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An Integrated Approach for Developing Adaptation Strategies in Climate Planning: A Case Study of Vulnerability in Dukes County, Massachusetts

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An Integrated Approach for Developing Adaptation Strategies in Climate Planning: A Case Study of Vulnerability in Dukes County, Massachusetts

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An Integrated Approach for Developing Adaptation Strategies in Climate Planning: A Case Study of Vulnerability in Dukes County, Massachusetts

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Abstract

Climate Action Plans (CAP's) are recent innovations in policy that have been catalyzed by a need to adjust the relationship between human activity and the Earth's climate system. CAP's often are composed of methods to mitigate greenhouse gas emissions in addition to adaptation strategies. Research indicates, however, that many plans focus on mitigation strategies while adaptation policies related to predicted changes caused by climate change are often overlooked. This thesis presents an integrative framework for locating areas that are in need of adaptation strategies through a GIS based decision support system that visualizes vulnerability. It is operationalized through an empirical study of Dukes County, Massachusetts.

Dukes County is a New England county composed of the islands of Martha's Vineyard and Gosnold. The county has a long history of commercial fishing, but more recently caters to affluent seasonal tourists. With both economic activities heavily reliant upon the ocean as a resource, climate sensitive hazards, such as sea level rise and tropical storms, pose an important risk to the population, built environment, and the natural environment that has made the study area a highly desirable New England tourist destination.

1. Introduction

1.1 Problem Statement

The end of the 20th century and beginning of the 21st century presented a new planning challenge for policymakers throughout the international community: the growing consensus in the scientific community is that the Earth is warming and the most likely cause is anthropogenic. The Intergovernmental Panel on Climate Change, established by the United Nations to assess climate change, has issued four reports since 1990. Since the second report, published in 1995, the IPCC’s reports have adopted language increasing in certainty that humans have caused a warming trend and that mitigation efforts should be undertaken with haste to curb greenhouse gas emissions- the likely culprit of increased global average temperatures. It appears, however, that merely curbing emissions will not be enough. For instance, research indicates that the rapid deployment of low-carbon energy technology today will not curb warming until at least the second half of the century (Myhrvold and Caldeira, 2012). Climate change presents itself as an important threat to contemporary socioeconomic systems through such impacts as sea level rise and increased flooding, reduced supply of fresh water, changes in land cover and habitat, increased vulnerability to disease, and reduced biodiversity and habitat (Crane et al., 2010). Fundamentally, climate change threatens basic human needs: access to water, food production, health, and environmental degradation (Stern Review, 2006). It can also present an opportunity to become a more sustainable society, which is not a novel goal. A desire to live in harmony with the natural environment is a goal of human civilization that predates industrialization (Mebratu, 1998), but climate change presents a new problem, complex problem on the path to this goal. The stakeholders who are impacted have diverse worldviews and comprehension for understanding climate change. Additionally, potential solutions, related to the cause and symptoms of climate change, cannot be tested before implementation- they can only be evaluated in hindsight (Crane et al., 2010). Many communities, states, and some regions have implemented climate planning policies, often referred to as a Climate Action Plan (CAP) to articulate goals and move towards reducing greenhouse gas emissions and adapting to impacts. Research shows, however, that such plans are heavily skewed toward strategies to mitigate emissions (Bassatt and Shandas, 2010; Wheeler 2010), while their results (greenhouse gas reduction) remain of questionable success (Drummond, 2010; Wheeler 2010; Millard-Ball, 2012). Although adaptation strategies are complex they can also provide direct local benefits with little to no lag time (Stern Review, 2006). With this benefit in mind, and informed by a sentiment of futility in the scientific community of avoiding harmful climate change impacts, this thesis aims to present a framework for locating areas in need of adaptation strategies through a GIS based decision support system that visualizes vulnerability.

1.2 Research Questions

The lack of adaptation policies adopted in Climate Action Plans (Bassett and Shandas, 2010) makes the present an opportune time to define plausible frameworks. To this end, this thesis is guided by the overarching question “How can policymakers make better informed decisions related to adaptation to climate change?” and the specific research question “How can vulnerability mapping best integrate both physical and social landscapes to inform climate change adaptation policy?”

1.3 Thesis Structure

This thesis is composed of a review of relevant literature related to climate change and environmental hazards, a description of a novel theoretical framework for vulnerability mapping, an empirical case study of Dukes County, and finally, discussion and conclusions. The literature review, Chapter 2, will cover topics related to climate planning, in addition to vulnerability and resilience in the context of environmental hazards. The theoretical framework is presented in Chapter 3 and operationalized in Chapter 4, the Empirical Study. Finally, Chapter 5 features a discussion and conclusions of the thesis.

1.4 Summary

This thesis presents a geographic framework for aiding policymakers in the process developing climate change adaptation strategies. Through the scientific evaluation and visualization of variables related to both physical geography and demographic composition it is proposed that resources can be more efficiently allocated for adaptation to combat vulnerability to climate change. This novel theoretical framework serves as a guide to an empirical study case study of Dukes County, Massachusetts.

2. Literature Review

Adaptation to climate change is a complex issue that can involve numerous disciplines. This thesis draws upon previous research related to climate planning, environmental hazards, and climate science to contextualize a new theoretical framework for climate change adaptation strategies. While major international efforts towards climate planning began in the early 1990’s, the literature on environmental hazards in the

United States pertinent to this study can be traced to the 1970's. In this literature, the conceptual framework has heavily involved the concepts of vulnerability and resilience. The novel theoretical framework presented in this thesis enhances a well-known, existing model in environmental hazards, *The Hazard of Place*, with the goal of making it suitable for adoption in climate planning.

2.1 Climate Planning

The perceived threat of climate change has catalyzed policymakers to adopt planning practices that are often collectively known as a Climate Action Plan (CAP). Generally, climate planning involves two types of strategies: mitigation and adaption. Mitigation refers to the reduction of greenhouse gases, while adaptation aims to address the consequences of climate change (Crane, et al., 2010; Prabhakar et al., 2009). Such policies have been adopted at various scales and geographies in the United States.

Policies to reduce greenhouse gas concentrations began proliferating in the 1990's. Anthropogenic influence of the Earth's climate arguably became an issue at the forefront of the international community in 1992 when the United Nations catalyzed action on climate change through the United Nations Framework Convention on Climate Change in Rio de Janeiro. In the United States, this treaty inspired *The Climate Change Action Plan* from the Clinton Administration which stated dual goals of addressing global warming in addition to strengthening the economy (Clinton and Gore, 1993). These two actions provided the international community and the United States, respectively, with broad goals related to greenhouse gas emissions and encouraged the development of novel actions at the local scale.

The International Council for Local Environmental Initiatives – Local Governments for Sustainability (ICLEI) has provided the framework for confronting environmental issues at the local scale. ICLEI was founded in 1990 when representatives from over 200 local governments attended its inaugural conference. In 1993, this network began the Cities for Climate Protection Campaign (CCP), which has been the vessel in which the ICLEI carries out efforts related to climate change (ICLEI, 2008). Although this protocol has been designed with urban settings in mind, the themes are broadly applicable despite differences in scale or geography.

The first focus of the ICLEI's campaign is Mitigation of the impact on climate through a milestone process. The first two milestones are to *measure* how much greenhouse gasses are presently being emitted and to *commit* to the amount of emissions that will be reduced related to base and target years, respectively. Next, the cities *plan* how the emissions targets will be achieved and *implement* their Local Action Climate Plan. Lastly, cities *monitor* the reductions achieved. The second focus of ICLEI's work is Adaptation with the goal of being able to adopt successful strategies for the 21st century in light of the challenges presented by climate change, which is the focal point of this research. Developing adaptation strategies for potential, and inevitable, changes in local geography should also play a crucial role in climate planning. The last focus of the ICLEI's CCP program is Advocacy, the importance of which lies in consensus building within the context of the political system.

CAP's that have been adopted by communities have worked towards a diverse range in goals and various levels of success have been observed related to these goals. Although similarities exist between many CAP's, and have been documented by scholars

(Bassett and Shandas, 2010; Boswell et al., 2010), the effectiveness of these policies remain questionable. Since the end of the 20th century, environmental scientists and urban planners have recognized the importance of integrating ecological and socioeconomic processes (Guhathakakurta, 2003), most climate plans, however, do not reflect this. Despite similarities between CAP's and traditional planning strategies, and despite the benefits of holistic policy approaches (McEvoy et al., 2006; Viguié and Hallegate, 2012), professional planners are not directly involved in the development of most CAP's (Bassett and Shandas, 2010). Unlike traditional planning methods in the United States, the development of a CAP is far from a standardized process.

Although climate planning has grown dramatically in popularity in the past two decades, these policies remain questionable in their effectiveness. For instance, Millard-Ball (2012) presents the case that it is the local citizenship's environmental preferences that drive emission reductions rather than implemented climate action plans. Additionally, Drummond (2010) finds that state-level plans to reduce greenhouse gas emissions have produced modest results that "...remain small compared to the scope of the problem." These results, along with the lack of adaptation strategies, highlight the difficulty of coordinating policy and program development that effects diverse stakeholders and transcends a single discipline or city department.

Policy makers, however, remain faced with an uncertain future as emissions continue to warm our climate on the global scale. The effects of climate change are dynamic over space and time, which means it presents an inherently geographic, locally-scaled problem embedded in a global phenomenon. Consequently, the distribution of impacts can be extremely varied from one place to another. Mileti (1999) discusses natural disasters in the context of a *landscape of risk* that is influenced by the Earth's constantly changing physical systems, demographic composition and distribution, and the built environment. Since the distribution of these factors is highly uneven, any potential impact must be as well.

Research suggests that policymakers have not developed coping strategies for climate sensitive hazards. Adaptation strategies in the United States are in their infancy, as a recent survey found that only 25% of locally-scaled Climate Action Plans include adaption strategies related to local changes caused by climate change (Bassett and Shandas, 2010). With shifts in the climate all but assured in the upcoming decades and centuries, policy makers and stakeholders must accelerate the rate in which adaptation strategies are being developed and implemented if quality of life and economic opportunity are to be secured for the future. The nascent character of climate planning and climate adaptation policy presents a need for the development and deployment of a logical, scalable framework for assessing the spatial distribution of need for adaptation.

