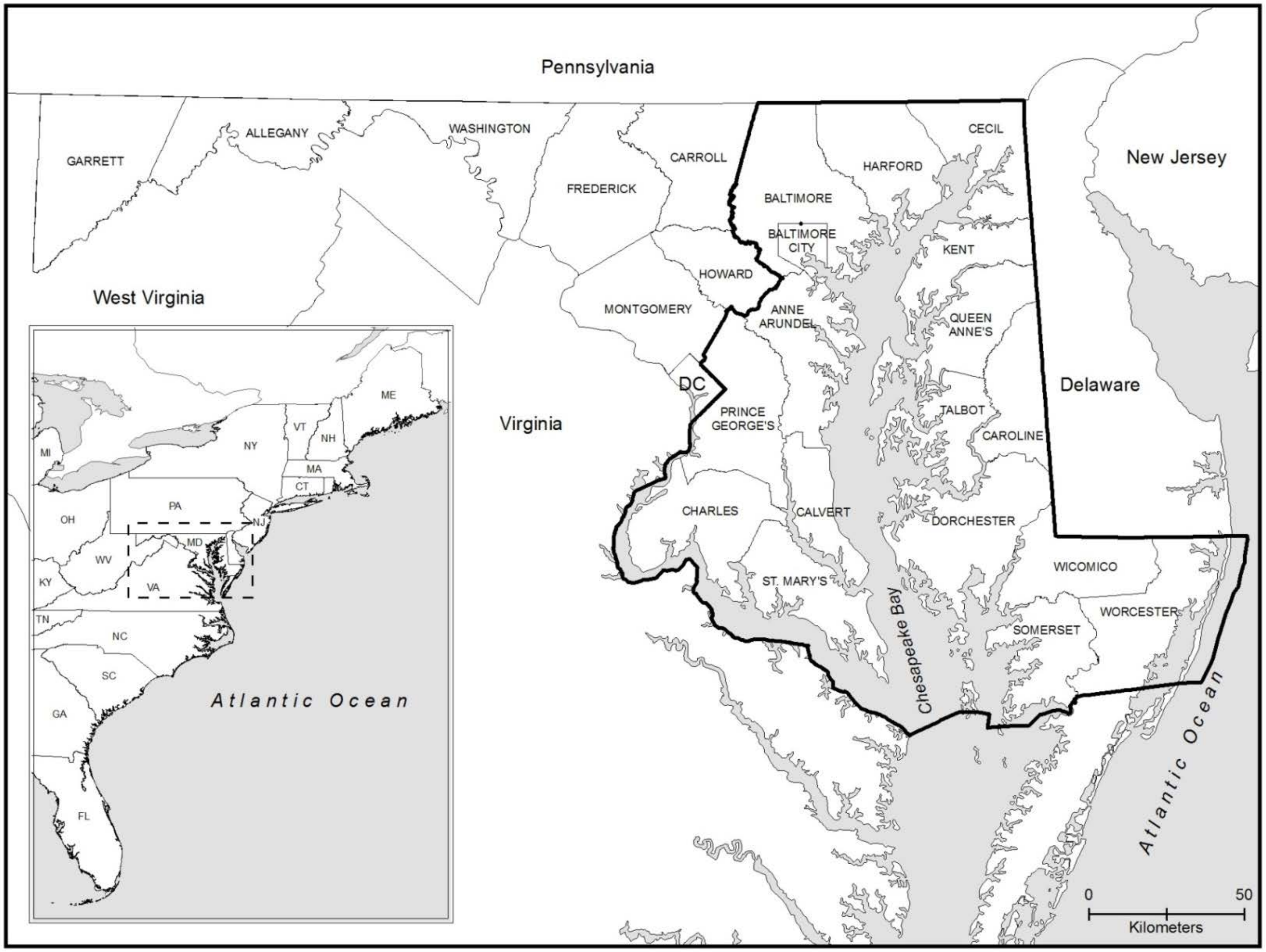

Figure 3.1. Project Study Area and its Regional Context

Western Maryland to the Coastal Plain of the Eastern Shore (Figure 3.2). A specific location could have been occupied for a short amount of time or over thousands of years. The oldest archeological sites in Maryland date to 10,000 B.C.

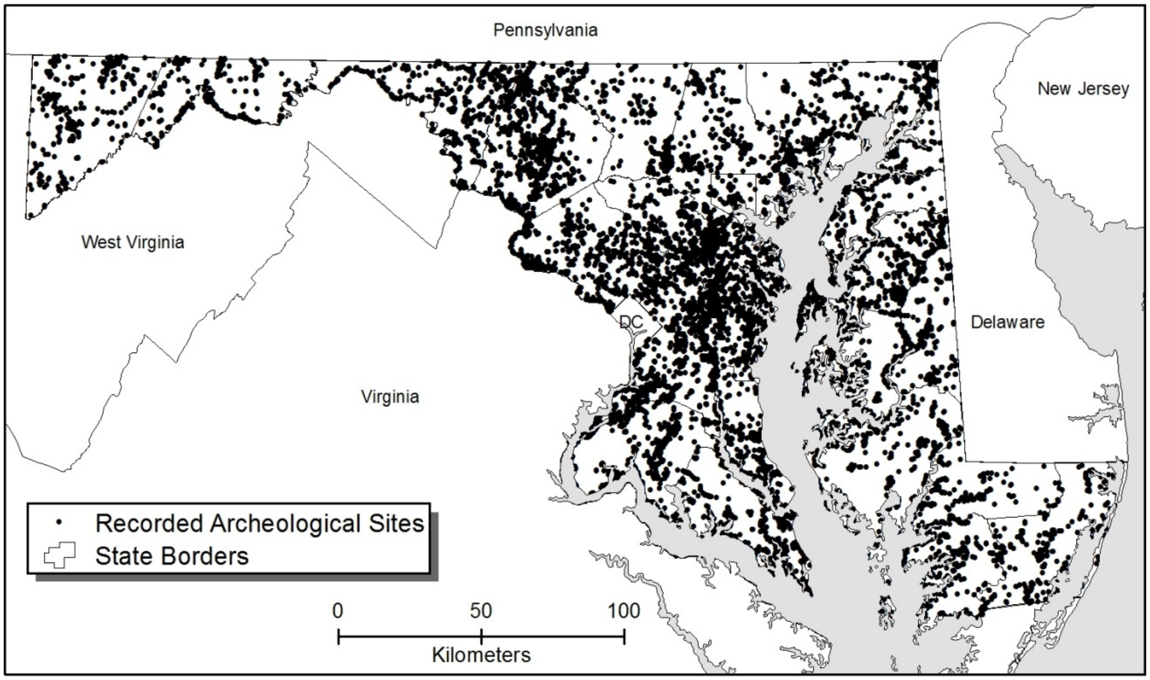

Figure 3.2. Archeological Sites Recorded in Maryland

Archeologists record sites based on presence of artifacts and features. The absence of an archeological site does not prove the absence of human occupation. The sites have specific boundaries based on evidence and survey limits. These data were collected by various methods for over the last century. Much of Maryland has never been surveyed for Archeology. Survey methods have changed over time and, as a result, areas that were surveyed in the last 50-60 years should be resurveyed with modern methods to determine if any archeological evidence was missed. All of this information is stored at the State Historic Preservation Office.

Maryland archeological sites are recorded on standardized Maryland Archeological site survey forms. Site types (cultural affiliation fields on the form) are broken into groups based on artifact assemblages and features excavated at sites. Evolution of artifact types and radio carbon dating have shaped our knowledge of the past. The categories used are widely accepted in the Archeology professional community. Information about sites not only includes a boundary but also includes data collected from a site. These data have a wide variety of information from geographical setting, time period, site type (function or use), survey methods, artifact or feature information. Data extracted for this project included attributes of historic/prehistoric, terrestrial/underwater and site type (time period/cultural affiliation).

Many archeological sites have also been destroyed or submerged. Sites that were occupied before the Chesapeake Bay was formed are submerged off of the coast on the continental shelf. Other sites have eroded away with exposure to environmental factors. Development has also played a major role in the destruction of sites before they were recorded. Once an archeological site is excavated or destroyed it can never be replaced. Archeological site data will be assessed by climate change factors to determine their risk level.

The first evidence of occupation in Maryland was 12,000 years ago which is identified as the Paleoindian period (10,000 BC – 7500 BC) (Figure 3.3). This was a time of rapid climate change at the end of the Pleistocene Epoch (end of the last ice age) and beginning of the Holocene Epoch. During this time people were hunter/foragers, lived in small groups or bands and moved between sources of lithic material and food sources. The material remains left behind were fluted projectile points. The present

Chesapeake Bay had not yet formed and sea-level rise was very low. The Susquehanna River channel ran from Cecil and Harford Counties to the south where the middle of the bay is now and out to the Atlantic Ocean off the continental shelf.

The Paleoindian period was followed by the Archaic period (7500 BC – 1000 BC) which is sub-divided into three sections: Early, Middle and Late. In Early Archaic, populations increased and became more localized. Large river terraces and edges of upland swamps were utilized most. Notched and stemmed projectile points and groundstone tools were evidence from this period. During the Middle Archaic period, a more seasonally variable climate developed and the embayment of the Susquehanna River had begun. New projectile point types and an increase in tool diversity developed during this period. Late Archaic was a period of increased sedentism. The Chesapeake Bay was mostly developed and estuarine resources were exploited including shellfish and anadromous fish. Steatite bowls and new projectile point types appear in the Late Archaic.

The Woodland period (1000 BC – AD 1600) came after the Archaic period. The Woodland period is also sub-divided into Early, Middle and Late periods. The Early Woodland period is known for the first appearance of pottery in Maryland. Sand and quartz were used as clay temper. Evidence of subterranean storage pits suggest increased sedentism. Middle Woodland is the transition from hunter/forager to agriculture. Seed plants were extensively collected. Analysis shows a carbon-rich diet. New ceramics were produced with crushed oyster temper. Late Woodland occupation was situated near large streams with soils suitable for agriculture. Larger villages developed, some with palisades. Corn, squash and beans were cultivated during this period. Material remains found at these sites were decorated ceramics, bone tools, clay tobacco pipes and beads.

Contact period is the transition from prehistoric to historic periods. Native American contact with European explorers and settlers marks the end of the prehistoric settlements in Maryland. Many tribes migrated north and west as Europeans settles in the area. Others were moved to reservations. Movements of some of the communities were documented in the historical record. The artifacts from this period contain evidence of European trade and European materials such as copper and gun flints in addition to traditional Native American goods.

Environmental Data

Climate change factors were derived from environmental data sets. The data sets used in this project are SLAMM (Sea level affecting marshes model) data, EVA (Erosion Vulnerability Assessment) data and shoreline inventory data. SLAMM data project sea-level rise affecting marshes at current water levels, projected water levels by 2050 and the year 2100. To model long term wetland and shoreline change, the model used elevation, accumulation of sediments, wetland accretion and erosion rates and sea-level rise. Values of one through twenty-four describe the dominant category of land cover in the thirty meter raster grid cells (Table 3.1).

