A VALIDATION ASSESSMENT OF THE HAZARDS OF PLACE MODEL OF VULNERABILITY FOR NORTHEASTERN NORTH CAROLINA

by

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As societal development continues to increase in floodplains, it is important to quantify the vulnerabilities associated with flooding. Using northeastern North Carolina as the study area, this thesis estimates the hazards of place model of vulnerability for sixteen counties in Northeastern North Carolina. The hazards of place model of vulnerability is developed from the combination of two quantitative indicators: the Geophysical Risk Index (GPRI) which incorporates two types of geophysical risk factors (percent of block group within the floodplain and the percent of human development within the floodplain); the Social Vulnerability for Evacuation Assistance Index (SVEAI) which examines four evacuation dimensions of U.S. census data (population and building structures, differential access to resources, special evacuation needs, and a combination of every dimension).

Using the hazards of place model of vulnerability, this thesis prioritizes low, medium, and high risk block groups into a matrix classification. The results from the matrix classification are validated by a sub-block group analysis of parcel data and an interview with one emergency official. Results reveal that the inclusion of human development land cover data and the combination of census data are important factors for estimating the hazards of place model of vulnerability. However, the interview suggests that there are a few geophysical and social systems that could not be identified by quantitative indicators. Overall, the matrix classification

of the hazards of place model of vulnerability was successful at prioritizing levels of risk in the study area.

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Chapter 1

Introduction

Flooding is the most common natural hazards in the world today (Kron 2005; FEMA 2010). Floods are capable of destroying drainage systems, causing raw sewage to spill out into bodies of water, damaging building structures, generating economic stress, causing surface erosion, and contribute to human deaths (FEMA 2010; National Geographic 2010). These findings serve to highlight the destructive capabilities of flooding, specifically in the United States.

According to FEMA (2010), floods cause approximately $3 billion in property damages every year. Property damages are caused by hydrodynamic forces, debris impact, hydrostatic forces, soaking, sediment, and contamination (FEMA 2010). These damages are usually experienced by populations that have developed their communities in areas that are flood prone. A natural floodplain is an example of an area in which flooding is more likely to occur, and floodplain development has contributed to heightened human vulnerability to flood risk.

When flooding events occur, floodplains with lower populations and less structural development receive minimum damages compared to floodplains occupied by larger populations with more development (Gerritsen 2005). Increased structural developments in floodplains increase impervious surfaces and reduce the amount of storage volume in natural retention areas which increases flood hazard potential, particularly for flash flooding (Kron 2005). In the United States, floodplains are the home to approximately 9.6 million households and $900 billion worth of property are subject to flood risk (FEMA 2010).

Since structural development contributes to human flood hazard potential, considerable effort has been made to establish federal programs like the National Flood Insurance Program (NFIP) to reduce floodplain development (FEMA 2010). The NFIP allows property owners in communities to purchase insurance as a protection against flood losses and damages. In exchange for insurance, the communities must agree to adopt and enforce floodplain management regulations to reduce future flood damages (FEMA 2010). The insurance acts as an alternative to disaster assistance to reduce the costs of damages caused by flooding (FEMA 2010).

According to FEMA (2010), approximately 20,000 communities participate in the NFIP. These communities are provided flood insurance if the floodplain management regulations are adopted and enforced, which must meet the minimum requirements of the NFIP (FEMA 2010). The community is responsible for issuing or denying floodplain development permits, inspecting all development, maintaining floodplain development records, preparing and revising floodplain maps, and providing information to residents about flood hazards.

Although the NFIP provides communities with flood insurance to reduce floodplain development, individuals who live in floodplains are still vulnerable to flooding, and they can range in levels of vulnerability due to differences in social and economic characteristics that predispose their susceptibility to flooding (Kelly et al. 2000; Tockner et al. 2002; FEMA 2010). Populations living in the floodplains can be described using various socioeconomic characteristics such as income, minority, elderly, single parent home, and handicap status (Cutter et al. 2000, 2003).

Social factors can also influence risk perception and response, thereby making individuals located in certain places even more vulnerable to hazards (Cutter et al. 2000). Factors that can influence risk perception include the following: lack of access to economic or information resources; limited access to political power; social capital; physically limited individuals; and household infrastructure (Cutter et al. 2000). Spatial differences in these characteristics give rise to differing levels of flood vulnerability and variations in the ability to respond and recover from the hazard (Borden 2007).

Recent flooding events in the United States or brought to light societal inequalities by revealing an individual's exposure to flood risk and ability to cope with floods. For example, the inability to access resources, failure of emergency planning and response systems, and late responses to residential evacuations increased the human death rates from flooding during the events of Hurricane Katrina in New Orleans, Louisiana (Cutter et al. 2000, 2003; Thomalla 2006). The floods from Hurricane Katrina destroyed many low income residential communities and left many survivors homeless (Thomalla 2006). Inadequate reactions to Katrina's aftermath were not solely based on the failures in emergency response but also to failures to sustain the social support systems of the city's poorest populations (Cutter 2005).

Impacts from Hurricane Katrina illustrate the differential effects of flooding on society. Although floods are difficult to prevent, it is possible to measure geophysical risk of flood occurrence and social vulnerability to flood hazard by using quantitative indicators, which can be used to evaluate the vulnerability of places. Indicators like the Geophysical Risk Index (GPRI) and the Social Vulnerability for Evacuation Assistance Index (SVEAI) are appropriate models to measure flood risk and estimate place vulnerability metrics (Chakraborty et al. 2005).

The *hazards of place* concept is defined as a combination of geophysical risk and social vulnerability, which describes hazard vulnerability within a geographic area or domain (Cutter 1996; Cutter et al. 2003). As stated by Cutter (1996), hazards of place can be considered an integration of both geographic and social space. Geographic space is defined as the location where vulnerable people and places are located (Cutter 1996). Social space includes the places where the most people are vulnerable (Cutter 1996). These concepts exemplify the main focus of this analysis, to develop hazards of place models describing flood hazard vulnerability for a northeastern North Carolina study area encompassing sixteen counties. A further discussion of these concepts will be examined in future chapters.

1.1 Research Problem

Existing methods have not been tested in their ability to integrate floodplain and human development data with socioeconomic variables to illustrate patterns of vulnerability and validate the Hazards of Place Model of Vulnerability (Cutter 1996) for Northeastern North Carolina. Therefore, the goal of this research is to estimate the hazards of place model of vulnerability for sixteen counties in Northeastern North Carolina. This research intends to prioritize low, medium, and high risk block groups and provide a sub-block group analysis of parcel data for a quantitative and qualitative validation assessment of the Hazards of Place Model of Vulnerability (Cutter 1996) in northeastern North Carolina.

1.1.1 Research Objectives

The main objective of this research is to produce an alternative for the Hazards of Place Model of Vulnerability (Cutter 1996) for northeastern North Carolina, using both quantitative and qualitative methods. The objective behind the validation process is to determine whether the results from the quantitative indicators are valid. More specific objectives are as follows:

1) To determine the appropriate geophysical risk and social vulnerability factors for the hazards of place model. The selection process is based on a correlation analysis and a visual assessment of the spatial patterns of the geophysical risk and social vulnerability models.

2) To examine hazards of place metrics through a correlation analysis and visual assessment of the spatial distribution maps. Hazards of place metrics are calculated using the geophysical risk and social vulnerability metrics.

3) To create a hazards of place matrix based on the groupings of the hazards of place metrics. The hazards of place analysis combines geophysical risk and social vulnerability metrics to establish a classification of block groups, ranging from low to high place vulnerability.

4) To perform sub-block group analyses to further validate the results from the hazards of place matrix. The hazards of place matrix is examined using parcel level data for validation purposes.

5) To validate the hazards of place results through an interview analysis. The validation process uses the results from the quantitative analysis for an interview. A thirty to forty five minute interview will be conducted with an emergency official. The interview analysis addresses whether other dimensions of geophysical risk and social vulnerability exist that could not be identified through the quantitative analysis.

1.1.2 Research Questions

As stated earlier, the main objective of this research is to validate the hazards of place metrics. This research seeks to answer five questions about the hazards of place in northeastern North Carolina. The research questions that guide this analysis include the following:

1) Is there an association between the spatial patterns of biophysical vulnerability for different Geophysical Risk Index (GPRI) measures? Does the inclusion of human land cover data representing locations of human activity make a difference?

2) Is there an association between the spatial patterns of social vulnerability for different Social Vulnerability for Evacuation Assistance Index (SVEAI) measures? How similar or different is social vulnerability, depending on the choice of input variables?

3) How do patterns of social vulnerability compare to the patterns of geophysical risk? How does the interaction of geophysical risk and social vulnerability contribute to hazards of place vulnerability?

4) To what extent does a sub-block group level analysis using land parcel and air photos validate the hazards of place results? How well do the results perform?

5) Based on interview data with a local emergency planner, how well do the result perform? Do results agree with expert local knowledge?

1.1.3 Benefits of Research

The research is important for various reasons for both the academic and applied professional community that relate to flood risk and mitigation:

1) It integrates multiple quantitative models to estimate hazards of place metrics, and groups them into a hazards of place matrix to reveal patterns of place vulnerability. These patterns may be useful to emergency managers.

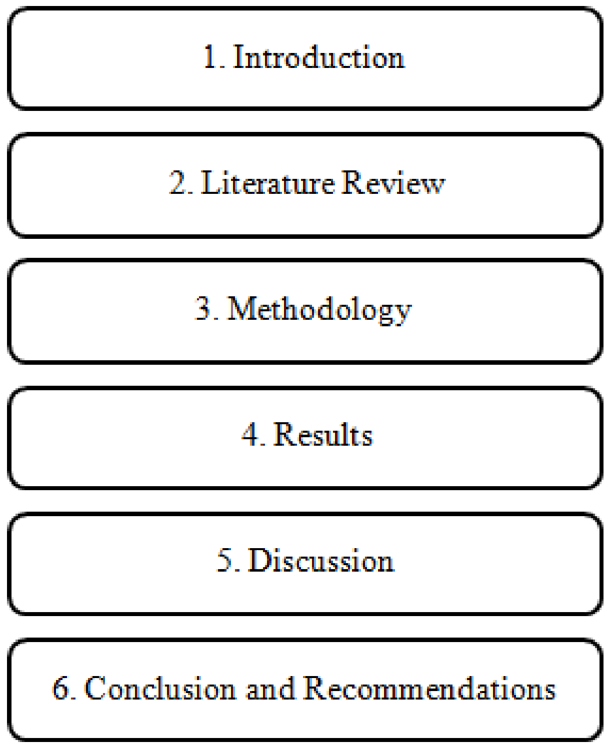
2) It validates the hazards of place metrics through quantitative and qualitative analysis.

3) It provides other dimensions of social vulnerability, geophysical risk, and place vulnerability through an interview analysis with an emergency informant.

1.1.5 Research Structure

This research focuses on the objectives mentioned in Section 1.1.1 of this chapter. The structure of this thesis consists of six chapters, shown in Figure 1. Chapter 1 includes background information on the research, the research objectives, benefits of the research, and thesis structure. Chapter 2 serves as a review of the literature review that informs this research and includes a discussion of geographical hazard literature, the concepts of risk, methodological issues related to the use of quantitative social indicators and social vulnerability indices. Chapter 3 describes the characteristics of the North Carolina study area and describes the research methodology. Chapter 4 presents the results and determines whether the research questions can be answered. Chapter 5 discusses the implications of this research for flood risk. Finally, Chapter 6 concludes this analysis and provides recommendations for future research.

Figure 1. Research Structure



Chapter 2

Literature Review

The concepts of social vulnerability, geophysical risk, and the hazards of place model are identified in this chapter because they form the theoretical and analytical foundation guiding this research. It is the purpose in this literature review to explain the history of hazards research, define the main concepts of vulnerability, discuss the origins of the social indicators movement, and to evaluate human development in natural floodplains.

2.1 Hazards Research

The purpose of this section is to provide information about the field of natural hazards and disaster research. This section aims to explain the intellectual trajectory of hazards research, primarily focusing on geographical contributions but also covering other disciplinary contributions given the multidisciplinary nature of the topic. It begins with an outline of the history of hazards research and the scientific contributions to the field. It concludes with a discussion of the progression of hazards research.

2.1.1 History of Hazards Research

Contributions to the origins of hazards research is are not chronologically organized in the literature (Cutter et al. 2000; Peek et al. 2002). In a discussion of the origins of hazards research, Peek et al. (2002) identify John Dewey as an early and significant contributor to hazards research. John Dewey explored social behavior using a human ecological perspective. He believed that humanity exists in a hazardous world that can cause humans to be insecure in their own environment (Peek et al. 2002).

Academic researchers also took interest in hazards research during the 1960s. According to Peek et al. (2002), Dewey's ideas influenced the geographer Gilbert White to focus on natural hazards research and management. White believed that the interaction between both social and natural forces result in hazards and disasters (White 1974). He also believed that hazard impacts can be reduced through individual and social adjustment mechanisms (White 1974). The major purpose of White and his research team's research was to identify hazards and analyze the range of adjustments that were available to society (Cutter et al. 2000).

Cutter et al. (2000) traced the origins of geographical hazards research further back to Harlon Barrows, and his research entitled, "Geography as Human Ecology" (Barrows 1923). Barrows and his students were interested in a human ecological approach and researched how individuals and society adjust to environmental extremes (Barrows 1923). One of Barrow's main contributions was the initiation of the human ecological approach within geography that focused on how society copes with environmental hazards, specifically flooding (Barrows 1923; Cutter et al. 2000).

2.1.2 Progression of Hazards Research

Hazards research became popular within multiple scientific disciplines during the 1970's (Peek et al. 2002). During this time, geographer Gilbert White and sociologist Eugene Haas published the United States first comprehensive assessment of natural hazards (White et al. 1975; Peek et al. 2002). The report published by White et al. (1975) entitled, "Assessment of Research on Natural Disasters," provided a direction for national policy.

Mileti (1999) included the second national assessment of hazards and disasters in his publication of "Disasters by Design: A Reassessment of Natural Hazards in the United States." This publication was created in 1990s at the University of Colorado's Natural Hazards Center, and summarized relevant hazards information in every field relating to science and engineering, evaluated the success or failures of various United States programs designed to reduce human vulnerability, and suggested recommendations for future work and approaches (Mileti 1999). As a result, the assessment created a holistic model for future programs and research on hazards (Mileti 1999). These programs linked hazard mitigation, planning response, recovery, and reconstruction to sustainable development (Mileti 1999; Peek et al. 2002). The holistic approach received national recognition and is credited as the framework for national and international programs (Peek et al. 2002).

2.2 Vulnerability

Vulnerability has an established history in geography and natural hazards literature (Cutter et al. 2000). The scientific use of the term has become a central concept in numerous disciplines (Cutter et al. 1996, 2000, 2003, 2008; Brooks 2003; Ligon et al. 2003; Chakraborty et al. 2005). In addition, disciplines including economics, political ecology, physical science, anthropology, psychology, and engineering have all incorporated vulnerability concepts into hazards research (Cutter 1996; Adger 2006). Each discipline incorporates their own definition of vulnerability into academia (Brooks 2003). This section will focus on the definitions and framework of vulnerability.

Before vulnerability is defined, it is helpful to examine the root etymology of vulnerability. The root of vulnerability originates from the Latin word *vulnus* and *vulnerare*, meaning to wound or be wounded (Kelly et al. 2000; Merriam Webstar 2010). Kelly et al. (2000) acknowledge the Late Latin word *vulnerabilis* as one of the largest contributions to vulnerability. *Vulnerabilis* means enlightening, which was used by the Romans to describe a wounded soldier at risk of a future attack on the battle field (Merriam Webstar 2010). This interpretation relates to the modern usage of vulnerability as it explains the preexisting conditions of a group being affected by future hazard outcomes (Kelly et al. 2000).

2.2.1 Defining Vulnerability

The literature provides examples of various definitions for vulnerability (Cutter 1996; Clark et al. 1998; Cutter et al. 2000; Kelly et al. 2000; Cutter et al. 2003; Borden et al. 2007;). This research focuses on definitions and themes provided specifically by the hazards literature. Hazards literature defines vulnerability as a system's susceptibility to harm and losses from natural hazards in specific locations (Cutter 1996; Clark et al. 1998; Cutter et al. 2003; Borden et al. 2007; Kelly et al. 2000). A system consists of individuals, locations, or infrastructures that respond to changes in hazards (Borden et al. 2007; Kelly et al. 2000). Kelly et al. (2000) define vulnerability as the capacity to be physically damaged. Cutter (1996) has defined vulnerability simply as the potential for loss.

Expanding on this literature, this analysis focuses on two broad categories of vulnerability (Cutter 1996). The first relates to geophysical risk which is concerned with the impacts of a hazard event (Cutter 1996; Brooks 2003; Schmidtlein et al. 2008). Geophysical risk is often viewed in terms of the amount of damage experienced by a system as a result of an encounter with a hazard exposure or measuring a population's sensitivity to natural disasters (Brooks 2003). The amount of damage from these natural disasters enhances vulnerability (Adger 1999).

The theme for the second attribute, social vulnerability, identifies itself as society's resilience or ability to anticipate, cope, resist, and recover from the impact of a natural hazard (Adger 2000; Cutter et al. 2008; Schmidtlein et al. 2008; Kelly et al. 2000). The framework behind social vulnerability consists of social differences or inequalities within a population (Wisner et al. 2004; Cutter et al. 2006). Populations can vary across different social factors or socio-economic structures that make them more susceptible to loss (Cutter et al. 2003; Yamin 2005). Social factors might include household income, occupation, ethnicity, gender, health status, age, race, family, and the nature and extent of social networks (Cutter et al. 2003; Wisner et al. 2004). These socio-economic groups experience the negative impacts from hazardous events, such as hunger, famine, economic loss, or the loss of productive assets (Wisner et al. 2004). This research incorporates the socioeconomic aspects of social vulnerability.

2.2.2 Themes within Vulnerability

Cutter et al. (2000) identifies three primary themes within vulnerability research. These themes can help organize our understandings of how people and places are differentially vulnerable to environmental hazards (Cutter et al. 1996, 2000). The first theme, *vulnerability as a pre-existing condition*, examines the potential exposure or risk of geophysical or technological hazards (Cutter 1996). This theme focuses on the distribution of hazardous conditions, human occupancy of hazardous zones, and the potential loss from a natural disaster (Cutter 1996). Research related to this theme examines the distribution of structural losses and vulnerability reduction from natural disaster events (Cutter 1996).

The second theme, *vulnerability as tempered response*, is concerned with society's resistance to hazards, its resilience to hazards, and its ability to cope with disasters (Cutter 1996). According to Cutter (1996), the nature of a hazardous event is viewed as a social construct, rather than a geophysical condition. The research relating to this theme examines environmental disturbances such as climate change, drought, environmental change, and famine (Cutter 1996). This theme sets up the social dimension of vulnerability by focusing on how societies define hazards as well as their ability to cope and respond to disasters (Cutter 1996).

The third theme, *vulnerability as hazard of place*, is used as the theoretical framework for this analysis. The Hazards of Place Model of Vulnerability (Cutter 1996) takes ideas from the first two themes by determining vulnerability within specific locations (Cutter 1996). This theme combines aspects of geophysical risk and social response within a specific location (Cutter 1996). The location consists of areas where vulnerable people and places are located or the individuals in those places that are most vulnerable (Cutter 1996).

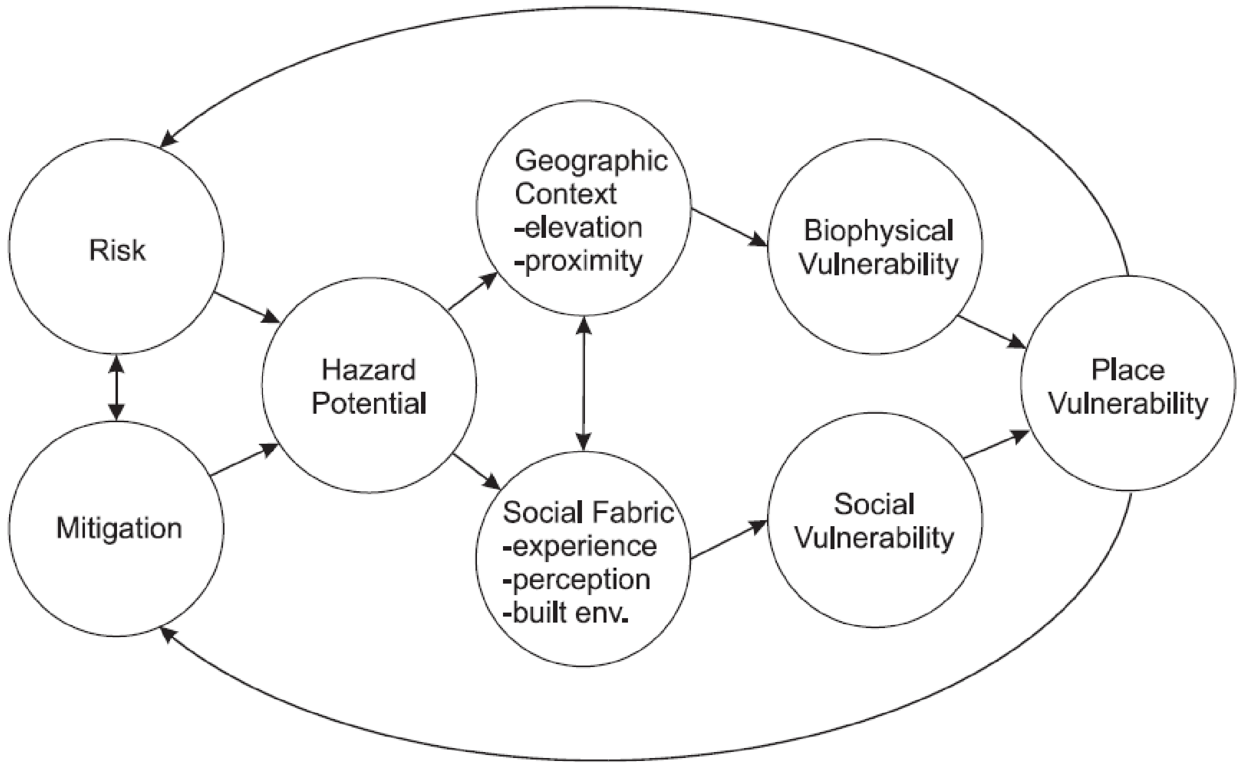
Growing literature exists that incorporates the third theme of hazards of place (Cutter 1996; Cutter et al. 2003). Cutter (1996) attempted to unify the approaches of societal exposure and social conditions by developing the Hazards of Place Model of Vulnerability (Cutter 1996). The model serves as an alternative for understanding the factors that contribute to the vulnerability of places (Cutter 1996). Figure 2 illustrates the original version developed by Cutter (1996).

The model begins with risk and mitigation. Risk combined with mitigation produce an overall hazard potential (Cutter 1996). According to Cutter (1996), the hazard potential is passed through the social fabric of society to determine the social vulnerability of place. The hazard potential is also passed through geographic context to determine geophysical vulnerability (Cutter 1996). The product of geophysical risk and social together create place vulnerability (Cutter 1996). Place vulnerability eventually loops back to the beginning of the model, which reduces or enhances risk and mitigation (Cutter 1996).

2.3 Measuring Vulnerability

One way researchers attempt to study vulnerability is through measurement. This research attempts to measure and identify vulnerable populations by incorporating quantitative and qualitative measures. To identify vulnerable populations, social indicators were developed as a measurement tool to provide statistical information to explain human tribulations (Cobb et al. 1998). Cobb et al. (1998) defines a social indicator as a set of quantitative data that serve as a metaphor for problem that is not directly measurable. To understand the rationale of social indicators, a literature review of its foundation into vulnerability research is required. This section explains the origins and types of social indicators used in vulnerability research.

Figure 2. The Hazards of Place Model (Source: Cutter 1996)



2.3.1 The Social Indicators Movement

The social indicators movement paradigm was shaped by a series of published reports during the twentieth century (Cobb et al. 1998; Michalos 2004). The first report of this paradigm, *Recent Social Trends*, was published in 1933 (United States, President's Research Committee on Social Trends et al. 1933). This report is acknowledged as the predecessor for social measurement publications. The social indicators movement further gained popularity in the United States as an approach for guiding public policy during the 1960's (Cobb et al. 1998; King et al. 2000; Gahin et al. 2001; Cutter et al. 2003). Some of the problems in public policy included domestic issues in poverty, race, unemployment, and public housing (Gahin et al. 2001).

In 1966, the requirement for an improved public policy lead to the development of a project entitled, *Social Indicators* (Bauer 1966). This project published a collection of statistics as a social report (Cobb et al. 1998). Another publication issued by the U.S. Department of Health and Welfare entitled, *Toward a Social Report*, established an annual social report (U.S. Department of Health, Education and Welfare 1969). The purpose of this publication was to enhance social indicators research and encourage its continued development (U.S. Department of Health, Education and Welfare 1969; Cobb et al. 1998).

Organizations like the Russell Sage Foundation and the Social Science Research Council were responsible for funding community indicators projects and other data orientated approaches to developing social indicators (Cobb et al. 1998). The Russell Sage Foundation published *Indicators of Social Change* in 1968, a volume that was a successor to the *Recent Social Trends* publication from the 1930s (Sheldon et al. 1968). One of the editors of the publication, Eleanor Bernert Sheldon, wanted to improve social indicators research by suggesting an inductive approach (Sheldon et al. 1968). This inductive approach consisted of the following ideas: gathering descriptive data; developing categories that would allow significant generalization; working towards an analysis of social change (Cobb et al. 1998).

There was another approach supported by the Russell Sage Foundation entitled *The Human Meaning of Social Change*, which was published to improve social indicators research during this time. This report focused on the subjective measurement of well-being (Campbell et al. 1972). According to Campbell et al. (1972), the subjective measurement of well-being measures an individual's perception of their current state of mind. The concept of measuring human perceptions received credibility by appearing in the *Social Indicators Research* journal (Cobb et al. 1998).

Interest in social indicators research began to decline in the late 1970's (Cobb et al. 1998; Gahin et al. 2001). The declined interest can be attributed to a couple of factors including reduced government finances and governments adapting to more conservative priorities (Sharpe 1999). According to Cobb et al. (1998), political pressures from the government influenced social indicator reports to provide only descriptive statistics with limited interpretation. These descriptive statistics were strong at acknowledging factual information but could no longer explain social measures (Cobb et al. 1998). Organizations like the Center for Coordination of Research on Social Indicators began to lose funding and eventually closed (Gahin et al. 2001).