2.2 Vulnerability, Resilience, & Adaptation

In the context of climate change, vulnerability often involves probabilistic methods for impact assessments in combination with varying climate change mitigation scenarios (Gosling et al., 2011), while the idea of resilience can provide policy makers with a long term perspective on the implications of human development (Nelson, 2011). Although scholars have disagreed on specifics regarding vulnerability and resilience, certain motifs permeate the literature on environmental hazards. Space, time, and scale, fundamentals of Geography, prove to be essential in defining environmental hazards.

Framing climate policies in these concepts enables policy makers to apply scientific methods and forward-looking thinking to a myriad of planning considerations involved in adaptation, which can be thought of as minimizing the harmful effects of climate change.

Vulnerability to hazards related to climate change has become a recent focal point in the research community. Climatic hazards are unique in that their examination crosses a diverse range in scale. Turner et al. (1990) present two distinct types of global environmental change in regard to scale. *Systemic* global change directly impacts of the functioning of a global system while *Cumulative* global change has a global effect through the widespread distribution of local change. In terms of climate change, systemically, the climate system is changing due to increased concentrations of greenhouse gases (Mann et al., 1998; Matthews and Caldeira, 2008; Mann et al., 2008). At the local scale, changes such as those in sea level, precipitation, ocean chemistry, air and oceanic circulation, biodiversity, and land cover, can accumulate to catalyze environmental change felt at the global scale.

Vulnerability is commonly considered to be composed of pre-hazard event characteristics while resilience refers to post-hazard event characteristics (Cutter et al., 2008). While both concepts are understood to be dynamic over space and time, static observations are used for the purposes of evaluation. Since the national assessment of natural hazards by Haas and White (1975), the dialogue of the human-interaction with environmental hazards has expanded tremendously. Füssel (2007) presents five approaches to vulnerability: Risk Hazards, Political Economy, Pressure-and-Release, Resilience, and Integrated. The Risk Hazard approach usually refers to a descriptive examination of physical infrastructure that is indifferent towards socioeconomic factors and root causes. The Political Economy approach examines the social distribution of vulnerability- asking the questions “Who?” and “Why?”- while the Pressure-and-Release model defines risk as a product of hazard and vulnerability by examining global, regional, and local phenomena. The Community and Regional Resilience Initiative defines resilience as:

> “…the capability to anticipate risk, limit impact, and bounce back rapidly through survival, adaptability, evolution, and growth in the face of turbulent change” (Plodinec, 2009).

Generally, scholars have defined resilience as the ability to rebound after a hazardous event (Klein et al., 2003; Cutter et al., 2008). Factors that have been cited as critical in determining social resilience related to natural hazards include institutions for collective action, robust governance systems, in addition to diverse livelihood choices (Adger, 2005).

Although all of these approaches to vulnerability can involve some level of human-environment interaction, the integrated approach through the *Hazard of Place*, first presented by Cutter (1996), most clearly synthesizes the risk associated with biophysical phenomena with the ability of populations to cope with hazards. As it is understood that environmental hazards disproportionately affect needy populations, such as women and children (Cutter, 1995), the benefit of such an approach is that it “…helps to identify those characteristics and experiences of communities (and individuals) that enable them to respond to and recover from environmental hazards” (Cutter et al., 2003). Using this integrated framework to analyze the vulnerability of coastal communities, as the case study in Chapter 4 does, is similar to previous research conducted over the last decade. Wu et al. (2002), Rygel et al (2006), and Kleinosky et al. (2007) have applied this model to various coastal geographies.

3. Theoretical Framework

Although the literature on vulnerability and resilience has certainly furthered the understanding of the interaction between socioeconomic systems, the built environment, and environmental hazards, concepts in these paradigms remain problematic within the context of climate policy. For example, Klein et al. (2003) state that rather than the definition of resilience providing a measurable attribute, it has become an “umbrella concept” for desirable system attributes. Current definitions of vulnerability and resilience also seem to be based upon a temporal continuum of pre-hazard (vulnerability), hazard event occurrence, and post-hazard (resilience). This continuum becomes problematic in examining chronic hazards that are driven by climate change, such as sea level rise, erosion, or loss of freshwater resources through glacier recession, and the planning effort to combat them, which are continuous rather than finite in nature. Such chronic hazards differ from hazard events in that they are constant. Similar to the way in which a slow, steady stream will carve rock over many years, decades, or centuries, so too does a chronic hazard impact the landscape. Impacts may be felt over the scale of generations rather than years, but climate driven processes such as changes in sea level are always happening, will impact physical and social landscapes, and can exacerbate hazard events. These hazards do not conform to a temporally discrete approach that currently dominates the definitions of vulnerability and resilience in the environmental hazards literature (Figure 1).

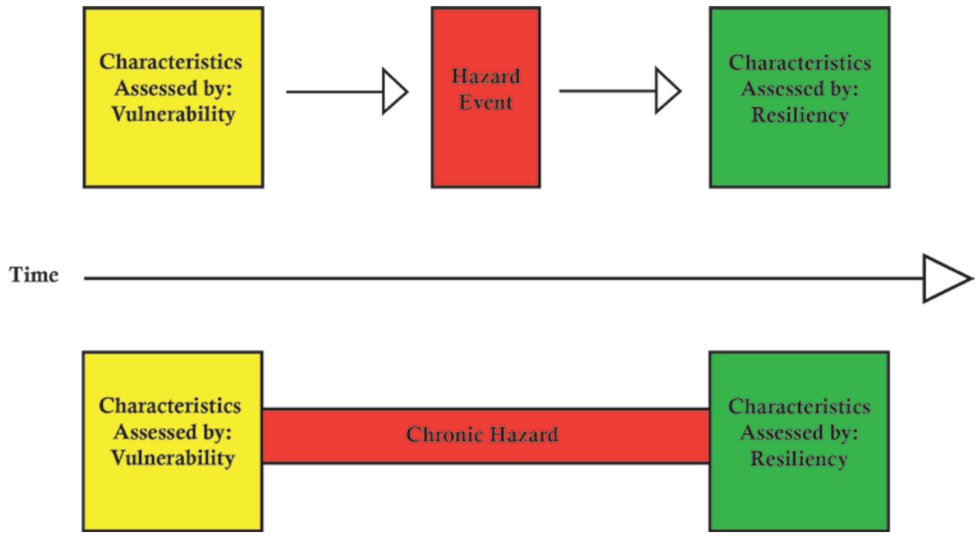


Figure 1. Temporal Dilemma in Environmental Hazards

For inclusion in climate planning, and in order to clarify the aforementioned temporal relationship, vulnerability can be defined by the risk associated with exposure to potential hazard events and actual exposure to chronic hazards and is a function of physical and human geographies, climate planning, and climate trends (Figure 2). Resilience can be defined by a community's ability to thrive despite new conditions catalyzed by climate change.

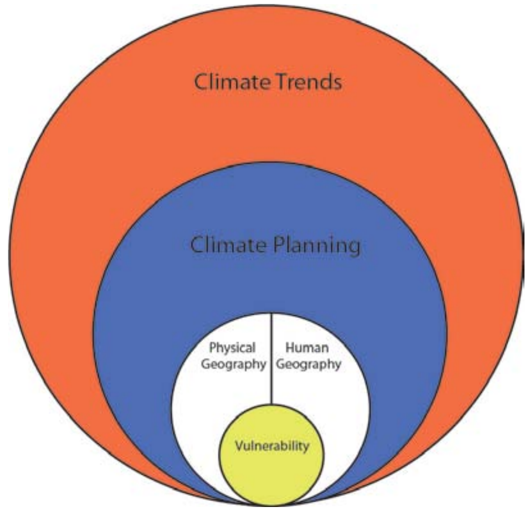


Figure 2. Climate Vulnerability as a Nested Concept

Furthermore, vulnerability and resilience can be defined as dynamic, inversely dependant concepts; all other variables remaining equal, as resilience increases vulnerability decreases and if resilience decreases then vulnerability increases. Moser (2008) directly refutes this conceptualization in a recent CARRI report:

> "Communities may be able to reduce deep-seated vulnerabilities and renew and rebuild better after a hazardous events, if they are prepared and able to take advantage of their vulnerability and challenges. Resilience, on the other hand, can produce systems that are "trapped" in unhealthy, unproductive, or otherwise undesirable states. Thus, vulnerability is not always a bad thing and resilience not always good."

For the purposes of consensus building and evaluation in the process of incorporating climate action plans, however, it is useful to reconceptualize vulnerability and resilience so that they are directly related and intuitive. Simplifying jargon is justified in this sense as the nature of an integrated assessment can be viewed as lying somewhere between science and policy as they serve to help answer questions and help assess potential responses; within this context, lies uncertainty, the need to be informed by multiple sources of knowledge and explicit recognition of social values in the policy-making process (Rothman and Robinson, 1997). This integration necessarily means a crosscutting of disciplines and inclusion of diverse stakeholders.

Füssel and Klein (2006) extend the research presented by Rothman and Robinson (1997) by focusing specifically on integrated assessments of vulnerability to climate change. The authors denote *first-generation assessments*, characterized as accounting for non-climatic factors and recognizing the ability for adaptation to reduce potential impacts, *second-generation assessments*, which are characterized by paying particular attention to the ability of a system or population to adapt, and *adaptation policy assessments*, which "aim to contribute to policy-making by recommending specific adaptation measures, thus representing a fundamental shift in the assessment purpose." The framework presented here furthers the discussion on adaptation policy assessments through the creation of a framework that synthesizes two important concepts in environmental hazards, vulnerability and resilience with the explicit purpose of locating those places that are in need of adaptation.

By framing these concepts thusly, policymakers can identify areas associated with risk and articulate successful adaptation strategies in a communicable manner consistent with involving diverse stakeholders. In this framework, vulnerability and resilience are intimately tied together, but their respective evaluation is not solely dependant upon one another. Vulnerability, consequently, remains a term associated with risk while resilience refers to an ability to prosper under the threat of actual and potential hazards. This conceptualization includes framing ideas in both prevention (vulnerability) and promotion (resilience) contexts. According to Columbia University's Center on

Environmental Decision Making, some people may prefer the prevention frame while others are more oriented toward a promotional focus. Incorporating both frames can capture a broader audience and encourage more sustained positive actions towards objectives (Shome and Marx, 2009).