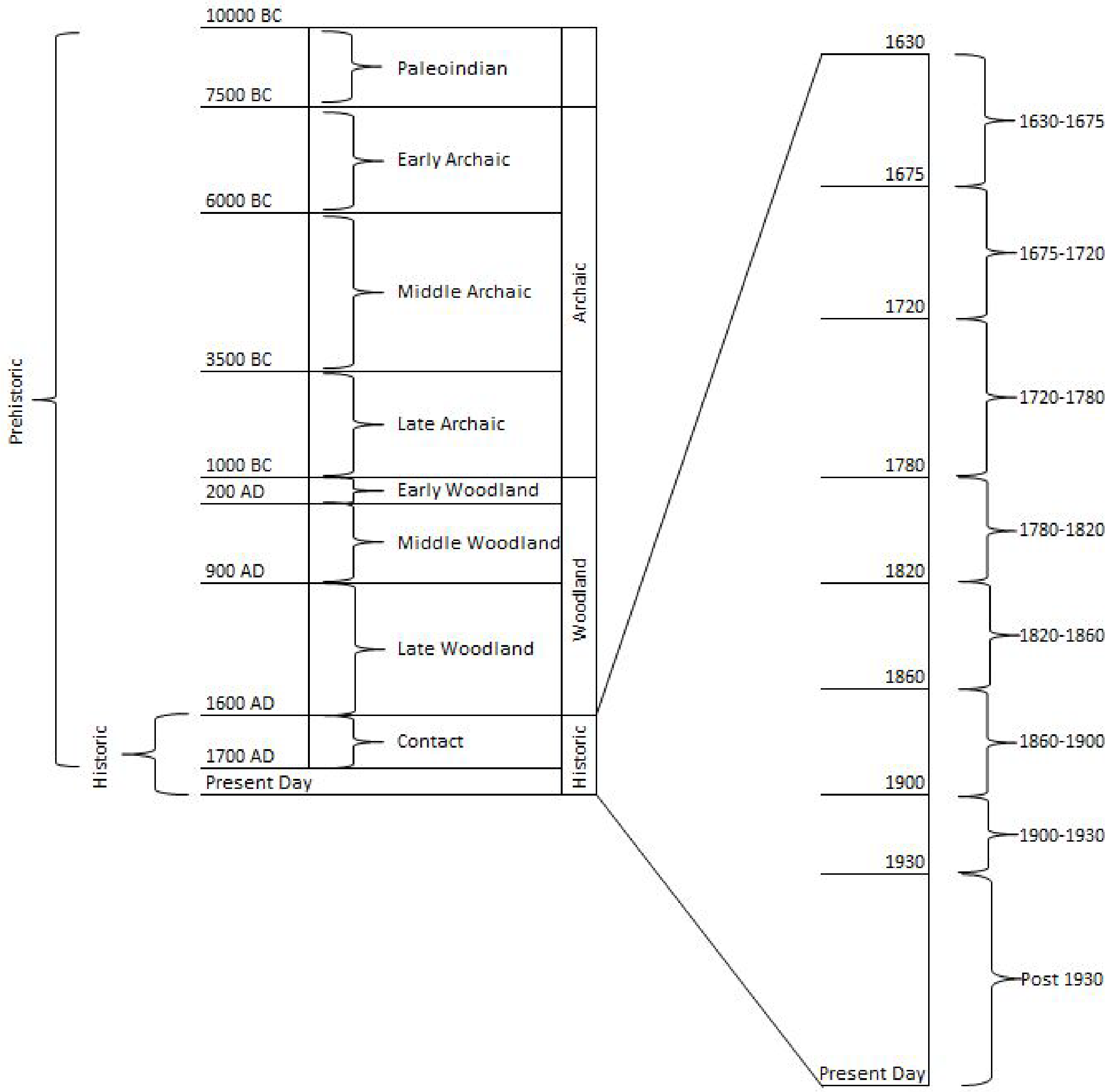

Figure 3.3. Archeological Time Periods in Maryland

Table 3.1. Sea Level Affecting Marshes Model Data Values

Value	Category	Value	Category
1	Developed Land	13	Ocean Flat
2	Undeveloped Dry Land	14	Rocky Intertidal
3	Freshwater Swamp	15	Inland Open Water
4	Cypress Swamp	16	Riverine Tidal Open Water
5	Inland Freshwater Marsh	17	Estuarine Open Water
6	Tidal Freshwater Marsh	18	Tidal Creek
7	Transitional Salt Marsh	19	Open Ocean
8	Regularly Flooded Marsh	20	Irregularly Flooded Marsh (brackish)
10	Estuarine Beach	22	Freshwater Shoreline
11	Tidal Flat	23	Tidal Swamp
12	Ocean Beach	24	Blank

EVA data measure erosion rates per year for Maryland shoreline. The raster is coded in values from 0 to 9. They take into account accretion, no change, slight to high erosion levels as well as protected shoreline (Table 3.2). These data were interpreted from DOQQs (Digital Ortho Quarter Quads) that were at a scale of 1:12,000. The data are in vector format. Data were calculated using recent shoreline (1988 – 1995) as well as historical shorelines (1841 – 1977) to develop linear rates of shoreline change.

Table 3.2. Erosion Vulnerability Assessment Erosion Rates

Category	Average Erosion Rate (m/yr)	Value
No change	0	0
Accretion	+0.15	1
Slight	-0.3	2
Low	-0.9	3
Moderate	-1.8	4
High	-3.4	5
Protected	0	6
No Data	0	9

Shoreline inventories for Maryland document data for the riparian zone, the bank and the shoreline. The bank (land use bank cover data) is evaluated for stability using height, cover and natural protection (Table 3.3). Data were collected by a two-person field crew from a small boat navigating along the shoreline. Bank cover values were recorded as no data, bare or less than 25% covered, partial coverage of 25%-75% and full coverage of greater than 75% coverage. Bank height values are no data, 0-5 feet, 5-10 feet, 10-30 feet and greater than 30 feet. The bank condition values are no data, low erosion, high erosion or undercut.

Table 3.3. Land Use Bank Cover Attribute Values

LUBC Attributes	Values				
HEIGHT	No data	0 – 5 feet	5 – 10 feet	10 – 30 feet	> 30 feet
COVER	No data	Bare or less than 25% covered	Partial coverage (25-75% coverage)	Full coverage (greater than 75% coverage)	
CONDITION	No data	Low erosion	High erosion	Undercut	

Ranking Criteria

Statewide environmental shoreline data were used to derive measurements for five variables for developing vulnerability index in this project (Table 3.4). Any vector datasets were converted to rasters and cells were reclassified with values of zero to three to reflect their risk level. A high-risk level was given a score of three, moderate-risk level was given a score of two, low-risk level was given a score of one and minimal risk level was given a score of zero. The grid cell size was set to 30 meters because this was the largest cell size of the native raster datasets. Most archeological sites in Maryland are greater than 30 meters in diameter so the data were not distorted by factoring in extra land area.

Table 3.4. Ranking Criteria for Archeological Site Vulnerability

			Risk Level			
Factor	Variables		Minimal	Low	Moderate	High
			0	1	2	3
Inundation Level (I)	Open water level (m)		After 2100	By 2100	By 2050	Current
			> 1	1	0.4	0
Shoreline Risk (s) $\frac{(e+bc+bh)}{3}$	Erosion rate (e) (m/yr)		0 – +0.15	0	0 – -0.9	-0.9 – -3.4
	Bank cover (bc)			> 75%	25 – 75%	0 – 25%
	Bank height (bh) (height + condition undercut)	Bank height (m)	> 9	3 – 9	1.5 – 3	0 – 1.5
		Bank condition				Undercut
Distance (d)	Resource’s distance to shoreline (m)		> 300	150 – 300	30 – 150	0 – 30

Inundation data used for this analysis comes from DNR’s Sea Level Affecting Marshes Model data (SLAMM). All open water land cover categories were used to define inundation (Table 3.5). The inundation data were broken into three levels: current open water level, open water level at 0.4 meter inundation (projections for the year 2050), and open water level at 1 meter inundation (projections for the year 2100). Current open water level was assigned high risk, open water level at 0.4 meter inundation was assigned moderate risk and open water level at 1 meter inundation was assigned low-risk level (Figure 3.4).

Table 3.5. Sea Level Affecting Marshes Model Open Water Classifications

Value	Category
15	Inland Open Water
16	Riverine Tidal Open Water
17	Estuarine Open Water
18	Tidal Creek
19	Open Ocean

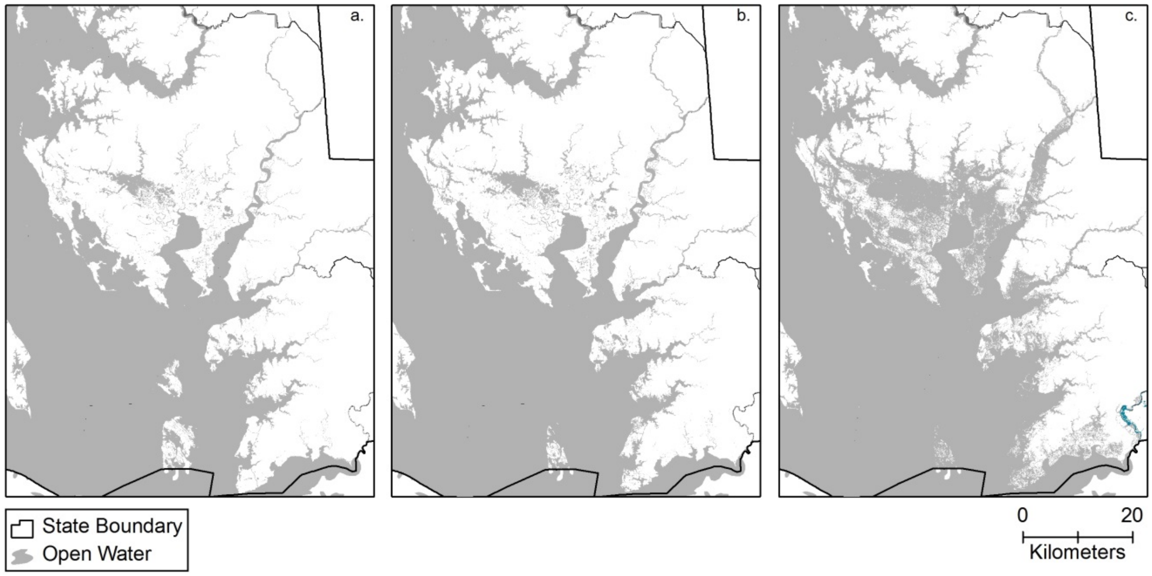

Figure 3.4. Open Water Levels as Predicted by SLAMM. a. Current Water Level; b. 0.4 Meter Sea-Level Rise Predicted by 2050; c. 1 Meter Sea-Level Rise Predicted by 2100

The erosion rate dataset came from the Erosion Vulnerability Assessment (EVA) produced by DNR. Erosion rates vary from accretion (where more than 0.15 meters per year is gained) to erosion (where up to 3.4 meters per year is lost). Erosion rates were grouped into four categories: high to moderate, low to slight, no change or protected, and accretion. Since erosion is a major factor in the destruction of archeological sites, high-to-moderate erosion was given a high-risk level and low-to-slight erosion was given a moderate-risk level (Table 3.6). Shoreline that is protected or shows no change was given a low-risk level and accreting shorelines were given a minimal risk level. Any no data attributes in the erosion data were assigned a value of -10.

Table 3.6. Erosion Rates Reclassified

Category	Average Erosion Rate (m/yr)	Risk Value
No Data	0	-10
Accretion	+0.15	0
Protected	0	1
No change	0	1
Slight	-0.3	2
Low	-0.9	2
Moderate	-1.8	3
High	-3.4	3

The attributes for bank cover, bank height and bank condition were extracted from the shoreline inventories land use bank cover (lubc) layer. Vegetation cover on the bank is beneficial as it slows down the erosion process. The bare bank cover category was assigned a high-risk level, partial was assigned moderate risk and full vegetation was assigned low-risk level. Bank height varies from zero meters to greater than nine meters. Lower bank heights are likely to erode quicker than higher bank heights so the smallest bank heights were assigned the highest risk level and the largest bank height were assigned the lowest risk level. Bank height data were categorized into four groups: 0 to 1.5 meters, 1.5 to 3 meters, 3 to 9 meters and greater than 9 meters. The only value of bank condition data used in this study was undercut. If a bank is undercut, it is more likely to collapse and erode. The undercut bank condition was merged with bank height data using the “Over” function tool in Spatial Analyst. Any bank that was classified as undercut was given a high-risk level regardless of the bank height. Any no data attributes in the shoreline inventories were assigned a value of -10.