2.3.2 Legacy of Social/Environmental Indicators

Although the social indicators movement was over in the early 1980's, international agencies were influenced by the movement's contribution to (Cobb et al. 1998). Concerns over the environment influenced the creation of new indicators during the 1980s (Cobb et al. 1998; Gahin et al. 2001). The social indicators movement led to development of environmental indicators (Cobb et al. 1998; Gahin et al. 2001). Organizations like the Council on Environmental Quality and the Environmental Protection Agency began to contribute to environment indicators by publishing reports and developing indicators to monitor the stability of the environment (Cobb et al. 1998; Gahin et al. 2001). In countries outside of the United States, new approaches were developed by researchers (Cobb et al. 1998). For example, the Pressure State Response Framework was one of the approaches created in Canada and the Netherlands (Cobb et al. 1998).

The social indicators movement experienced a revival in the late 1980's and early 1990's (Cobb et al. 1998; Gahin et al. 2001). The next decade of environmental indicators had less motivation from federal agencies and major national institutions (Cobb et al. 1998). There was a greater emphasis on sustainable development, and sustainability indicators were models that determined the relationships between social, environmental, and economic concerns (Cobb et al. 1998).

2.3.3 Modern Conceptual Models

Recent conceptual models have been developed to measure vulnerability by integrating Geographic Information Systems (GIS) and quantitative, social indicator metrics (Adger 2006; Cutter et al. 2003). This analysis focuses on current models that relate to the goals of this research. Models relating to this analysis are separated into two categories: indicators that measure only social vulnerability, and indicators that integrate social vulnerability and geophysical vulnerability.

Cutter et al. (1997) created a handbook for measuring social vulnerability in Georgetown County, SC. This handbook provided county emergency managers with a method for identifying the most vulnerable areas to flooding, and included a step by step guide for creating a Social Vulnerability Index (SoVI), which is credited as one of the first modern indicators that measured social vulnerability to hazards risk. The original SoVI only measured the social aspects of vulnerability. The combination of geophysical risk and the social vulnerability elements of the Hazards of place Model served as a framework the SoVI.

The SoVI used United States county census data from 1990 (Cutter et al. 1997). A subset of eight socioeconomic variables was included in the model to estimate the levels vulnerability (Cutter et al. 1997). These variables were selected because they encompassed the factors of previous research on disaster vulnerability, including social factors as age, gender, race, house value, and income status (Cutter et al. 1997). Once each social variable was standardized, the physical hazard and social vulnerability zones were overlaid to map the total vulnerability (Cutter et al. 1997).

Cutter et al. (2000) expanded upon their research in Georgetown County, SC. The SoVI model developed by Cutter et al. (1997) and Cutter (2000) used similar variables. These variables included total population, total housing units, number of females, number of nonwhite residents, number of people under age 18, number of people over age 65, and mean house value (Cutter et al. 2000). The SoVI calculation followed the same procedure as the SoVI developed by Cutter et al. (1997). The standardized values were summed for each block group to standardize the variables to produce an aggregate value for social vulnerability (Cutter et al. 2000). The results were combined with values from geophysical vulnerability aggregate results using GIS.

2.3.4 Applications and Models of SoVI

The following indicators incorporate geophysical risk and social vulnerability elements. The Social Flood Vulnerability Index (SFVI) was developed to measure the impact of floods in communities (Tapsell 2002). Tapsell (2002) used the SFVI to predict areas and populations that are likely to be most affected in terms of health and other flood impacts (Tapsell 2002). The variables used for Tapsell's research were elderly, single parents, preexisting health problems, and financial deprivation (Tapsell 2002).

Wu et al. (2002) incorporated the SoVI but used different socioeconomic variables to produce an overall flood vulnerability map with flood hazard zone data (Wu et al. 2002). The map depicts how sea level rise increases the vulnerability of populations and high risk areas in Cape May County, NJ (Wu et al. 2002). The results from the flood vulnerability map illustrate an increase in vulnerability and exposed populations to the risk of flooding (Wu et al. 2002).

Chakraborty et al. (2005) provides the framework for the methodology approach that will be used in this thesis. Their analysis develops a Geophysical Risk Index (GPRI) and a Social Vulnerability for Evacuation Assistance Index (SVEAI). The GPRI was developed to represent the probabilities of occurrence for hurricanes and tropical storms (Chakraborty et al. 2005). Metric values were calculated by summing the two individual probabilities together (Chakraborty et al. 2005).

The SVEAI was created as a method to compute and illustrate the spatial patterns of social vulnerability in Hillsborough County, FL with respect to the need for flood evacuation assistance. The SVEAI follows the same framework as the SoVI by inputting and standardizing variables. However, there are two differences between the SVEAI and SoVI (Cutter et al. 2003 and Chakraborty et al. 2005). First, rather than using the Principle Components Analysis to reduce and standardize input variables, the SVEAI standardizes variable metrics using the maximum value ratio observed in each county (Chakraborty et al. 2005). The maximum value ratio determines the ratio value of the variable in the block group to the total number of that variable in the county. Second, the SVEAI separates the variables into three categories:

population and structure; differential access to resources; and population with special evacuation needs (Chakraborty et al. 2005)

The results from the GPRI and SVEAI metrics illustrate the spatial distribution of vulnerability in the study area (Chakraborty et al. 2005). Findings from the results indicate that specific areas with high GPRI metric values are not the same as the areas with high SoVI metric values. Also, the variables used in the vulnerability analysis identified approximately 40,000 to 150,000 people who live in the high risk areas (Chakraborty et al. 2005). These results help emergency officials develop more accurate emergency plans for evacuation purposes.

The hazards literature identifies other indicators and methods to guide the decision making process for disaster risk management (Cardona 2006; Chakraborty et al. 2005; Cutter 1996). Cardona (2006) identified four indicators that measured risk accurately to reduce and control it. The Disaster Deficit Index (DDI) allows decision makers to measure county risk from a financial perspective, by estimating the economic loss that a specific county could suffer when a natural disaster occurs (Cardona 2006). The Prevalent Vulnerability Index (PVI) determines a county's pattern of vulnerable conditions by measuring exposed areas (Cardona 2006). The Prevalent Vulnerability Index (PVI) measures exposure in hazard prone areas and the lack of social resilience to illustrate vulnerable conditions (Cardona 2006). The Risk Management Index (RMI) combines a group of indicators to measure a county's risk management performance (Cardona 2006).

FEMA (2010) developed the HAZUS software program for mitigation, recovery, and preparedness to natural disasters. HAZUS estimates losses from natural disasters, including flooding (FEMA 2010). According to FEMA (2010), HAZUS incorporates Geographic Information Systems (GIS) to estimate geophysical and social impacts from natural disasters.

The software provides users with the ability to create a pre-disaster planning process by providing a visual representation of the spatial relationships between populations and structures for the specific hazard being modeled (FEMA 2010).

2.4 The Physical Environment

A literature review of the physical environment of floodplains is required to understand human vulnerability in flood prone areas. The first section defines floodplains through various literature (Holway et al. 1990; Bender 1991; Nanson et al. 1991; Gerritsen et al. 2005). Determining the contribution of development to vulnerability is highlighted in the following section. This section focuses on the positive and negative contributions of floodplains in society. The final section identifies various literatures relating to floodplains and vulnerability.

2.4.1 Understanding Floodplains

The literature presents several definitions for floodplains (Holway et al. 1990; Bender 1991; Gerritsen et al. 2005). A majority of the meanings of floodplains presented in literature include flooding or inundation into their definition (Junk et al. 1989; Nanson et al. 1991; Tockner 2002). Literature from Montz et al. (1986), Few (2003), and Kron (2005) defines floodplains as representations of sediment sinks with low lying surfaces that accumulate water and undergo processing for long periods of time. Tockner et al. (2002) broadly defines floodplains as areas of low lying land that are more susceptible to flooding by the overflow of water from associated bodies of water. Floodplains can be specifically defined as land that is capable of being inundated by the overflow of lakes, rivers, deltas, estuaries, or direct precipitation (Junk et al. 1989; Nanson et al. 1992; Tockner 2002).

Bender (1991) and Nanson et al. (1992) explain different perspectives in the literature that define floodplains. The topographic explanation defines floodplains as flat surfaces that are adjacent to a stream (Bender 1991). In geomorphology, floodplains are defined as a landform composed of unconsolidated material from sediments that are transported by a stream (Bender 1991). The geomorphology definition of floodplains provided by Nanson et al. (1992) is explained as the horizontally bedded alluvial landform adjacent to a channel and built of sediment transported by the current flow regime.

This research focuses on the hydrological explanation as opposed to geographic, which is defined as a landform that is susceptible to periodic flooding from a nearby stream (Bender 1991). According to Bender (1991), the amount of time a floodplain is considered flooded depends on the size of the stream, the channel slope, and the characteristics of the climate. The hydrological definition provided by Nansen et al. (1992) is explained as the surface next to the channel that will eventually be flooded. These definitions serve as a background for understanding the risk of human development in floodplains.

2.4.2 Human Activities in Floodplains

Depending on how the land is used and developed determines a population's level of vulnerability to flooding (Burton et al. 1968; Bender 1991; Kron 2005; FEMA 2010). Bender (1991) provides a couple of examples that explain how variations in development increase human vulnerability to flooding. First, floodplain development increases surface runoff rates because the rate in which the surface land area can absorb rainfall is decreased (Burton et al. 1968; Bender 1991; FEMA 2010). Thus, the rate in which the water flows into the sewers and drainage systems are increased (Kron 2005; FEMA 2010). Second, deforestation and overgrazing practices are other examples that increase human vulnerability (Bender 1991). Both of these practices decrease vegetation cover and expose soil to erosion which reduces the lands level of flood absorption (Bender 1991; FEMA 2010).

There are numerous factors that contribute to the vulnerability of populations in developed floodplains (Gerritson et al. 2005; Kron 2005; FEMA 2010). The most important factor that contributes to this research involves the alteration of runoff conditions from human development (Bender 1991; FEMA 2010). The alteration of runoff conditions produces population vulnerability in areas where impervious surfaces, gutters, storm sewers, are located (FEMA 2010). By altering runoff conditions, flash floods are more likely to happen from an increase of stream flow during normal rainfall cycles (Bender 1991; Kron 2005; FEMA 2010).

The literature presented above illustrates the importance of minimizing development in natural floodplains. Significant research in the floodplain literature has identified numerous reasons for preserving natural floodplains (Gerritsen et al. 2005). Reducing human development in natural floodplains increases the strength of flood defenses from flooding events, and reserves environment stability (Gerritsen et al. 2005). Gerritsen et al. (2005) explain that natural floodplains can control flooding by floodwater detention, defined as the temporary storage of water entering a floodplain as surface runoff (Gerritsen et al. 2005). This natural system delays and reduces river peak discharge which reduces flood potential (Gerritsen et al. 2005).

Chapter 3

Methodology

The literature review from the previous chapter suggests that recent social indicators research has mainly focused on the quantification of geophysical risk and social vulnerability. While this approach is becoming more common, no previous study has rigorously validated resulting products. The lack of validation does not specify the extent to which these communities are actually vulnerable. For example, a community identified as highly vulnerable through the SVEAI estimation may not actually be vulnerable based on its physical location with respect to the hazardous area. Thus, the starting point for this analysis is to estimate the hazards of place, following Cutter's (1996) Hazards of Place Model of Vulnerability. This research defines hazards of place as the product of geophysical risk and social vulnerability. The results from the hazards of place estimation inform and guide the selection of the sub-block group analysis.

This chapter introduces the analysis through a series of procedures. First, the study area is examined. The study design is provided second, followed by the method for assembling and collecting required data. The next two sections explain the construction of geophysical risk and social vulnerability metrics for the census block groups in the study area. A statistical analysis of the geophysical risk and social vulnerability metrics is executed next to determine the relationships with the data. The metrics are used to calculate hazards of place metrics and create the hazards of place matrix. The final section explains the validation process for hazards of place results.

3.1 Northeastern North Carolina

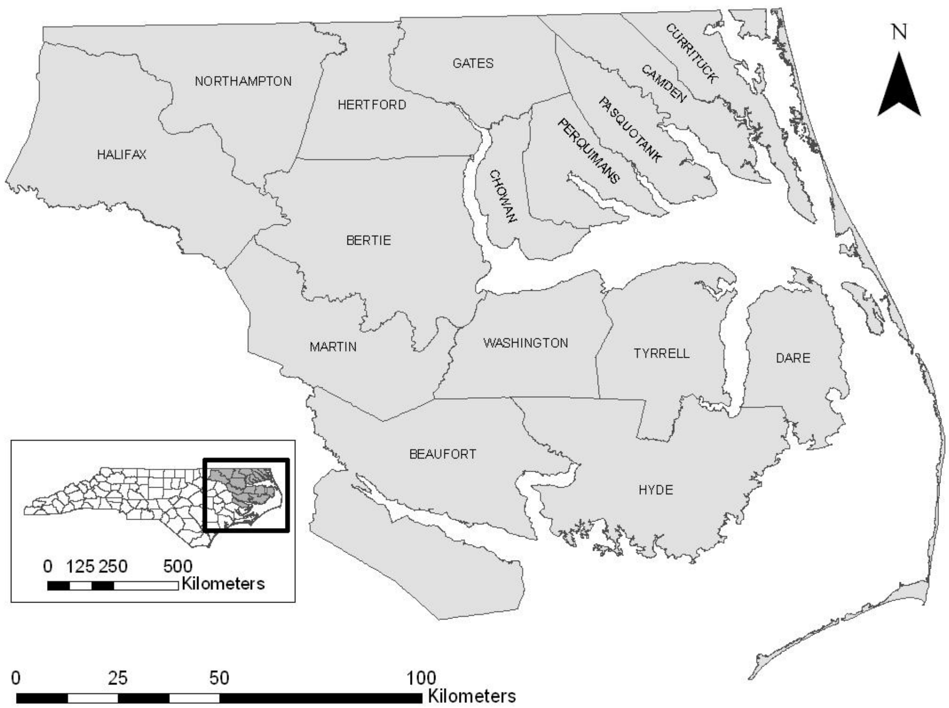
In order to estimate geophysical risk and social vulnerability, Northeastern North Carolina was selected as the study area for this research, shown in Figure 3. Northeastern North Carolina was selected because of its low lying elevation which makes it vulnerable to flooding. The region's vulnerability to natural hazards exemplifies the importance for emergency officials and communities to be aware of their flood risk environment. Also, research in Northeastern North Carolina has not examined the spatial patterns of populations living in vulnerable areas at the relatively fine census block group level of analysis.

3.1.1 Physical Characteristics

The purpose of this section is to describe the physical characteristics of the study area. Northeastern North Carolina is geographically located in the areas that extend from the Atlantic Ocean to the Piedmont Plateau. This classification is known as the Coastal Plain physiographic region (State Climate Office of North Carolina 2010). This region encompasses 24,330 km^2 in area which is the size of the state Massachusetts (Gordon 1996). Its surface is typically low-lying and contains many wetlands and lakes (State Climate Office of North Carolina 2010).

North Carolina varies in different topographical regions across the state, however, the climate remains constant (State Climate Office of North Carolina 2010). Northeastern North Carolina has a similar climate to areas with warm temperate zones (State Climate Office of North Carolina 2010). According to the State Climate Office of North Carolina (2010), the entire state of North Carolina is located at the same parallel of latitude as the Mediterranean but is

Figure 3. Study site of northeastern North Carolina



affected by its position with the ocean in the eastern region. The ocean's influence reduces change in temperature but increases the amount of precipitation (State Climate Office of North Carolina 2010).

Average precipitation in northeastern North Carolina varies each year (State Climate Office of North Carolina 2010). The greatest precipitation occurs during the summer and is often connected with frequent showers and thunderstorms, while the driest season occurs during the fall (State Climate Office of North Carolina 2010). Precipitation during the winter and spring are influenced by migratory low pressure storms, which average one inch per year during these seasons (State Climate Office of North Carolina 2010).

The State Climate Office of North Carolina (2010) also states that North Carolina accumulates the most economic loss from tropical hurricanes and flooding during the summer season. North Carolina's weather is influenced by tropical hurricanes about twice in an average year (The State Climate Office of North Carolina 2010). Tropical hurricanes produce floods which significantly damage inland property, specifically in the coastal areas of Northeastern North Carolina (The State Climate Office of North Carolina 2010). The properties of coastal communities in areas like the Outer Banks occasionally suffer severe damage from associated with floods (The State Climate Office of North Carolina 2010).

3.1.2 Population

In 2000, the coastal region had a population of 336,470 (Northeast North Carolina Commission for Economic Development 2010). The most densely populated areas in the region come from its three largest cities, Elizabeth City (population 19,056), Roanoke Rapids (population 16,505), and Washington (population 10,060) (Northeast North Carolina Commission for Economic Development). The rest of northeastern North Carolina's population is dispersed across the region in rural areas and smaller towns including Kill Devil Hills (population 6,614), Williamston (population 5,583), Edenton (population 4,989), Ahoskie (population 4,313), and Plymouth (population 3,957) (Northeast North Carolina Commission for Economic Development). The 2000 and 2010 Census population for each county is shown Table 1.

Table 1. 2000 and 2010 Census Population for each County

County Name	2000 Population	2010 Population	Percent Change (+/-)
Beaufort	44,598	46,414	+4.07%
Bertie	19,773	19,345	-2.16%
Camden	6,885	9,730	+41.32%
Chowan	14,526	14,784	+1.78%
Currituck	18,190	24,216	+33.13%
Dare	29,967	34,296	+14.45%
Gates	10,516	11,768	+11.91%
Halifax	57,370	54,582	-4.86%
Hertford	22,601	23,283	+3.02%
Hyde	5,826	5,211	-10.56%
Martin	25,593	23,337	-8.81%
Northampton	22,086	20,136	-8.83%
Pasquotank	34,897	41,578	+19.14%
Perquimans	11,368	12,734	+12.02%
Tyrrell	4,149	4,078	-1.71%
Washington	13,723	12,851	-6.35%
Total	342,068	358,343	+4.76%

3.2 Data Collection

The first stage of the methodology required assembling GIS spatial data layers for the geophysical risk and social vulnerability estimation. Assembling spatial data is mandatory to identify the hazards of place of vulnerability in Northeastern North Carolina. The spatial data used in this research are summarized in Table 2.

The second stage is to obtain land cover data to undertake the geophysical risk estimation. The final stage is to identify and obtain socioeconomic variables through Census data. Additional information from an interview with an emergency official is acquired to get the opinions, preferences, and concerns for the verification of the obtained data. The following sections describe the data methodology.

Table 2. Spatial Data

Boundary Data	County Boundaries; Source: ESRI County Block groups; Source: ESRI
Flood Data	Floodplain Maps; Source: North Carolina Floodplain Mapping Program
Development Data	Land Cover Data; Source: Multi-Resolution Land Characteristics Consortium
Socioeconomic Data	Census; Source: Census Fact Finder

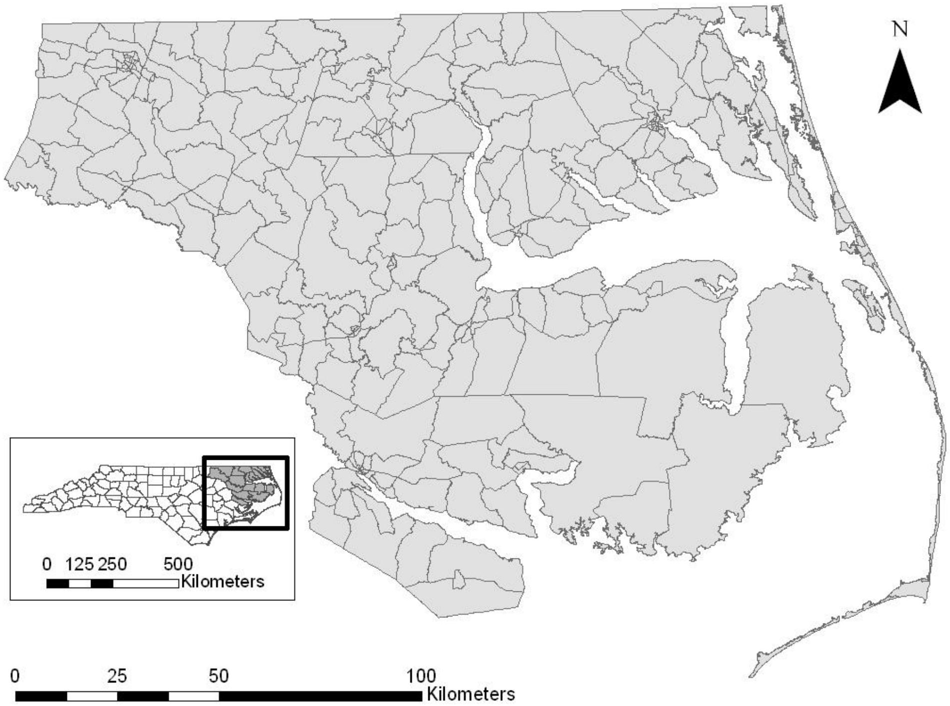
3.2.1 County Boundaries and Block Group Data

Obtaining detailed county boundaries and US Census block groups is one of the first steps for the data collection. County boundaries were provided and assembled by ESRI. The data set includes the sixteen counties of Northeastern North Carolina: Beaufort, Bertie, Camden, Chowan, Currituck, Dare, Gates, Halifax, Hertford, Hyde, Martin, Northampton, Pasquotank, Perquimans, Tyrrell, and Washington. Year 2000 US Census block groups for these counties are also obtained from ESRI (2010). The detailed county boundaries and census block groups are shown in Figure 4.

3.2.2 Flood Data

This section explains the process for obtaining flood data for geophysical risk estimation. Floodplain data were downloaded from the North Carolina Flood Mapping Program (NCFMP) website. Floodplains were represented as vector polygon feature classes, which were located in the geodatabases provided by NCFMP. Each floodplain feature class is made up of flood zones. The Federal Emergency Management Agency (FEMA) has defined flood zones as geographic areas with various levels of flood risk. Flood zones show the levels of flood risk pertaining to

Figure 4. Detailed County Boundaries and Census Block Groups



that location. Definitions for each flood zone designation are provided in Table 3. These zones are represented on a Flood Insurance Rate Map (FIRM) or Flood Hazard Boundary Map (Cutter et al 1997). For example, Figure 5 illustrates a digital flood zone map of Pasquotank County, NC, provided by the North Carolina Flood Mapping Program (2010).

Areas classified as being within the 100 year floodplain are used in this analysis. The one hundred year floodplain or 1% annual chance flood has a one percent annual chance of being equaled or flooded in any given year. The 1% annual chance flood data is made up of “A” and “AE” zones. “A” zones are areas inundated by one hundred year (1%) flooding with no established base flood elevations (FEMA 2010). “AE” zones are areas inundated by one year flooding with established base flood elevations (FEMA 2010). Figure 6 shows an illustration of

Table 3. Definitions of Flood Zones

Zone Title	Description
A	Areas with a 1% annual chance of flooding.
AE	The base floodplain where base flood elevations are provided.
AH	Areas with a 1% annual chance of shallow flooding, usually in the form of a pond, with an average depth ranging from 1 to 3 feet.
AO	River or stream flood hazard areas and areas with a 1% or greater chance of shallow flooding each year, usually in the form of sheet flow, with an average depth ranging from 1 to 3 feet.
AR	Areas with a temporarily increased flood risk due to the building or restoration of a flood control system (such as a levee or a dam).
A99	Areas with a 1% annual chance of flooding that will be protected by a Federal flood control system where construction has reached specified legal requirements.
V	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. No Base Flood Elevations are shown within this zone
VE	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. Whole-foot Base Flood Elevations derived from the detailed hydraulic analyses are shown at selected intervals within this zone
X	Areas that are determined to be outside the 100 and 500 year floodplains.
D	Areas with possible but undetermined flood hazards. No flood hazard analysis has been conducted.

the 1% annual chance flood (North Carolina Department of Crime Control and Public Safety 2008).

3.2.3 Human Development Land Cover Data

Past research has not included land cover data in the framework for measuring vulnerability. This analysis attempts to use land cover data as one of the dimensions of the

Figure 5. Digital Flood Zone (Source: NC Floodplain Mapping Program 2011)

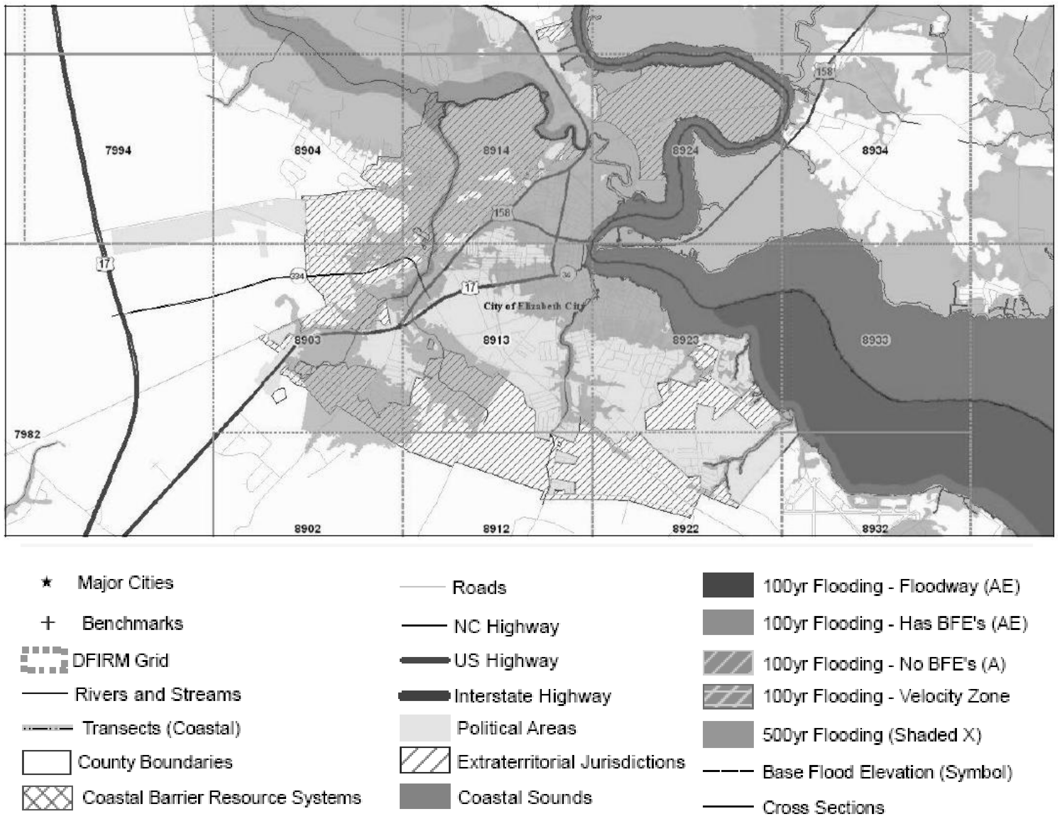
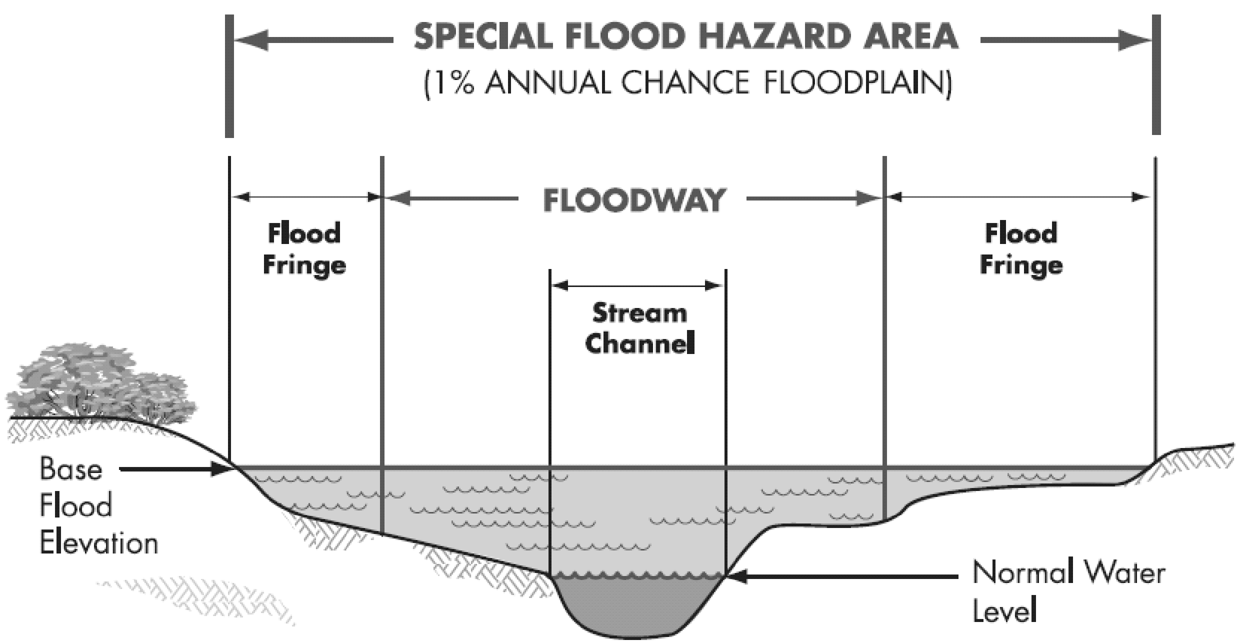


Figure 6. 1% Annual Chance Floodplain (Source NC Floodplain Mapping Program 2011)



vulnerability matrix classification system. The inclusion of land cover data is important to determine where human development is actually located with respect to floodplain zones. The Multi-Resolution Land Characteristics (MRLC) Consortium provides 2001 land cover data sets for the United States. The MRLC provides sixteen, regional superzones available for download. The state of North Carolina requires Zone 13 and Zone 14 for complete state coverage which were downloaded and clipped in *ArcGIS Desktop 9*.