Policies developed in response to the hazards presented by climate change should be scalable and flexible so that assessments and allocation of resources can be efficient and methodical. It requires flexibility at the local scale (Crane et al., 2010), which can be accomplished through evaluating vulnerability and resilience. In such a framework, vulnerability can be defined through a spatial analysis of natural hazards, social vulnerability, infrastructure, and land use. While it is not the focus of this thesis and is left to future research, the evaluation of resilience in the presented framework would incorporate the results of a vulnerability assessment in addition to variables such as social cohesion, economic flexibility, access to critical goods and services, and intervention strategies already enacted (See Table 1). Notable, successful intervention strategies increase resilience while unsuccessful strategies may reduce resilience.

Table 1. Generalized Variables for the Presented Framework

Vulnerability	
Variable	*Correlation*
Actual Exposure to Chronic Hazard	+
Potential Exposure to Event Hazard	+
Social Vulnerability	+
Resilience	-
Resilience	
Variable	*Correlation*
Vulnerability	-
Social Cohesion	+
Economic Flexibility	+
Access to Critical Goods & Services	+
Intervention Strategies	+/-

Synthesis of planning policies related to adaptation to climate change, vulnerability, and resilience can be achieved through a cyclical conceptualization of: (1) Assessment of local vulnerability to climatic hazards, (2) Assessment of local resilience to climatic hazards, (3) development and implementation of intervention strategies, (4) creation of new human and physical geographies (See Figure 3).

Figure 3. Visualizing Cyclical Assessments

The goal of an iteration of this cycle by a community would be to empower areas that are vulnerable to climatic hazards and possess low resilience, in order to increase adaptive capacity. This approach resembles the organizational processes of adaptation outlined by Berkhout (2012), which are described as Perception, Evaluation, Enactment, and Feedback. When it is *perceived* that climate change is affecting or will affect a place, vulnerability and resilience are *evaluated* so that intervention strategies can be *enacted*. The new physical and social landscape, or *feedback*, is then evaluated.

The strength in developing climate adaptation policies within this framework is the concept's relevance at multiple scales and flexibility in relation to geography. While items such as availability of data, population characteristics, and pertinent hazards may change, cohesion related to applicable planning policies and practices, at differing scales and geography, can be maintained. Additionally, this approach is consistent with principles for sustainable adaptation. Erikson et al. (2012) describes these as (1) recognizing the context for vulnerability, including multiple stressors, (2) acknowledge that different values and interests affect adaptation outcomes, (3) integrate local knowledge into adaptation responses, and (4) consider potential feedbacks between local and global processes. The framework presented here is consistent with these principles through consideration of local human and physical geography, evaluation and re-evaluation of intervention strategies, and in an acute recognition of the importance of scale. Applying this model, it is proposed, will allow policymakers to gain a better understanding how resources should be allocated to increase resilience to actual and potential climatic hazards.

4. Empirical Study

4.1 Study Area

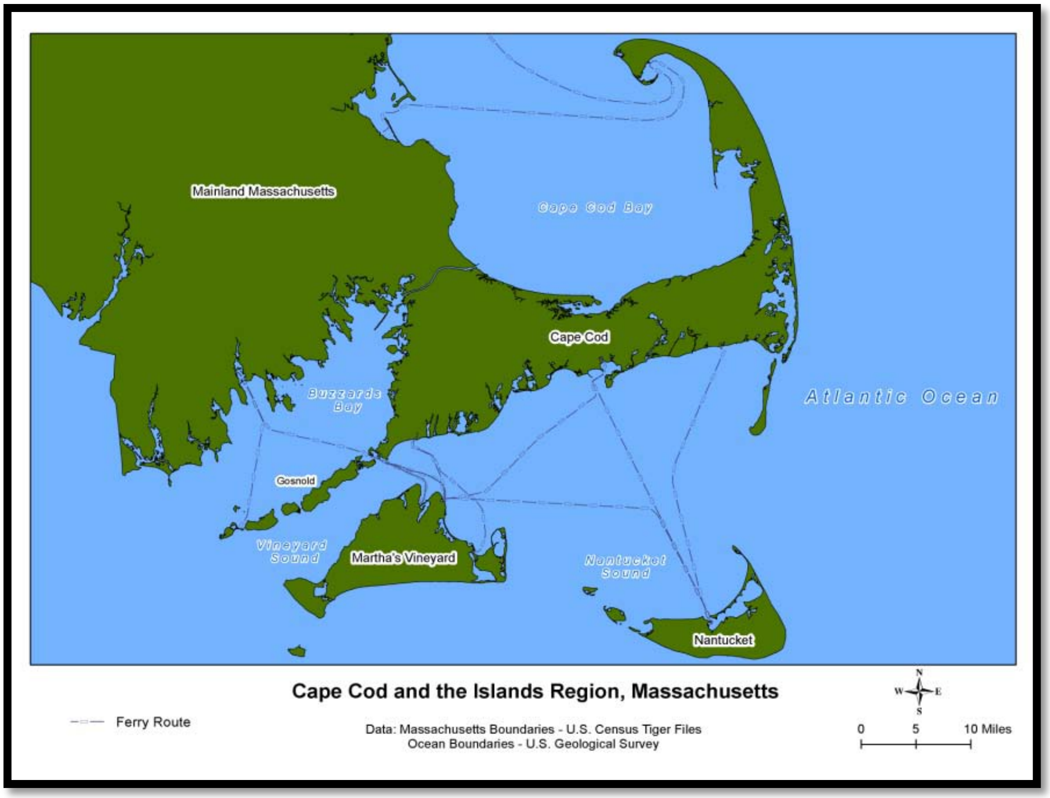


Figure 4. Cape Cod and the Islands Region

Dukes County is the Massachusetts County that includes the county subdivisions located on the island of Martha's Vineyard in addition to the group of small islands to the northwest of the Martha's Vineyard collectively known as Gosnold (See Figure 4). In response to a substantial increase in development in the 1970's, the communities of the county created a regional planning agency, the Martha's Vineyard Commission (MVC), which has overseen development and planning since its inception. The county has a long history of commercial fishing, but more lately caters to affluent seasonal tourists. With both economic activities heavily reliant upon the ocean as a resource, long term sea level rise and storm surge events pose a particularly important risk that could result in loss of land, damage to infrastructure, as well degradation of economic opportunity.

The jurisdiction of the Martha's Vineyard Commission presents a natural geography for a case study in climate planning. Presently, the MVC is authorized to review "developments that are either so large or have such significant impacts on their surrounding that they would affect more than one town", which are designated as Developments of Regional Impact (MVC, 2006). In addition, the MVC restricts development in areas that have been designated a District of Critical Planning Concern (DCPC) (MVC, 2006). There are eight types of restricted areas designated as DCPC:

- Drinking Water Resource District Fishing Resource District
- Farming resource District
- Wildlife, Natural, Scientific, or Ecological Resource District
- Cultural or Historic Resource District
- Economic or Development Resource District
- Major Public Hazard District
- Hazardous District

The two aforementioned policies provide the precedent for MVC's regional planning efforts while the Island Plan, adopted in 2009, affirms it. The Island Plan outlines a comprehensive, albeit broad, future for the communities of Martha's Vineyard. It is defined as:

> "…a regional planning document to be used by the Commission, the community and the Towns for guidance and inspiration, in conjunction with Town master plans and other plans and policies which have been and may be adopted from time to time. The Commission is committed to the Island Plan being a dynamic living document and expects that there will be new ideas and adjustments incorporated into the Plan as times may change and the community and Towns consider it and work to implement it (MVC, 2007)."

While issues regarding climate change are mentioned, the document is not sufficient in terms of identifying vulnerable areas to climate-induced hazards or in developing strategies to increase resiliency in regards to changing climatic variables.

Climate Change is cited as one of eighteen challenges in the Island Plan and has a devoted sub-chapter, fittingly entitled *Climate Change.* This section states some of the science behind climate change, states preparing for Climate Change as an objective and presents preliminary strategies for meeting this goal. *The Island Plan* unequivocally states "We need to assess the vulnerability of the Vineyard to the diverse impacts related to climate change and plan accordingly to conserve human and natural resources" (MVC, 2009).

Although the MVC has enacted successful regional planning policies for decades, planning in regards to climate change adaptation will require a novel approach, and most likely, external resources. In order to analyze the impacts of changing global climatic variables on the island's socio-demographic, cultural, and physical landscapes this research will use Geographic Information Systems within the Hazards of Place framework to identify areas that are vulnerable to sea level rise and hurricane storm surge. Successfully identifying socially and physically vulnerable areas will aid policymakers and stakeholders in the justification for allocation of resources that are available locally in addition to seeking external funding for adaptation efforts.

4.2 A Changing Climate

4.2.1 The Climatic Record

The present-day climate of Dukes County is heavily influenced by the ocean and Gulf Stream in addition to general circulation patterns moving west to east across the North American continent. As a result of the impact of the aforementioned maritime influences, the climate is categorized as a Humid Sub-Tropical climate in the Koppen-Geiger Climate Classification system (Kottek et al., 2006). The Gulf Stream, in addition to the thermal inertia of the ocean work to moderate the temperature of Dukes County, while its proximity to water ensures a reliable supply of moisture for the formation of clouds that create precipitation events. The Gulf Stream moves northward along the Atlantic Coast of the United States and brings heat from the tropics to create a warmer climate than the region would otherwise have. This influence is felt most intensely in the two shallow bodies of water to the northeast and northwest of the island, the Nantucket Sound and the Vineyard Sound, respectively. Here, ocean temperatures can be dramatically warmer than other locations New England.

The physical geography of Dukes County was born out of long term climate processes. The geologic history of the island is relatively short and dominated by the influence of the Laurentide Ice Sheet, which covered much of North America. Oldale (2001) provides a concise geologic history of the Cape Cod, Martha's Vineyard and Nantucket region: The Laurentide Ice Sheet formed during the last glacial maximum, the Wisconsinian stage. As the Laurentide began to retreat due to a warming climate about 18,000 years ago, glacial deposition, known as drift, was consequently exposed. The shape of Martha's Vineyard was created by the forces of two glacial lobes of the Laurentide: the Cape Cod Bay Lobe and Buzzards Bay Lobe. Finally, as ice sheets melted and global sea level began to rise, the low lying lands between the island of Martha's Vineyard and Cape Cod filled with water, forming the Nantucket Sound.