Distance was generated by calculating archeological sites’ distance to shoreline. First, archeological site data were converted to a 30-meter cell raster dataset. The “Euclidean Distance” tool in Spatial Analyst calculated the distance from the archeological site raster cells to the shoreline raster dataset (Figure 3.5). Distance-to-shoreline values were grouped into four categories: 0 to 30 meters, 30 to 150 meters, 150 to 300 meters and greater than 300 meters (Figure 3.6). The closer an archeological site is located to the shoreline, the greater potential it has for erosion. Distances of 0 to 30 meters were assigned the highest risk level because archeological sites touching the shoreline are in imminent danger of eroding or are already actively eroding away. Distances of 30 to 150 meters were assigned moderate risk level. The amount of shoreline that could be eroded away by the year 2050 at the highest erosion rate of 3.4 meters per year (in 40 years) is 136 meters. This value was rounded up to 150 meters to account for the use of 30-meter cell grid. Distances of 150 to 300 meters were assigned a low-risk level. The amount of shoreline that could be eroded away by the year 2100 at the highest erosion rate of 3.4 meters per year (in 90 years) is 306 meters. This value was rounded down to 300 meters to account for the use of 30-meter cell grid. Any archeological site with a distance greater than 300 meters was assigned a minimal risk level.

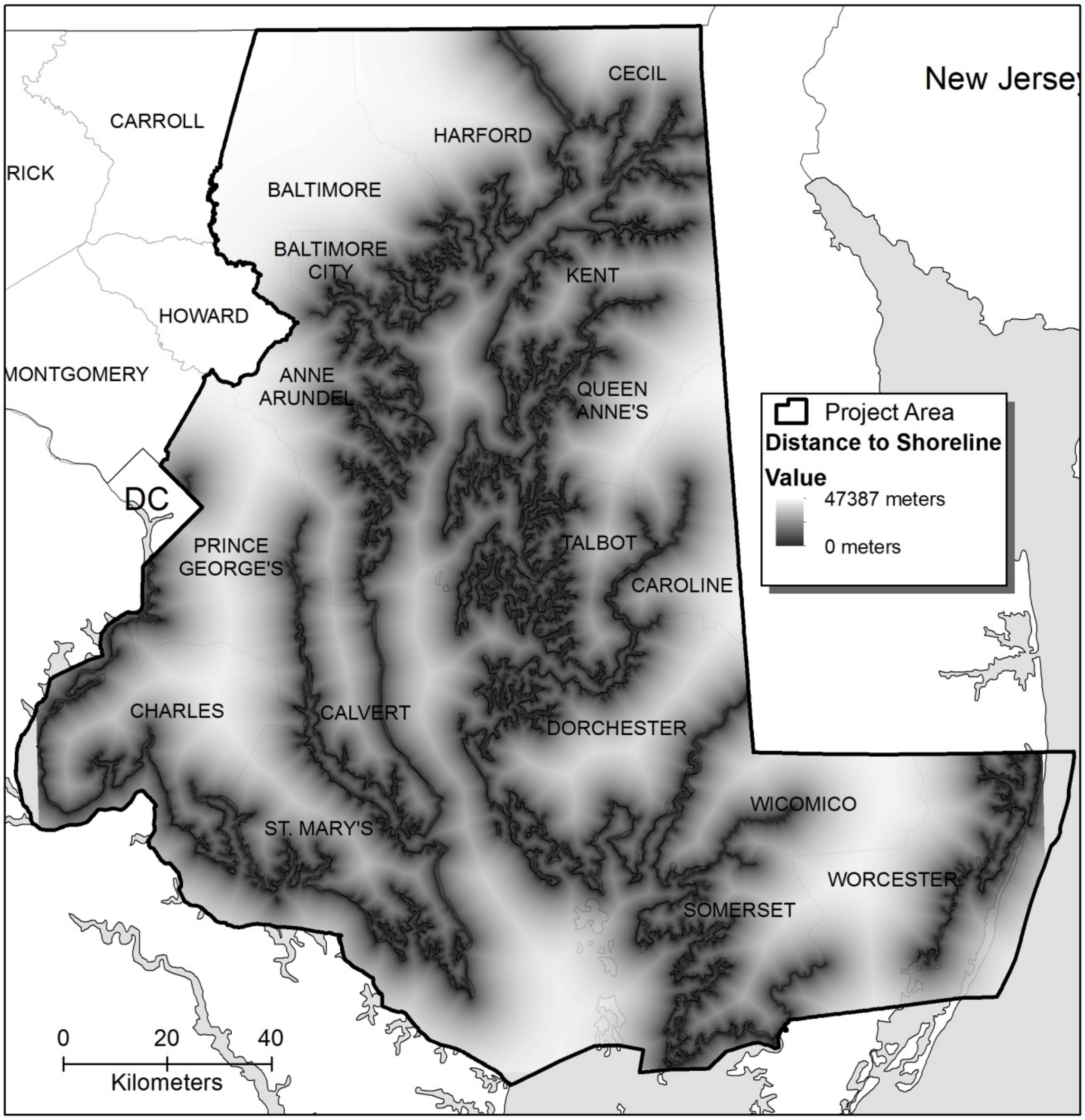

Figure 3.5. Euclidean Distance from Shoreline

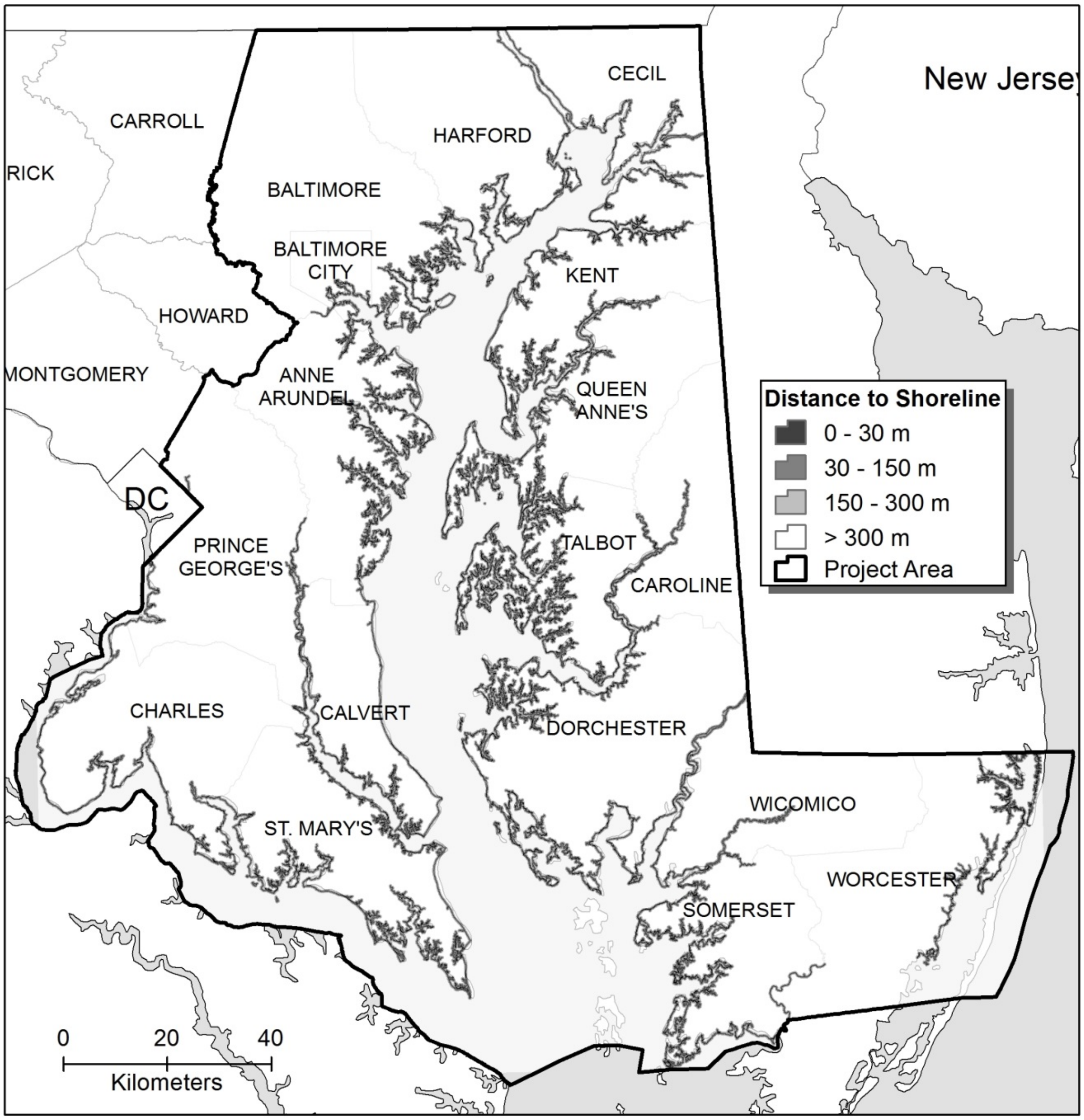

Figure 3.6. Euclidean Distance from Shoreline Reclassified

A subset of statewide archeological data were used for this analysis. As of 2011, there were a total of 13,133 archeological sites recorded in the state of Maryland. Archeological sites within the 0 to 1.5 meter inundation level were extracted from the archeological site polygon layer to be used for the analysis (Table 3.7 and 3.8). Archeological sites recorded as underwater only were removed from the analysis.

Archeological sites recorded with both terrestrial and underwater components were included in the analysis. The analysis sample included a total of 3,306 archeological sites (Figure 3.7). This represents 25% of the total number of recorded archeological sites in Maryland and 34% of sites recorded in the counties studied.

Table 3.7. Archeological Sites Analysis Sample by County

County	All Sites	Project sites	
	N	N	%
Anne Arundel	1,618	445	28
Baltimore County	578	59	10
Baltimore City	175	5	3
Caroline	242	49	20
Cecil	375	96	26
Charles	687	161	23
Calvert	498	165	33
Dorchester	486	364	75
Harford	321	58	18
Kent	426	169	40
Prince George’s	1,028	9	1
Queen Anne’s	1,027	476	46
Somerset	372	315	85
Saint Mary’s	921	427	46
Talbot	416	309	74
Wicomico	199	114	57
Worcester	267	85	32
TOTAL	9,636	3,306	34

Notes: N = Number of Archeological Sites. Not all counties are located in the project area.

Table 3.8. Archeological Sites Analysis Sample by Site Type

Site Type	All Sites	Project Sites	
	N	N	%
Prehistoric	8,532	2,336	27
Historic	6,042	1,220	20
Paleoindian	88	30	34
Early Archaic	602	97	16
Middle Archaic	529	85	16
Late Archaic	1,990	377	19
Early Woodland	1,109	240	22
Middle Woodland	1,095	341	31
Late Woodland	1,756	569	32
Contact	73	23	32
1630 to 1675	117	40	34
1675 to 1720	283	80	28
1720 to 1780	963	229	24
1780 to 1820	1,645	287	17
1820 to 1860	2,594	401	15
1860 to 1900	3,424	554	16
1900 to 1930	2,811	414	15
Post 1930	1,922	241	13

Notes: N = Number of Archeological Sites.
Not all counties are located in the project area.