The land cover data set is a raster data layer with various categories. There were originally a total of twenty-nine categories of land cover data. For example, Figure 7 illustrates the categories for Tyrell County. This analysis focuses on the human development classifications. The four different types of human development land cover data were classified to values of 1, with all other categories received values of 0. The land use codes, names, and descriptions are shown in Table 4. These categories are merged together in *ArcGIS Desktop 9*. A merged, development land cover map for Tyrell County is shown in Figure 8.

3.2.4 Land Parcel Data

Land parcel data were acquired for one county to aid in the validation of analytical results. For example, Figure 9 illustrates an online mapping of the integration of land parcel and aerial photograph data in Bertie County, North Carolina. Online land parcel data are available from the county's GIS webpage. Also, the Geospatial Data Services on the North Carolina State University webpage provides links to the county's GIS webpage.

Figure 7. Land Cover Categories for Tyrell County

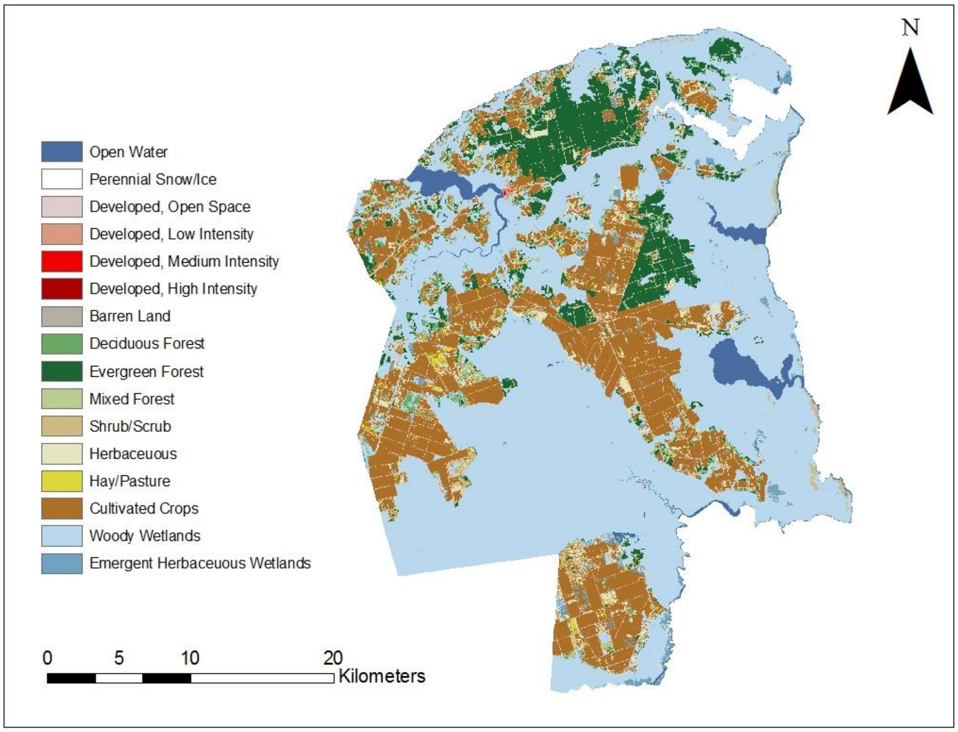


Figure 8. Merged Land Cover Development Categories for Tyrell County

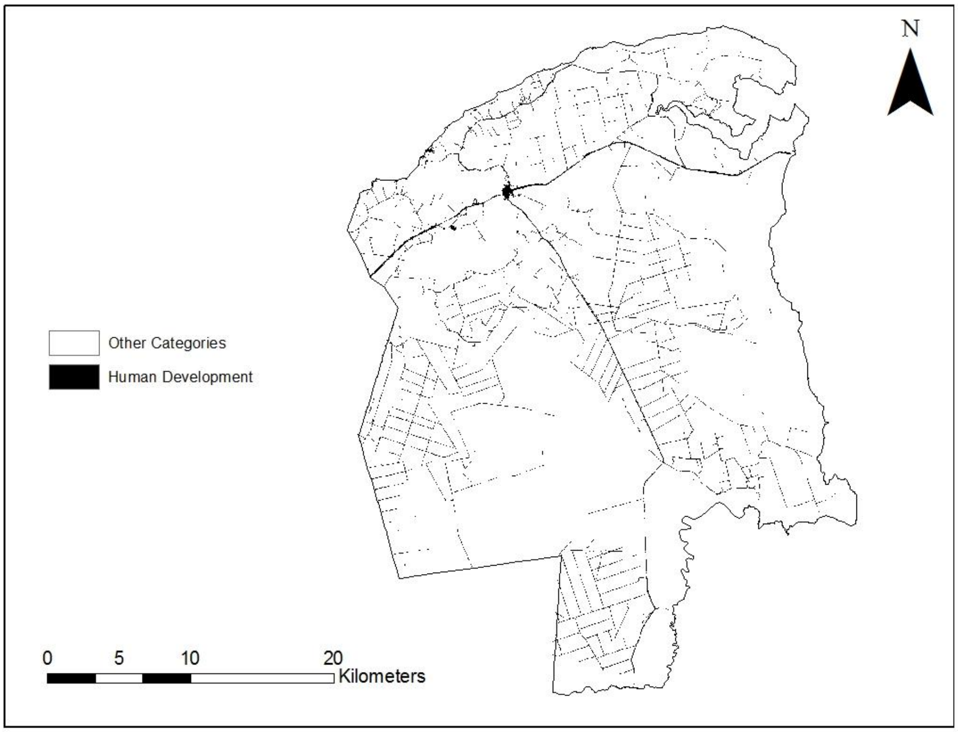


Table 4. Types of Human Development Land Cover Data

Land Use Code and Name	Description
21: Developed, Open Space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes
22: Developed, Low Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.
23: Developed, Medium Intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.
24: Developed, High Intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

Figure 9. Land parcel and aerial photograph data in Bertie County, North Carolina

Originally, land parcel data was desired for all counties but this was not possible for various reasons. First, the land parcel data availability was limited because some counties did not have land parcel data available online. Also, some of the available parcel data were outdated or did not contain the metadata needed for this analysis. To obtain some of the missing parcel data, local GIS supervisors were contacted. Second, while evaluating the land parcel data for each county strengthens the accuracy of the validation process, since more block groups would be compared in the analysis. Due to time constraints, this was not possible.

3.2.5 Socioeconomic Data

There is a wide range of socioeconomic variables available for this research that has been used in prior work to measure social vulnerability. An issue with socioeconomic data is determining which variables to include for a focused analysis. Instead of creating a new set of variables, the same variables from Charakraborty et al. (2005) were used in this analysis. These variables are shown in Table 5.

Variables were selected based on their relevance to the characteristics of the population that are important from the risk perspective. Three characteristics were identified and included: general population and structural attributes; access to resources; and special evacuation needs. To represent the variables within each characteristic, US Census data was downloaded from the U.S. Census Bureau American Fact Finder (2010) webpage.

Table 5. Socioeconomic Variables

Variable Name	Description
Total Population	Identifying large population densities is an important variable to consider when combining known hazard occurrence areas (Cutter et al. 1997). More assistance from local and emergency officials is required to notify these large population groups (Cutter et al. 1997).
Number of Housing Units	Like total population, the number of housing units identifies where the greatest number of people live (Cutter et al. 1997). This variable is important to show the intersection of hazard zones because it shows how many people are potentially more prone to hazard damages.
Number of Mobile Homes	Mobile homes are built and factories and taken to a location where they will be occupied. Mobile homes are easily destroyed and more vulnerable to hazards (Clark et al. 1998; Cutter et al. 2003).
Population Below Poverty Level	People that have lower incomes and live in poverty are less capable of recovering from hazard impacts (Cutter at al. 1997, 2003). According to Cutter et al. (2003), wealthy populations are able to absorb losses more quickly due to insurance and social safety nets (Cutter et al. 2003).
Occupied Housing Units with No Telephones	Telephones serve as a tool for communication. Households without telephones are limited to current knowledge and updates on potential disasters (Clark et al. 1998).
Occupied Housing Units with No Vehicles	Households utilize vehicles for transportation purposes. During a natural disaster, a vehicle is an important commodity for households to find a way out arms way (Clark et al. 1998) According to Clark et al. (1998). households with no vehicles are limited to evacuation accessibility.
Institutionalized population in group quarters	Institutionalized populations consist of people under supervised care in institutions at the time. It is difficult to monitor the number of individuals living in an institutionalized environment monitor during natural disasters, making them more vulnerable (Clark et al. 1998).
Population age 5 years or under	Children and infants are one of the most stressed demographic groups affected the most by disasters (Cutter et al. 2003). For example, parents lose money when caring for the children when daycare and school systems are affected (Cutter et al 2003).
Population age over 85 years	Elderly populations are the one of most affected demographic groups (Cutter et al. 2003). Elderly populations require more attention because they have more mobility constraints than other age groups (Cutter at al. 1997, Cutter et al. 2003).
Population (age over 5 years) with disabilities	Individuals with disabilities have unique needs that require more detailed planning in the event of a disaster (Clark et al. 1998; Cutter et al. 2003). Clark et al. (1998) states that disabilities can intervene with any actions taken to reduce vulnerability.

3.3 Data Processing

As mentioned earlier, the purpose of this research is to provide a detailed analysis of hazard vulnerability by incorporating the hazards of place assessment and Geographic Information Systems (GIS). The first step was to obtain the data for the geophysical risk and social vulnerability assessment. After the data were obtained, the next step was to provide a methodology for producing the hazards of place and the matrix classification of low, medium, and high risk block groups. Methodologies used by Cutter et al. (1997) and Chakraborty et al. (2005) provide frameworks for estimating vulnerability and creating the matrix for the block groups in Northeastern North Carolina. The methodology begins with calculating geophysical risk and social vulnerability metrics to produce the hazards of place index. Using the metrics from the hazards of place model, a matrix classification of risk is created as described below.

3.3.1 Geophysical Risk Assessment

Chakraborty et al. (2005) provide a methodology for developing an indicator to calculate the GPRI. The GPRI results in metric values for the 286 block groups in the study area. Two GPRI measures using different approaches are presented for grouping different factors in order to calculate metric values. These GPRI models are shown in Table 6. GPRI1 is the percent of the block group within the floodplain, and GPRI2 is the percent of development in each block group within the floodplain.

Table 6. Determining Geophysical Risk

Approach Title	Description
GPRI1	Calculating the percent of the block group within the floodplain
GPRI2	Calculating the percent of development in each block group within the floodplain

Since GPRI1 does not include aspects of the human built environment or development, GPRI2 is expected to be the main contribution to this analysis as it relates to one of the primary goals of this research. For example, Figures 10 and 11 illustrate the significance of human development land cover data on the GPRI. Figure 10 illustrates a GPRI1 model representation of a block group in Pasquotank County with a high percentage of its land located within the floodplain. However, in Figure 11, a GPRI2 model representation is shown for the same county. Even though a high percentage of the block group is located in the floodplain, there is a low percentage of human development within the floodplain. Thus, the block group is not as susceptible to flooding based on the GPRI2 visual representation.

Before calculating GPRI metrics, a series of raster editing tools in *ArcGIS Desktop 9* are used to edit the geophysical data. Utilizing editing tools in *ArcGIS Desktop 9* serves to calculate the geometric intersection of floodplain and block group data. The intersect tool is used to calculate and produce an output of the intersected floodplain and block group data.

Raster editing tools in *ArcGIS Desktop 9* are important to emphasize and merge the human development characteristics of the land cover data set. The land cover data sets are edited through various tools which include the following: mosaic; spatial analyst calculator; spatial analyst reclassify; and zonal statistics. The zonal statistics tool is the most important function since it summarizes the human development land cover raster data set with values of 0 or 1

Figure 10. GPRI1 Pasquotank County Block Group

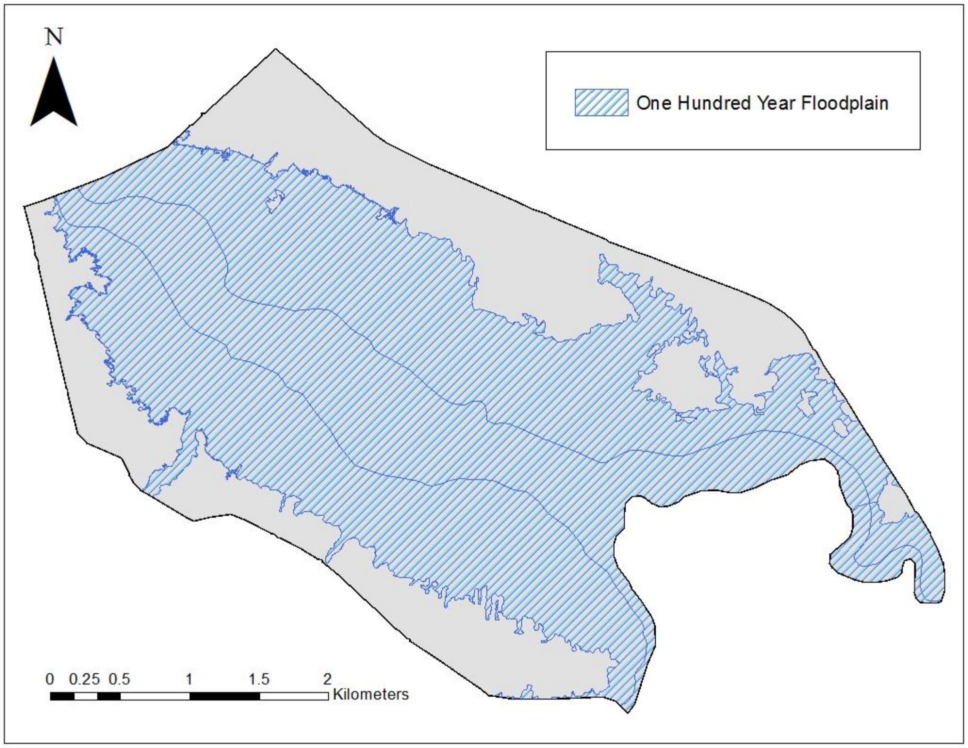
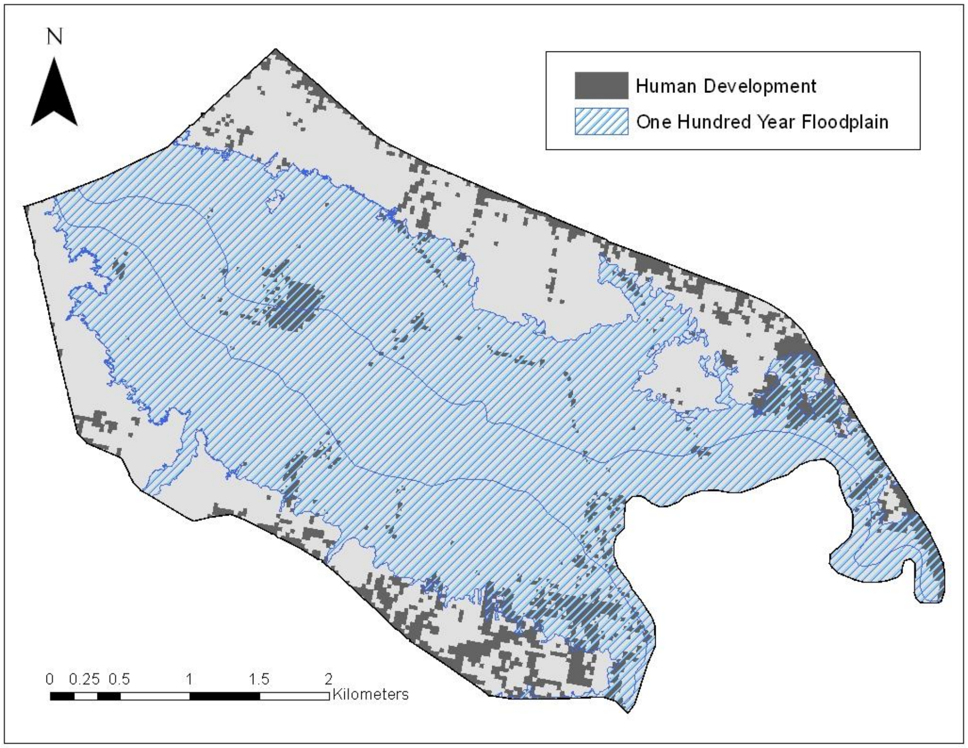


Figure 11. GPRI2 Pasquotank County Block Group



within the floodplain data. A value of 0 represents non-developed land cover pixels and 1 represents human development land cover pixels.

Tabular calculations are required to calculate the percentage of development in each block group. Area values are needed to calculate the tabular data for each block group and DFIRM in the study area. The area values required for the tabular data calculations include the following: total block group area; total block group area within floodplain; total developed area; and total developed area in floodplain.

The GPRI metrics use the area values mentioned above to determine the percent of the block group located in the floodplain and the percent of development in each block group within the floodplain. To calculate the percent of each block group located in the floodplain, the total block group area is divided by the total block group area within the floodplain, multiplied by 100. To calculate the percent of development in each block group within the floodplain, the total developed area is divided by the total developed area in the floodplain.

3.3.2 Social Vulnerability Assessment

The approach for evaluating social vulnerability is based on the models developed by Cutter et al. (1997) and Chakraborty et al. (2005). As mentioned in the literature review, Cutter et al. (1997) developed the Social Vulnerability Index (SoVI) and the Social Vulnerability for Evacuation Assistance Index was developed by Chakraborty et al. (2005). Conceptualizing ideas from both models serves two purposes within this research: calculating social vulnerability metric values for each variable; and grouping variable metric values to illustrate the spatial patterns of vulnerability. First, the models in the literature are examined to determine their relevance to this analysis.

Although both models calculate social vulnerability metrics, they vary in scale. As mentioned in the literature review, the SoVI developed by Cutter et al. (1997) measures vulnerability on a county block group level. However, this research follows the same direction as Chakraborty et al. (2005) by computing social vulnerability on a census block group level. The SVEAI developed by Chakraborty et al. (2005) modified the original SoVI model by computing social vulnerability on a census block group level.

The methods mentioned above were used in this analysis to calculate the four SVEAI measures for each block group, using the selected variables. These SVEAI models are listed in Table 7, along with the groupings of each variable. Before the vulnerability metric values are calculated for each variable, the variables are grouped together and standardized to develop metrics for each characteristic. The rationale for the grouping variables together is to evaluate the differences that might exist between different variables (Chakraborty et al. 2005). Variables are grouped together based on a series of characteristics provided by Chakraborty et al. (2005).

Table 7: Variable Characteristics Used to Determine Social Vulnerability

Characteristics	Variables
SVEAI1: Population and Structure	Total Population Number of Housing Units Number of Mobile Home
SVEAI2: Limited Access to Resources	Population Below Poverty Level Occupied Housing Units with No Telephones Occupied Housing Units with No Vehicles
SVEAI3: Populations with Special Evacuation Assistance	Institutionalized population in group quarters Population age 5 years or under Population age over 85 years Population (age over 5 years) with disabilities
SVEAI4: All Variable Characteristics	All variables

Chakraborty et al. (2005) summarizes the methodology for computing and standardizing each metric value, shown in Table 8. The overall social vulnerability metric value for each block group is standardized from 0 to1. Lower metric values in the SVEAI represent lower vulnerability for the block group. Higher metric values indicate greater vulnerability.

For example, the metric values for the number of mobile homes in each census block group are shown in Table 9 (Cutter et al. 1997; Cutter et al. 2000). The same approach is used for the SVEAI calculation. The value of X is calculated using the following expression:

X = Number of a given variable in census block/ Number of the given variable in county

The desired variable metric is calculated by dividing the percentage score by the maximum percentage out of every block group. This calculation places all social variables on the same scale:

Desired Variable Score = X/Maximum X

The mean housing value variable does not use the same calculation. Negative numbers are possible in this calculation and the absolute value of the difference between block and county values are used. An example of the mean housing value calculation is shown in Table 10 (Cutter et al. 1997; Cutter et al. 2000). The mean housing value is determined by three steps that calculated the lowest mean house value. The variable calculated represents the lowest mean

Table 8. Methodology for Computing and Standardizing Each Variable Metric

Step 1:	For each variable *i*, determine the ratio of the variable in the block group to the total number of that variable in the county (*Ri*)
Step 2:	Compute a standardized social vulnerability for SVEAI*i* for variable *i* using the maximum ratio value (Rmax) observed in the county
Step 3:	To combine multiple variables in the assessment of social vulnerability, calculate the arithmetic mean of the vulnerability indices by dividing the sum of index values of all variables by the number of variables (*n*) considered $SVEAI = \frac{\Sigma SVEAI_i}{N}$

Table 9. SVEAI Mobile Homes Estimation

Census Block	# of Mobile Homes in Census Block	# of Mobile Homes in the County	X	Mobile Home Score
Block A	125	3,500	0.036	1.00
Block B	76	3,500	0.022	0.55
Block C	4	3,500	0.001	0.03
Block D	21	3,500	0.006	0.17

Table 10. SVEAI Mean House Value Estimation

Census Block	Mean House Value in Census Block	County Average Mean House Value	X	Y	Mobile Home Score
Block A	41,286	75,000	33,714	69,364	1.00
Block B	110,650	75,000	-35,650	0	0.00
Block C	76,776	75,000	-1,776	33,874	0.49
Block D	64,900	75,000	5,100	40,750	0.58

house value and is used as an indicator of poverty (Cutter et al. 1997). To determine how different each block is from the county mean, the difference between county and block housing needs to be computed. This is calculated by taking the county average of mean house value and subtracting the mean house value for each census block:

X= County Mean House Value – Mean House Value for Census Block

To remove negative values, the absolute value of the maximum X is added to X:

Y = X + Absolute Value of Maximum X

To calculate the mean house value index metric value, the ratio of the new value Y is divided by the maximum Y:

Mean House Value Score = Y/ Maximum Y

3.3.3 Statistical Analysis

The main objective of the statistical analysis is to establish relationships and correlations among the GPRI and SVEAI metrics. It is important to assess the different GPRI and SVEAI models by determining the extent to which each model is correlated. If the models are highly correlated, they measure aspects of geophysical risk and social vulnerability. Otherwise, the models measure different outcomes.

To determine potential correlations and differences within the GPRI and SVEAI data, the statistical operations were executed in *PSAW 17*. The first set of correlations examined the relationships between the two GPRI models. The second set of correlations explained the relationships between the four SVEAI models.

To visually determine the relationships between the two GPRI model characteristics, a scatter plot and correlation matrix were created. Since there are only two GPRI models, the scatter plot of the GPRI characteristics was created. The relationship between two variables was visually identified as data points on a scatter plot. Once the scatter plot was interpreted, a correlation matrix is computed. Characteristics from the GPRI and SVEAI models are used in the correlation matrix.

3.3.4 Spatial Distribution Maps

After the statistical analysis, maps were created to visualize the spatial distributions of geophysical risk and social vulnerability in the study area. Examining the spatial distributions for each quantitative model helps to identify spatial patterns. *ArcGIS Desktop 9* is used to map the metric values numerically or by groupings. More specifically, raw scores and classified metric values, ranging from low to high were mapped.

3.3.5 Producing Hazards of Place

The metrics from the geophysical risk and social vulnerability assessment are used to produce hazards of place (Chakraborty et al. 2005). Table 11 shows a description of the GPRI and SVEAI models. The two GPRI metrics are multiplied with four SVEAI metrics to produce eight, hazards of place metrics, shown in Figure 12.

3.3.6 Hazards of Place Matrix

The hazards of place matrix was produced from the GPRI2 and SVEAI4 metrics. Creating the hazards of place matrix with quantitative rankings of low, medium, and high permits the prioritization of risk among various block groups in northeastern North Carolina. The matrix provides a classification of these block groups into different rankings by categorizing them on a nine-celled grid. Geophysical risk is the first dimension of the matrix. Social vulnerability is the second dimension of the matrix. The 3x3 matrix is shown in Table 12.