Paleoclimate reconstructions for the New England region since the formation of the islands of of the region have a relatively high resolution. Proxies including pollen are used to trace the retreat of the Laurentide ice sheet across North America and to calibrate models of paleoclimatic conditions (Ruddiman, 2008). In addition to pollen, glacial varves (Rittenour, 2000), δD values of behenic acid from sediment cores (Hou et al., 2007), radiocarbon dated sediment cores, and changes in freshwater levels (Shuman et al., 2001) have been used to reconstruct paleoclimatic conditions in New England region from the Late Pleistocene to the advent of instrument technology. It is clear that the region has warmed since it was once covered by ice, but research has also demonstrated cooling periods in the region, most notably the Younger Dryas (Peteet et al., 1990; Shuman, 2002).

During the 20th century, greenhouse gas concentrations in the atmosphere have been found to be the dominant force driving changes in the climate system via a multiproxy network including ice core, ice melt, dendroclimatic, instrumental, and historical records (Mann et al., 1998). In addition, proxies including tree rings, marine sediment, speleothems, ice cores and corals have shown that global average temperatures are now warmer than they have been in over a millennium (Mann et al., 2008), with an increase of nearly degree Celsius in the past 150 years alone (IPCC, 2007). The most likely variations are in the State of Massachusetts are warmer average temperatures and an increase in annual precipitation (The Commonwealth of Massachusetts, 2011). These alterations are expected to be amplified by the end of the 21st century.

4.2.2 Climate Sensitive Hazards

Climate is not a static phenomenon and, over the next 40 years, the climate in New England is predicted to change. A shift in climatic patterns also presents a change in hazards related to climate, which can be classified as either chronic hazards or event-based hazards consistent with the theoretical framework presented in Chapter 3. In the case of Duke's County, the most critical hazards are long term sea level rise, a chronic hazard, and storm surge events such as tropical cyclones and nor'easters.

Warmer conditions are reflected in the rising of average global sea level. Since the late 19th century, the Earth's average sea level has risen at a rate of 2.1 mm/yr; the highest rate in over two millennia (Kemp et al., 2011). Furthermore, significantly faster rates of rising are observed in the 1990's when compared to the rest of the 20th century, albeit the significance of this in terms of the climate system is uncertain because rates of rising have differed greatly at various time scales (Edwards, 2008). Even with this uncertainty, these data are compelling given that Kemp et al.'s (2011) research documenting sea level change in North America over the past two millennia shows a recent, steeply sloped increase that is similar to the infamous "hockey stick" Northern Hemisphere temperature graph first presented by Mann et al. (1998).

In addition to sea level rise, extreme weather is expected to be influenced by changes in the climate system. Located in the Atlantic Basin, Dukes County has been repeatedly exposed to tropical cyclones. Although model outputs have differed, generally, global warming simulations have shown a tendency toward an increase in the intensity of hurricanes, and other precipitation events, with a decrease in the frequency of such events (Emanuel, 2008; Vecchi et al., 2008). Like the aforementioned increase in temperature and rise in sea level, an increase in the frequency of stronger tropical cyclones in the Atlantic Basin has been observed since the 1990's (Elsner, 2008). This increase in intensity cannot, however, be conclusively linked to a long term warming trend because of the difficulty in detecting long term signals in a framework of high annual and decadal variability that includes El Niño/Southern Oscillation (van Aalst, 2006). Regardless of the cause, an increase in the intensity of tropical cyclones could have disastrous economic implications as one study finds that a 10% increase in potential intensity is found to increase annual direct economic losses by 54% on the U.S. Atlantic and Gulf Coasts (Hallegatte, 2007).

4.3 Methods

The social landscape is investigated through demographic variables while the physical landscape in this study is examined through the evaluation of hypothetical sea level rise scenarios and worst case storm surge scenarios in the context of their effects on the various land uses and infrastructure of the study area. Data have been analyzed and presented through ArcGIS and Microsoft Excel.

4.3.1 Data Acquisition

Two types of data are used in this analysis; socioeconomic data which was acquired in tabular format and geospatial. These data, which are related to socioeconomic status of the population, infrastructure, and land use, are integrated into a single assessment which identifies vulnerabilities in Dukes County.

Socioeconomic data is an important indicator of vulnerability. Socioeconomic data reveal populations that are less able to cope with natural hazards (Cutter, 2003). Researchers have long identified the relationship between populations and their vulnerability to hazards. For example, White and Haas (1975) note that accelerated commercial and residential development in areas vulnerable to hurricanes had increased loss of human life and property in the United States in their comprehensive assessment over 35 years ago.

Current socioeconomic data for this research has been acquired through the U.S. Census Bureau's database, the American Factfinder. The second crux to this vulnerability assessment is geospatial data. The aforementioned socioeconomic data is joined with

U.S. Census TIGER files to enable visualization. Other geospatial data including biophysical, land use, infrastructure have been acquired from the Massachusetts Office of Geographic Information Systems (MassGIS).

4.3.2 Data Analysis

The first dimension of vulnerability evaluated in this case study is that of the population. Literature suggests data related to income/poverty, gender, age, people with disabilities, and non-white residents can be used to indicate social vulnerability to environmental hazards (Cutter et al., 2000; Wu 2002; Rygel et al., 2006; Kleinosky 2007). The analysis presented here departs from the literature in the use of one variable, median household income. Social indices are often calculated using home values (i.e. Wu, 2002), but median income is used here instead because of the perceived disparate relationship between home values and year-round residential income values; although property values often reach the millions in Dukes County, the median income is well below $100,000. Each variable is normalized by calculating the ratio of each value to the maximum value for the county. Consequently, the maximum value that can be attained, which indicates the highest level of vulnerability, is 1:

$V = N/N_{Max}$

Where V = Vulnerability Score,

N = Value for an individual county subdivision,

N_{Max} = Maximum Value of all county subdivisions in Dukes County

In the case of median income, where a lower value equates to higher vulnerability, the following equation is used:

$V = N_{Min}/N$

Where V = Vulnerability Score,

N = Value for an individual county subdivision,

N_{Min} = Minimum value of all county subdivisions in Dukes County

A composite score is then created by adding the resulting vulnerability score for each socioeconomic variable. The social vulnerability composite scores, in addition to other aforementioned geospatial data, were entered into a GIS environment where they could be visualized.

In addition to social vulnerability, vulnerability of land to sea level rise and storm surge is also calculated in this thesis. Sea level rise is calculated by reclassifying an elevation raster while worst case storm surge scenarios have been acquired through MassGIS. These data, in addition to land use and infrastructure data from MassGIS, were processed using the Intersect Tool in ESRI's ArcMap to find land types affected by worst case storm surge and sea level rise, respectively. The results for this land use analysis are presented at both the scale of the county (Chapter 4) and county subdivision (Appendices).

4.4 Results

4.4.1 Social Vulnerability

Table 2. Social Vulnerability Results

County Subdivision	Composite Score
Aquinnah	1.31
Chilmark	1.65
Edgartown	5.71
Gosnold	1.10
Oak Bluffs	6.75
Tisbury	5.98
West Tisbury	3.65

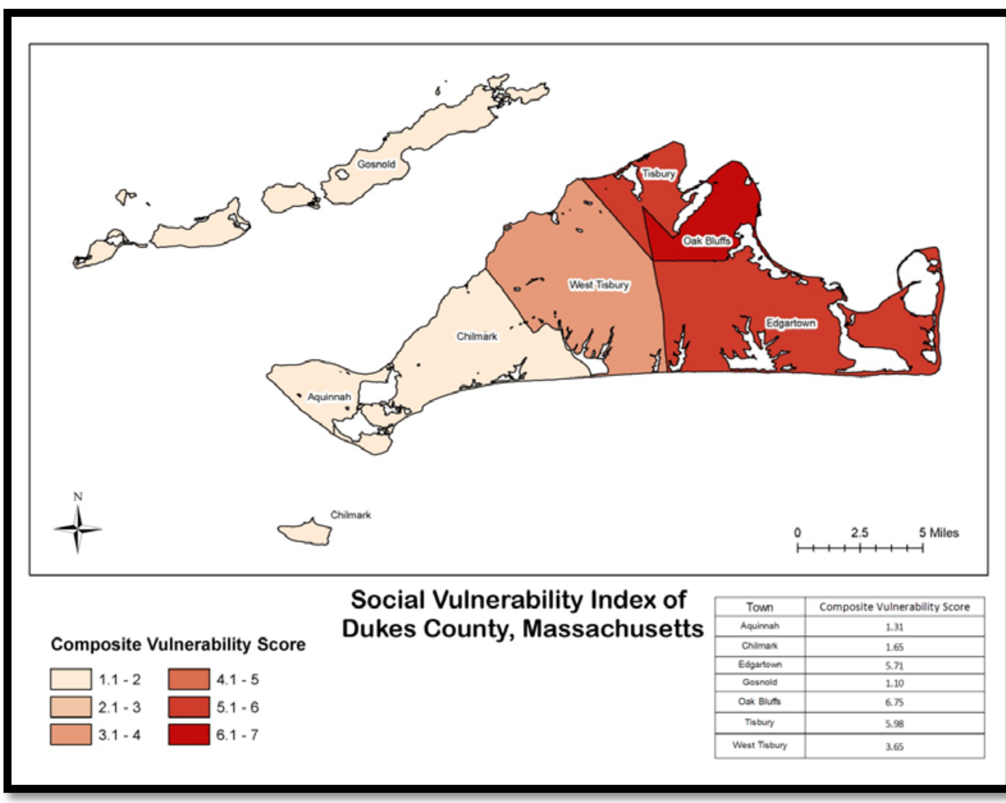


Figure 5. Social Vulnerability Results

The results of calculating the social vulnerability index indicates that Oak Bluffs, Tisbury, and Vineyard Haven have the most vulnerable populations in Dukes County. Oak Bluffs, in particular, has an especially high composite vulnerability score, which is driven by the presence of relatively high total population, numbers of females, non-whites, young people, and elderly people. Tisbury's high score is driven by the number of females, elderly, and renter occupied housing units. Lastly, Edgartown's relatively high score is driven by the presence of large numbers of females, young people, elderly people, and housing units. Gosnold and Aquinnah have low vulnerability scores, much of which is due to their smaller populations.

