Multiple hazards and community vulnerability in Hillsborough County, Florida

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Multiple Hazards and Community Vulnerability
in Hillsborough County, Florida

by

Keith A. Albury

A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Arts
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Dedication

To Beth Ellen for her love, support, and encouragement.
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Multiple Hazards and Community Vulnerability in Hillsborough County, Florida

Keith Albury

ABSTRACT

Hillsborough County, Florida is subject to a variety of natural and technological hazards, which have the potential to threaten both the population and the built environment. This research focuses on several natural hazards (coastal flooding, sinkhole, and hurricane) and technological hazards (toxic transportation spills and toxic release from fixed storage facilities) and the population that is potentially exposed to these hazards. Social vulnerability for this population was determined using racial composition, gender, age and household rental/ownership status.

Both social vulnerability and exposure to hazardous conditions occur as a continuum across geographical space. The determination of who is exposed; the extent of exposure; and the hazardousness of their environment; requires converting this continuum into discreet values. There is little agreement on how this should be accomplished. The goal of this project is to improve on this situation by developing a multiple hazard map and a social vulnerability map using the best available data with a focus on data integration.

The resulting maps were used to determine the extent that the community of Hillsborough County is exposed to hazardous conditions and the social vulnerability of that exposed community. The impact of hazard analysis is dependant on the creation of
the hazard map. The hazard map can be affected by application of weighting factors to the individual or groups of hazards. Weighted linear combinations were used to examine how the exposed population changes when different hazard models are used.

A technique of cumulative frequency mapping was used to examine how the composition of the exposed population changed as the hazard scores increased. This was useful in visualizing that different vulnerable communities were not exposed to hazards equally. This technique will be useful for future vulnerability/hazard assessments.

The results of this research show that the most vulnerable populations in Hillsborough County, Florida are not exposed to the most extreme hazards. Instead the preponderance of the population is moderately vulnerable and is exposed to moderate hazards. It is important to focus on this population to help prepare for and respond to hazardous events and to work toward diminishing their social vulnerability.
Chapter 1: Introduction

Hazards and social vulnerability are inextricably intertwined by their very nature. The study of hazards and social vulnerability each have a voluminous body of work that spans many disciplines and is utilized for many different kinds of research including: emergency planning, risk exposure, or insurance adjustment, and many other purposes. Geography plays an important role in determining the location, intensity and extent of the hazards, as well as the location and the composition of the exposed population. Mapping is a tool which can be used to help visualize the interactions between hazards and the potentially exposed population. This research will examine both hazards and social vulnerability individually and then in combination and focus on the methods used to determine the potentially exposed population.

Hazards

Natural hazards such as hurricanes, floods, droughts, tornadoes, and earthquakes threaten people all over the world. Technological hazards such as toxic emissions, toxic spill, radioactive emissions, smog, and acid rain can affect large populations. Hazards vary in size, effect and duration. A tornado, for example, generally has a small and localized effect, although it is very destructive for the population affected (Glass et al. 1980). Others can affect larger areas, for example, hurricane could affect several square
miles (Ayscue, 1996). Other hazards such as droughts have a very large area of influence and are often long in duration.

The destructive power of an event can sometimes be described by relatively simple single variables. (e.g. the depth of the flooding, the speed of the wind, the area of subsidence for a sinkhole). More often hazards result from combinations of coincident events and the result of this combination describes the effects. Flooding for example may result from storm events or due to structural failure of some dam upstream or even a combination of the two. In order to describe these hazardous events it is necessary to describe and map the extents of each component.

Hazards can be compounded and individual events are the catalyst for other hazards. For example, prolonged drought can lead to deforestation and desertification. Fires can further denude the area. When the rains return, the parched land is unable to absorb the downfall and flooding and erosion can result. The impact on the affected community will be a combination of all of the components.

The extent, intensity, frequency, and duration of hazardous events will have different impacts on communities depending on the social vulnerability of the community that is potentially exposed.

**Social Vulnerability**

The distribution of people in a given community is not uniform because the population density and the socio-economic characteristics vary across the geographic landscape. This variation causes some communities to be better able to cope with and recover from hazardous events than others. The goal of social vulnerability analysis is to
determine what components will be used to assess the social vulnerability of a population based on the best data available. It is impossible to determine where every individual is located at all times and therefore social vulnerability assessment must rely on aggregations of the population as snapshots of the total population. This research will examine how the size of the aggregation unit affects the selection of the potentially exposed population.

**Mapping of Hazards and Social Vulnerability**

The ability to map the natural and built environment has made it possible to delineate the boundaries and measure quantifiable values about the environment. This ability has been facilitated and accelerated by the availability of desktop computer software known as Geographical Information Systems (GIS). “Maps” or “layers” in the GIS vernacular consist of points, lines or polygons representing geographic features of the environment. The layers are attributed with values representing a measure of some characteristic of that geographical location (e.g. flow in a stream, temperature at a point, soil type, etc.)

Most GIS packages provide the ability to overlay these geographic layers and determine where they overlap. This technique can be use to combine these maps in various ways and examining the interactions between various layers. It can be used for a variety of different purposes because the output depends on the input layers, the methods used to determine the interaction between the layers, the weighting or significance of one layer over another and the methods used to aggregate the results. The results of any GIS
analysis are dependent on the decisions about what layers to use, the quality of the data used to create the layers, the significance of that layer (which is represented by the weighting value), and the techniques used to overlay these layers. These issues will be considered as they pertain to hazards in Hillsborough County.