Since every variable does not have the same values in each block group, the values in each ranking classification vary depending on the selected variable. Tools in *ArcGIS Desktop 9* are used as an alternative to numerically categorize the matrix. A natural breaks classification categorizes risk into three numerical classes. Class values are used as separators between the low, medium, and high classifications. Metric values below the lowest threshold receive a value

Table 11. Description of Quantitative Models

Quantitative Models	Description
GPRI1	Percent of block group within the floodplain
GPRI2	Percent of development in each block group within the floodplain
SVEAI1	Population and structure evacuation characteristic
SVEAI2	Limited access to resources evacuation characteristic
SVEAI3	Populations with special evacuation assistance evacuation characteristic
SVEAI4	Combination of all SVEAI models

Figure 12. Hazards of Place Models

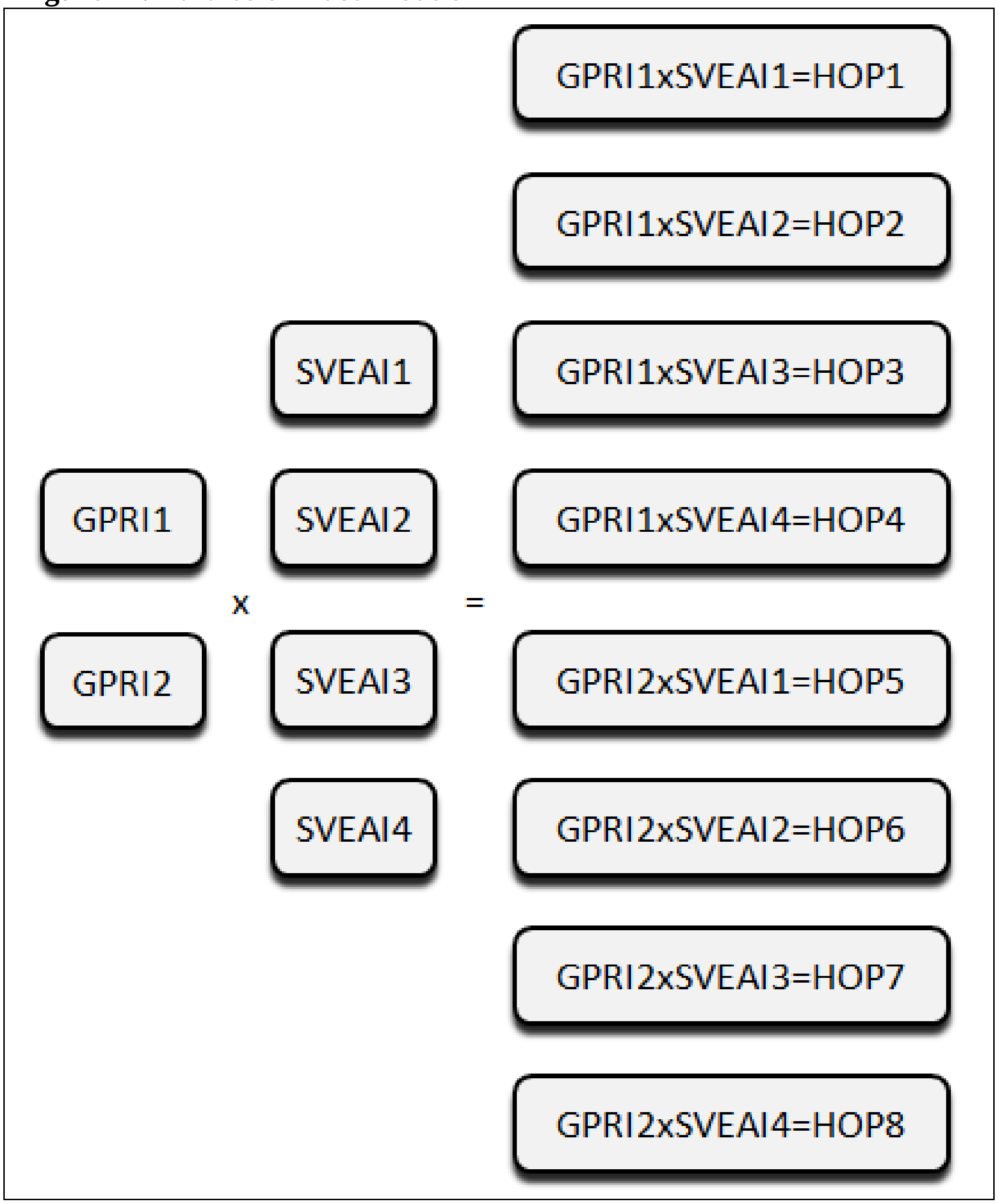


Table 12. Matrix Classification

GPRI	SVEAI		
	1 (Low)	2 (Medium)	3 (High)
1 (Low)	1_1	1_2	1_3
2 (Medium)	2_1	2_2	2_3
3 (High)	3_1	3_2	3_3

of “1.” Values between the second and first threshold receive a value of “2.” Metric values between the third and second threshold receive a value of “3.” Matrix values identified as “1_1,” “2_2,” and “3_3” are used in the next section to validate the Hazards of Place Model of Vulnerability (Cutter 1996). “1_1” or “Low Low” block groups have the lowest hazards of place due to low geophysical risk and low social vulnerability. Block groups identified as “2_2” or “Medium Medium” have the most intermediate hazards of place due to medium geophysical risk and medium social vulnerability. The block groups identified as “3_3” or “High High” have the highest hazards of place due to high geophysical risk and high social vulnerability.

3.4 Validating the Hazards of Place Model of Vulnerability

Previous literature identifies geophysical risk and social vulnerability metrics as the end point for quantitative models (Cutter et al. 2000; Tapsell 2002; Wu et al. 2002; Chakraborty et al. 2005; Cardona 2006). However, it is important to pursue the validation of quantitative models by assessing the degree to which high hazards of place block groups actually are located within the one hundred year flood zone. This research expands beyond the results of the hazards of place matrix to validate the “Low Low,” “Medium Medium,” and “High High” risk block groups in northeastern North Carolina.

As stated earlier, the purpose of this section is to explain the methodology for validating the Hazards of Place Model of Vulnerability (Cutter 1996). The results are validated through two procedures: providing a sub-block group analysis of the hazards of place matrix, specifically residential parcels whose actual building footprints intersect with the one hundred year floodplains; and an interview with a key informant about their knowledge of vulnerability in northeastern North Carolina. The key informant was a local county emergency planner.

3.4.1 Sub-Block Group Analysis

It is expected from the hazards of place matrix that “High High” risk block groups have higher percentages of their developed land within the one hundred year floodplain than “Low Low” and “Medium Medium” risk block groups. However, the hazards of place matrix does not specifically determine whether residential properties are located within the floodplain. Thus, the sub-block group analysis serves as a quantitative assessment that attempts to validate the hazards of place matrix.

This research conducts a sub-block group analysis for two counties to validate the hazards of place matrix. The counties selected for this sub-block group analysis were Currituck and Dare. County selection was based on the availability of land parcel and the existence of block groups spanning the “Low Low,” “Medium Medium,” “High High” continuum. Before the sub-block group analysis was performed, parcel data, DFIRMs, and aerial photos for Currituck and Dare County were imported into *ArcGIS Desktop 9*.

The first step in this analysis was to identify residential parcels that intersect with the one hundred year floodplain. Using the selection tool in *ArcGIS Desktop 9*, residential parcels that intersect with the one hundred year floodplain were identified and given values of 1. The other residential parcels that did not intersect with the one hundred year floodplain were given values of 0.

The second step of the analysis required a more detail examination of the parcel data. This step determined whether or not the building footprint within the residential parcel was located in the one hundred year floodplain. For each residential parcel that intersected with the one hundred year floodplain, the parcels were evaluated further by zooming in to see if the actual building footprint was located in the floodplain. The location of each building footprint within the floodplain was interpreted visually. Thus, if the household was actually located in the floodplain, the land parcel received a value of 1. Otherwise, the land parcel received a value of 0.

The final step of the sub-block group analysis was to calculate the percentages of building footprints located in the one hundred year floodplain for the selected block groups. Percentages were calculated by dividing the total number of residential parcels that intersect with the one hundred year floodplain by the actual number of parcels with building footprints located in the one hundred year floodplain. Thus, applying these percentages help validate or reject the hazards of place matrix.

3.4.2 Interview

Although this analysis uses quantitative models to calculate geophysical risk, social vulnerability, and hazards of place metrics for northeastern North Carolina, the qualitative analysis provides an approach to further validate the results. This qualitative analysis consists of an interview with an emergency official from Currituck County. The purpose of interviewing the emergency management representative is to provide validates the results from the GPRI, SVEAI, and HOV Assessment. Thus, attempting to validate the quantitative results through an interview analysis will either strengthen or weaken the results from the assessment.

The first step towards completing an interview analysis will be to select the interviewee from Currituck County. Potential candidates were selected from Currituck County's department webpage and invited through email to participate in this research (NC Government 2010). Interview candidates were chosen for their qualifications, availability, and immediate response to the research invitation. The assumption was that each interview candidate possessed expertise in vulnerability and flooding. Based on this criterion, only one candidate was selected for the interview. The selected interviewee was a representative from the emergency management department of Currituck County.

This interview begins with the emergency official's perception of where the most significant areas of geophysical risk, social vulnerability, and hazards of place are located in their county. GPRI, SVEAI, and HOV maps of Currituck County were provided to the emergency representative as visual cues, shown in Figures 13 through 15. These maps consisted of block group boundaries and roads, which acted as aids to identify significant areas within the community. A marker was provided to the emergency official to hand draw boundaries of these significant areas.

The map results provided by the emergency official will be compared to the spatial distribution maps from the quantitative results. Interpretations of the map results are twofold. First, the map results could suggest that the results from the quantitative models were accurate in

Figure 13. GPRI Map of Currituck County

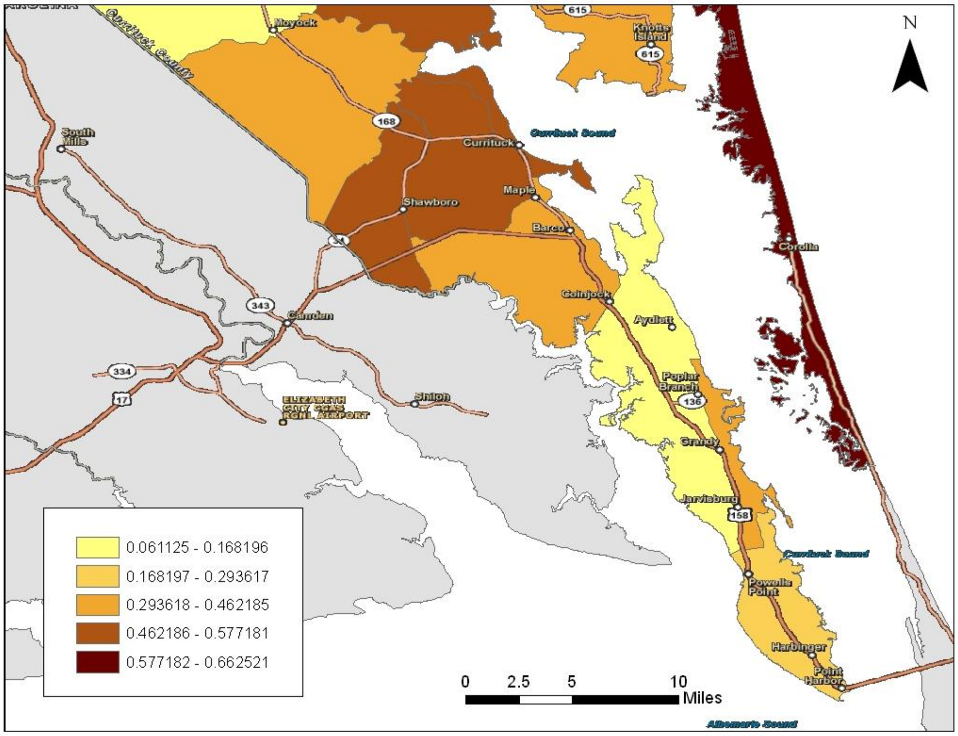


Figure 14. SVEAI Map of Currituck County

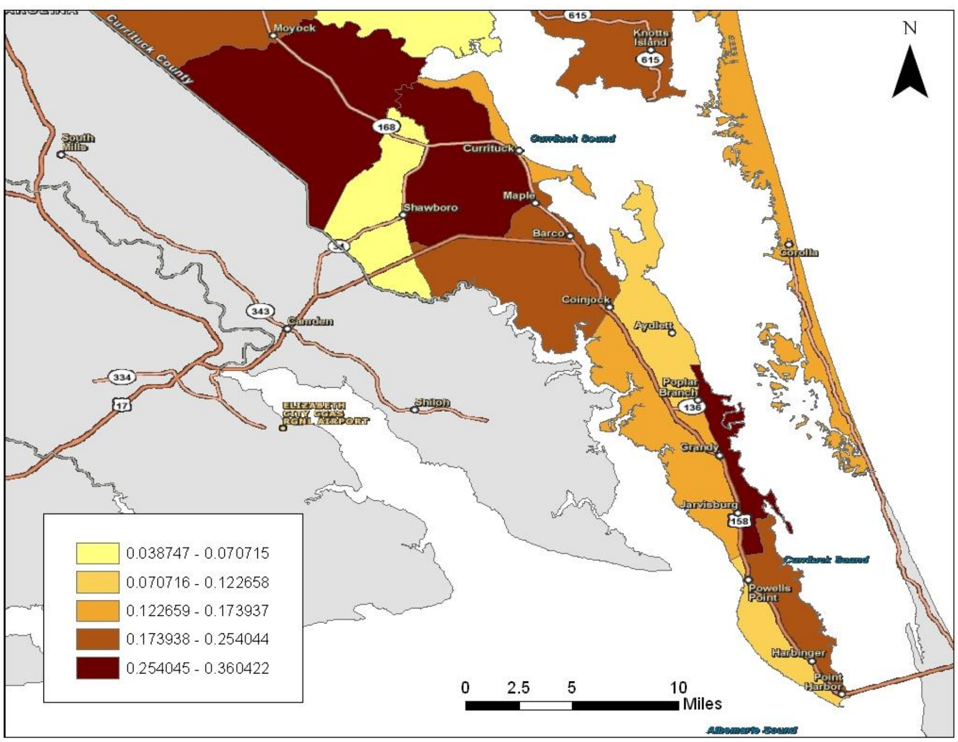
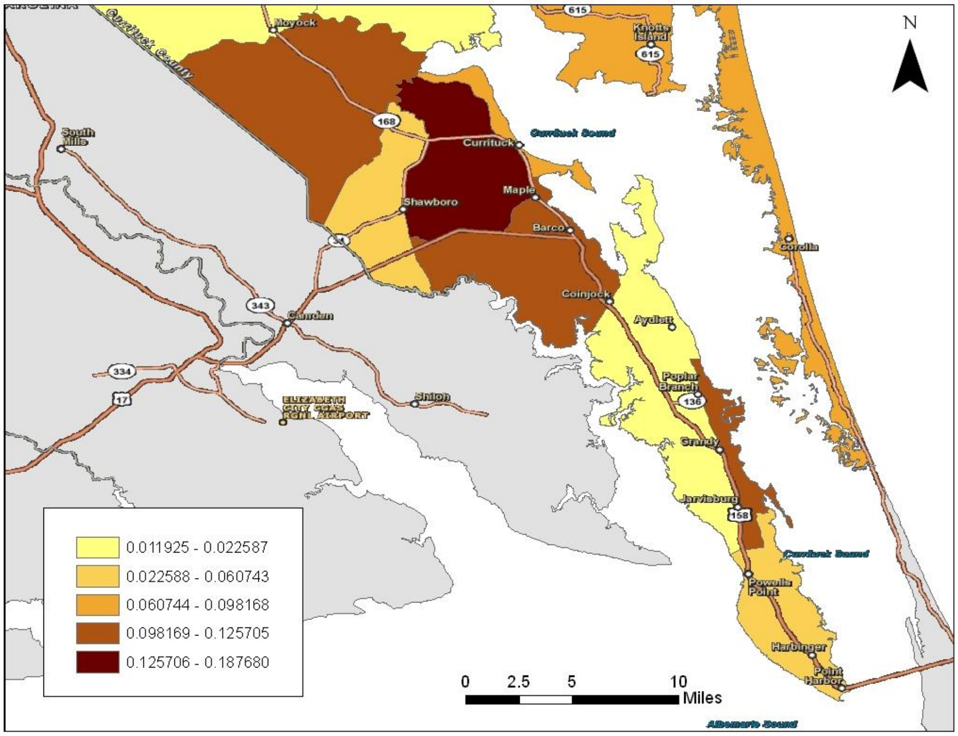


Figure 15. HOV Map of Currituck County



identifying at risk areas. Second, the comparison of the two maps could determine potential areas the key informant identified as high risk that the spatial distribution maps did not recognize.

Since the goals of the interview analysis have been identified, it is important to outline the questions for the analysis. The emergency representative was provided with a specific set of open ended questions. These questions enable the emergency official to provide her perspectives of vulnerability and the importance of assisting these populations during flooding events. The questions explore the following aspects: identifying areas that are more susceptible to flood events; identifying areas where humans are more susceptible to flooding; identifying areas where the combination of geophysical risk and social vulnerability are high; and the methods taken to evacuate communities.

Chapter 4

Results

This chapter presents analytical results from the hazards of place assessment. The detailed results are presented in the form of tables and maps. These results are illustrated through a series of stages: correlation analysis and spatial patterns of the two GPRI and four SVEAI indices; spatial patterns of the hazards of place model of vulnerability; spatial patterns of the hazards of place matrix; sub-block group analysis of the land cover parcel data; and an interview with the emergency official.

4.1 Geophysical Risk Index (GPRI)

As mentioned in the previous chapter, two GPRI models were created to estimate geophysical risk metrics for every block group in northeastern North Carolina. The two GPRI models include the following: calculating the percent of the block group within the floodplain; and calculating the percent of development in each block group within the floodplain. Table 13 shows the average GPRI1 and GPRI2 metric values for each county. Each GPRI metric was standardized from 0 to 1. This section determines the most significant GPRI to include as the geophysical risk factor in the hazards of place matrix.

Table 13. Average GPRI Metrics by County

County	GPRI1 Metrics	GPRI2 Metrics
Beaufort	.43	.39
Bertie	.20	.06
Camden	.59	.37
Chowan	.20	.09
Currituck	.60	.38
Dare	.65	.68
Gates	.32	.05
Halifax	.13	.04
Hertford	.16	.02
Hyde	.83	.85
Martin	.20	.05
Northampton	.17	.02
Pasquotank	.39	.35
Perquimans	.22	.21
Tyrrell	.87	.81
Washington	.28	.14

4.1.1 Correlations

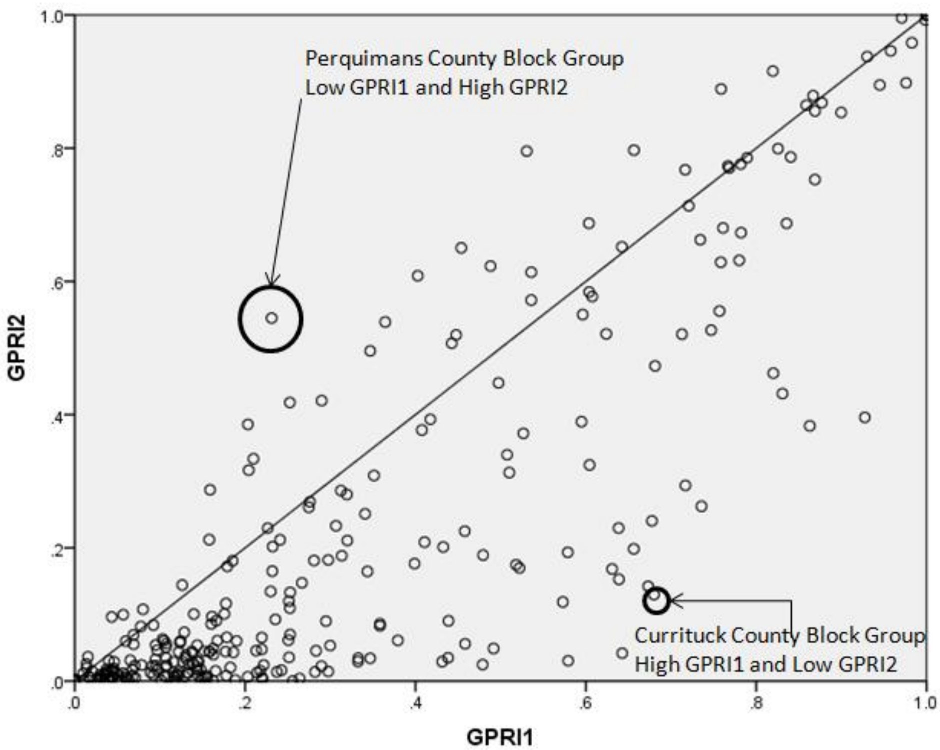
In order to understand the relationship between GPRI1 and GPRI2, a Spearman's Rank Order correlation coefficient and scatter diagram were executed in *PSW Statistics 18*. Table 14 shows the Spearmen's Correlation Coefficient for the two GPRI models. The results show that GPRI1 and GPRI2 are strongly correlated. The correlation coefficient between the GPRI models is 0.864, and the correlation is significant at the 0.01 level ($p < 0.05$).

Figure 16 represents the scatterplot for the two GRPI models. Each dot represents a block group in the study area. The dots above the line represent block groups with higher GPRI2 values and the dots below the line represent block groups with higher GPRI1 values. Although the scatter plot reveals a positive, linear relationship between GPRI1 and GPRI2, there are various outliers. Most of the outliers fall below the line, with higher GPRI1 values. Since the outliers below the line do not include human land cover data, these outliers over estimate

Table 14. Spearman's Correlation Coefficient for the GPRI Models

			GPRI1	GPRI2
Spearman's rho	GPRI1	Correlation Coefficient	1.000	.822**
		Sig. (2-tailed)	.	.000
		N	286	286
	GPRI2	Correlation Coefficient	.822**	1.000
		Sig. (2-tailed)	.000	.
		N	286	286
**. Correlation is significant at the 0.01 level (2-tailed).				

Figure 16. Scatter Plot of the GPRI Models



vulnerability. Thus, the outliers above the line, with high GPRI2 values, are better models to approximate vulnerability.

More specifically, the points highlighted in Figure 16 represent block groups in Perquimans and Currituck County. The Perquimans County block group has a low GPRI1 metric value of 0.23, and a high GPRI2 metric value of 0.55. This indicates that 55% of the human development is within the floodplain, and 23% of the block group's area is within the floodplain. Thus, the Perquimans County block group is still considered at high risk even though a low percentage of its area within the floodplain, as shown in Figure 17.

In contrast to the Perquimans County block group, the Currituck County block group has a GPRI1 metric value of 0.68 and a GPRI2 metric value of 0.13. This indicates that 68% of the human development is within the floodplain, and 13% of the block group's area is within the floodplain. Thus, the Currituck County block is considered low risk even though a high percentage of its area within the floodplain, as shown in Figure 18.

Although the results from the correlation analysis show a high correlation between GPRI1 and GPRI2, the scatter plot suggests a different relationship between the two geophysical risk indices. First, a block group with high GPRI1 value and a low GPRI2 value are less vulnerable. Second, a block group with a low GPRI1 value and a highGPRI2 value are more vulnerable Thus, the inclusion of human development land cover data is an important contribution to the geophysical risk assessment.

4.1.2 Spatial Distribution of GPRI Metrics

The spatial patterns of the GPRI metrics are presented in Figure 19 and 20. The GPRI is based on the percent of each block group located in the floodplain and the percent development in each block group within the floodplain. The maps illustrate the differences between the characteristics that compose the GPRI results.