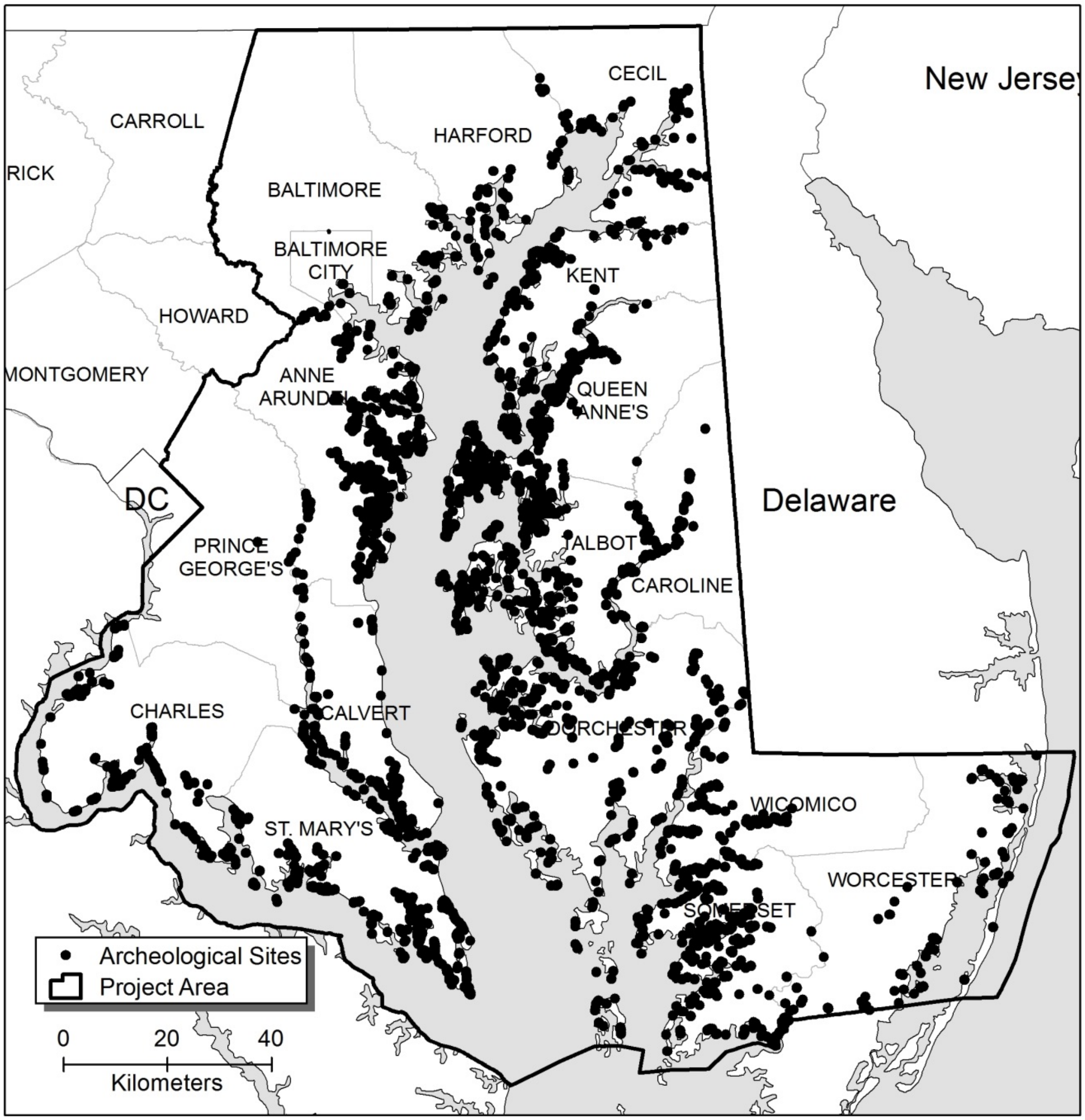

Figure 3.7. Archeological Sites Within 0 to 1.5 Meter Inundation Levels

Three climate change factors were derived from the variables for ranking vulnerability: inundation level, shoreline risk, and distance (to shoreline) (Table 3.4). Each category was given a score based on the risk level of the variables each of which range from 0 (lowest risk) to 3 (highest risk). Inundation level used open water level variable. Shoreline risk is the average of three variables: erosion, bank cover and bank height (Figure 3.8). Distance factor used archeological sites' distance to shoreline variable.

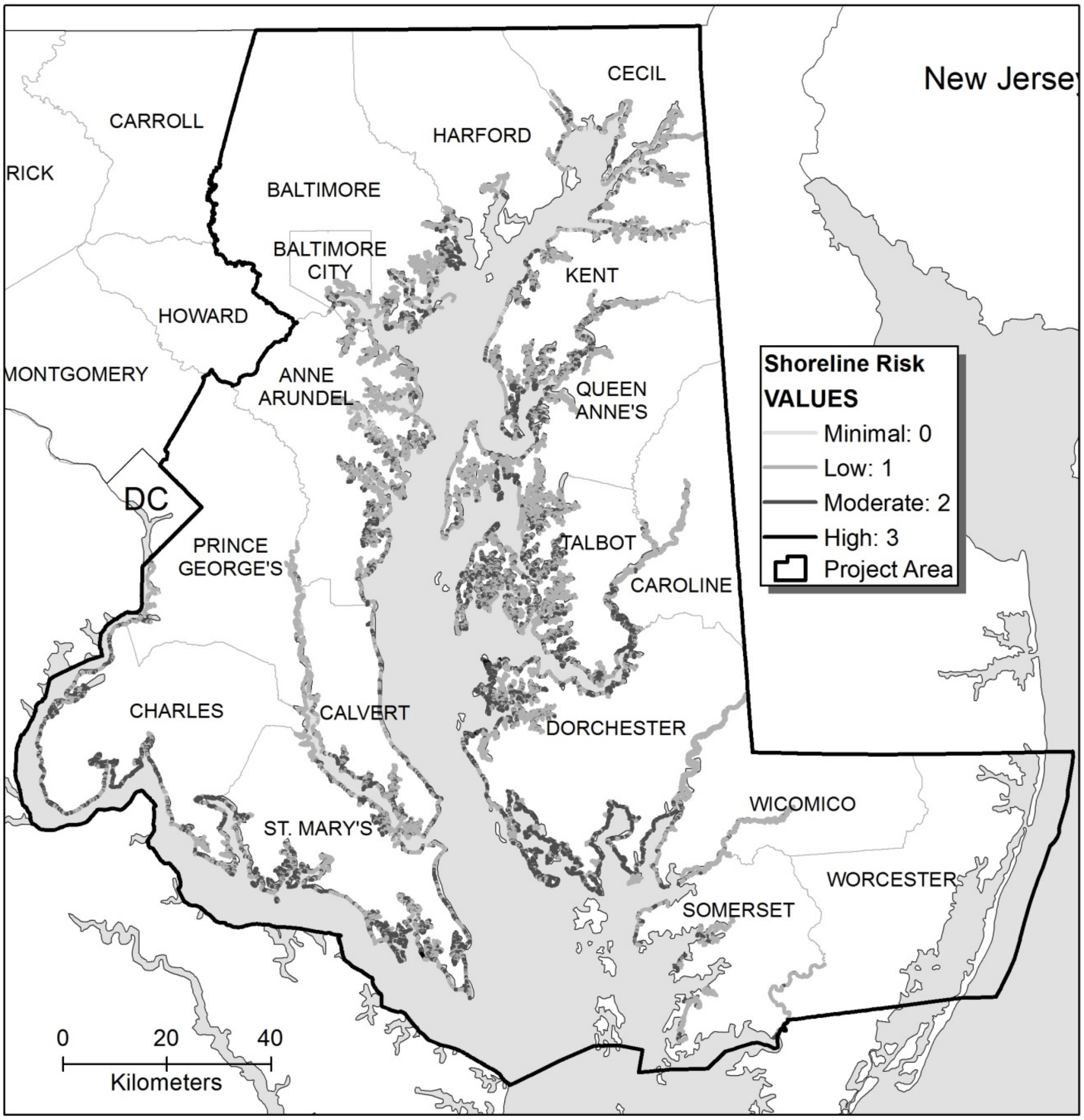

Figure 3.8. Shoreline Risk Vulnerability

Calculation of Vulnerability Score

To create the final output layer of archeological sites with the vulnerability score factors many steps were taken using Spatial Analyst tools. The "Euclidean Allocation" tool was used for the shoreline risk factor to assign a shoreline risk value to all of the raster cells (Figure 3.9). Next, all three of the vulnerability score factors needed to be clipped to the archeological site vector polygon boundaries. “Extract by Mask” tool was used for each vulnerability factor. Many of the archeological site boundaries included more than one raster cell and, as a result, the raster cells did not always have the same vulnerability rank within the site boundaries. The maximum function of the “Zonal Statistics” tool was used to identify the highest risk value of raster cells within an archeological site boundary. Next, the “Zonal Statistics as Table” tool was used for each of the layers to generate a table with the raster value and archeological site number. The tables for inundation level, shoreline risk and distance to shoreline were joined to the archeological site polygon layer. Archeological sites’ vulnerability factors are retained as separate attributes in order to run through different climate change vulnerability scenarios in the future.