4.4.2 Vulnerability to Sea Level Rise

The potential effect of sea level rise for the study area was evaluated through a raster based elevation analysis. Total land effected, is shown in Table 1. The areas most vulnerable to sea level rise are concentrated in the southern and eastern coasts of Martha's Vineyard, but results indicate a nominal effect if sea level rise remains below 2 meters. A rise in sea level of more than 2 meters, however, would cross a threshold that effected land goes from near negligible to almost 10% of the total land in Dukes County. If sea level were to rise 5 meters above its current elevation, it would inundate about 17% of Dukes County.

Table 3. Land Use Vulnerable to Sea Level Rise

Dukes County	1 Meter SLR	2 Meters SLR	3 Meters SLR	4 Meters SLR	5 Meters SLR
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	15.49	274.68	542.92	723.06
Brushland & Successional	0.23	30.27	326.35	635.82	789.21
Commercial	11.82	17.74	38.56	54.44	71.36
Forest	17.89	209.30	1791.14	3223.99	4120.08
Open Land, Recreation, &Transitional	1.14	34.42	271.38	463.15	544.65
Other Developed	1.41	4.29	27.70	130.60	202.34
Residential	7.26	67.92	576.93	980.67	1244.84
Sandy Beach	149.01	433.98	1461.94	1814.42	1913.51
Wetland	91.28	397.76	1115.91	1342.78	1416.84
Total	**280.03**	**1211.17**	**5884.59**	**9188.78**	**11025.89**
Total % of Dukes County	**0.4%**	**1.9%**	**9.2%**	**14.4%**	**17.2%**

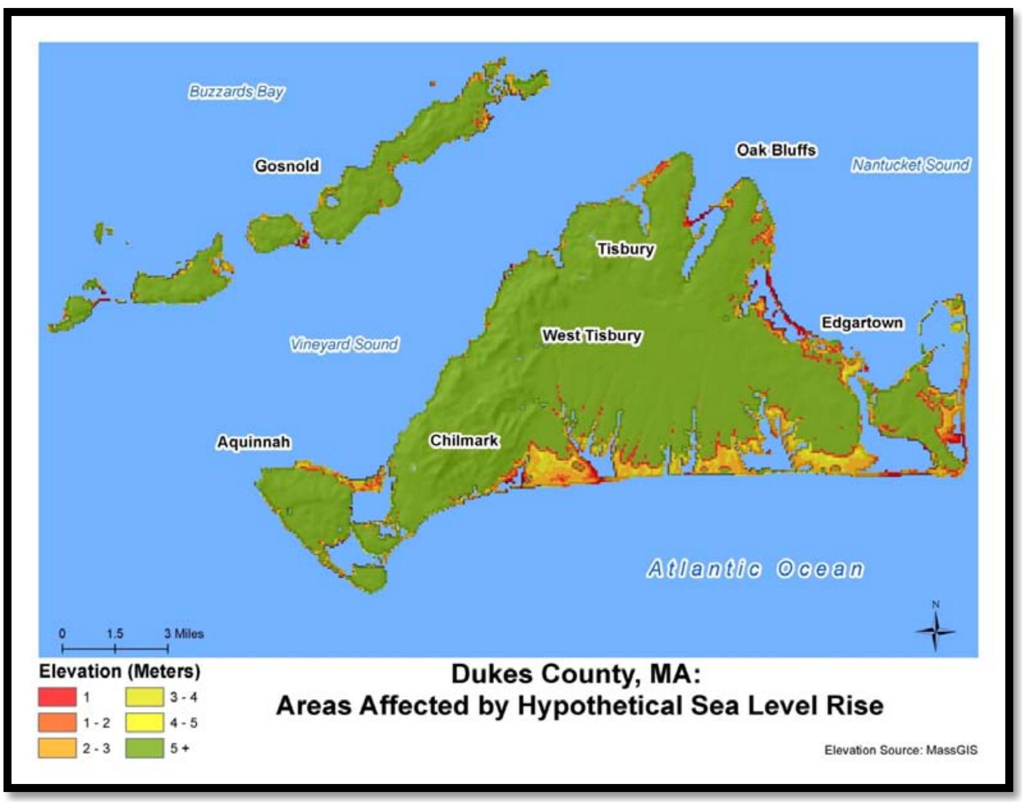


Figure 6. Land Vulnerable to Sea Level Rise

The land types that are most affected by hypothetical sea level rise are Sandy Beach, Wetlands, and Forest. All of the county subdivisions in the study area have such lands impacted by the hypothetical sea level rise scenarios. Other land use types that that are more developed are also affected such as lands classified as Agriculture, Commercial, and Residential. The magnitude of impact varies greatly between county subdivisions. For example, one meter of sea level rise would inundate nearly twelve acres of Commercial land whereas Edgartown's Commercial land would go unaffected until three meters of sea level rise and Aquinnah, Tisbury, and West Tisbury have no Commercial land at risk. Additionally, three meters of sea level rise would impact relatively large amounts of Residential land in the towns of Edgartown, Oak Bluffs, Tisbury, West Tisbury, and to some extent Chilmark, while not impacting large amounts of Residential land in Aquinnah or Gosnold. Chilmark, Edgartown, and West Tisbury are the towns that possess Agriculture land at greatest risk to chronic sea level rise, but the effect is mostly felt after crossing a threshold three meters or greater. Overall, Chilmark, Edgartown, Gosnold, and West Tisbury are at risk of losing the most land to sea level rise.

4.4.3 Vulnerability to Storm Surge

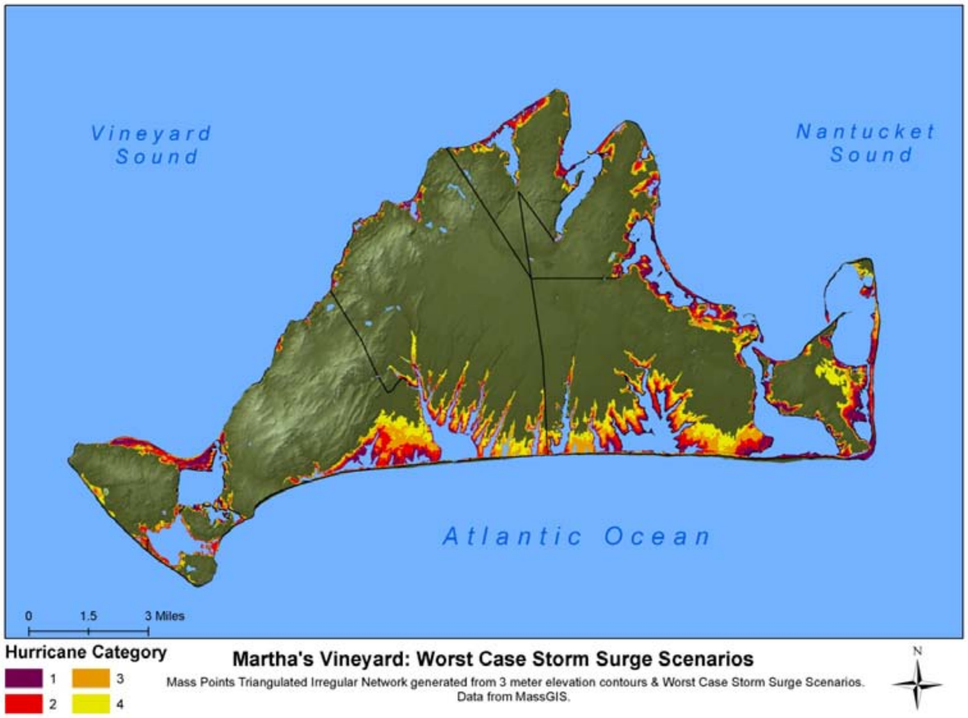


Figure 7. Land Vulnerable to Worst Case Storm Surge

Historically, Dukes County has been exposed to tropical storms, which are hazardous events that can cause tremendous amounts of damage- especially through storm surge. According to the analysis done with a storm surge data set created by the U.S. Army Corps of Engineers and land use data from MassGIS, the amount of land affected in Dukes County for worst case storm surge scenarios is as follows:

Table 4. Land Vulnerable to Worst Case Storm Surge

Dukes County	Category 1 Hurricane	Category 2 Hurricane	Category 3 Hurricane	Category 4 Hurricane
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	41.93	221.74	526.90	767.30
Brushland & Successional	64.95	240.70	486.10	654.66
Commercial	20.24	36.32	49.59	67.77
Forest	531.57	1592.24	2986.53	4586.38
Open Land, Recreation, &Transitional	60.87	258.86	462.40	587.32
Other Developed	8.28	18.96	88.84	187.40
Residential	148.98	453.18	838.94	1215.33
Sandy Beach	1530.64	2167.61	2476.83	2699.00
Wetland	1121.93	1407.06	1535.50	1625.13
Total	**3529.39**	**6396.66**	**9451.62**	**12390.28**
Total % of Dukes County	**5.5%**	**10.0%**	**14.8%**	**19.4%**

The amount of land impacted in these worst case scenarios ranges from about 5% of the county to nearly 20% of the county. The land uses most affected by volume are undeveloped lands such as sandy beach, wetlands, and forest. Similar to the sea level rise analysis, however, more developed lands such as Agriculture, Commercial, and Residential are also be impacted. Agricultural lands are most visibly vulnerable, by volume, in Edgartown and Chilmark, with West Tisbury also having substantial land impacted with a Category 3 or 4 strength hurricanes.

The vulnerability of critical infrastructure is a major concern in the occurrence of a hazardous event. Results of this geospatial analysis indicate that infrastructure including police and fire buildings, schools, hospitals, and airports are, for the most part, not located in vulnerable areas. There are, however, important buildings that could be exposed to damage at some point. For instance, the analysis reveals the Tisbury Fire

Department Headquarters could be affected by a Category 3 hurricane, the Oak Bluffs Police Station could be affected by a Category 4 hurricane, Katama Airport could be partially inundated by a Category 3 hurricane, and the Martha's Vineyard Hospital is very near to the line that delineates the worst case storm surge for a Category 4 hurricane. Additionally, a police facility in Chilmark (located in the village of Menemsha) could be cut off from the land-based transportation network by a Category 3 hurricane. Police and fire facilities in Gosnold and West Tisbury do not appear to be at risk to storm surge at the present time. Lastly, in addition to the land-based infrastructure at risk that is described above, water-based infrastructure is vulnerable throughout the county. See Appendix D for maps of infrastructure vulnerability to storm surge.