Figure 17. Perquimans County Block Group

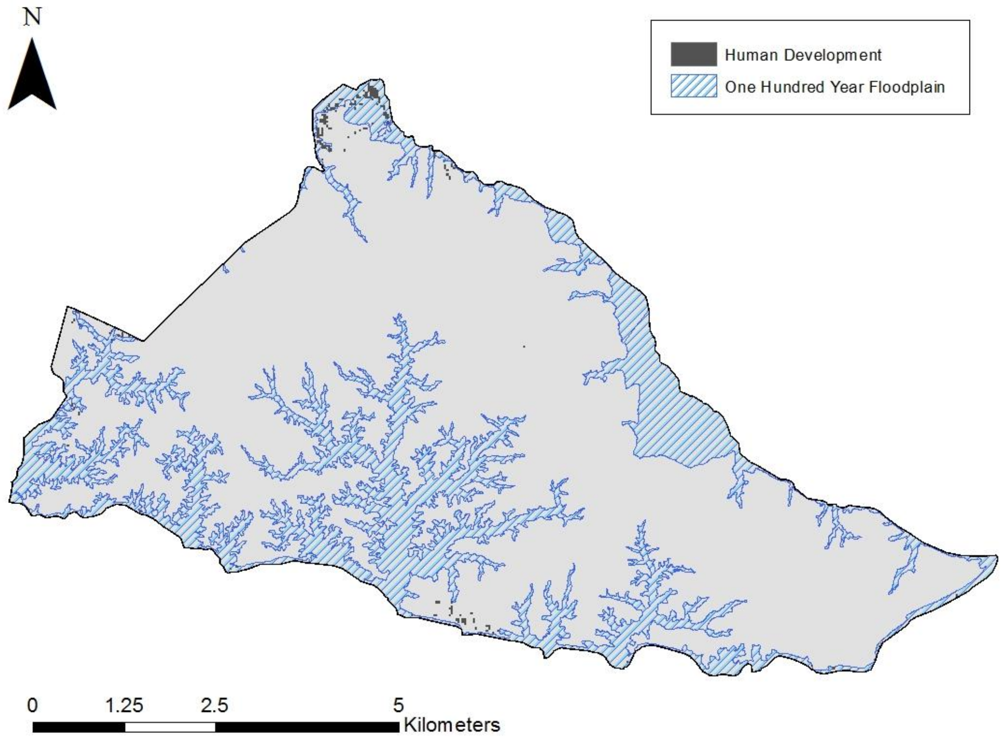


Figure 18. Currituck County Block Group

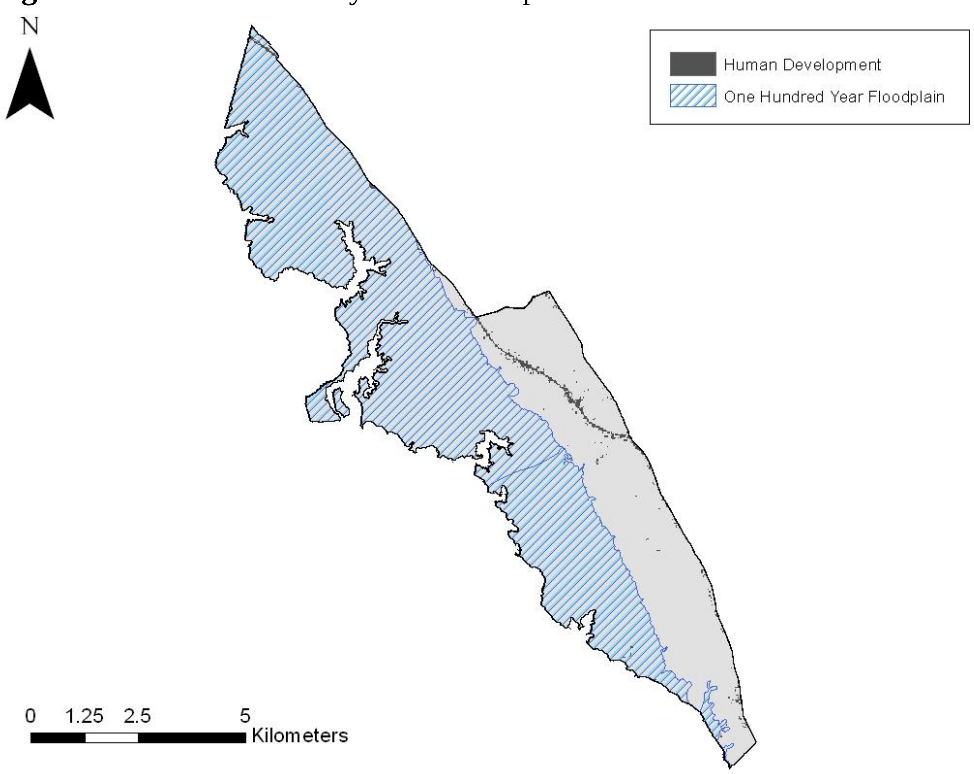


Figure 19. GPRI1 Spatial Patterns

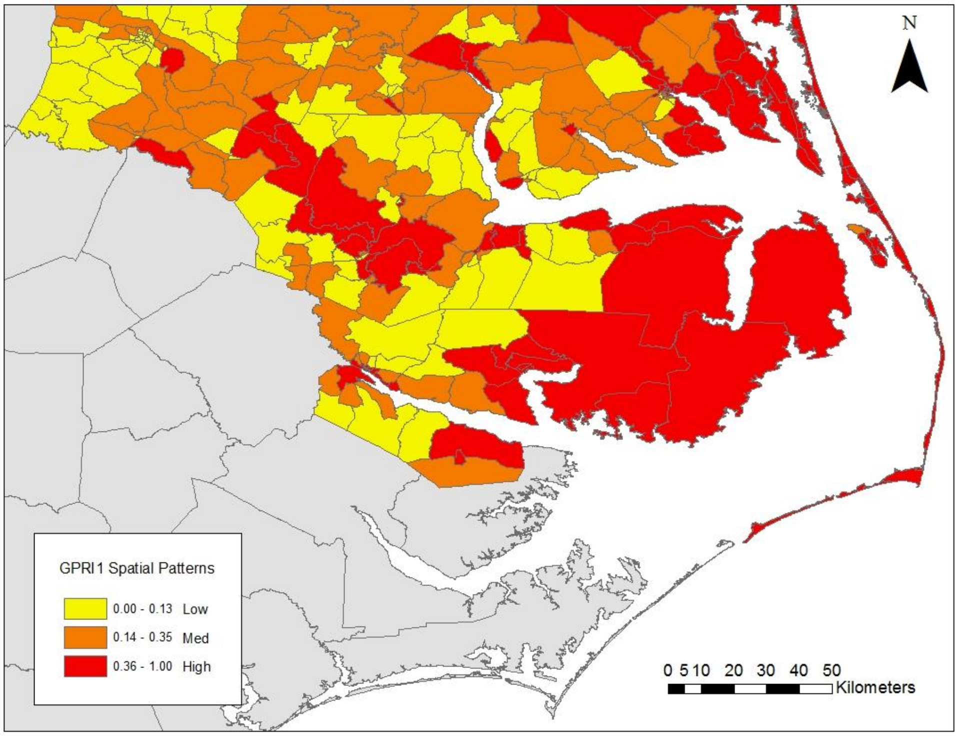
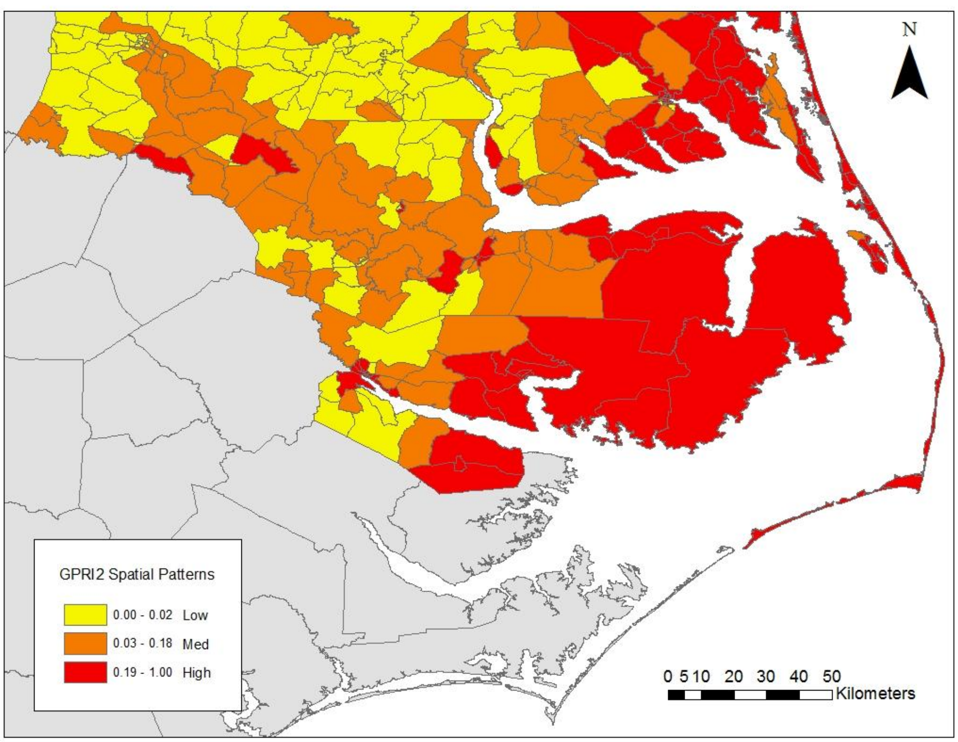


Figure 20. GPRI2 Spatial Patterns



In Figure 19, the GPRI metrics represent the percent of each block group located in the floodplain. The majority of the block groups identified as low and medium risk areas are clustered in the western region. High risk block groups are located along the eastern coast and inland. Figure 20 illustrates a different pattern using the percent development in each block group within the floodplain. A majority of the block groups are categorized as low and medium risk, specifically in the western region. There are various high risk block groups distributed along the southeastern coastal areas.

Both maps illustrate how geophysical risk is distributed along the eastern coastal areas of northeastern North Carolina. From a geophysical risk perspective, the block groups with the highest metric scores are the most susceptible to flooding. These areas are located primarily in the coastal areas of northeastern North Carolina. Emergency managers can use these maps as a guide to prioritize geophysical risk within their communities.

4.1.3 GPRI Summary

For the hazards of place analysis, the GPRI2 model was selected as the geophysical risk factor, based on the results from previous sections. By conducting the correlation and visual analysis for the GPRI metrics, the importance of integrating human land cover data is demonstrated. It is possible for a block group to still be identified as vulnerable with a low GPRI1 value, and a high GPRI2 value. Thus, the inclusion of human development land cover data is an important contribution to the hazards of place analysis. The inclusion of human development land cover data is essential to pinpoint societal development and their proximity to floodplains.

4.2 Social Vulnerability for Evacuation Assistance Index (SVEAI)

As mentioned in the methodology, the SVEAI is measured by grouping variables into four models. These four models include the following: population and structure; differential access to resources; population with special evacuation needs; and a combination of all evacuation characteristics. Table 15 shows each SVEAI, average metric value for each county in northeastern North Carolina. The results from the table show that Hyde and Pasquotank County have the highest, average metric values in each SVEAI.

The purpose of this section is to examine the results from the social vulnerability assessment to determine the most significant model to include in the hazards of place matrix. The results are examined through Spearman's Correlation Coefficient and visual assessment of spatial distribution maps for the social vulnerability characteristics.

Table 15. Average SVEAI Metrics by County

County	SVEAI1 Metrics	SVEAI2 Metrics	SVEAI3 Metrics	SVEAI4 Metrics
Beaufort	.27	.24	.17	.22
Bertie	.23	.26	.17	.21
Camden	.25	.14	.15	.18
Chowan	.23	.25	.18	.22
Currituck	.29	.12	.16	.19
Dare	.36	.12	.15	.20
Gates	.23	.18	.15	.18
Halifax	.23	.28	.19	.23
Hertford	.22	.24	.18	.21
Hyde	.33	.25	.24	.27
Martin	.21	.22	.17	.20
Northampton	.23	.26	.18	.22
Pasquotank	.24	.24	.20	.23
Perquimans	.26	.17	.16	.19
Tyrrell	.24	.22	.16	.21
Washington	.20	.20	.15	.18

4.2.1 Correlations

The result of the correlation analysis is shown in Table 16. In this particular case, every SVEAI is significant at the 0.01 level. Each SVEAI significance value is less than 0.05 ($p < 0.05$). Although the social vulnerability indices are positively correlated, the relationships between each SVEAI vary depending on the variables used in each characteristic.

For example, SVEAI1 and SVEAI2 have a weaker, correlation of 0.22. These results suggest that out of 286 block groups, there is a weak relationship between the variables grouped together for the population and structure characteristic of SVEAI1 and the differential access to resources characteristic of SVEAI2. SVEAI1 and SVEAI3 have a stronger correlation of 0.626. Thus, there is a stronger relationship between the variables grouped together for the population and structure characteristic of SVEAI1 and the population with special evacuation needs characteristic of SVEAI3. SVEAI1 and SVEAI4 have a strong correlation of 0.745. These results

Table 16. Spearman's Correlation Coefficient for the SVEAI Models

			SVEAI1	SVEAI2	SVEAI3	SVEAI4
Spearman's rho	SVEAI1	Correlation Coefficient	1.000	.223**	.626**	.745**
		Sig. (2-tailed)	.	.000	.000	.000
		N	286	286	286	286
	SVEAI2	Correlation Coefficient	.223**	1.000	.547**	.740**
		Sig. (2-tailed)	.000	.	.000	.000
		N	286	286	286	286
	SVEAI3	Correlation Coefficient	.626**	.547**	1.000	.881**
		Sig. (2-tailed)	.000	.000	.	.000
		N	286	286	286	286
	SVEAI4	Correlation Coefficient	.745**	.740**	.881**	1.000
		Sig. (2-tailed)	.000	.000	.000	.
		N	286	286	286	286

suggest that there is a stronger relationship between the variables grouped together for the population and structure characteristic of SVEAI1 and the combination of all the characteristics for SVEAI4.

There is a strong correlation between SVEAI2 and SVEAI3 at 0.547. Thus, there is a stronger relationship between the variables grouped together for the limited access to resources characteristic of SVEAI2 and the population with special evacuation assistance characteristic of SVEAI3. For SVEAI2 and SVEAI4, the two indices have a much stronger correlation of 0.740. These results suggest that there is a strong relationship between the variables grouped together for the limited access to resources characteristic of SVEAI2 and the combination of all the characteristics for SVEAI4. Finally, SVEAI3 and SVEAI4 have the strongest correlation at 0.881. These results suggest that there is a strong relationship between the variables grouped together for the populations with special evacuation assistance of SVEAI3 and a combination of all the characteristics for SVEAI4.

The results from the correlation analysis have confirmed some expectations about the social vulnerability indices. Since SVEAI4 is a combination of every variable and characteristic, it is not surprising that the strongest correlations were associated with SVEAI4. Also, the correlation between SVEAI1 and SVEAI3 was the strongest among SVEAI1, SVEAI2, and SVEAI3. Thus, the variables grouped together for the population and structure characteristic were strongly related to the population with special evacuation needs characteristic of SVEAI3.

4.2.2 Spatial Distribution of SVEAI Metrics

Figures 21 through 24 illustrate the spatial patterns of the variables. It is apparent that the SVEAI spatial patterns are dispersed, indicating that the scored areas are irregularly scattered throughout the study area. Irregular, scattered patterns increase the complexity of defining social vulnerability in the study area. Emergency representatives would be able to prioritize their evacuation plans more effectively based on the distributions of higher metric values. However, block groups with a high SVEAI may not have a high GPRI.

Figure 21 represents block groups that reflect the population and structure characteristic of the SVEAI. There are various low and medium risk block groups clustered throughout the northern and southern regions. High risk block groups are clustered along the outer perimeter of the study area. Figure 21 suggests that the block groups with the largest populations and structures are clustered in the coastal areas.

Figure 22 shows block groups with populations with differential access to resources. Low risk block groups are distributed in the northeastern parts of the study area. Most of the medium and high risk block groups are located in the western parts of the study area. Thus, block groups with populations that are limited in access to resources are scattered throughout the western region.

Figure 23 shows the spatial patterns of populations with special evacuation needs. Block groups identified as low and medium risk are distributed throughout the study area, while high risk block groups are distributed in coastal and inland areas. Figure 24 represents a combination of all the SVEAI characteristics. Block groups identified as low, medium, and high risk are distributed throughout the study area.

4.2.3 SVEAI Summary

Similar to the GPRI, a SVEAI model is selected as the social vulnerability factor for the HOV analysis. Results of the social vulnerability assessment identified SVEAI4 as the selected model for the hazards of place, based on the results of the correlation matrix and the visual assessment of the spatial distribution maps, as discussed in sections 4.2.1 and 4.2.2. In Section 4.2.1, the results of the correlation matrix indicated that various observed relationships were strong. More specifically, the correlation matrix indicated that SVEAI4 was strongly correlated with the other SVEAI models.

Section 4.2.2 further validates SVEAI4 as the selected model for the hazards of place matrix. The results from Section 4.2.2 indicate that each SVEAI had similar spatial patterns. Similar spatial patterns appear in block groups with higher metric values. This finding supports the notion that all of the characteristics estimate similar, high risk areas in the study area. Thus, it is appropriate to select SVEAI4 as the social vulnerability aspect of the hazards of place analysis since it is a combination of every social vulnerability characteristic for the SVEAI.

4.3 Hazards of Place Model of Vulnerability

HOV metrics are produced by the product of geophysical risk and social vulnerability (GPRI X SVEAI) metrics. Section 4.1 identified GPRI2 as the geophysical risk factor for the hazards of place estimation. The metrics from SVEAI4 are used as the social vulnerability factor.

Figure 21. SVEAI1 Spatial Patterns

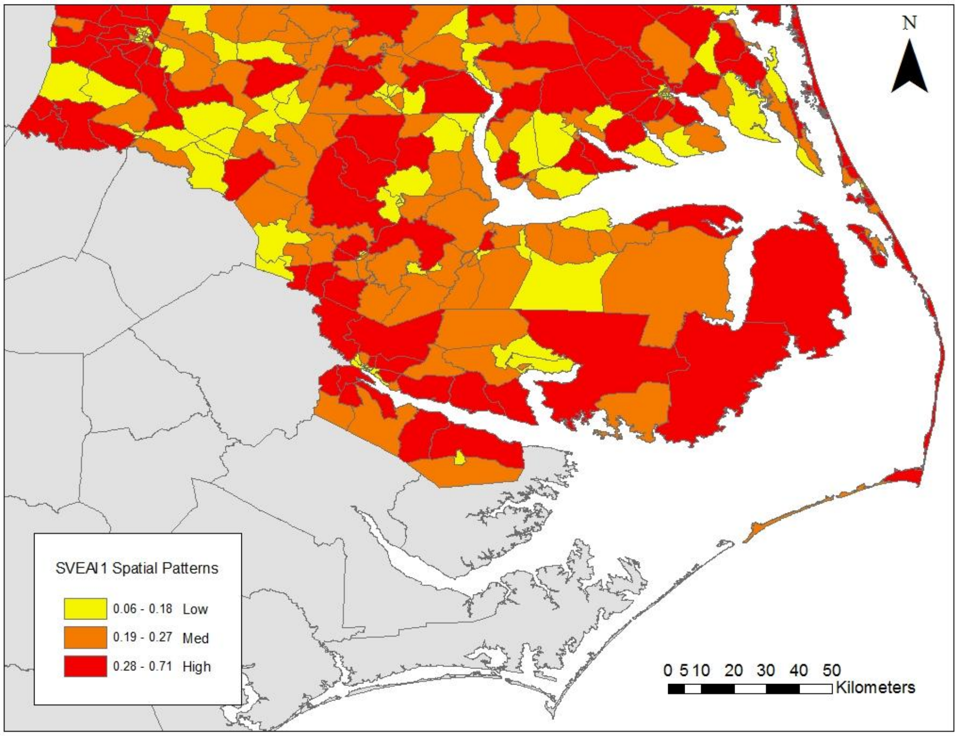


Figure 22. SVEAI2 Spatial Patterns

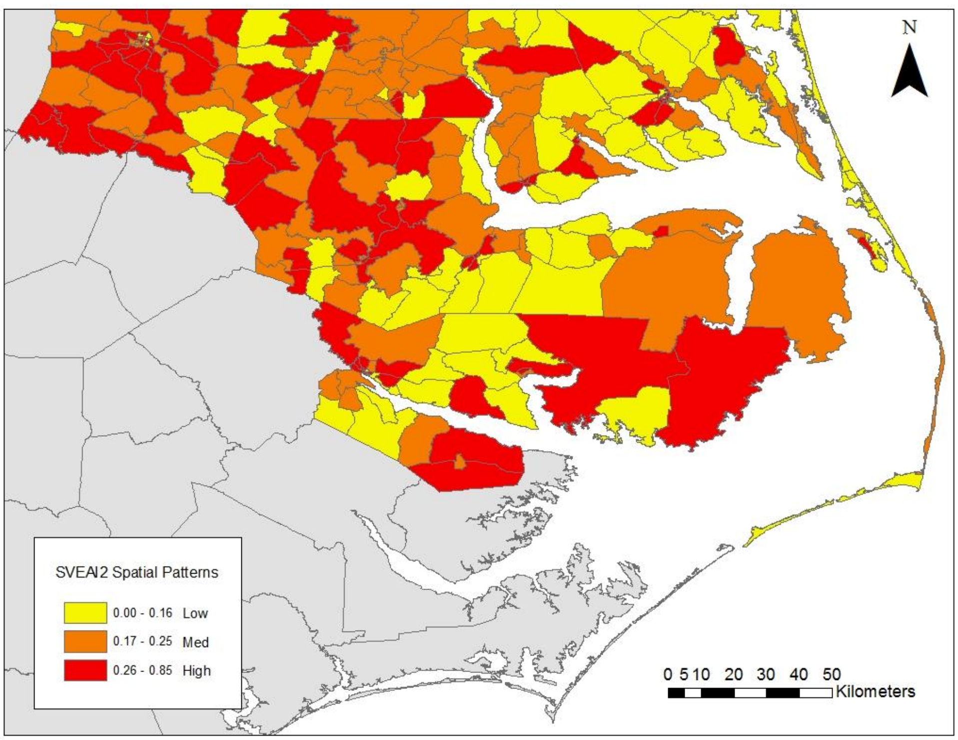


Figure 23. SVEAI3 Spatial Patterns

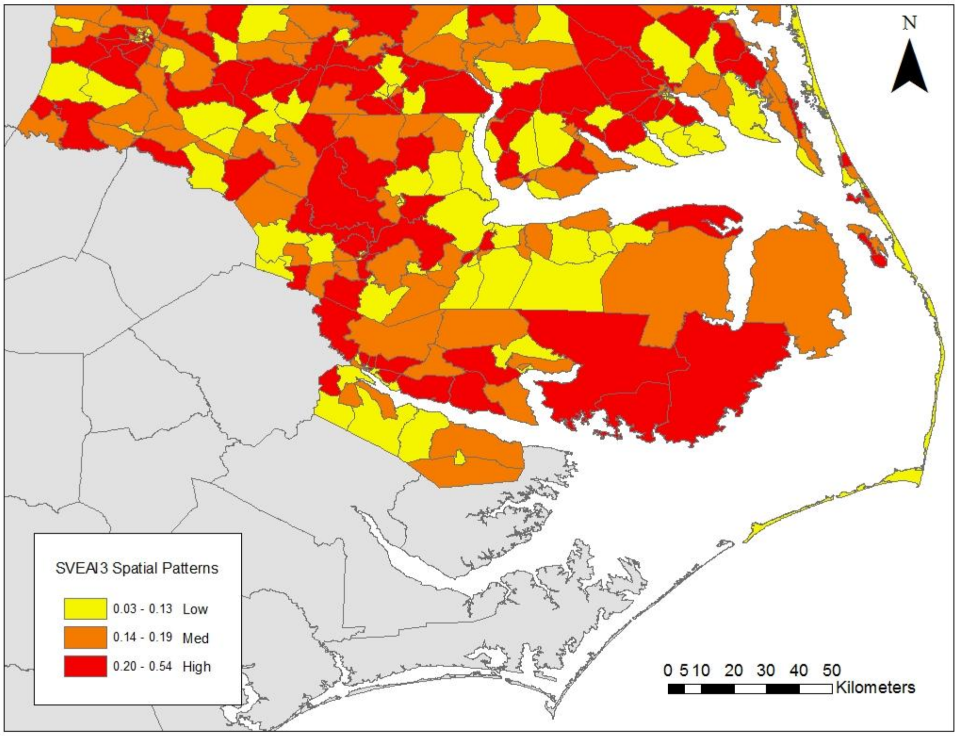
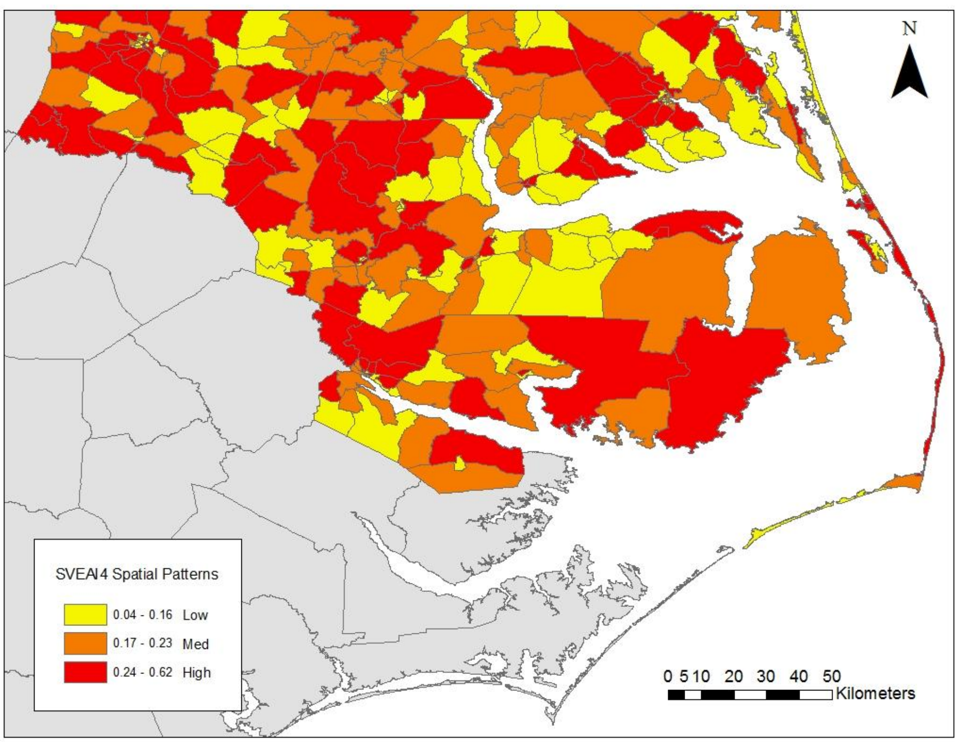


Figure 24. SVEAI4 Spatial Patterns



4.3.1 Hazards of Place Metrics

As mentioned before, the hazards of place metrics were calculated by multiplying the GPRI2 metrics with the SVEAI4 metrics. The results from this procedure are shown in Table 17, which shows the average hazards of place metric value for each county in the study area. The highest, average SVEAI metric values are in Dare County, Hyde County, and Tyrrell County.

The spatial patterns are shown in Figure 22. Most of this region consists of block groups with lower metric values, but a few block groups have higher metric values. Low risk block groups are distributed in the western region, and various medium block groups are distributed in the coastal region. High risk block groups are clustered in the east.

4.3.2 Hazards of Place Findings

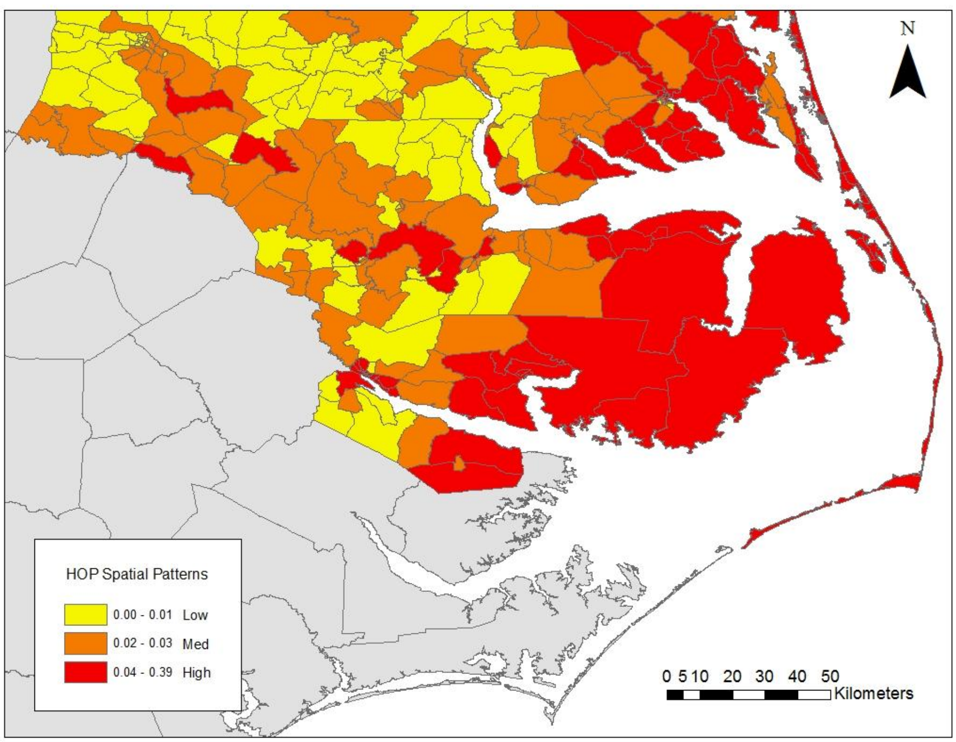
The results from the hazards of place analysis support two findings from the data. First, it is evident that block groups in the western region of the hazards of place assessment are less vulnerable to flood risk. When compared to the SVEAI map, higher metric values are scattered throughout the western region, while the GPRI map shows lower metric values in the western region. This indicates that the western region has minimum geophysical risk, with high levels of social vulnerability.