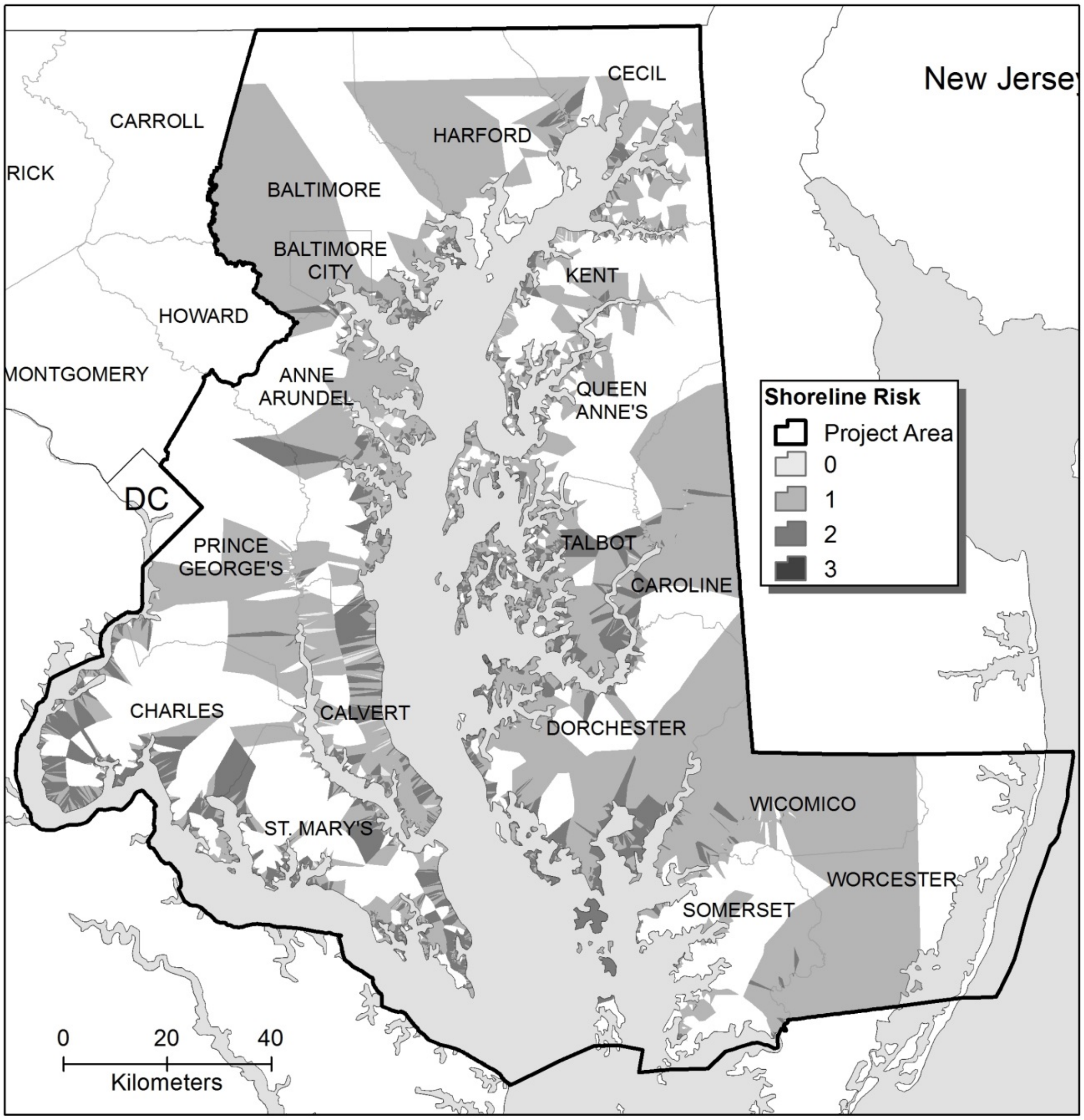

Figure 3.9. Euclidean Allocation of Shoreline Risk

Calculation of Climate Change Risk

Finally, climate change risk value was generated for each archeological site. An equally weighted cumulative index score was calculated for climate change risk. The three vulnerability factors (inundation level, shoreline risk and distance) were summed together to generate the overall risk level for each archeological site. Climate change risk values range from 0 (lowest risk) to 9 (highest risk) and less than 0 (for no data). Any sites that had no data values in the shoreline risk category generated a negative value for the climate change risk. All negative values were grouped in a less than 0 category.

CHAPTER 4

RESULTS

The results of the analysis are consistently presented in the following ways. First, a brief description is provided to characterize all archeological sites affected by climate change. Then, site vulnerabilities due to potential inundation, coastal erosion and shoreline proximity are mapped with ranks and summarized by type and county respectively in three different sections. Finally, climate change risk is described as overall site vulnerability with combined index scores calculated and their spatial patterns identified.

Characteristics of Archeological Sites around Chesapeake Bay

Archeological sites located on the Lower Eastern Shore are at highest risk from climate change. The most affected counties are Talbot, Dorchester and Somerset counties. These counties have the highest summed percentages of impacted archeological sites in all three vulnerability categories. Also, Paleoindian, Contact Period and 17th century European sites are among the most vulnerable archeological site types. In addition to these three types of sites, other high-risk site types include Middle Woodland, Late Woodland and late 17th to early 18th century archeological sites.

Site Vulnerability due to Potential Inundation

Inundation level risk factor ranked archeological sites' vulnerability according to current water level, water level by the year 2050 (0.4 meter inundation), water level by the year 2100 (1 meter inundation) and inundation levels greater than 1 m. Of the 3,306 archeological sites used in the analysis, 1,386 (42%) are high risk at current water levels (Figure 4.1). Only 226 of the high-risk sites are recorded as having terrestrial and underwater components in the archeological site file (partially inundated at the time of recordation). The remaining high-risk sites were recorded as terrestrial only and these are now potentially inundated.

The counties that have the largest number of archeological sites in the project area at current water level are Queen Anne's (197), Dorchester (178), Talbot (162), and Saint Mary's (157) (Table 4.1). Paleoindian sites are the most impacted site type in the high-risk inundation level (73% of sites with Paleoindian components in the project area) followed by Early Archaic (51%), Late Archaic (51%), Middle Woodland (49%) and Late Woodland (49%) sites (Table 4.2). In reality, many of the high ranking sites are either actively eroding away or have already been completely destroyed. A comprehensive survey would be needed to document the condition of these high ranking sites.

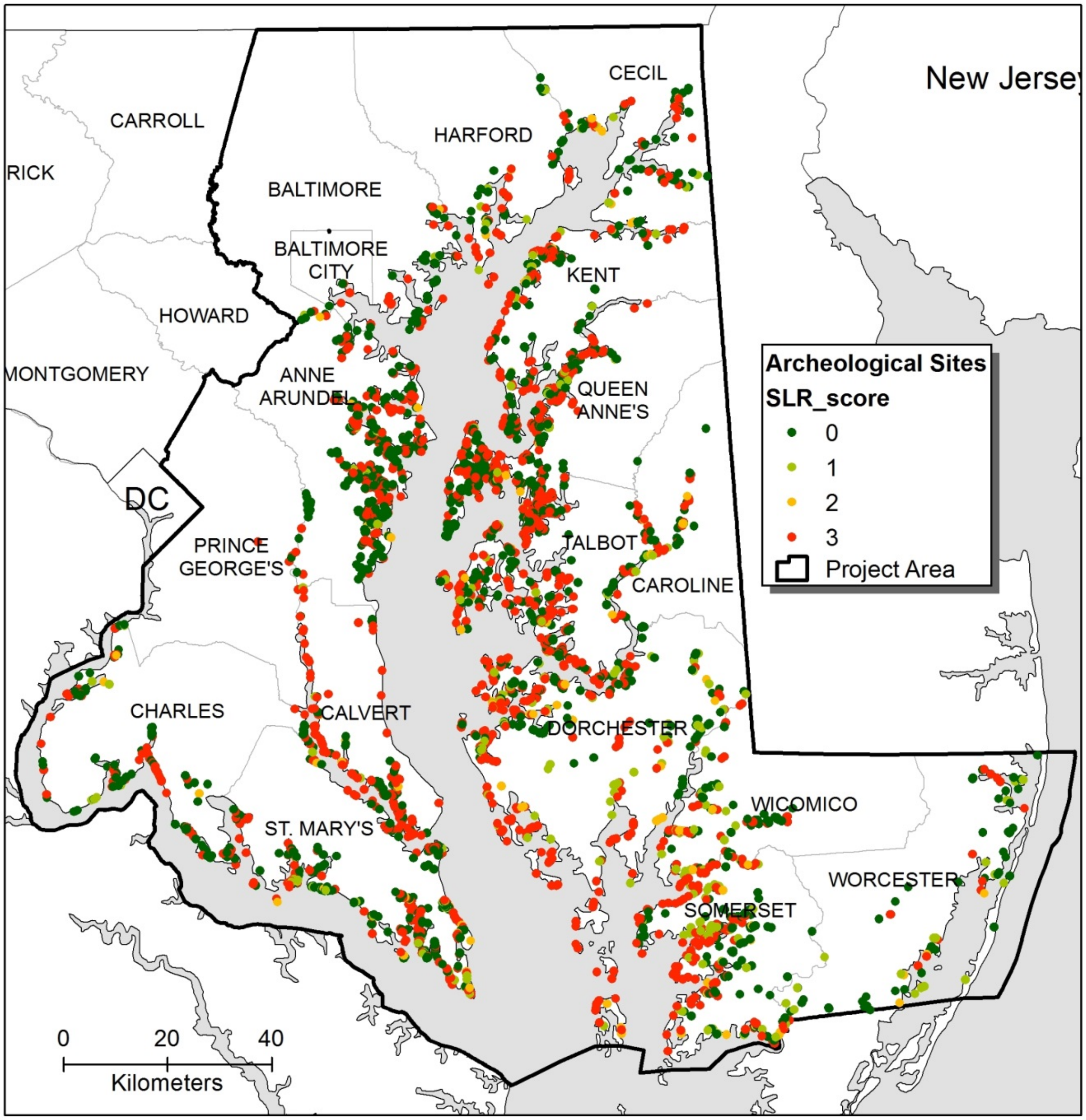

Figure 4.1. Inundation Score of Archeological Sites

Table 4.1. Inundation Induced Site Vulnerability by County

County	Project Sites	SLR Score = 0		SLR Score = 1		SLR Score = 2		SLR Score = 3	
	N	N	%	N	%	N	%	N	%
Anne Arundel	445	274	62	9	2	8	2	154	35
Baltimore County	59	41	69	2	3	1	2	15	25
Baltimore City	5	1	20	0	0	0	0	4	80
Caroline	49	18	37	4	8	3	6	24	49
Cecil	96	52	54	8	8	9	9	27	28
Charles	161	94	58	8	5	3	2	56	35
Calvert	165	60	36	5	3	4	2	96	58
Dorchester	364	106	29	60	16	20	5	178	49
Harford	58	22	38	7	12	3	5	26	45
Kent	169	79	47	10	6	5	3	75	44
Prince George’s	9	5	56	0	0	0	0	4	44
Queen Anne’s	476	256	54	15	3	8	2	197	41
Somerset	315	89	28	56	18	18	6	152	48
Saint Mary’s	427	219	51	36	8	15	4	157	37
Talbot	309	122	39	15	5	10	3	162	52
Wicomico	114	42	37	24	21	5	4	43	38
Worcester	85	47	55	17	20	5	6	16	19
TOTAL	3,306	1,527	46	276	8	117	4	1,386	42

Notes: SLR = Sea-Level Rise. N = Number of Archeological Sites.

Table 4.2. Inundation Induced Site Vulnerability by Site Type

Site Type	Project Sites	SLR Score = 0		SLR Score = 1		SLR Score = 2		SLR Score = 3	
	N	N	%	N	%	N	%	N	%
Prehistoric	2,336	1,000	43	212	9	90	4	1,034	44
Historic	1,220	623	51	102	8	42	3	453	37
Paleoindian	30	6	20	2	7	0	0	22	73
Early Archaic	97	38	39	6	6	4	4	49	51
Middle Archaic	85	34	40	7	8	4	5	40	47
Late Archaic	377	133	35	37	10	16	4	191	51
Early Woodland	240	108	45	29	12	7	3	96	40
Middle Woodland	341	120	35	35	10	20	6	166	49
Late Woodland	569	223	39	45	8	23	4	278	49
Contact	23	10	43	1	4	1	4	11	48
1630 to 1675	40	25	63	3	8	0	0	12	30
1675 to 1720	80	51	64	6	8	1	1	22	28
1720 to 1780	229	132	58	16	7	6	3	75	33
1780 to 1820	287	159	55	21	7	7	2	100	35
1820 to 1860	401	211	52	34	8	15	4	142	35
1860 to 1900	554	267	48	51	9	18	3	218	39
1900 to 1930	414	207	50	28	7	12	3	167	40
Post 1930	241	141	59	16	7	5	2	79	33

Notes: SLR = Sea-Level Rise. N = Number of Archeological Sites.

Site Vulnerability due to Shoreline Vulnerability

Shoreline vulnerability ranked archeological sites according to their erosion rate, bank cover and bank height (and condition). Of the 3,306 archeological sites used in the analysis, only 8 sites were ranked in the highest shoreline risk category (5 in Dorchester, 2 in Saint Mary's and 1 located in Queen Anne's County) (Table 4.3). Six of these sites are located 30 meters or less to the shoreline while the other two sites are greater than 30 meters away. Thirty-three percent of archeological sites had moderate shoreline risk (Figure 4.2) and 48% of sites had low shoreline risk. Saint Mary's (179), Talbot (163), Dorchester (154), and Queen Anne's (152) counties had the largest number of archeological sites within the project area with moderate shoreline risk. The most affected archeological site types in the project area with moderate shoreline risk are Paleoindian (50%), Early Archaic (49%), Late Archaic (40%) and Middle Woodland (40%) sites (Table 4.4). When analyzing specific archeological sites with high or moderate shoreline risk, distance to shoreline should be factored in for prioritizing site surveys.