4.5 Discussion & Conclusions of the Case Study

Results of this case study indicate that the highest concentration of social vulnerability in Dukes County is in the northern and eastern towns of the island of Martha's Vineyard. Additionally, the areas most vulnerable to hazards related to climate change are located in the towns of southern, northeastern, and eastern parts of Martha's Vineyard. Although the geographic distribution of vulnerability varies for each analysis, overall it seems that the flatter, low lying towns down-island[1] have been more conducive to development, which is vulnerable to hazards associated with climate change. Vulnerability does exist in the up-island[2] communities, but it is the natural landscape that is at risk rather than human development.

A relic of the last ice age, the glacier moraine that so heavily shapes the physical landscape of the study area remains an important factor in shaping the geography and

[1] Down-island is commonly used to refer to the communities of Edgartown, Oak Bluffs, and Tisbury
[2] Up-island is commonly used to refer to the communities of Aquinnah, Chilmark, and West Tisbury.

spatial distribution of vulnerability in Dukes County. Flatter land that is also lower in elevation down-island has traditionally been developed and inhabited more than the up-island land of Martha's Vineyard and the islands of Gosnold. Consequently, larger populations and more developed land are at risk to hazards whose exposure is largely dependent upon elevation, like storm surge and sea level rise. These areas also have larger vulnerable populations such as minorities, the young, and the elderly. Additionally, more critical infrastructure is at risk down-island, including police, fire, and transportation (Katama Airport) facilities.

Although sea level is rising slowly throughout the Northeast of the United States, its impact presents a chronic hazard for policymakers that will exacerbate damage done through more visible event hazards like hurricanes. NOAA observations close to this study area indicate a rising rate of between two to three millimeters a year (NOAA, 2012). Although this rate may seem slow and safe for policymakers, research indicates that the last time the Earth was 2° C to 3° C warmer, the sea level was 25 to 35 meters higher than today (Hansen, et al., 2006). Thus, projected anthropogenic warming may lead to a more rapid rise in sea levels and presents a chronic hazard that is both actual and potential in nature. With such massive changes to the landscape on the horizon, it would be advantageous for such forward-thinking knowledge to be considered when defining present policies.

This case study has highlighted the down-island communities of Edgartown, Oak Bluffs, and Tisbury as being more vulnerable than their up-island counterparts of Aquinnah, Chilmark, and West Tisbury. The increased vulnerability is a function of lower elevation coastal land, larger populations, and larger amounts of developed land that includes critical infrastructure. For this reason, policymakers may consider allocating more resources for adaptation to these communities.

The analysis presented does have limitations. For example, this analysis does not attempt to evaluate the value of land types that are vulnerable and such considerations could change the study greatly. Questions like “Are Sandy Beaches in one area of the island more valuable or important than those located somewhere else in the county? What are the implications for tourism if some of the natural landscape is lost?” are left to future research. Other limitations to this study include not differentiating between densities of residential land and the generalization of land uses into the categories presented in the results and appendices sections. Even with these limitations, the case study presented demonstrates an uneven distribution, both spatially and temporally, that should be considered when developing relevant policy.

5. Discussion & Conclusions

Planning in regards to climate change, fundamentally, is an examination and evaluation of how to best facilitate human activity within the confines of our environment. Although mitigation efforts are worthy and necessary in order to treat underlying causes, it is becoming increasingly clear that adaptation strategies need to be developed and implemented with a sense of urgency in order to treat inescapable symptoms. Through the development of a theoretical framework and case study of vulnerability in a coastal New England county, this thesis has presented an approach to locating places that are in need of such policies.

The case study presented in the previous chapter demonstrates that the theoretical approach developed in Chapter 3 evaluates vulnerability through the physical geography and human geography of a study area and the examination of relevant climate sensitive hazards. In this context, vulnerability is driven by the size, characteristics, and distribution of population in addition to the physical characteristics of the area. For example, the flat, lower-lying land down-island is naturally more vulnerable to coastal hazards. This type of topography, however, is also conducive to development and settlement. Although Haas and White warned of the risks of increased development in coastal areas like this on the eastern seaboard over thirty years ago, it appears that development patterns make such concerns still very much relevant today. Such facts are disconcerting when coupled with the knowledge that climate change will probably increase the frequency of major hurricanes whose affects could be amplified by another symptom of a warming climate, higher sea levels.

Consequently, the narrative of adaptation that is needed is a synthesis of the ancient landscape, modern development, and possible futures. The case study presented in this thesis demonstrates that a landscape whose formation is dominated by glacier processes that occurred tens of thousands of years ago have a high degree of influence on the societal landscape through the spatial distribution of development and vulnerability. Although this is a singular example, the theoretical framework suggests that the Earth processes, some of which operate on a much longer temporal scale than that of society, have dramatic impacts on physical and social landscapes of a place. Thus, such phenomena should be understood and incorporated into adaptation strategies in climate planning.

Future research should focus upon the next step of the presented theoretical framework; evaluating the distribution of resilience. Here, resilience has been defined as the ability to thrive despite new conditions catalyzed by climate change. The purpose of this evaluation would be to describe those factors already in place that will enhance that place's ability to adapt. Preliminarily, such a study would incorporate an evaluation of vulnerability, an examination of intervention strategies that have been enacted (i.e. coastal armoring, water conservation policies), in addition to the variables mentioned in the Vulnerability, Resilience, and Adaptation section of this thesis: social cohesion[3], economic flexibility[4], and access to critical goods and services (i.e. water). In the context of the case study presented in this thesis, such a study might ask questions such as has there been armoring of the coastline in areas vulnerable to inundation? Are residents and organizations well-insured against property loss? Can the economy of Dukes County continue to compete if climate change disturbs a critical sector such as tourism? Once vulnerability and resilience are evaluated and understood in Dukes County, policymakers will be able to intervene favorably by developing informed adaptation strategies.

An additional line of future research is to synthesize various scales of such studies. The theoretical framework described in this thesis is designed explicitly for application at varying scales. Consequently, it should be possible to embed studies conducted at different scales. For example, how does Dukes County's vulnerability and resilience fit embedded within the state of Massachusetts, and the rest of the country?

[3] Variables to evaluate could include membership in community organizations such as the Parent Teacher Association (Cutter, 2012) or voting turnout.
[4] Can a place compete economically if climate change alters economic conditions?

What intervention strategies are being implemented in Massachusetts, the northeast region of the country, and nationally, and do these policies affect Dukes County?

The research presented in this thesis aims to contribute towards a better understanding of the need for social adaptation in light of climate change. The impacts of climate change, which vary over space, time, and scale, are inherently geographic phenomenon. For this reason, the distribution of vulnerability and resilience should be studied and understood before developing policies that aim to mitigate the hazardous impacts of climate change. By gaining a better understanding the distribution of need thusly, such an approach should aid policymakers in the allocation of funds for adaptation.

Appendix A: Social Vulnerability by County Subdivision

County Subdivision	Total Population	Occupied Housing Units	Non-White Population	Population Under 16	Population 65 & Over	Renter Occupied Housing Units	Median Household Income	Composite Score
Oak Bluffs	1.00	1.00	1.00	1.00	1.00	0.97	0.78	6.75
Tisbury	0.87	0.91	0.75	0.83	0.83	1.00	0.79	5.98
Edgartown	0.90	0.90	0.66	0.92	0.78	0.86	0.68	5.71
West Tisbury	0.61	0.60	0.20	0.63	0.49	0.48	0.65	3.65
Chilmark	0.19	0.20	0.04	0.18	0.25	0.15	0.63	1.65
Aquinnah	0.07	0.07	0.18	0.07	0.04	0.08	0.80	1.31
Gosnold	0.02	0.02	0.00	0.01	0.02	0.03	1.00	1.10

Appendix B: Land Vulnerable to Sea Level Rise by County Subdivision

Aquinnah	1 Meter SLR	2 Meters SLR	3 Meters SLR	4 Meters SLR	5 Meters SLR
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	0.00	0.00	0.00	0.00
Brushland & Successional	0.00	1.36	10.31	14.37	15.96
Commercial	0.00	0.00	0.00	0.00	0.00
Forest	1.02	7.50	46.84	85.66	111.65
Open Land, Recreation, &Transitional	0.00	5.72	16.46	17.67	23.43
Other Developed	0.00	0.00	0.00	0.00	0.00
Residential	0.00	0.58	11.02	17.21	21.37
Sandy Beach	15.48	52.47	209.41	274.61	301.49
Wetland	4.52	22.36	79.81	123.72	135.63
Total	**21.02**	**90.00**	**373.87**	**533.24**	**609.53**

Chilmark	1 Meter SLR	2 Meters SLR	3 Meters SLR	4 Meters SLR	5 Meters SLR
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	4.80	77.04	167.90	181.43
Brushland & Successional	0.00	2.07	36.23	80.62	107.50
Commercial	0.00	0.00	0.13	0.13	0.13
Forest	0.00	10.96	188.51	355.94	529.76
Open Land, Recreation, &Transitional	0.00	6.41	97.03	167.20	176.93
Other Developed	0.00	0.00	2.01	2.01	2.01
Residential	0.00	5.01	41.69	79.99	125.82
Sandy Beach	3.49	36.01	193.54	254.13	278.26
Wetland	16.52	61.12	201.65	218.98	228.95
Total	**20.01**	**126.38**	**837.82**	**1326.88**	**1630.79**

Edgartown	1 Meter SLR	2 Meters SLR	3 Meters SLR	4 Meters SLR	5 Meters SLR
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	4.69	146.32	279.01	414.33
Brushland & Successional	0.00	2.16	86.44	166.49	181.12
Commercial	0.00	0.00	9.73	21.85	31.32
Forest	10.84	114.62	967.90	1692.66	2126.92
Open Land, Recreation, &Transitional	0.00	12.97	96.86	161.19	201.26
Other Developed	0.00	0.00	6.11	95.48	158.62
Residential	2.94	36.56	308.62	540.81	666.92
Sandy Beach	55.79	195.83	627.25	733.63	752.91
Wetland	53.53	199.46	481.68	550.72	562.15
Total	**123.11**	**566.29**	**2730.90**	**4241.83**	**5095.56**