The rationale for this argument is further supported by the tables and spatial pattern maps from Section 4.1. The tables show the GPRI and SVEAI average metric values for each county in the study area. Areas with higher SVEAI metric values are in the west, and the GPRI 2 spatial

Table 17. Average Hazards of Place Metrics by County

County	Hazards of Place Metrics
Beaufort	.07
Bertie	.01
Camden	.07
Chowan	.02
Currituck	.07
Dare	.14
Gates	.01
Halifax	.01
Hertford	.00
Hyde	.23
Martin	.01
Northampton	.00
Pasquotank	.07
Perquimans	.04
Tyrrell	.17
Washington	.02

Figure 25. HOP Spatial Patterns



pattern map has similar results. Both maps show the cluster of low risk block groups in the western region.

For the second argument, high risk block groups in the eastern region are more vulnerable to flood risk from geophysical risk and socioeconomic factors. Like the western region, the eastern region is further analyzed by the visual assessment of the GPRI and SVEAI spatial distribution maps. The GPRI and SVEAI maps reveal distributions of higher metric values in the eastern region.

4.3.3 Hazards of Place Matrix

Producing the vulnerability matrix of low, medium, and high rankings was accomplished by categorizing the GPRI2 and SVEAI4 metrics. The following results from the matrix demonstrate the levels of geophysical and social vulnerability within the study area. The first dimension of the matrix comes from the geophysical risk metrics, while the second dimension of the matrix comes from the social vulnerability metrics.

Table 18 shows the hazards of place matrix. The table identifies numerous block groups with lower HOV metric values. A total of 78 block groups were determined as “Low Low” risk areas. These block groups make up a total of 27% of the study area. The “Medium Medium” risk areas represent 7% of the study area. This is a total of 28 block groups. Only 6 block groups were identified as “High High” risk areas, which make up 2% of the study area.

The hazards of place matrix is further analyzed through a spatial distribution map, shown in Figure 26. The map in Figure 26 reveals similar spatial patterns as Figure 25. Both maps show that the higher risk block groups, more specifically “High High” block groups, are concentrated

Table 18. Hazards of Place Matrix, Counts and Percentages of Block Groups

GPRI	SVEAI		
	1 (Low)	2 (Medium)	3 (High)
1 (Low)	78 (27%)	78 (27%)	25 (9%)
2 (Medium)	23 (8%)	21 (7%)	10 (3%)
3 (High)	27 (9%)	18 (6%)	6 (2%)

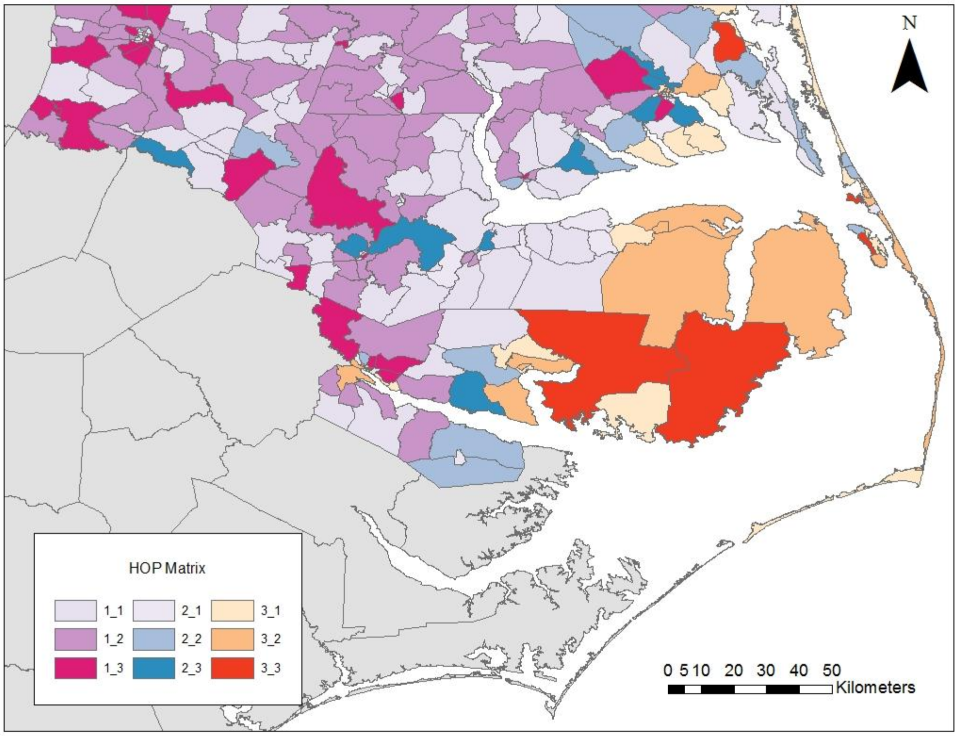
in the southeastern region. Figure23reveals that the western region consists of "Low Low," "Low Medium," and "Low High" block groups.

4.3.4 Hazards of Place Matrix Findings

The results from the hazards of place matrix support the arguments from Section 4.3.1. The first argument focuses on the geophysical risk and social vulnerability aspect of the western region. The hazards of place matrix results show that the areas in the western region are more vulnerable to flood risk from socioeconomic factors. Various block groups identified "Low Low," "Low Medium," and "Low High" risk areas are distributed in that area.

The second part of the first argument is further examined by the geophysical risk aspect. The results from the hazards of place matrix validate the findings of the limited flood risk in the western region. The previous paragraph mentioned that there were various "Low Low," "Low Medium," and "Low High" risk areas in the western region. As stated before, the first dimension of the matrix is geophysical risk. These results indicate that these areas are more vulnerable to flood risk from socioeconomic factors but a lower percentage of the block group's human development is within the one hundred year floodplain.

Figure 26. HOP Matrix Distributions



Supporting evidence from the hazards of place matrix results validates the second argument. Results from Sections 4.3.1 and 4.3.3 show a smaller distribution of higher values, specifically in the southeastern region. According to the matrix, these block groups have "High High" values. This further supports the second argument that areas in the eastern region are more vulnerable to flood risk from socioeconomic factors and are in danger of flood risk since a higher percentage of their development is within the one hundred year floodplain.

4.4 Hazards of Place Model of Vulnerability Validation

Validation is important to verify the quality of the hazards of place results. It is the purpose of this section to show the results from the quantitative validation. Considerable effort has gone in to validating the results through procedures other than quantitative methods. This section provides and interprets the results from the in depth analysis of parcel and flood data. Section 3.4.1 provided the methodology for the analysis. The results from this analysis will either validate the hazards of place matrix or illustrate the discrepancies with the results by identifying the degree to which land parcels are located within the one hundred year floodplain.

4.5 Sub-Block Group Analysis

It is the purpose of this section to quantify the number of residential parcels with building structures within the one hundred year floodplain. These residential parcels are reported as a percentage. A sub-block group analysis was undertaken for a block group identified as "Low Low" for Currituck County. This is shown in Figures 27 and 28. Figure 27 illustrates the residential parcels with households located in the one hundred year floodplain. Figure 28 is an aerial representation of the Figure 27 map. The results from the analysis revealed that 5% of the residential parcels that intersected with the one hundred year floodplain have residential building footprints located in the floodplain.

In terms of the hazards of place matrix, two block groups were identified as "Medium Medium" risk for Currituck County. The first block group is shown in Figures 29 and 30. The map shown in Figure 29 illustrates the residential parcels with households located in the one hundred year floodplain. Figure 30 is an aerial representation of the Figure 29 map. The results from the analysis reveal that 23% of the residential parcels that intersected with the one hundred year floodplain have residential building footprints located in the floodplain.

The second block group is shown in Figures 31 and 32. Figure 31 is a map of the residential parcels with households located in the one hundred year floodplain. Figure 32 is an aerial representation of the Figure 31 map. The results from the analysis revealed that 38% of the residential parcels that intersected with the one hundred year floodplain have residential building footprints located in the floodplain.

Figures 33 and 34 are maps of the block group identified as “High High” risk for Currituck County. “High High” means that the block group has a high GPRI2 and a high SVEAI4. Figure 33 shows residential parcels with households located in the one hundred year floodplain. Figure 34 is an aerial representation of the Figure 33 map. The results from the analysis revealed that 38% of the residential parcels that intersected with the one hundred year floodplain have households located in the floodplain. The hazards of place matrix did not determine any “Low Low” block groups for Dare County.

The block group identified as “Medium Medium” risk for Dare County is shown in Figures 35 and 36. As mentioned before, “Medium Medium” means that the block group has a medium GPRI2 and a medium SVEAI4. Figure 35 illustrates the residential parcels with households located in the one hundred year floodplain. Figure 36 is an aerial representation of the Figure 35 map. The results from the analysis revealed that 12% of the residential parcels that intersected with the one hundred year floodplain have residential building footprints located in the floodplain.

Two block groups were identified as “High High” for Dare County. The first block group is shown in Figures 37 and 38. As mentioned before, “High High” means that the block group has a high GPRI2 and a high SVEAI4. The map shown in Figure 37 represents the residential parcels with households located in the one hundred year floodplain. Figure 38 is an aerial representation of the Figure 37 map. The results from the analysis revealed that 69% of the residential parcels that intersected with the one hundred year floodplain have building footprints located in the floodplain.

The second block group is shown in Figures 39 and 40. Figure 39 is a map of the residential parcels with households located in the one hundred year floodplain. Figure 40 is an aerial representation of the Figure 39 map. The results from the analysis revealed that 95% of the residential parcels that intersected with the one hundred year floodplain have building footprints located in the floodplain.

To further emphasize the results from the sub block group analysis, aggregate results are provided in Table 19. An interpretation of these results suggests that the percentage of the parcels located in the floodplain appears to increase with each block group classification, from “Low Low” to “High High.” The estimate from the “Low Low” block group indicates that 5.67% of the residential parcels are located within the one hundred year floodplain. This estimate increases for “Medium Medium” block groups. 13.67% of the residential parcels for the “Medium Medium” block groups are located within the one hundred year floodplain. For “High High” block groups, 40.05% of the residential parcels are located in the one hundred year floodplain.

The results from this analysis suggest that the number of residential parcels in the block group corresponds to the percentage of the residential building footprints located in the floodplain. As mentioned previously, there were a total of three “High High” risk block groups examined in the sub-block group analysis. The block groups consisted of 5748 parcels. Out of the 5748 parcels, 2302 building footprints were located within the floodplain. Thus, the execution of a sub-block group analysis is an important contribution to this research.