Table 4.3. Shoreline Risk Induced Site Vulnerability by County

County	Project Sites	SHL Score = -10		SHL Score = 0		SHL Score = 1		SHL Score = 2		SHL Score = 3	
	N	N	%	N	%	N	%	N	%	N	%
Anne Arundel	445	38	9	8	2	273	61	126	28	0	0
Baltimore County	59	7	12	0	0	25	42	27	46	0	0
Baltimore City	5	0	0	0	0	3	60	2	40	0	0
Caroline	49	6	12	0	0	36	73	7	14	0	0
Cecil	96	35	36	1	1	47	49	13	14	0	0
Charles	161	23	14	0	0	55	34	83	52	0	0
Calvert	165	6	4	2	1	106	64	51	31	0	0
Dorchester	364	43	12	0	0	162	45	154	42	5	1
Harford	58	35	60	1	2	16	28	6	10	0	0
Kent	169	10	6	1	1	91	54	67	40	0	0
Prince George’s	9	4	44	0	0	5	56	0	0	0	0
Queen Anne’s	476	46	10	0	0	277	58	152	32	1	0
Somerset	315	194	62	0	0	85	27	36	11	0	0
Saint Mary’s	427	100	23	2	0	144	34	179	42	2	0
Talbot	309	8	3	0	0	138	45	163	53	0	0
Wicomico	114	6	5	0	0	100	88	8	7	0	0
Worcester	85	54	64	0	0	30	35	1	1	0	0
TOTAL	3,306	615	19	15	0	1593	48	1075	33	8	0

Notes: SHL = Shoreline. N = Number of Archeological Sites.

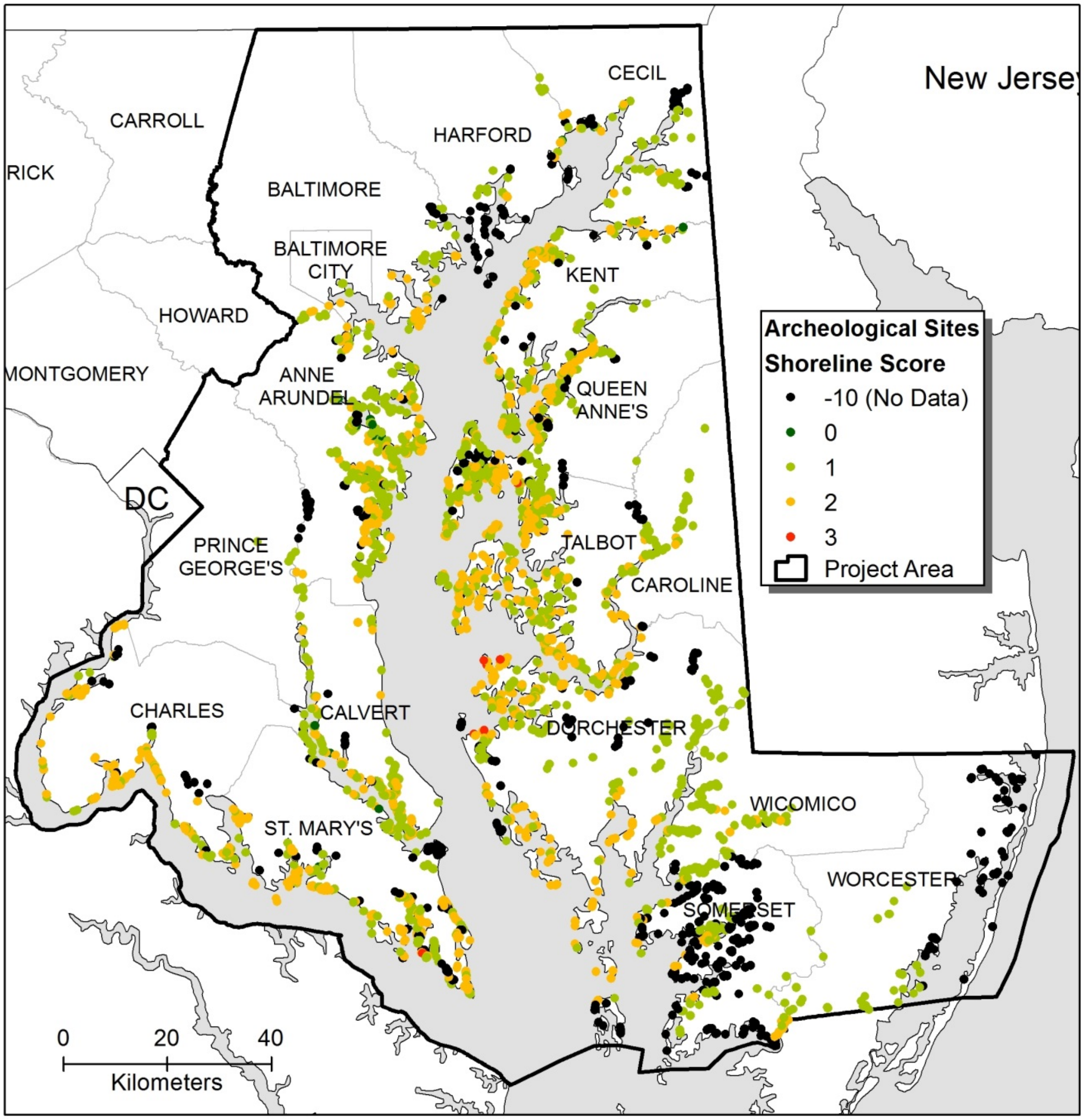

Figure 4.2. Shoreline Score for Archeological Sites

Table 4.4. Shoreline Risk Induced Site Vulnerability by Site Type

Site Type	Project Sites	SHL Score = -10		SHL Score = 0		SHL Score = 1		SHL Score = 2		SHL Score = 3	
	N	N	%	N	%	N	%	N	%	N	%
Prehistoric	2,336	392	17	14	1	1109	47	815	35	6	0
Historic	1,220	285	23	3	0	601	49	326	27	5	0
Paleoindian	30	3	10	0	0	12	40	15	50	0	0
Early Archaic	97	17	18	0	0	32	33	48	49	0	0
Middle Archaic	85	21	25	0	0	31	36	33	39	0	0
Late Archaic	377	81	21	1	0	141	37	151	40	3	1
Early Woodland	240	41	17	2	1	119	50	76	32	2	1
Middle Woodland	341	49	14	3	1	151	44	136	40	2	1
Late Woodland	569	96	17	7	1	273	48	192	34	1	0
Contact	23	7	30	0	0	10	43	6	26	0	0
1630 to 1675	40	7	18	0	0	18	45	15	38	0	0
1675 to 1720	80	16	20	0	0	42	53	21	26	1	1
1720 to 1780	229	60	26	0	0	118	52	50	22	1	0
1780 to 1820	287	82	29	0	0	141	49	64	22	0	0
1820 to 1860	401	106	26	1	0	199	50	93	23	2	0
1860 to 1900	554	138	25	2	0	264	48	147	27	3	1
1900 to 1930	414	97	23	0	0	209	50	106	26	2	0
Post 1930	241	48	20	0	0	134	56	57	24	2	1

Notes: SHL = Shoreline. N = Number of Archeological Sites.

Site Vulnerability due to Shoreline Proximity

Distance to shoreline vulnerability ranked archeological sites risk level according to their distance to shoreline. Sites closest to the shoreline were assigned a higher risk level than sites further away from the shoreline. Of the 3,306 archeological sites used in the analysis, 2,162 (65%) were located less than 30 meters from shoreline (Figure 4.3). Counties that had the largest number of archeological sites in the project area near the shoreline were Anne Arundel (337), Queen Anne’s (305), Saint Mary’s (295), Talbot (233) and Dorchester (221) (Table 4.5). Archeological site types that had the highest percentage of sites in the project area near shoreline were Middle Woodland (72%), Late Woodland (71%), Late Archaic (69%) and Paleoindian (67%) (Table 4.6).

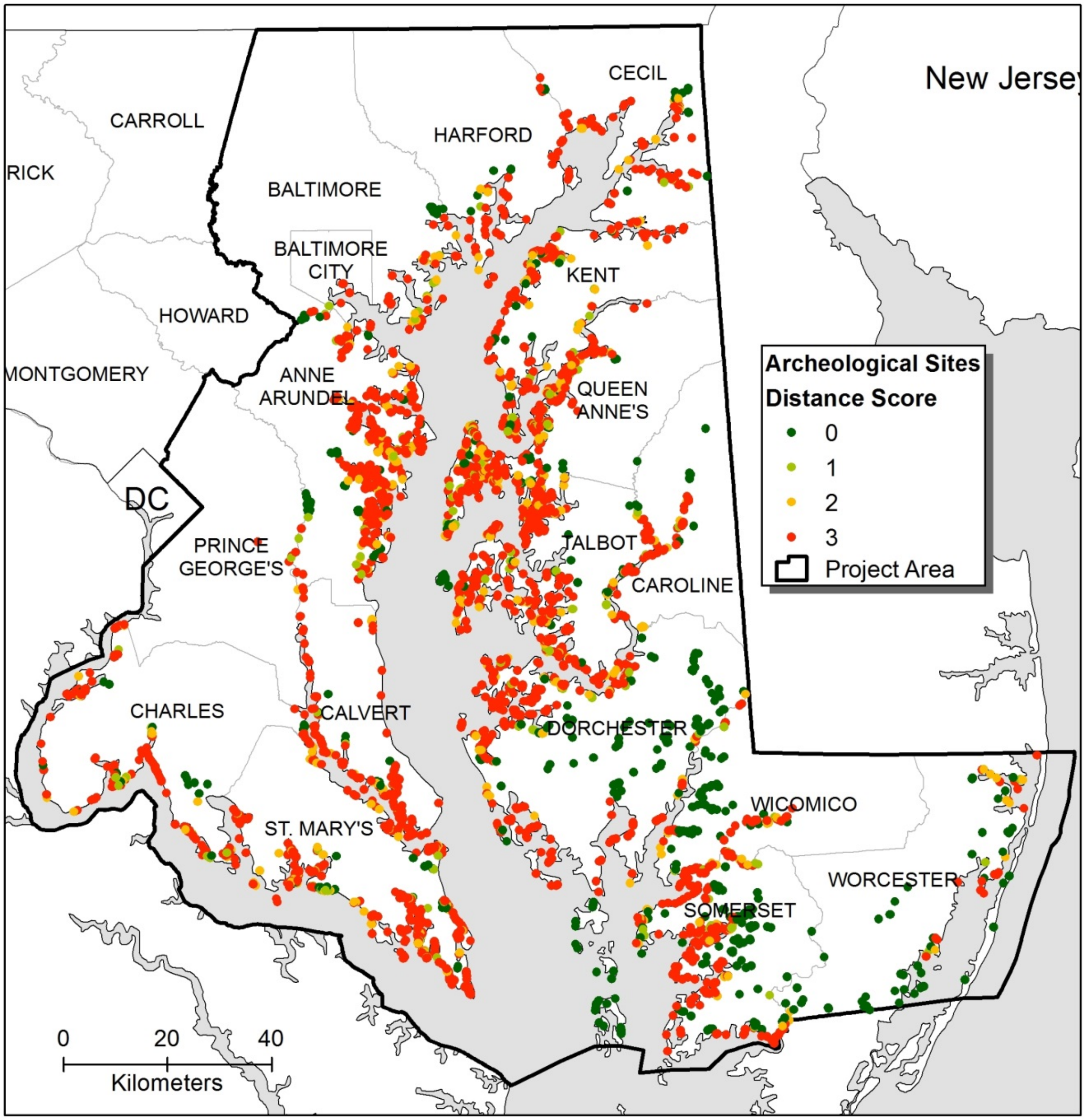

Figure 4.3. Distance Score for Archeological Sites

Table 4.5. Proximity to Shoreline Based Site Vulnerability by County

County	Project Sites	Distance Score = 0		Distance Score = 1		Distance Score = 2		Distance Score = 3	
	N	N	%	N	%	N	%	N	%
Anne Arundel	445	37	8	15	3	56	13	337	76
Baltimore County	59	8	14	11	19	13	22	27	46
Baltimore City	5	0	0	0	0	0	0	5	100
Caroline	49	9	18	1	2	7	14	32	65
Cecil	96	9	9	4	4	15	16	68	71
Charles	161	23	14	13	8	15	9	110	68
Calvert	165	9	5	4	2	21	13	131	79
Dorchester	364	97	27	15	4	31	9	221	61
Harford	58	9	16	1	2	4	7	44	76
Kent	169	15	9	11	7	24	14	119	70
Prince George’s	9	4	44	1	11	1	11	3	33
Queen Anne’s	476	41	9	44	9	86	18	305	64
Somerset	315	111	35	12	4	24	8	168	53
Saint Mary’s	427	32	7	28	7	72	17	295	69
Talbot	309	21	7	18	6	37	12	233	75
Wicomico	114	53	46	6	5	10	9	45	39
Worcester	85	52	61	4	5	10	12	19	22
TOTAL	3,306	530	16	188	6	426	13	2,162	65