Gosnold	1 Meter SLR	2 Meters SLR	3 Meters SLR	4 Meters SLR	5 Meters SLR
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	2.03	23.15	33.61	41.86
Brushland & Successional	0.23	22.19	134.93	260.03	350.46
Commercial	0.00	0.00	0.00	0.00	0.00
Forest	4.29	29.02	197.23	310.17	376.46
Open Land, Recreation, &Transitional	0.00	1.10	17.60	37.11	46.07
Other Developed	0.00	0.00	0.03	0.32	0.32
Residential	0.00	2.08	15.27	25.64	31.50
Sandy Beach	18.97	48.43	182.49	245.79	268.79
Wetland	12.12	57.38	181.12	239.98	264.52
Total	**35.60**	**162.22**	**751.81**	**1152.64**	**1379.98**

Oak Bluffs	1 Meter SLR	2 Meters SLR	3 Meters SLR	4 Meters SLR	5 Meters SLR
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	0.00	1.05	2.66	2.76
Brushland & Successional	0.00	0.00	0.09	0.09	0.16
Commercial	0.00	0.47	6.84	9.91	15.26
Forest	0.58	11.73	90.41	142.43	179.05
Open Land, Recreation, &Transitional	0.00	3.78	20.45	37.58	42.44
Other Developed	0.00	1.15	14.75	27.99	35.30
Residential	1.13	11.60	88.80	135.12	183.61
Sandy Beach	31.31	48.16	92.14	103.80	106.71
Wetland	3.35	28.90	79.12	92.90	95.23
Total	**36.37**	**105.78**	**393.65**	**552.47**	**660.52**

Tisbury	1 Meter SLR	2 Meters SLR	3 Meters SLR	4 Meters SLR	5 Meters SLR
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	0.00	1.07	1.07	1.07
Brushland & Successional	0.00	0.00	0.00	0.00	0.00
Commercial	11.82	17.27	21.87	22.56	24.66
Forest	0.05	10.98	90.67	135.29	156.78
Open Land, Recreation, &Transitional	1.14	4.45	11.95	18.00	20.60
Other Developed	1.41	3.14	4.80	4.80	5.15
Residential	3.19	9.82	65.14	95.56	113.51
Sandy Beach	16.23	33.89	70.17	81.57	83.13
Wetland	0.87	11.78	34.62	39.74	41.39
Total	**34.71**	**91.32**	**300.28**	**398.59**	**446.29**

West Tisbury	1 Meter SLR	2 Meters SLR	3 Meters SLR	4 Meters SLR	5 Meters SLR
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	3.97	26.05	58.68	81.60
Brushland & Successional	0.00	2.49	58.36	114.22	134.01
Commercial	0.00	0.00	0.00	0.00	0.00
Forest	1.11	24.49	209.59	501.84	639.45
Open Land, Recreation, &Transitional	0.00	0.00	11.03	24.41	33.93
Other Developed	0.00	0.00	0.00	0.00	0.95
Residential	0.00	2.27	46.38	86.33	102.12
Sandy Beach	7.72	19.19	86.95	120.90	122.21
Wetland	0.37	16.75	57.91	76.74	88.96
Total	**9.21**	**69.17**	**496.27**	**983.12**	**1203.24**

Appendix C: Land Vulnerable to Worst Case Scenario Storm Surge by County Subdivision

Aquinnah	Category 1 Hurricane	Category 2 Hurricane	Category 3 Hurricane	Category 4 Hurricane
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	0.00	0.00	0.00
Brushland & Successional	0.08	5.30	8.53	14.16
Commercial	0.05	0.05	0.05	0.05
Forest	5.50	52.40	96.14	163.03
Open Land, Recreation, &Transitional	0.39	8.45	17.68	26.00
Other Developed	0.00	0.00	0.00	0.00
Residential	4.16	9.60	15.79	17.27
Sandy Beach	190.86	305.28	362.95	393.29
Wetland	91.30	142.53	165.14	179.99
Total	**292.35**	**523.61**	**666.27**	**793.79**

Chilmark	Category 1 Hurricane	Category 2 Hurricane	Category 3 Hurricane	Category 4 Hurricane
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	9.37	77.47	160.31	185.76
Brushland & Successional	5.82	41.69	90.52	83.09
Commercial	0.16	0.72	1.36	1.85
Forest	28.35	184.63	387.51	676.35
Open Land, Recreation, &Transitional	18.16	112.06	180.95	197.96
Other Developed	0.23	0.57	1.36	2.28
Residential	9.41	36.48	95.94	162.70
Sandy Beach	194.90	306.65	359.78	386.76
Wetland	185.25	262.38	274.19	282.83
Total	**451.66**	**1022.65**	**1551.92**	**1979.58**

Edgartown	Category 1 Hurricane	Category 2 Hurricane	Category 3 Hurricane	Category 4 Hurricane
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	24.21	101.36	277.36	447.62
Brushland & Successional	34.14	80.63	133.77	172.90
Commercial	4.36	6.09	13.64	24.79
Forest	374.95	921.36	1624.11	2316.19
Open Land, Recreation, &Transitional	26.13	81.60	155.57	215.63
Other Developed	0.79	0.83	59.03	147.71
Residential	103.17	255.58	434.90	596.59
Sandy Beach	625.66	832.76	949.80	1066.83
Wetland	566.29	624.82	650.10	680.71
Total	**1759.69**	**2905.04**	**4298.28**	**5668.96**

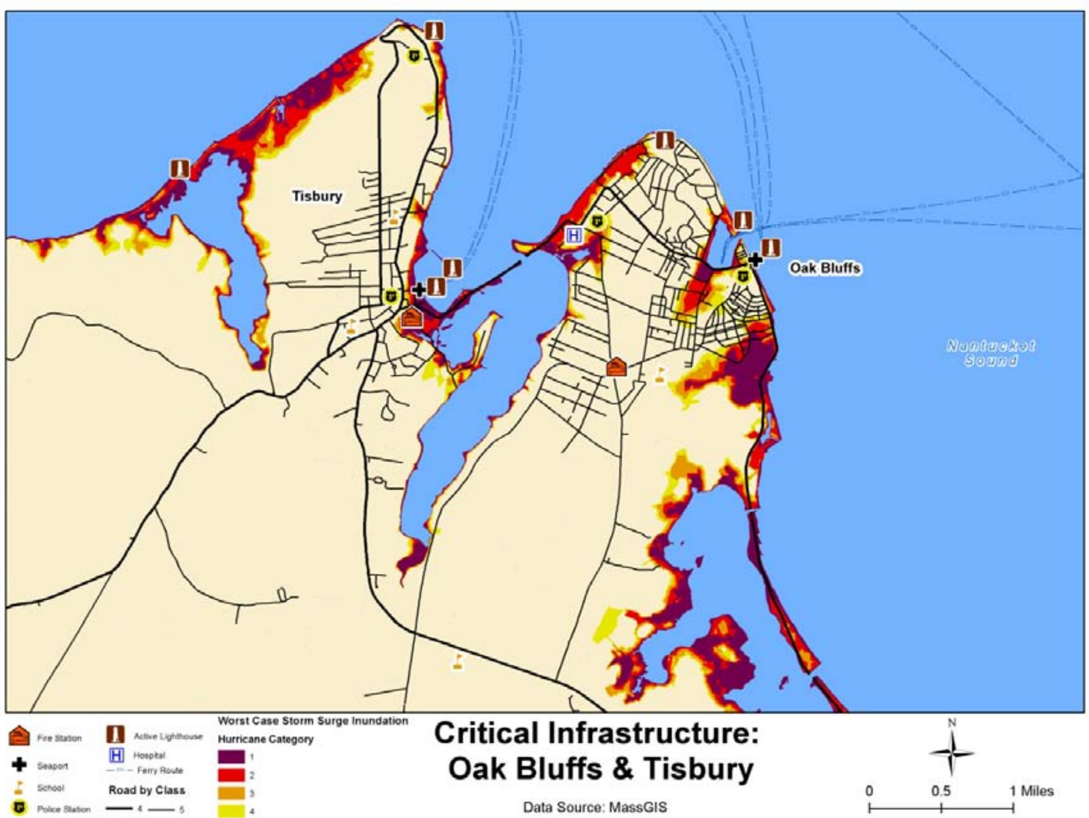
Gosnold	Category 1 Hurricane	Category 2 Hurricane	Category 3 Hurricane	Category 4 Hurricane
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	6.34	12.88	20.79
Brushland & Successional	16.47	66.13	146.62	243.56
Commercial	0.00	0.00	0.00	0.00
Forest	17.53	65.89	126.49	187.08
Open Land, Recreation, &Transitional	1.11	8.34	16.90	27.88
Other Developed	0.00	0.00	0.00	0.00
Residential	0.21	1.58	3.66	6.00
Sandy Beach	197.10	280.36	319.22	335.27
Wetland	90.58	134.67	174.04	188.97
Total	**322.99**	**563.30**	**799.80**	**1009.54**