Figure 27. “Low Low” Block Group for Currituck County

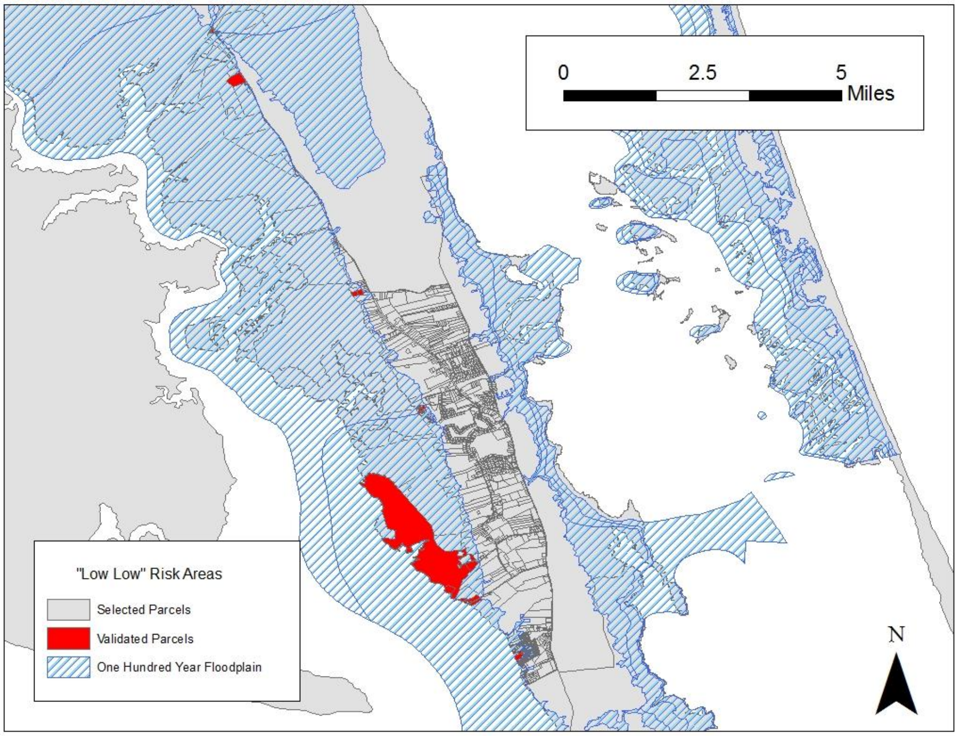


Figure 28. “Low Low” Block Group for Currituck County with Aerial Photo

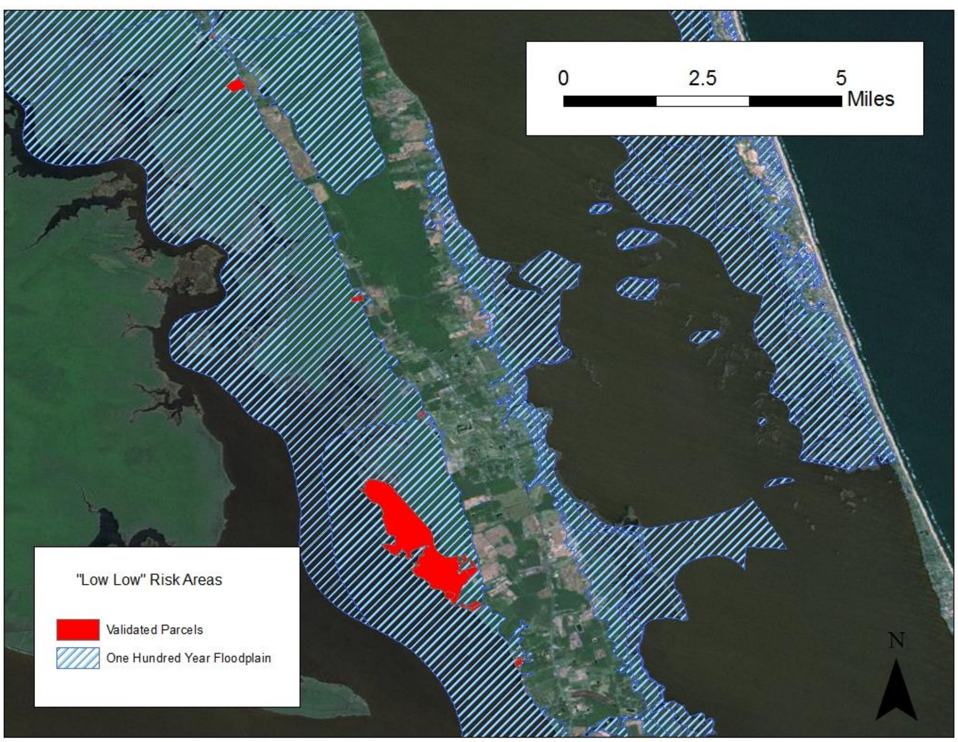


Figure 29. "Medium Medium" Block Group for Currituck County

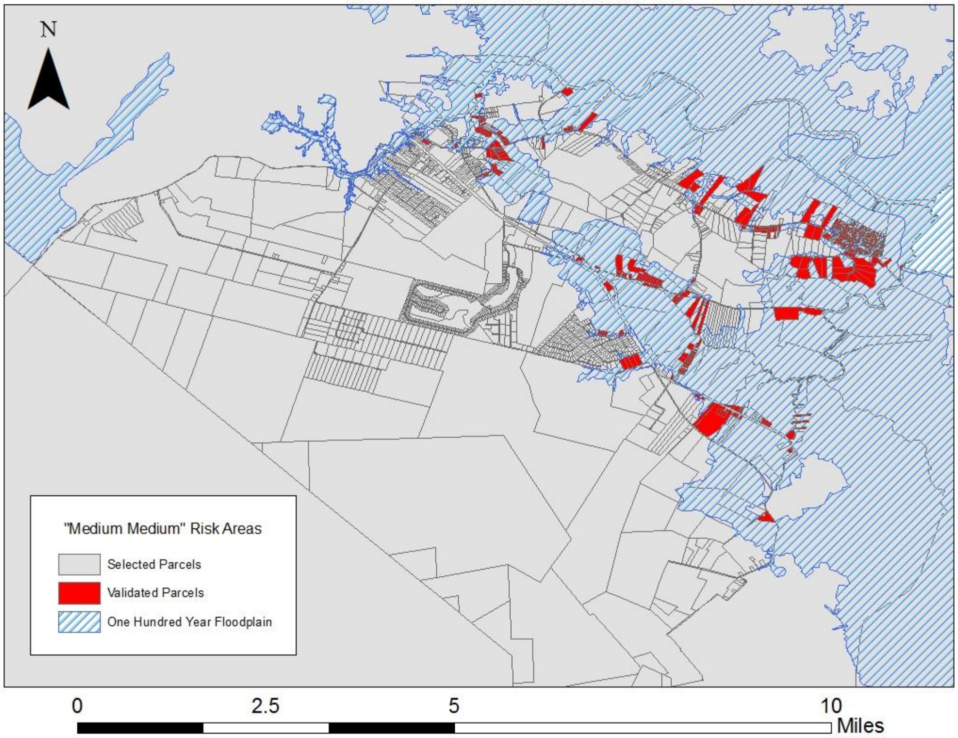


Figure 30. "Medium Medium" Block Group for Currituck County with Aerial Photo

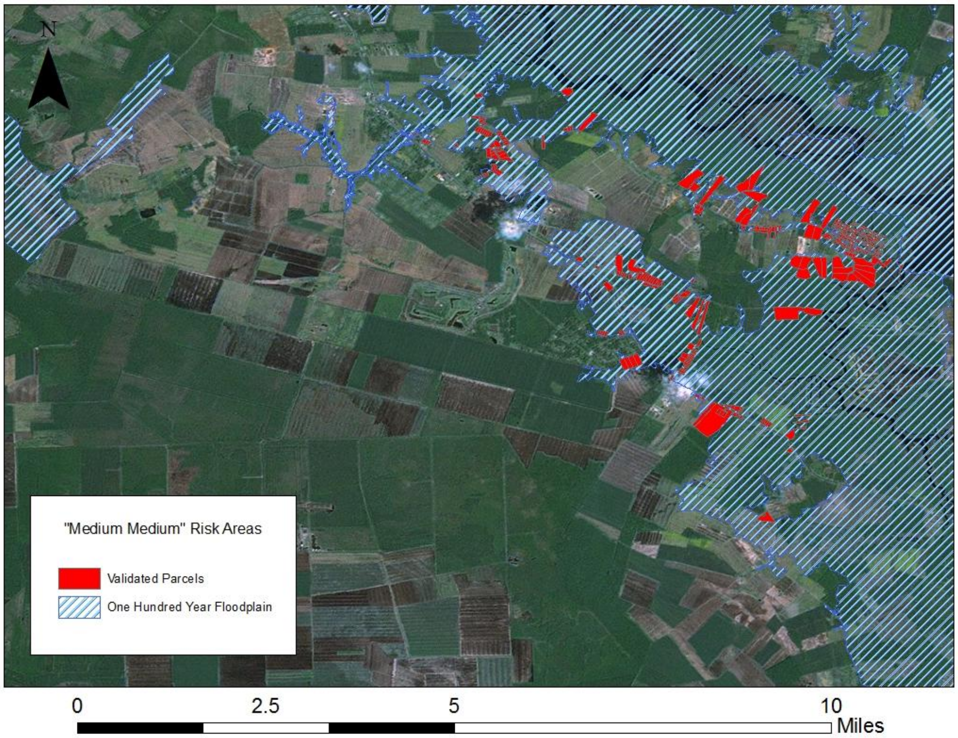


Figure 31. "Medium Medium" Block Group for Currituck County

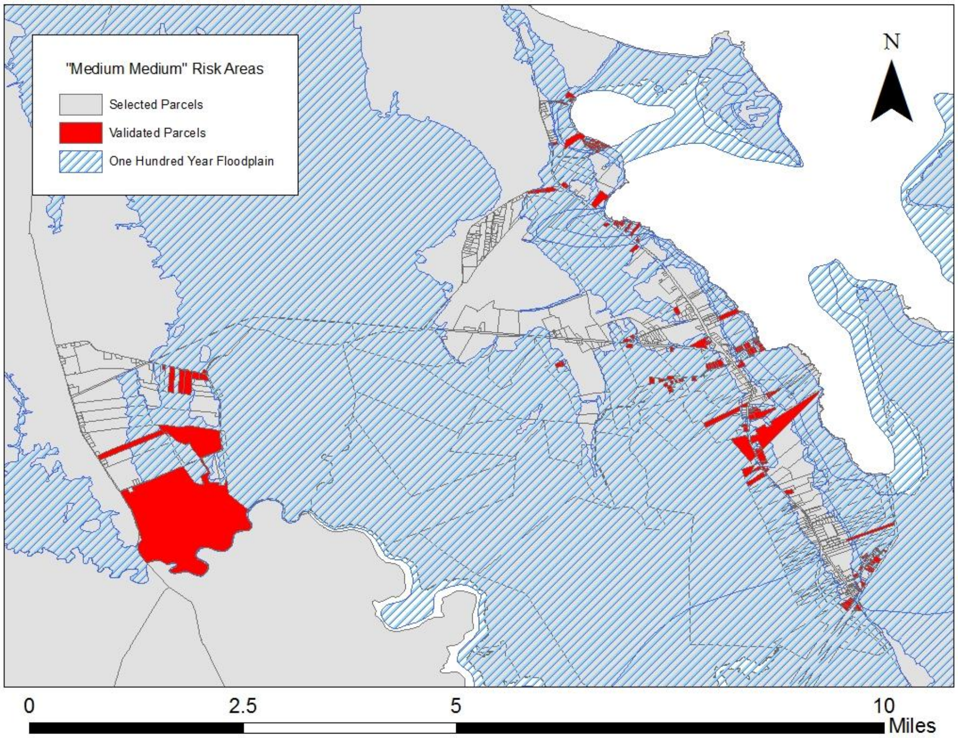


Figure 32. "Medium Medium" Block Group for Currituck County with Aerial Photo

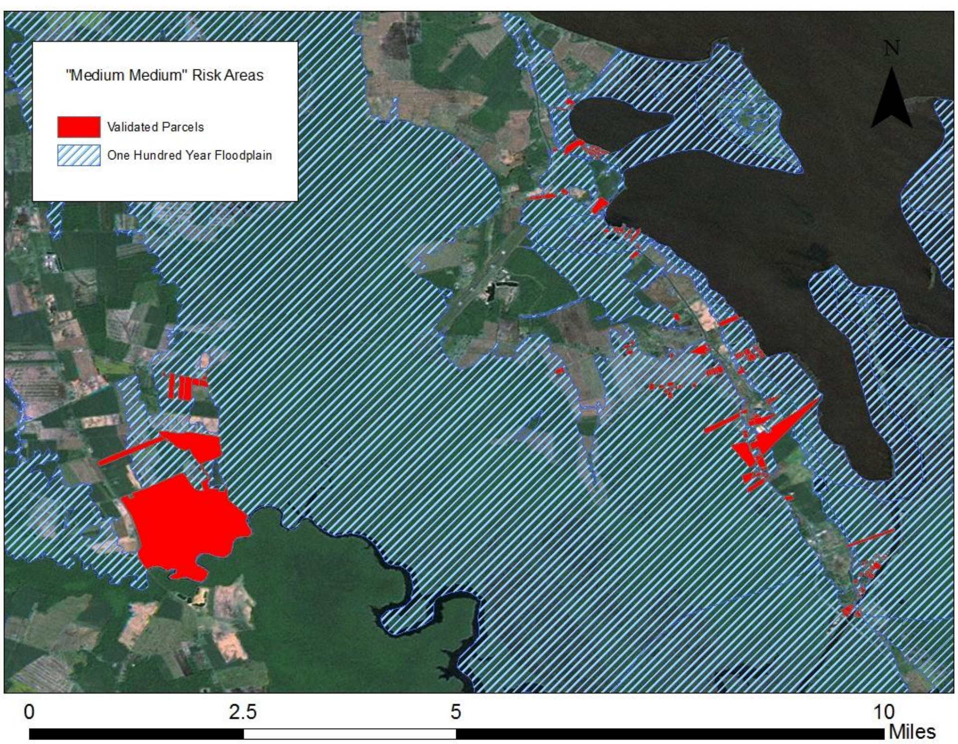


Figure 33. "High High" Block Group for Currituck County

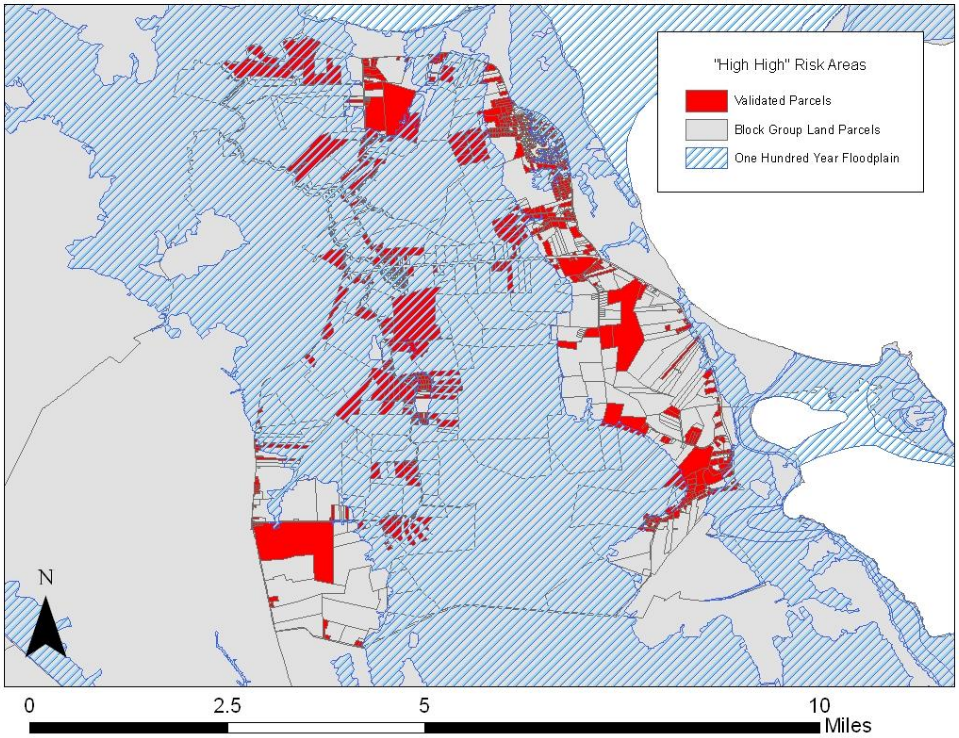


Figure 34. "High High" Block Group for Currituck County with Aerial Photo

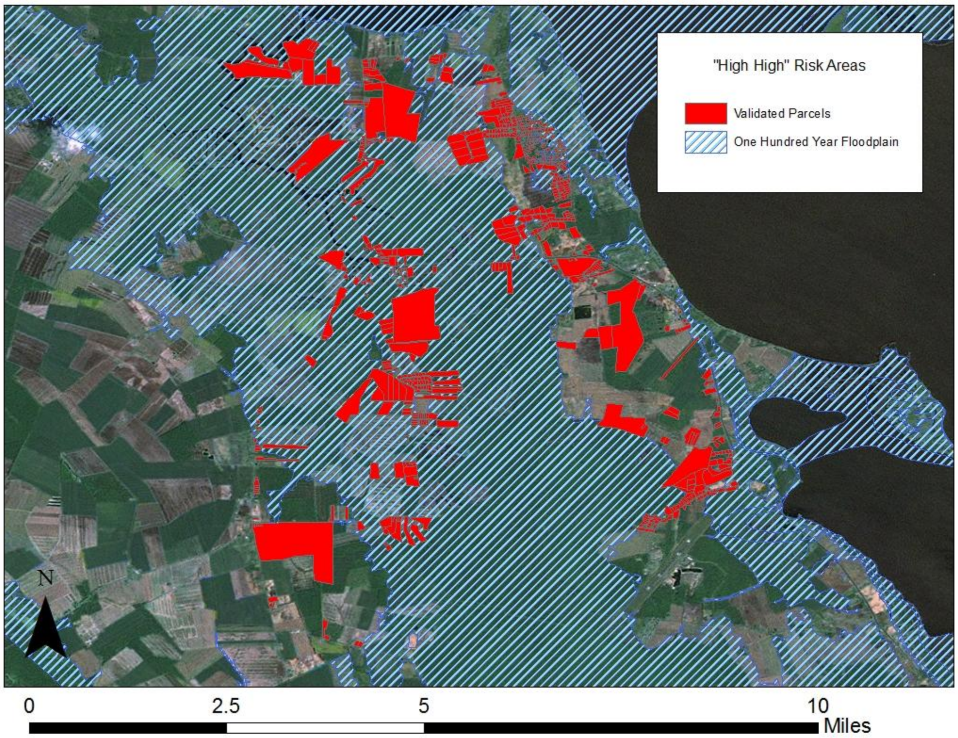


Figure 35. "Medium Medium" Block Group for Dare County

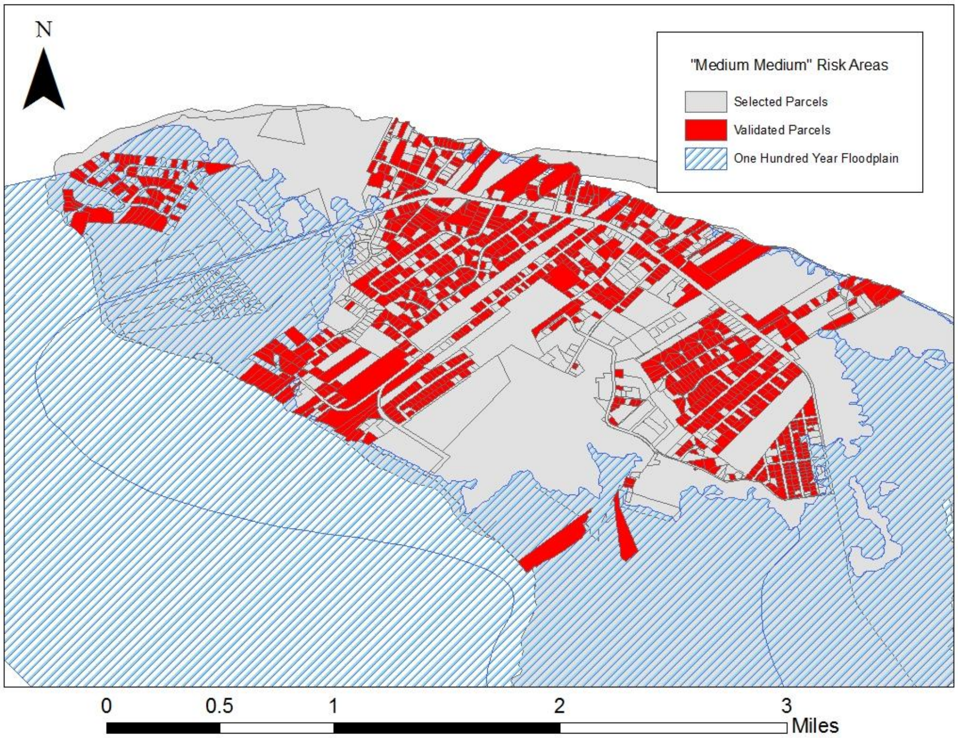


Figure 36. "Medium Medium" Block Group for Dare County with Aerial Photo

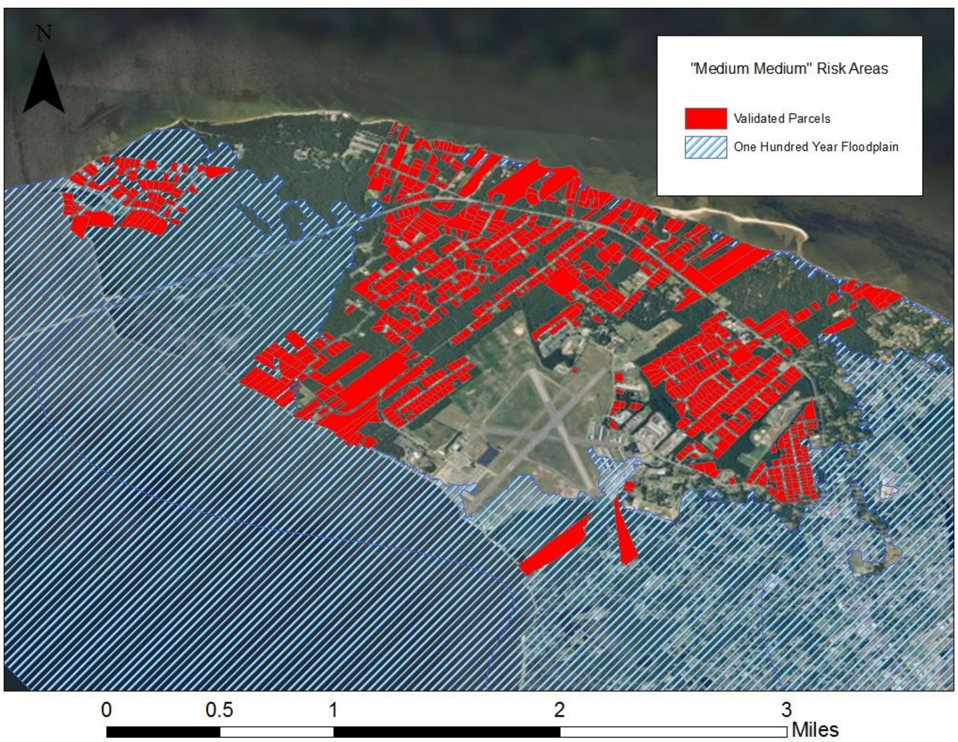


Figure 37. "High High" Block Group for Dare County

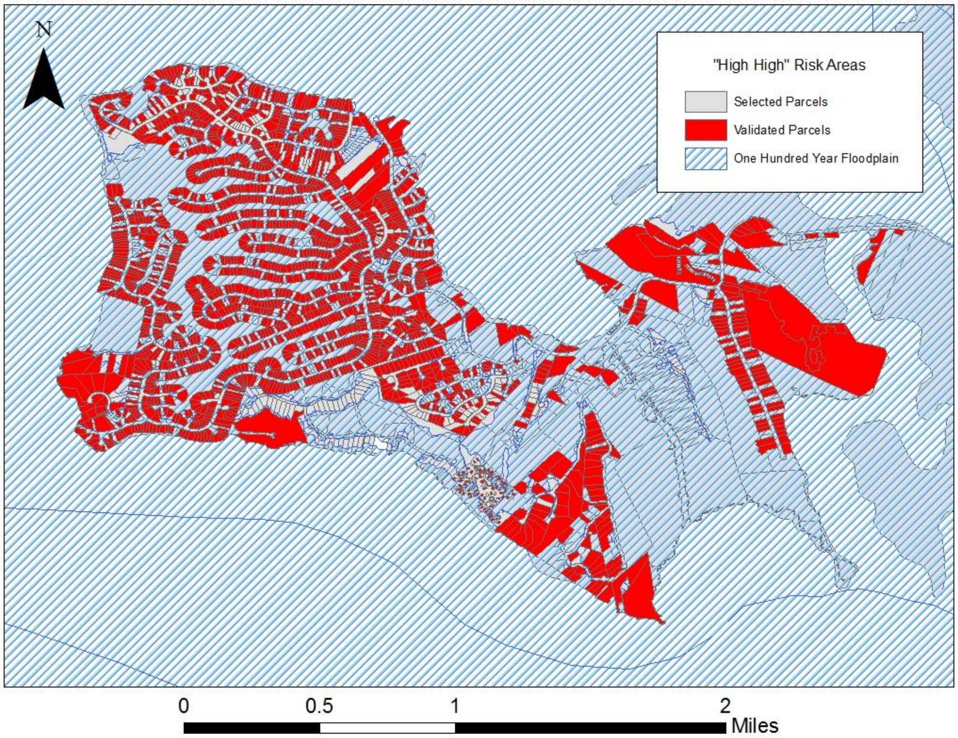


Figure 38. "High High" Block Group for Dare County with Aerial Photo

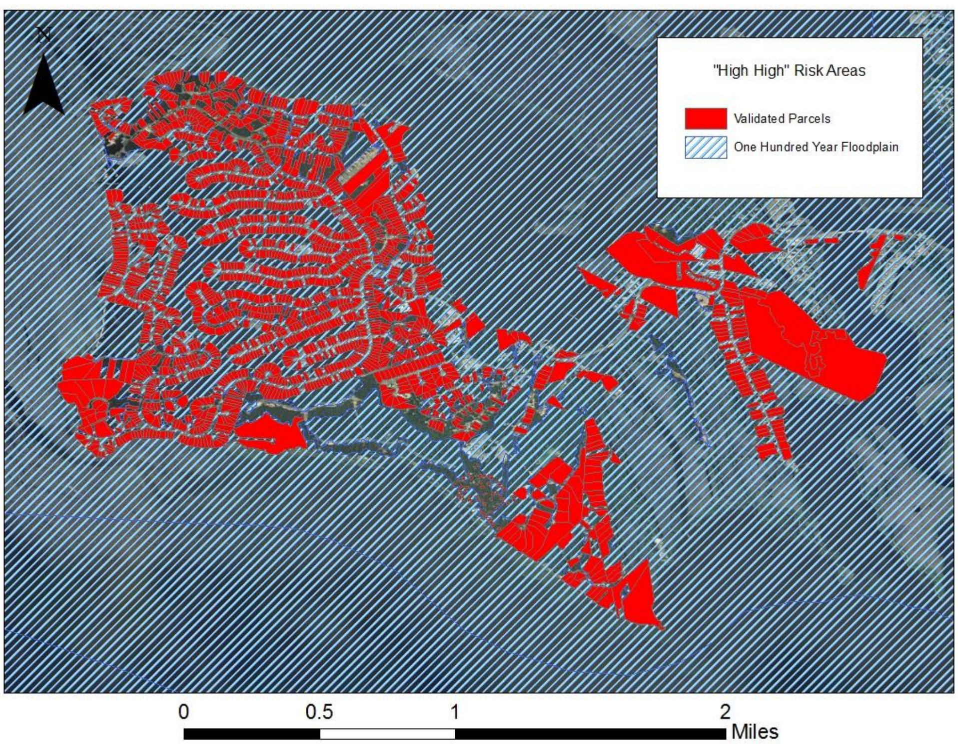


Figure 39. "High High" Block Group for Dare County

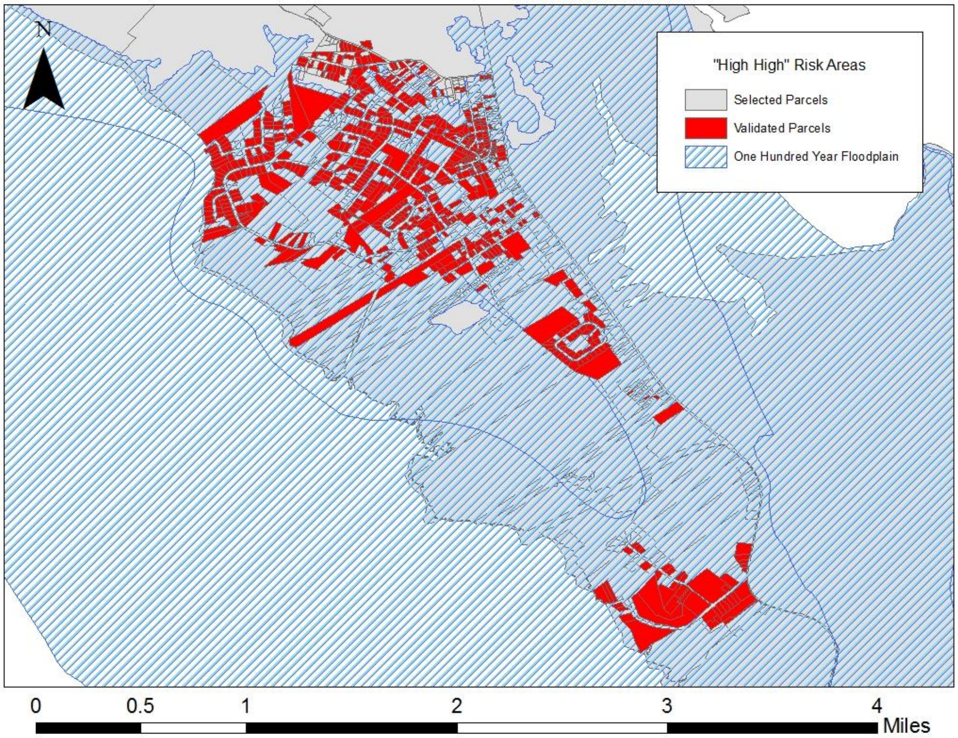


Figure 40. "High High" Block Group for Dare County with Aerial Photo

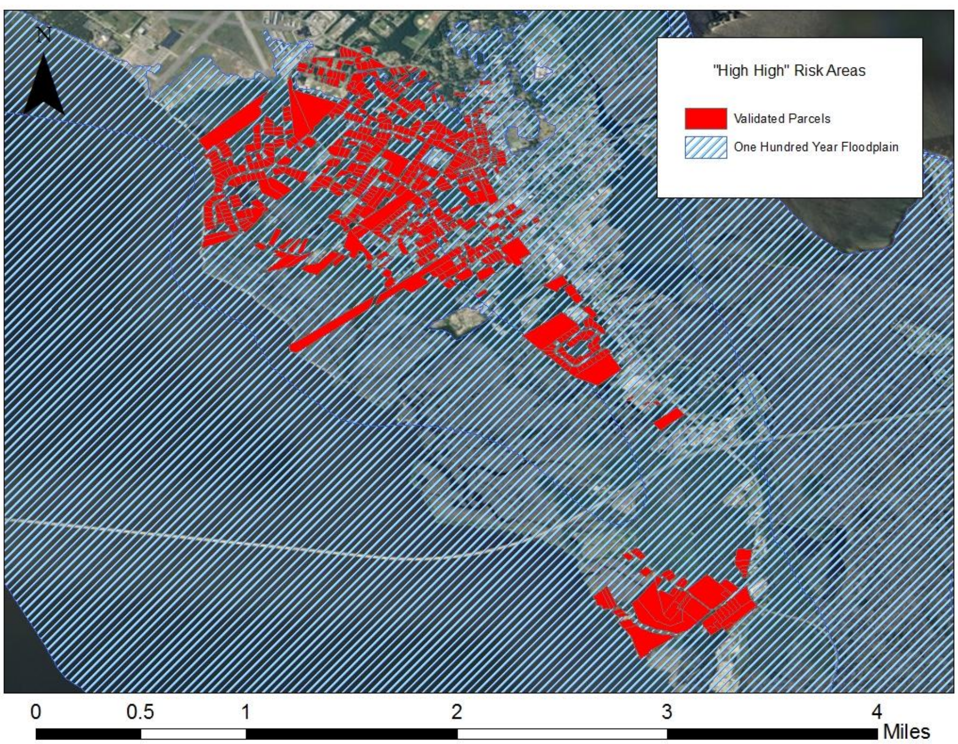


Table 19. Aggregate Results for Sub-Block Group Analysis

	# of Block Groups	# of Parcels	# of Residential Building Footprints in Floodplain	% of Residential Building Footprints in Floodplain
Low Low	1	723	41	5.67%
Medium Medium	3	4704	643	13.67%
High High	3	5748	2302	40.05%

4.6 Interview

The results from the interview are separated into four sections, based on the research questions from Section 3.4.2. The first section explains the boundaries identified by the key informant that are the most susceptible to flooding. In the second section, the boundaries identified by the key informant explained where humans are the most susceptible to flooding. The third section explains the areas identified by the key informant that are combinations of geophysical risk and social vulnerability. The final section explains the methods taken to evacuate communities.

4.6.1 Geophysical Risk Analysis

Figure 41 shows the boundaries identified by the emergency representative in Currituck County that are susceptible to flooding. This map was scanned into the computer. There are various reasons why the emergency representative identified some of these areas as flood prone. First, most of the areas identified in the map are located in the coastal region. The emergency representative explained that the coastal region consists of various low lying surfaces that are susceptible to flooding.

Other areas that the emergency representative identified as susceptible to flooding include unpaved surfaces in the Carova Beach region. Unpaved surfaces are a problem because they are capable of holding large amounts of water which can cause flooding. Another identified area is located in Knotts Island. Knotts Island has a higher elevation than most areas. However, the bridge that connects the population to the mainland is low lying and frequently floods. The flooding of the bridge causes the population to be separated from the rest of the county.

Figure 41 was compared to the GPRI spatial pattern map of Currituck County, shown in Figure 42. The spatial patterns of the map clarify the locations of high and low risk block groups from the GPRI metrics. Currituck County is situated on the coast, and the high risk block groups are located in the eastern, coastal areas of the county. Lower risk areas are distributed in the western coastal region of the county.

Figure 41. Boundaries identified by the Emergency Representative for Currituck County

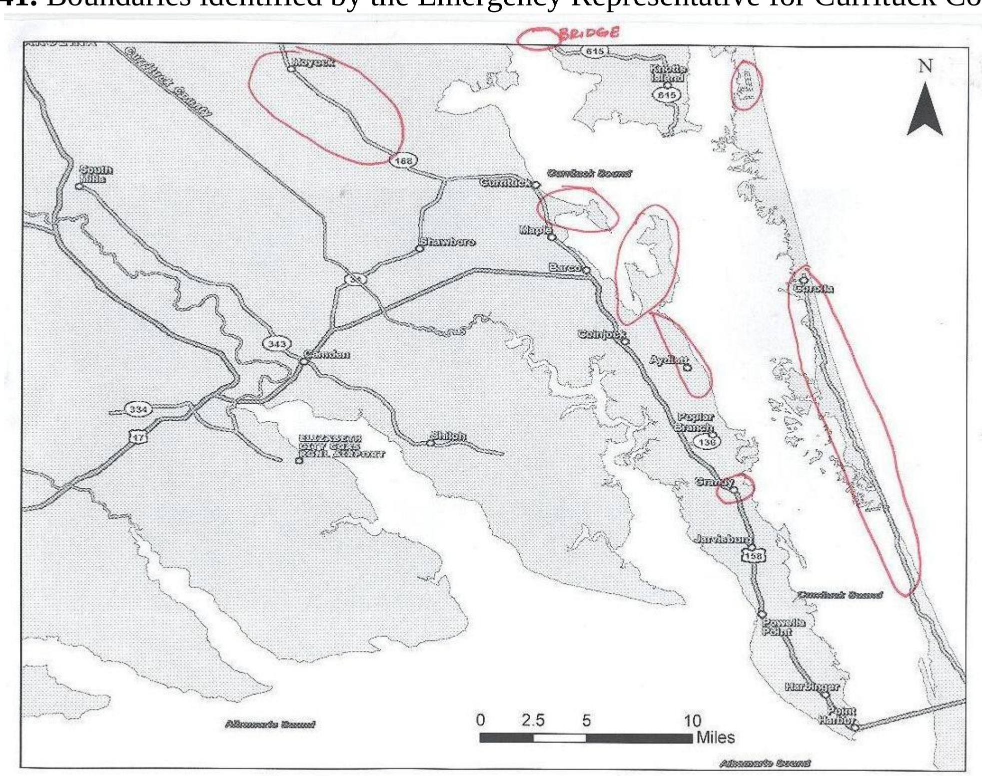
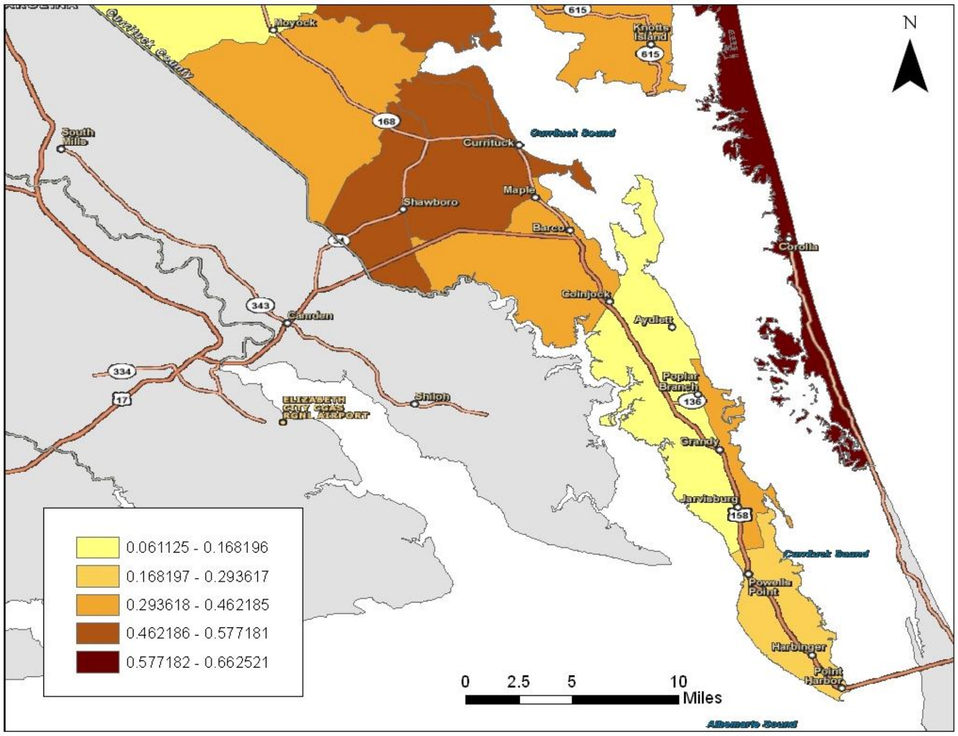


Figure 42. GPRI Spatial Distribution Map of Currituck County



Both maps have similarly identified areas in the county as high risk. One specific example is the town of Currituck, which is low lying and susceptible to flooding. The town of Currituck is located in a block group with a high metric value. There were a few areas from Figure 42 that did not correspond with the boundaries identified in Figure 41. More specifically, the emergency official identified the town of Moyock and Aydlett as high risk areas. However, the GPRI map shows the block groups that included the towns as low risk areas. The emergency representative identified Knotts Island as a high risk area but it was identified as a medium risk area in Figure 42. The differences between the two maps suggest that there are other factors that could not be measured quantitatively in the GPRI metrics and suggests the importance of local knowledge.

4.6.2 Social Vulnerability Analysis

In Figure 43, the key informant identified areas that explain where humans are the most susceptible to flooding. Similar to Section 4.4.2.1, there are various reasons why the emergency representative selected these areas. The emergency representative identified areas along the coast and inland. These areas consist of various mobile home and camping communities. As mentioned in Section 3.2.5, mobile homes are easily destroyed and more vulnerable to floods. Mobile home parks are distributed throughout the county in the towns of Aydlett, Barco, Maple, and Moyock. For the camping communities, their vulnerability level is typically higher because they do not live in stable living conditions. The camping community is located in the coastal areas of Aydlett and Poplar Branch.

The SVEAI spatial pattern map of Currituck County is shown in Figure 44. The spatial patterns of the map clarify the locations of high and low risk block groups from the SVEAI metrics. Medium and high risk block groups are distributed throughout the northern and southern regions of the county. There are only two low risk block groups which are located in the northern region of the county.

A similar comparison analysis used in Section 4.4.2.1was accomplished in this interview. The emergency representative's responses to Figures 43 and 44 were generally mixed. The emergency representative suggested that Figures 43 and 44 have similar, high risk areas. An example of this area is located west of highway 168. The emergency representative has identified this area as a home for various mobile home communities. The area is located within the block group identified as high risk, based on the socioeconomic variables provided in Section 3.2.5.

The emergency representative distinguished between Figures 43 and 44. As the emergency representative observes low risk block groups in Figure 44, an argument is made. The argument is based on the emergency representative's assumption of low risk block groups. She suggests that the low risk block groups should have higher metric values since these block group are more susceptible to flooding. Susceptibility to flooding is based on the types of populations that live there. These populations include mobile home and camping communities. The differences between the two maps suggest that specific populations could not be measured quantitatively.

4.6.3 Hazards of Place Analysis

A spatial distribution map of the hazards of place metrics was shown to the emergency representative for the validation process. This map is illustrated in Figure 45. The emergency representative provided a personal outlook of the spatial distribution map's accuracy. This outlook was based on her knowledge of the county.

Results from the emergency representative's response to the validity of the HOV spatial distribution map were mixed. A majority of the block groups identified from low to high risk were approved by the emergency representative. However, the emergency representative did not agree with the results from the hazards of place analysis that identified a block group as a high risk area.