Notes: N = Number of Archeological Sites.

Table 4.6. Proximity to Shoreline Based Site Vulnerability by Site Type

Site Type	Project Sites	Distance Score = 0		Distance Score = 1		Distance Score = 2		Distance Score = 3	
	N	N	%	N	%	N	%	N	%
Prehistoric	2,336	323	14	113	5	276	12	1624	70
Historic	1,220	264	22	101	8	188	15	667	55
Paleoindian	30	5	17	0	0	5	17	20	67
Early Archaic	97	23	24	3	3	10	10	61	63
Middle Archaic	85	21	25	3	4	6	7	55	65
Late Archaic	377	63	17	15	4	39	10	260	69
Early Woodland	240	44	18	14	6	27	11	155	65
Middle Woodland	341	50	15	12	4	34	10	245	72
Late Woodland	569	85	15	15	3	65	11	404	71
Contact	23	7	30	1	4	3	13	12	52
1630 to 1675	40	5	13	3	8	10	25	22	55
1675 to 1720	80	17	21	8	10	20	25	35	44
1720 to 1780	229	39	17	22	10	47	21	121	53
1780 to 1820	287	58	20	25	9	57	20	147	51
1820 to 1860	401	103	26	33	8	72	18	193	48
1860 to 1900	554	129	23	50	9	78	14	297	54
1900 to 1930	414	86	21	41	10	55	13	232	56
Post 1930	241	49	20	31	13	40	17	121	50

Notes: N = Number of Archeological Sites.

The Overall Climate Change Risk

Vulnerability factors were combined to develop an overall risk level for each archeological site called the climate change risk value. The climate change risk value was generated by summing the factors together generating a new value of less than 0 for no data and 0 (lowest risk) to 9 (highest risk) (Figure 4.4 and Table 4.7). Of the 3,306 archeological sites used in the analysis, 1,089 (33%) have a climate change risk value of 7 or higher. Counties that had the largest amount of archeological sites with climate change risk of 7 or higher in the project area were Queen Anne's (176), Talbot (150), Dorchester (141), Anne Arundel (139) and Saint Mary's (131) (Table 4.8). Dorchester is the only County that had sites with climate change risk value of 9. Archeological site types that had the highest percentage of sites in the project area with climate change risk of 7 or higher were Paleoindian (47%), Middle Woodland (41%), Early Archaic (39%), Late Archaic (37%) and Late Woodland (37%) (Table 4.9). Late Woodland (212) had the largest number of sites in the project area with climate change risk of 7 or higher.

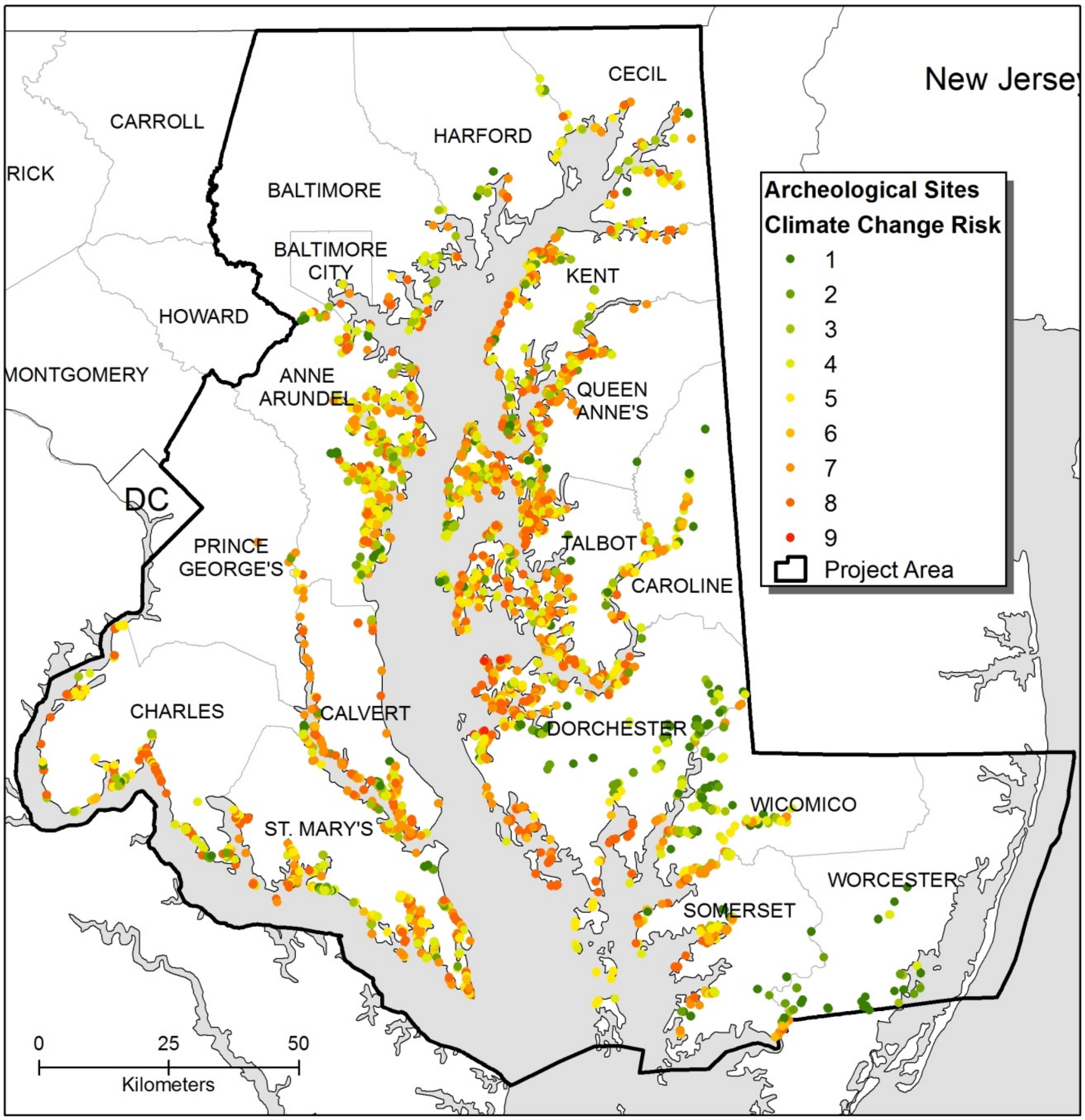

Figure 4.4. Climate Change Risk Site Vulnerability

Table 4.7. Climate Change Risk Levels

CC Risk Value	Number of Project Sites	%
< 0	615	19
0	0	0
1	157	5
2	153	5
3	244	7
4	556	17
5	374	11
6	118	4
7	575	17
8	508	15
9	4	0

Table 4.8. Climate Change Vulnerability by County

County	Project Sites	Climate Change Risk Score										
	N	< 0	0	1	2	3	4	5	6	7	8	9
Anne Arundel	445	38	0	19	10	45	121	63	10	87	52	0
Baltimore County	59	7	0	0	7	17	7	8	0	3	10	0
Baltimore City	5	0	0	0	0	0	1	0	0	2	2	0
Caroline	49	6	0	4	1	3	9	6	2	15	3	0
Cecil	96	35	0	3	0	7	23	7	4	11	6	0
Charles	161	23	0	9	8	10	28	27	5	10	41	0
Calvert	165	6	0	5	5	13	25	11	6	60	34	0
Dorchester	364	43	0	25	26	17	45	47	20	49	88	4
Harford	58	35	0	3	2	3	6	4	0	2	3	0
Kent	169	10	0	4	13	12	29	22	7	44	28	0
Prince George's	9	4	0	0	1	0	0	0	1	3	0	0
Queen Anne's	476	46	0	23	26	54	96	42	13	103	73	0
Somerset	315	194	0	9	4	5	20	17	14	34	18	0
Saint Mary's	427	100	0	8	16	31	68	56	17	67	64	0
Talbot	309	8	0	8	14	14	47	51	17	65	85	0
Wicomico	114	6	0	20	14	10	27	13	2	21	1	0
Worcester	85	54	0	17	6	3	4	0	0	1	0	0
TOTAL	3,306	615	0	157	153	244	556	374	118	577	508	4

Notes: N = Number of Archeological Sites.

Table 4.9. Climate Change Vulnerability by Site Type

Site Type	Project Sites	Climate Change Risk Score										
	N	< 0	0	1	2	3	4	5	6	7	8	9
Prehistoric	2,336	392	0	98	101	147	406	256	95	419	418	4
Historic	1,220	285	0	73	74	118	179	132	31	191	135	2
Paleoindian	30	3	0	0	1	0	7	4	1	6	8	0
Early Archaic	97	17	0	6	3	3	12	14	4	11	27	0
Middle Archaic	85	21	0	6	3	3	8	12	1	11	20	0
Late Archaic	377	81	0	14	14	15	45	49	19	58	81	1
Early Woodland	240	41	0	16	15	12	41	31	10	36	37	1
Middle Woodland	341	49	0	13	17	18	45	38	20	64	76	1
Late Woodland	569	96	0	20	20	37	100	58	26	104	107	1
Contact	23	7	0	3	1	2	2	1	0	3	4	0
1630 to 1675	40	7	0	3	0	6	5	7	1	5	6	0
1675 to 1720	80	16	0	8	5	13	7	13	1	9	7	1
1720 to 1780	229	60	0	10	17	25	33	27	5	29	22	1
1780 to 1820	287	83	0	15	16	33	39	31	8	39	24	0
1820 to 1860	401	106	0	25	24	47	56	35	10	64	34	0
1860 to 1900	554	138	0	32	34	53	69	58	11	94	65	0
1900 to 1930	414	97	0	25	27	42	53	32	6	76	56	0
Post 1930	241	48	0	19	24	30	34	19	2	35	30	0

Notes: N = Number of Archeological Sites.