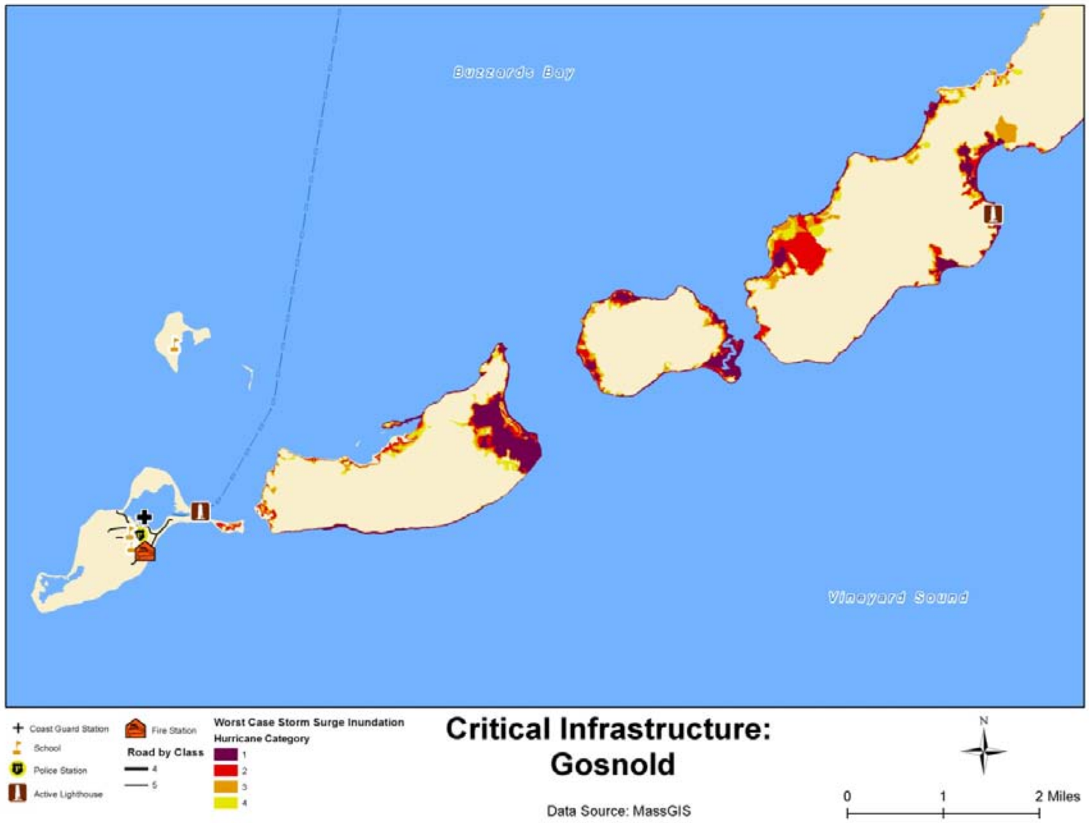
Oak Bluffs	Category 1 Hurricane	Category 2 Hurricane	Category 3 Hurricane	Category 4 Hurricane
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.00	0.75	2.01	2.76
Brushland & Successional	0.05	0.16	0.16	0.16
Commercial	0.83	6.67	9.75	13.73
Forest	23.30	70.20	123.72	177.66
Open Land, Recreation, &Transitional	9.30	24.23	43.78	52.11
Other Developed	3.73	12.96	22.85	31.46
Residential	12.06	60.96	117.18	179.46
Sandy Beach	80.97	140.26	157.52	174.78
Wetland	83.97	104.96	110.44	110.96
Total	**214.22**	**421.15**	**587.42**	**743.09**

Tisbury	Category 1 Hurricane	Category 2 Hurricane	Category 3 Hurricane	Category 4 Hurricane
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	0.29	0.49	0.74	3.04
Brushland & Successional	0.00	0.00	0.00	0.00
Commercial	14.84	22.79	24.79	27.35
Forest	24.81	82.75	140.62	203.80
Open Land, Recreation, &Transitional	3.02	13.95	21.64	24.82
Other Developed	3.53	4.58	5.45	5.75
Residential	12.15	51.32	88.02	130.57
Sandy Beach	108.77	143.92	150.94	153.00
Wetland	51.41	57.12	57.98	60.71
Total	**218.81**	**376.91**	**490.17**	**609.04**

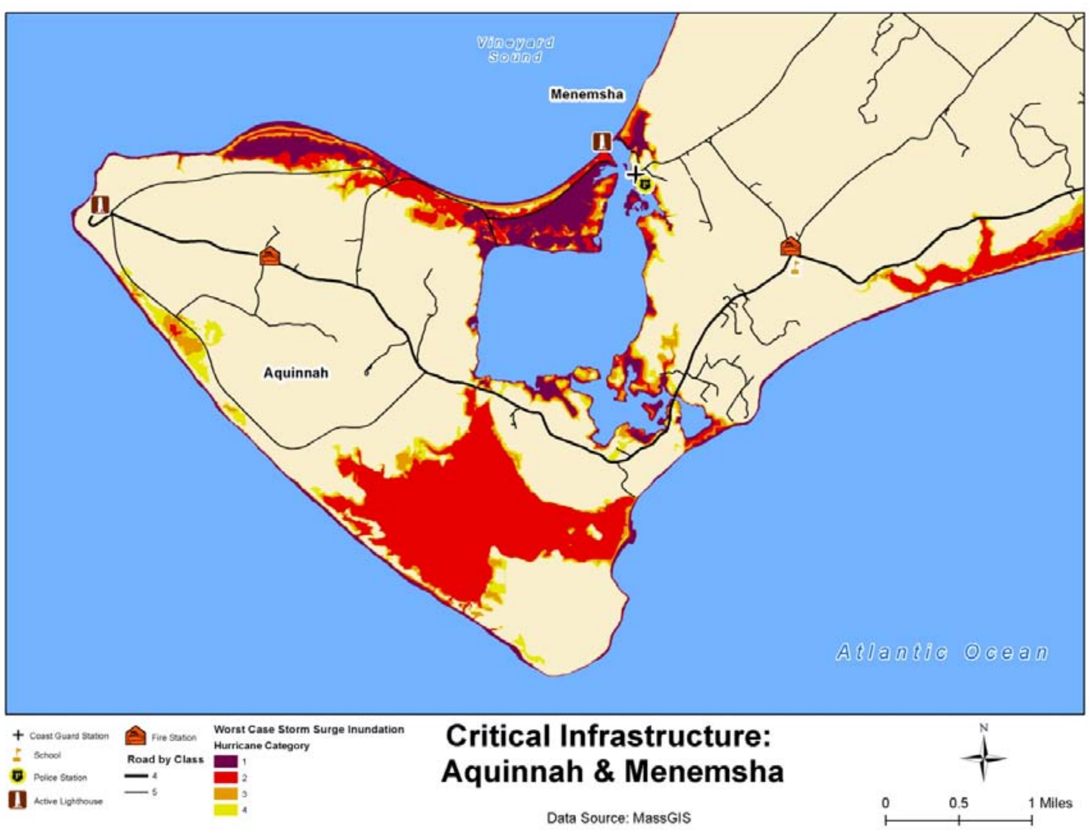
West Tisbury	Category 1 Hurricane	Category 2 Hurricane	Category 3 Hurricane	Category 4 Hurricane
Land Use	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Agriculture	8.06	35.34	73.60	107.32
Brushland & Successional	8.39	46.79	106.49	140.80
Commercial	0.00	0.00	0.00	0.00
Forest	57.13	215.01	487.94	862.27
Open Land, Recreation, &Transitional	2.75	10.23	25.88	42.93
Other Developed	0.00	0.01	0.15	0.19
Residential	7.83	37.66	83.45	122.74
Sandy Beach	132.37	158.38	176.64	189.07
Wetland	53.13	80.58	103.60	120.96
Total	**269.67**	**583.99**	**1057.75**	**1586.28**

Appendix D: Infrastructure Vulnerability to Storm Surge

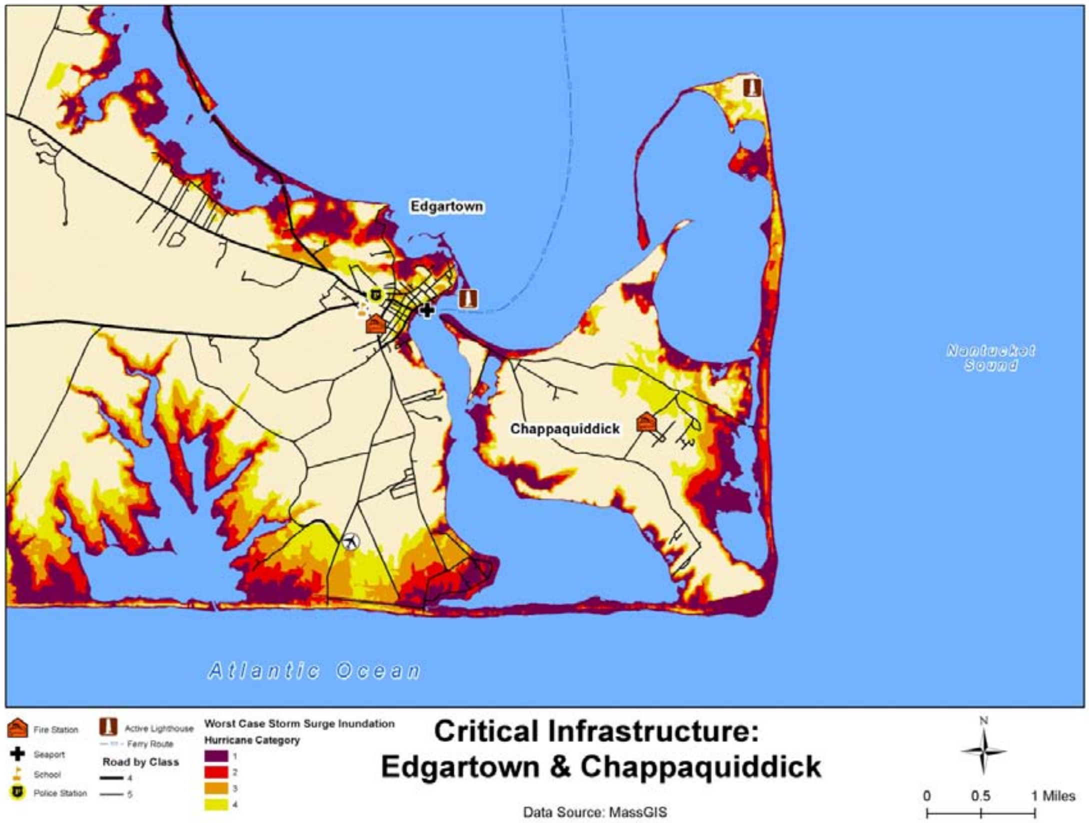




Critical Infrastructure: Gosnold



Critical Infrastructure: Aquinnah & Menemsha


Edgartown
Chappaquiddick
Nantucket Sound
Atlantic Ocean
Fire Station
Seaport
School
Police Station
Active Lighthouse
Ferry Route
Road by Class
4
5
Worst Case Storm Surge Inundation
Hurricane Category
1
2
3
4
Critical Infrastructure:
Edgartown & Chappaquiddick
Data Source: MassGIS
N
0
0.5
1 Miles

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