From the emergency representative's perspective, other block groups are more susceptible to flooding than the block group identified as high risk in the map. The combination of low lying surfaces and poorly built homes make these block groups more susceptible to

Figure 43. Boundaries Identified by the Emergency Representative for Currituck County

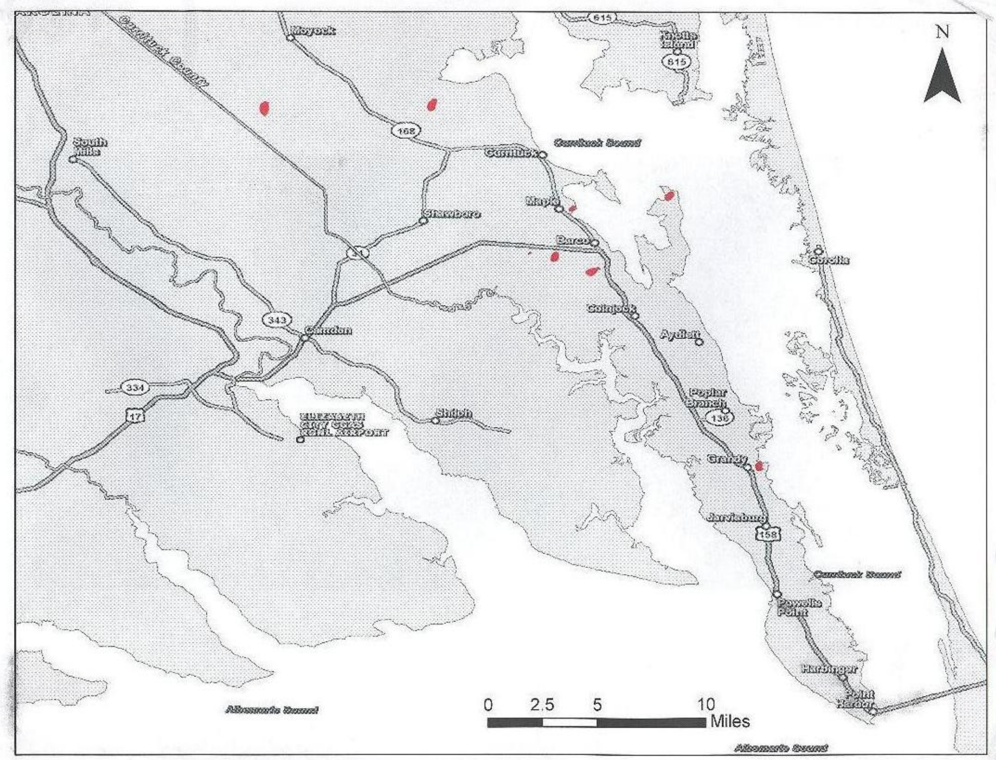


Figure 44. SVEAI Spatial Distribution Map of Currituck County

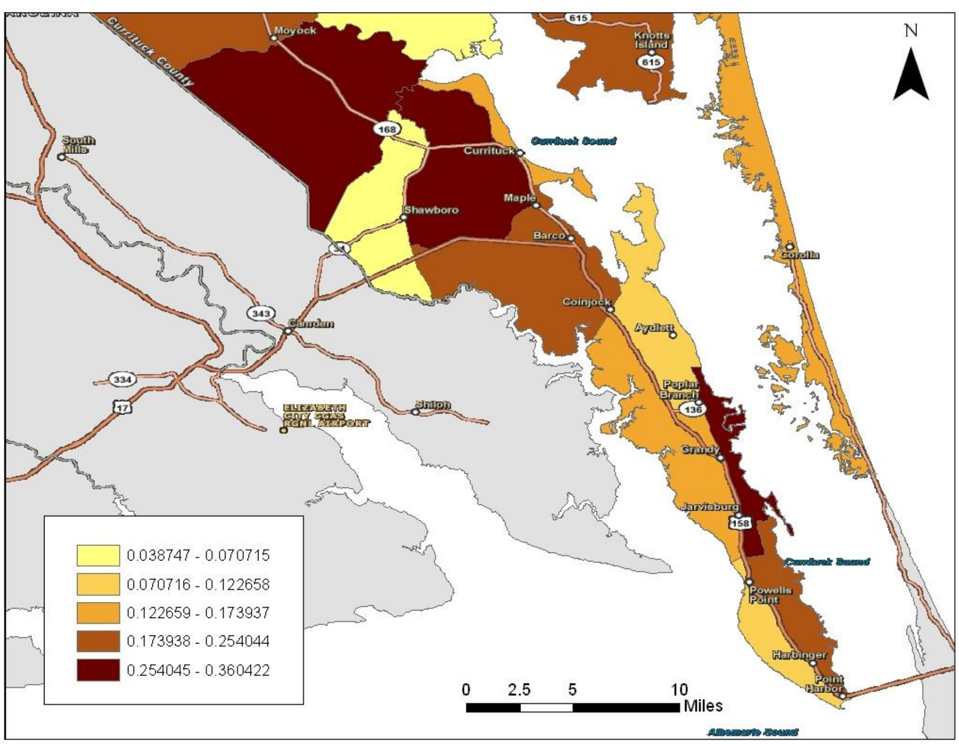
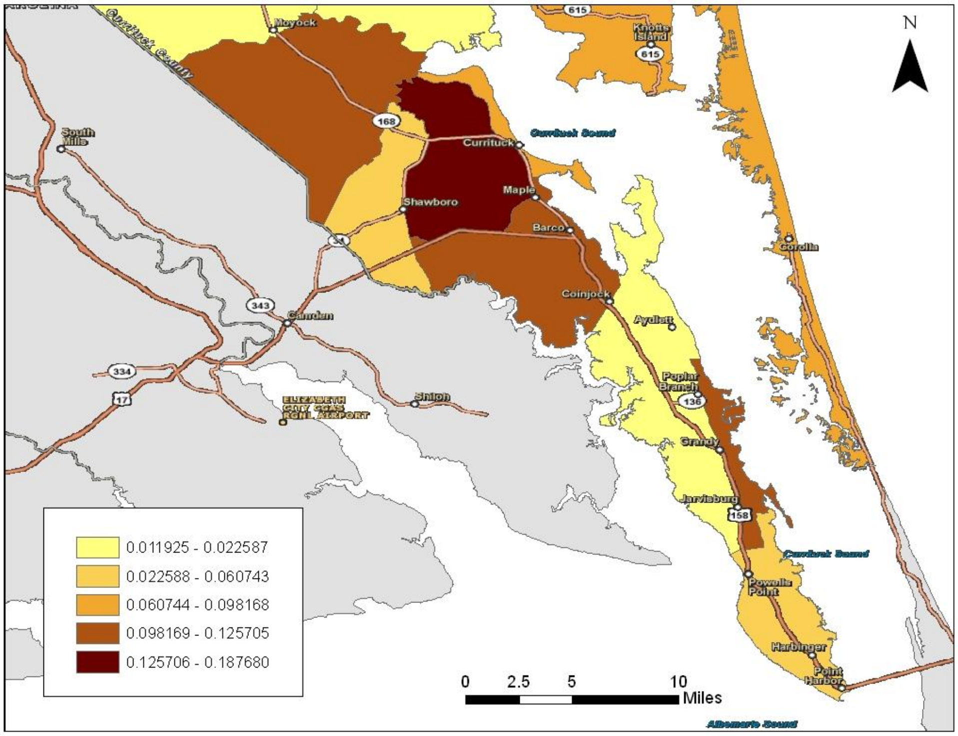


Figure 45. HOV Spatial Distribution Map of Currituck County



flooding than the calculated, high risk block group. These other block groups are located in the northern region, in proximity to the high risk block group.

4.6.4 Emergency Response

The results from the emergency official's boundary selections and the maps depicting results are important to understand the evacuation procedure for Currituck County. Incorporating these maps will provide additional support to the evacuation procedure. These maps would serve as a way to mitigate evacuations by identifying the most vulnerable areas in the county.

A standard flood evacuation procedure was provided by the emergency official, the main purpose, of which is to inform the population about the flood evacuation. According to the emergency representative, the county's public information officer would advertise the evacuation through the radio, television, and county webpage. Populations without access to electronics like television, radio, or internet, would have to be notified in another way. The first responders would have to locate these populations announce the evacuation through loud speakers in the neighborhoods. Thus, the maps would help identify the areas where these populations are located.

CHAPTER 5

Discussion

The purpose of this chapter is to discuss the results from this analysis in order to address the research questions. Conclusions related to the research questions are provided in this chapter. This chapter begins with a discussion of the inclusion of land cover data in the geophysical risk analysis. A discussion of the spatial patterns of grouped variables is explored. Next, the comparisons of the spatial patterns are provided. Third, a discussion of the sub-block group analysis serves to validate the hazards of place matrix. The final section discusses potential social mechanisms from the interview analysis.

5.1 Inclusion of Land Cover Data

In answer to the first research question, the inclusion of human development land cover data is defended by the visual interpretations of the spatial distribution maps. Block groups located in the eastern coast of both geophysical risk maps share similar results of higher metric values. Spatial patterns of the two maps show a combination of metric values that range from low to medium in the western region. The GPRI1 map shows the distribution of higher metric values in the western region, while the GPRI2 map shows lower metric values in the western region.

Although both maps display the distribution of higher metric values along the eastern coast, block groups with higher GPRI1 metric values overestimate vulnerability. As mentioned previously, the GPRI1 does not take into account the locations of development. It is possible for a block group to have a high percent of its area within the floodplain. However, without the inclusion of human development data, it is difficult to determine whether or not people are actually vulnerable since there is no indication of where they are located in proximity to the floodplain.

Another scenario is discussed to indicate the strengths of including human land cover data with the GPRI. Individuals residing in block groups with lower GPRI1 metric values can still be identified as vulnerable. This refers to a block group with a lower percentage of its area within the floodplain but a higher percentage of its human development within floodplain. Thus, the GPRI2 metric values approximate the validity of the GPRI model in comparison to GPRI1.

5.2 Spatial Patterns of Grouped Variables

To answer the second research question, this analysis found that the groupings of variables used in the SVEAI models alter the spatial patterns of social vulnerability. A visual assessment of each SVEAI reveals variations in spatial patterns. Block groups with higher population and structure densities are located throughout northeastern North Carolina. There are fewer block groups with high differential access to resources metrics, and they are also located primarily in the western region of the study area. Higher concentrations of populations with special evacuation needs are located in the northern and western regions. The result of all three characteristics combined show higher vulnerability in the northern and western regions as well.

5.3 Comparison of Spatial Patterns

The first research question addresses the relationship between geophysical risk and social vulnerability through an analysis of all the spatial distribution maps. A visual assessment of the spatial patterns for each quantitative model was presented. The visual assessment, block groups with the highest GPRI2 metrics were identified in the eastern, coastal areas of northeastern North Carolina. Thus, the lands in the eastern coast are more susceptible to flooding. The SVEAI4 model presents different spatial patterns. The highest metric values are scattered throughout the study area.

Comparing the geophysical risk and social vulnerability maps suggests that there are differences in the spatial patterns. There are fewer block groups with high SVEAI metric values than the high GPRI block groups. Block groups with lower social vulnerability metrics are still capable of being at risk based on the corresponding GPRI model. For example, a block group with lower social vulnerability metrics is capable of being at risk if the block group has a high, geophysical risk. They are still vulnerable if they reside in block groups with a higher percentage of their development located within floodplain.

5.4 Sub-Block Group Analysis

As a result of the sub-block group analysis, a couple of conclusions can be made about the hazards of place matrix. First, the results suggest that the hazards of place matrix is an accurate indicator for classifying low, medium, and high risk block groups in the study area. However, there are a couple of discrepancies with the results. As mentioned before, Dare

County’s block group percentages are organized in their respective orders. The “High High” percentage value is higher than the “Medium Medium” and “Low Low” block groups.

The validation process is weakened by Currituck County’s block group percentages. Both “High High” and “Medium Medium” block groups have equivalent percentage values. This indicates that the metrics from the hazards of place analysis overestimate or underestimate the geophysical risk and social vulnerability results. The “High High” block group should either have a higher percentage or the “Medium Medium” should have a lower percentage.

5.5 Other Existing Dimensions

Finally, the results from the interview analysis suggest that there are other dimensions of geophysical risk and social vulnerability that exist in the study area but were not identified by the quantitative models. For the geophysical risk aspect, the emergency representative identified unpaved surfaces and the Knotts Island Bridge as the areas that were susceptible to flooding but not identified in the GPRI.

For the social vulnerability aspect, the emergency representative provided information about a population that was not identified by the SVEAI. The populations identified by the emergency representative are the camping communities. Camping communities are more susceptible to flooding since they do not live in stable living conditions. These camping communities are located in the coastal areas of Aydlett and Poplar Branch.

CHAPTER 6

Limitations and Directions for Future Research

A series of limitations were encountered throughout this analysis and could be resolved by future studies of this research. Thus, the purpose of this chapter is to discuss the limitations of this analysis and recommendations for future research.

6.1 Updating Floodplain Data

For this analysis, floodplain data from the DFIRM databases were included in the GPRI models. Since the GPRI models include floodplain data from the 2010 DFIRM database, the results from this analysis are only accurate for the present time period. Due to events like climate change and sea level rise, DFIRM databases are constantly updated. In light of this, future research should be aware that the DFIRM database could become outdated and should be prepared to update the floodplain data for accurate results.

Future research should continue to use updated DFIRM databases to manage the HOP as well. According to Cutter et al. (2000), the vulnerability of places can change over time due to alterations in risk, mitigation, and the context in which hazards occur. Thus, the Hazards of Place Model of Vulnerability (Cutter 1996) will be reduced in accuracy if its floodplain data is not updated as well. Such an update would maintain the accuracy of the HOP.

6.2 Monitoring the Trends of Vulnerability

As discussed in previous chapters, the availability of US Census data significantly contributes to the Hazards of Place Model of Vulnerability (Cutter 1996). Due to the fact that census data is updated every ten years, the HOP will only be accurate for the year in which the socioeconomic data was selected. For every additional year, it would be difficult to determine whether the building footprints located in the one hundred year floodplain are truly socially vulnerable based on each block groups increase or decrease in population.

For this reason, it would be interesting to monitor the trends of vulnerability over a period of time. Evaluating the trends of vulnerability can be accomplished by incorporating data sets from different time periods. An analysis of the data sets would determine whether the block groups are increasing or decreasing in vulnerability over time. For example, a total of 286 block groups from the 2000, Census block group data sets were evaluated for this analysis. Census data sets from 1990 are currently available, while the 2010 census data sets will be available for download. Since census data are updated every ten years, it would be important to include updated, floodplain data into the analysis as well. The inclusion of updated geophysical risk or social vulnerability data sets would contribute to a comparison analysis with the current data set.

6.3 Investigating Building Footprints

Despite the accuracy of the sub-block group analysis, the procedure did not take into account the type of building footprint for each residential parcel. The building footprints could range from module homes, to mansions. Thus, the sub-block group analysis does not determine whether the houses are inhabited by poor or wealthy individuals. Future research may seek to alleviate this problem by determining the building footprint type for each residential parcel. For example, the inclusion of property values, residential building description would help clarify the types of building footprints that intersect with the one hundred year floodplain.

6.4 Interviewing More Emergency Informants

The purpose of interviewing an emergency informant was to validate the Hazards of Place Model of Vulnerability (Cutter 1996). An interview helped identify other dimensions of social vulnerability, geophysical risk, and hazards of place that do not exist in the quantitative models. Since two counties were used in the sub block group analysis, the interview procedure was limited to the number of emergency informants that could be contacted for this analysis. For this analysis, only one key informant was interviewed based on the availability of data and time constraints.

The results from the interview provided two dimensions of geophysical risk and one dimension of social vulnerability that could not be identified from the quantitative models. If it was possible to interview other key informants, other geophysical risk, social vulnerability, and hazards of place dimensions could be identified. However, if other dimensions were not identified, it would help validate the results from the Hazards of Place Model of Vulnerability (Cutter 1996).

CHAPTER 7

Conclusion

As mentioned in previous chapters, this research attempted to estimate and validate the Hazards of Place Model of Vulnerability (Cutter 1996) for northeastern North Carolina. Thus, the results from this analysis have made a number of contributions to hazards research. The most important contributions described in this analysis were summarized in various ways.

While previous research has measured geophysical risk quantitatively in the past, the inclusion of human development land cover data has not been integrated as a component of previous hazards research. Therefore, this first contribution involves the inclusion of human land cover data with the GPRI models. The specific locations of humans in proximity to the one hundred year floodplain were examined through this method.

Also, previous hazards research has not attempted to validate results through quantitative and qualitative methods. This analysis has explored individual residential parcels with building footprints located in the one hundred year floodplain. For the qualitative method, an interview with an emergency official was conducted to further validate the HOP results.

With the research contributions mentioned above, the intent of this analysis is proven useful. The contributions of this analysis reflect the five research objectives, mentioned in Chapter 1. These objectives were designed to provide insight into the validation process for the Hazards of Place Model of Vulnerability (Cutter 1996). This chapter serves to recall the research objectives to reflect the concluding ideas of this thesis.

7.1 First Objective: Determining Factors for the Hazards of Place Model

The goal of the first objective was to determine the appropriate geophysical risk and social vulnerability factors for the hazards of place model. As mentioned in the first chapter, the selection process was based on a correlation analysis and a visual assessment of the spatial patterns of the geophysical risk and social vulnerability. It was found from the correlation analysis that the two geophysical risk models are strongly correlated and have a positive, linear relationship. On the other hand, the spatial distribution maps illustrate differences in geophysical risk patterns. The spatial analysis suggested that block groups with a low percent of its area within the floodplain and a high percent of its development with the floodplain are still vulnerable to flooding. Thus, the inclusion of human development has a great influence on geophysical risk, which helped identify GPRI2 as the geophysical risk factor in the hazards of place analysis.

For the correlation analysis of four social vulnerability models, the models are positively correlated with one another, with similar spatial patterns. The spatial analysis shows similar spatial patterns of block groups with higher metric values. This finding supports the notion that all of the characteristics estimate similar high risk areas in the study area. Thus, it is appropriate to select SVEAI4 as the social vulnerability model of the hazards of place analysis. As mentioned in the previous chapter, SVEAI4 is a combination of all the evacuation characteristics.

7.2 Second Objective: Develop the Hazards of Place Model

The second objective of this research was to develop the hazards of place model. In order to respond to this objective, a visual assessment of the spatial distributions was undertaken to evaluate the results from the hazards of place model. It was found that the block groups in the eastern and western region illustrate different results. The block groups in the western region are less vulnerable to flood risk. Comparisons of the GPRI and SVEAI spatial distribution maps show that the block groups in the western region have lower geophysical risk metric values and high social vulnerability values. This indicates that the western region has minimum geophysical risk, with high levels of social vulnerability.

According to the HOV spatial distribution map, block groups in the eastern region are more vulnerable to flood risk. The map showed higher values in the eastern region. To further validate the results, a comparison of the GPRI and SVEAI spatial distribution maps reveals higher geophysical risk, and social vulnerability values. These results indicate that the eastern region has high levels of geophysical risk and social vulnerability.

7.3 Third Objective: Creating the Hazards of Place Matrix

The intention of the third objective was to create the hazards of place matrix based on the groupings of the HOV metrics. To achieve this objective, the hazards of place matrix of low, medium, and high rankings was created by categorizing the GPRI and SVEAI metrics. A total of seventy-eight block groups were classified as “Low Low” risk areas, which made up a total of 27% of the study area. The “Medium Medium” risk areas represented 7% of the study area, which is a total of twenty-eight block groups. Six block groups were identified as “High High” risk areas, which made up 2% of the study area.

It was found from the hazards of place matrix that the western region consists of various “Low Low,” “Low Medium,” and “Low High” block groups. This indicates that the western region consists of many block groups with low geophysical risk values and high, social vulnerability values. The eastern region consists of a small distribution of “High High” risk block groups. These results indicate that this region consists of various block groups with high geophysical risk values and high social vulnerability values.

7.4 Fourth Objective: Conducting Sub-Block Group Analysis

The fourth objective examined the sub-block group analysis of the block groups, land parcel data, and DFIRMs, with the intent of validating the hazards of place matrix. To obtain this objective, the sub-block group analysis was performed for Currituck and Dare Counties based on the availability of land parcel data. Every individual, residential parcel that intersected with the one hundred year floodplain was examined. If the household is actually located in the floodplain, the land parcel received a value of 1. Otherwise, the land parcel received a value of 0.

The results of the sub-block group analysis confirm the validity of the hazards of place matrix. For Dare County, “High High” classified block groups received the highest percentages of societal development within the floodplain, while the “Low Low” classified block groups obtained the lowest percentages of societal development within the floodplain. On the other hand, the validation process was weakened by the block groups in Currituck County. The “High High” and “Medium Medium” block groups acquired equivalent percentage values. It can be summarized that the metrics from the hazards of place analysis are capable of overestimating or underestimating the geophysical risk and social vulnerability results.

7.5 Fifth Objective: Interpreting the Interview Analysis

The aim of the fifth objective was to validate the hazards of place results through the interview process. The interview was conducted with an emergency informant in Currituck County. It was found that the higher metric values from the geophysical risk, social vulnerability, and HOP distribution maps had a similar relationship as the high risk areas identified by the key informant.

However, the key informant acknowledged other dimensions of geophysical risk and social vulnerability that could not be measured quantitatively. The emergency informant acknowledged unpaved surfaces and the Knotts Island Bridge as the geophysical risk factors that were not identified by the GPRI. For the social vulnerability aspect, camping communities were identified as social vulnerability factor that was not identified by the SVEAI. The results show that the hazards of place matrix is an accurate indicator for estimating vulnerability. However, there are other geophysical and social factors that are not able to be identified by quantitative indicators.

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APPENDIX A: INFORMATION LETTER

<u>CONSENT DISCLOSURE</u>

You are being invited to participate in a research study "A Validation Assessment of the Hazards of Place Model of Vulnerability for Northeastern North Carolina " being conducted by Bryce L. Carmichael, a student at East Carolina University in Geography Department, to validate the hazards of place model of vulnerability. The goal is to interview key informants with emergency backgrounds. The interview will take approximately thirty minutes to complete. It is hoped that this information will assist us to better understand human vulnerability. Your participation in the research is voluntary. You may choose not to answer any or all questions, and you may stop at any time. This interview will be recorded.

There would be no penalty for not taking part in this research study.

Please call principal investigator Ph. for any research related questions or the UMCIRB at 252-744-2914 for questions about your rights as a research participant.

Sincerely,

Bryce Carmichael

Email: carmichaelb09@students.ecu.edu
East Carolina University
Department of Geography

APPENDIX B: IRB APPROVAL

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
1L-09 Brody Medical Sciences Building• 600 Moye Boulevard • Greenville, NC 27834
Office **252-744-2914** • Fax **252-744-2284** • **www.ecu.edu/irb**

TO: Bryce Carmichael, 410 E. Firetower Rd., Apt. # 2, Winterville, NC 28590

FROM: UMCIRB KK

DATE: March 31, 2011

RE: Expedited Category Research Study

TITLE: "Validating the Hazards of Place Model of Vulnerability for Flood Risk in Northeastern North Carolina"

UMCIRB #11-0194

This research study has undergone review and approval using expedited review on 3.29.11. This research study is eligible for review under an expedited category number 6 & 7. The Chairperson (or designee) deemed this **unfunded** study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The above referenced research study has been given approval for the period of **3.29.11** to **3.28.12**. The approval includes the following items:

- Internal Processing Form (dated 3.13.11)
- Protocol Summary
- Informed Consent (received date 3.28.11)
- Interview Questions

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418
IRB00004973 East Carolina U IRB #4 (Behavioral/SS Summer) IORG0000418
Version 3-5-07

UMCIRB #11-0194
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APPENDIX C: IRB APPROVAL

********************IMPORTANT INFORMATION***********************

Continuing Review/Closure Obligation

As a investigator you are required to submit a continuing review/closure form to the UMCIRB office in order to have your study renewed or closed before the date of expiration as noted on your approval letter. This infomation is required to outline the research activities since it was last approved. You must submit this research form even if you there has been no activity, no participant s enrolled, or you do not wish to continue the activity any longer. The regulations do not permit any research activity outside of the IRB approval period. Additionally, the regulations do not permit the UMCIRB to provide a retrospective approval during a period of lapse. Research studies that are allowed to be expired will be reported to the Vice Chancellor for Research and Graduate Studies, along with relevant other administration within the institution. The continuing review/closure form is located on our web site at www.ecu.edu/irb under forms and documents. The meeting dates and submission deadlines are also posted on our web site under meeting information. Please contact the UMCIRB office at 252-744-2914 if you have any questions regarding your role or requirements with continuing review.
http://www.hhs.gov/ohrp/humansubjects/guidance/contrev0107.htm

Required Approval for Any Changes to the IRB Approved Research

As a research investigator you are required to obtain IRB approval prior to making any changes in your research study. Changes may not be initiated without IRB review and approval, except when necessary to eliminate an immediate apparent hazard to the participant. In the case when changes must be immediately undertaken to prevent a hazard to the participant and there was no opportunity to obtain prior IRB approval, the IRB must be informed of the change as soon as possible via a protocol deviation form.
http://www.hhs.gov/ohrp/humansubjects/guidance/45cfr46.htm#46.103

Reporting of Unanticipated Problems to Participants or Others

As a research investigator you are required to report unanticipated problems to participants or others involving your research as soon as possible. Serious adverse events as defined by the FDA regulations may be a subset of unanticipated problems. The reporting times as specified within the research protocol, applicable regulations and policies should be followed.
http://www.hhs.gov/ohrp/policy/AdvEvntGuid.htm

Version 02-26-07

APPENDIX D: INTERVIEW QUESTIONS

Bryce Carmichael

Interview Questions

1) Can you provide some background information on your position in Currituck County?
   "Thank you. Well one of the reason's I am conducting this research is to examine populations living in floodplains that are more susceptible to flooding through quantitative and qualitative methods"

2) What is your current knowledge of floodplains and flooding?

3) With this marker, could you please identify the areas where people live that are the most vulnerable to flooding events?
   "Thank you."

4) Why did you select these specific areas?

5) How would you describe the types of people that live in these areas? For example (Is it a predominately a Hispanic, African American, elderly, etc community?)

6) During flooding events, how are these communities warned and evacuated before the flooding events occur?

7) Are special assistance provided to these communities?

8) If so, what types of special assistance are provide towards these communities?
   OPTIONAL: Are there any social systems in place that help mitigate these populations?

9) If the National Weather Service has issued an evacuation for flooding in Currituck County, what would be the first steps to evacuate these communities?

10) Do the results from my quantitative analysis coincide with the areas that you identified as highly vulnerable?