CHAPTER 5

DISCUSSION

This analysis identifies high-risk areas and archeological sites that are vulnerable to climate change in coastal Maryland. The climate change factors are ranked separately and then combined to create an overall risk index which allows archeologists to analyze and answer the research questions raised in the thesis. It adds another dimension to the coastal vulnerability assessment previously done by Thieler and Hammar-Klose (1999). Compared to two recent studies completed locally (Chadwick-Moore and Kavanagh 2011, Sperling, Schiszik and Cox 2010), the research reveals a similar spatial pattern of the most vulnerable areas, but a greater degree of risk due to climate change. In this chapter, I will briefly describe the major findings and implications of the research before addressing its limitations.

Findings

The results of this analysis agree with some of the previous findings from past studies in Maryland. The preliminary study completed by the Maryland Historical Trust (MARCO 2010, Chadwick-Moore and Kavanagh 2011) found the Lower Eastern Shore counties have the highest percentage of archeological sites impacted by 0 – 2 ft sea-level rise (0 – 0.4 m) followed by the Upper Eastern Shore and Southern Maryland. Paleoindian, Contact and early to middle 17th century sites are among the most vulnerable site types from the previous study. This analysis shows the largest numbers of sites at current water levels are the Middle and Lower Eastern Shore followed by Saint Mary’s and Anne Arundel Counties on the Western Shore (Table 4.1). These same counties have the largest amount of sites in the project area with a Climate Change Risk score of 7 or greater (Table 4.8). Paleoindian sites are still the most impacted site type based on inundation factors and overall Climate Change Risk (Table 4.2 and Table 4.9). The findings revealed that Early and Late Archaic, Middle and Late Woodland also have the highest percentage of sites at current water level in the project area and also overall Climate Change Risk score of 7 or greater (Table 4.2 and Table 4.9).

The past study from Anne Arundel County (Sperling, Schiszik and Cox 2010) found that 30% of the archeological sites in the county were threatened by sea-level rise and 6% of sites are already submerged. Their fieldwork revealed that 23% of sites visited were completely destroyed. This analysis shows that 35% of Anne Arundel County sites in the project area are at current water levels (Table 5.1). These sites are most likely actively being destroyed or submerged. There are also 76 % of project area sites within 30 meters or less of shoreline. Anne Arundel County has a high percentage of sites that are being threatened by climate change.

Table 5.1. Anne Arundel County Sites Vulnerability

Factor	Score	Anne Arundel County	
		N	%
Sea-Level Rise	3	154	35
	2	8	2
	1	9	2
	0	274	62
Shoreline	3	0	0
	2	126	28
	1	273	61
	0	8	2
	-10	38	9
Distance	3	337	76
	2	56	13
	1	15	3
	0	37	8

Notes: N = Number of Archeological Sites.

Previous research shows that other factors in addition to sea-level rise are important to determine the vulnerability of archeological sites. Reeder, Rick and Erlandson (2010) in California showed that coastal vulnerability and proximity to the coast were important factors. Robinson et al. (2010) in Georgia showed how erosion and distance to shoreline were factors impacting the destruction of archeological sites.

This study used these added factors to assess the impacts of climate change on archeological sites in Maryland. These additional factors add to the value of research compared to the other studies completed in Maryland. This study found that 262 sites had a minimal sea-level-rise risk level but had a high-risk for proximity to shoreline (distance factor) and a high-to-moderate shoreline risk (Table 5.2). In the previous Maryland studies, these sites would be considered very-low risk. These sites will be destroyed by erosion long before they are inundated by sea-level rise.

Table 5.2. Sites Identified as Low Risk by Previous Study

County	Project Sites	SLR score = 0 Distance Score = 3 SHL Score = 2 or 3	
	N	N	%
Anne Arundel	445	55	12
Baltimore County	59	8	14
Baltimore City	5	0	0
Caroline	49	3	6
Cecil	96	2	2
Charles	161	25	16
Calvert	165	9	5
Dorchester	364	17	5
Harford	58	3	5
Kent	169	16	9
Prince George’s	9	0	0
Queen Anne’s	476	34	7
Somerset	315	0	0
Saint Mary’s	427	47	11
Talbot	309	39	13
Wicomico	114	4	4
Worcester	85	0	0
TOTAL	3,306	262	8

Notes: SLR = Sea-Level Rise. SHL = Shoreline.
N = Number of Archeological Sites.

This analysis used multiple factors of climate change to assess the vulnerability of archeological sites in Maryland. These factors were combined to generate an overall climate change score for archeological sites. This allows the findings to be used for multiple purposes. Archeologists can use the overall score or they can use the data to ask specific research questions that relate to specific factors of climate change.

Implications

This analysis ranked and prioritized archeological sites according to different types of vulnerability risks. The analysis ranked sites according to their inundation level, but also ranked sites according to their closest shoreline’s risk level and their proximity to shoreline. This analysis goes beyond previous studies in Maryland and allows archeologists prioritize their efforts on the most vulnerable archeological sites in Maryland. Around half of the archeological sites used in this study were classified as high risk and are in need of immediate attention. Archeologists need to further analyze the most vulnerable archeological sites to determine which ones to document or protect and which ones have already been destroyed and are beyond recovery.

Archeologists now have the answers to questions about archeological sites vulnerability risk to climate change. They have the ability to run through scenarios comparing different types of vulnerability. This analysis has shown that 42% of sites in the sample are at current water levels. Some of the sites are most likely already destroyed and many are currently in the process of being destroyed or inundated. More than half (65%) of the archeological sites tested are within 30 meters of shoreline and 35% of sites tested have a moderate shoreline risk.

With this new analysis, archaeologists can take these results and begin to ask more detailed research questions. The data are formatted so that archeologists can use it in the GIS system or run calculations in the data spreadsheets. Data can be used to direct funding or grants to use on the most vulnerable sites. Funding can be directed to high-risk areas for surveys to document these disappearing resources. Future research can be done on those specific areas where there are gaps in the data of this analysis. Data from this analysis can be used to rank archeological sites vulnerability risk based on other site attributes including feature type, site use, diagnostics or level of documentation. Other projects could incorporate additional datasets in the analysis as they become available.

This analysis can also be modified to assess the vulnerability of risks of other historical and cultural resources in Maryland.

Limitations of the Study

There are some limitations to this analysis. The purpose of this analysis was to identify and rank archeological sites that were vulnerable to climate change in the project area. The variables used in this analysis came from many different datasets. These datasets cover different geographic areas and have limitations (including some with missing data).

Archeological site data are imperfect because the state has not been systematically surveyed. Archeological surveys are mostly required when a state or federal permit is required. The majority of Maryland has not been surveyed to determine the presence of archeological sites. Only in surveyed areas can we determine the presence or absence of archeological sites. An area that does not show an archeological site does not mean there is not one present. Archeological sites also are not evenly distributed across the landscape. Settlement patterns changed over time depending on the change in landforms and resources needed for survival. Also, data collection methods have changed over the past century with different field methods, documentation and mapping technology. Archeological sites will need to be revisited to assess the accuracy of their location, condition and vulnerability risk and significance.

Even though the datasets used in the analysis cover the entire coastal plain, there are other areas of missing data. In Harford County, most of the coastal lands are part of Aberdeen Proving Grounds and no shoreline inventory data exists for these areas. No erosion rate data for shorelines on the Atlantic Ocean side of Worcester County exist and there is only partial shoreline inventory data for Somerset and Worcester counties. In Dorchester County, inland open water is only accounted for in the inundation dataset. Shoreline risk factors are not available for these areas. Further analysis will need to be done for areas that have missing data. This incomplete data may lower the vulnerability risk of sites within these counties, which should be taken into consideration when reviewing the results of this analysis.

Storm surge data was not used for this study because it did not add any risk value to sites within the project area. The storm surge data are based on the hazards analysis performed during a hurricane evacuation study that was completed in 2007 for the Maryland Eastern shore and 2010 for Maryland Western shore. The data delineated zones for hurricane evacuations for category one through category four hurricanes in Maryland. Category one hurricane evacuation zones covered the same area as most 0 to 1.5 meter inundation levels (the project area). The concern with storm surge is the inundation with wave action causing a large amount of shoreline erosion in a short period of time. Areas further inland may be inundated from storm surge but does not necessarily cause erosion and the destruction of archeological sites.

CHAPTER 6

CONCLUSIONS

Summary

This analysis ranked archeological sites using climate change vulnerability factors. The results show that Queen Anne's, Talbot, Dorchester, Anne Arundel and Saint Mary's counties have the largest amount of archeological sites most vulnerable to climate change. Paleoindian, Early Archaic, Late Archaic, Middle Woodland and Late Woodland have the highest percentage of climate change risk. Forty-two percent of the sites used in the analysis are at current water level. More than half (65%) of archeological sites are located less than 30 meters from the shoreline. Only 8 archeological sites had high shoreline risk and 1,075 (or 33%) of sites had moderate shoreline risk.

Maryland has the third most vulnerable coastline due to sea-level rise. It is estimated that relative sea-level rise will be as much as 0.4 meters by 2050 and 1 meter by 2100. Archeological sites are at risk from a combination of climate change factors including sea-level rise, erosion and storm surge. The goal of this project is to identify high-risk areas and archeological resources that are most vulnerable to climate change.

Archeologists have observed the effects of climate change on archeological sites for decades and around the world. Previous studies in Maryland have shown that 20% of sites are at risk from sea-level rise and some have already been destroyed or submerged. Paleoindian, 17th century and Contact sites are most at risk site types. These studies were only able to use sea-level rise as a factor of climate change.

This study encompasses the Maryland coastal plain that would be inundated with 1.5 meters of sea-level rise. Climate change factors were used to assess and prioritize the vulnerability of archeological sites. Factors of climate change risk are inundation level, shoreline risk and distance to shoreline. Archeological sites risk factor values were used to generate an overall climate change vulnerability risk value.

Numerous archeological sites are at risk of climate change in Maryland. Many sites have already been washed away or inundated while other sites are actively eroding or are in immediate danger of being destroyed. Archaeologists would prefer to keep all archeological sites intact but realize that it is not possible to save them all. With our current economy, time and resources (and money) are limited. Archaeologists need to prioritize the most important and most vulnerable sites for documentation and preservation. They need to think creatively and collectively to solve this problem, including partnerships with other agencies and volunteers. While we cannot stop climate change, we can take steps to document, preserve and protect our history and cultural heritage.

Recommendations

Archeologists can use these findings to develop comprehensive strategic plans. Sites can be prioritized based on vulnerability and location. These findings will allow archeologists to procure funding for region specific comprehensive surveys and documenting known archeological sites. Partnerships can be built to pool resources and maximize effort in the most vulnerable areas. Results of this study can be used for education and public outreach to illustrate the impacts of climate change on archeological resources in Maryland and to get more people engaged in protecting our history.

Future research will need to be done to fully utilize the results of this study. While the findings of this study reveal which archeological sites are vulnerable to climate change, the study does not assess the importance or quality of archeological sites. Archeologists need to rank and prioritize archeological sites according to significance, condition, research potential and level of documentation. This information, combined with the findings of this analysis, will give archeologists a list of high priority sites to preserve and protect.

Using the results of this analysis, archeologists can query subsets of the data based on different vulnerability risk scenarios. Smaller subsets of data can be analyzed on a site-by-site basis. Archaeologists can assess these data and identify which sites are most significant or which sites have the highest research potential.

Additional studies can extend the value of this research. The methods used to assess the vulnerability of archeological sites can be applied to other historical and cultural resources. The resources have comparable climate change risk factors as archeological sites. Studies using this methodology will allow architectural historians to protect and document above ground resources. As new data become available or climate change prediction assessments change, the analysis can be adjusted to develop more accurate results for future studies.

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