**Goals and Objectives of This Research**

The goal of this research is to create multiple variable hazard and social vulnerability maps to determine the extent to which socially vulnerable populations reside in potentially hazardous areas.

The objectives of this research are:

1. Create a composite hazard map by combining several individual hazard maps. The individual hazard maps will be constructed considering the availability of data and methods of modeling appropriate for combining individual hazard maps together into a multiple variable map.

2. Create a composite social vulnerability map based on the community demographics provided by the United States Census Bureau.

3. Determine the potentially exposed population and to analyze how modeling decisions affect the selection of this population.

This research expands on other hazard research in that it examines the method used to determine the potentially exposed population and how the individual components of social vulnerability vary depending on the hazard. The analysis of how various weighting factors can affect the determination of the potentially exposed population adds to the strength of this research.
Outline of the Chapters

The second chapter provides a literature review covering the methods used for hazard research as it pertains to the hazards selected for this research, methods used to determine social vulnerability, and the utilization of GIS as an analytical tool for this process. There is a diversity of opinion how the decisions about the components and methods used to create a geographical analysis can affect the results. The effect of how layers are integrated and weighted has been the topic of recent debate (Fuller et al 2003 and Malczewski 2003). These topics are discussed in this chapter.

The third chapter outlines the details of how the individual hazard maps were created and the methods used to combine them together. The first part of this chapter considers five individual hazards and how to map them; the second part considers the individual components of social vulnerability; and the third part examines spatial overlay techniques. The final part is the combination of hazard and social vulnerability maps using various weights on each component.

The fourth chapter examines the results from the various methods described in chapter three. The efficacy of each method was assessed and the best technique was selected for selecting the potentially exposed population.

Chapter five summarizes the results and provides an overview of the usefulness of the various methods described. Suggestions for improving this research and other considerations are described in this chapter.
This research uses Hillsborough County, Florida as a case study because Hillsborough County is subjected to a variety of hazards, Hillsborough County has experienced rapid growth which has caused increased exposure to these hazards, and the author has first hand knowledge of the area. Hillsborough County has been the subject of other hazard assessments including accidental toxic release (Stretesky and Lynch 1999), acute exposure to extremely hazardous substances (Chakraborty 2001), and multiple natural hazards (Emrich, 2000).

Hillsborough County is located in the west central part of peninsular Florida (Longitude 82.3 South and Latitude 27.9 East) and is bounded by Pinellas County to the west, Pasco County to the North, Polk County to the east and Manatee County to the south. Hillsborough County is also bounded by Tampa Bay to the south and west. (Figure 1)

Hillsborough County has experienced considerable population growth in the last half-century often exceeding 20% per decade. The maximum growth was in the 1970s when the population grew by 32%. This trend has been slowing and the change between 1990 and 2000 census was only 19%. (Figure 2) The rate of growth has been slightly less than that of Florida but about double the national average growth. Florida ranks seventh in the nation in rate of population growth during the past decade (1990 – 2000) and Hillsborough County ranked 46th in the state for population growth during the same period (SSDAN, 2004).

Hillsborough County is subject to a wide variety of environmental hazards because of its climate and geology. Hillsborough County is located in the sub-tropical
belt in the southeastern United States and is therefore exposed to hurricanes. Hillsborough County receives nearly 50 inches of rain annually and therefore riverine and coastal flooding are considerable risks. The underlying Karst geology is subject to sinkholes and therefore sinkholes are another risk to the local population. Florida ranks third in the nation for disaster declarations. During the period 1972-2000, the Federal Emergency Management Agency (FEMA) in the state of Florida declared 35 disasters (FEMA, 2003).

In addition to environmental hazards, the infrastructure required to maintain the economy of Hillsborough County generates a hazard to the surrounding population due to toxic releases or toxic spills. Port of Tampa commands a position as Florida’s largest seaport, handling nearly half of all sea borne commerce that passes through the state. It is the 12th largest cargo port in the nation. The Port has always relied on bulk cargo, such as phosphate, liquid sulfur, and petroleum (Tampa Port Authority 2004). A transportation infrastructure is required to move these materials to and from the port. This in conjunction with the necessity to store these hazardous materials represents another potential hazard that threatens the local population.
Figure 1: A location map for Hillsborough County, Florida
Figure 2: Total population change for Hillsborough County, Florida
Chapter 2: Literature Review

Hazards

The literature on hazard, risk, exposure, and social vulnerability is voluminous and a multitude of disciplines have contributed to this research. Hazard research is often complicated because of the variety of different disciplines that have contributed to the field. Each discipline has a slightly different perspective of the subject (Crozier 1988). It is important to examine the different definitions that have been applied to words like hazard, risk, and disaster.

*Hazard* is a naturally occurring or human-induced process or event with the potential to create loss (Smith, 1996). Natural hazard is defined by Burton at al. (1993) as ‘those elements of the physical environment harmful to Man and caused by forces extraneous to him’. Natural hazard means the probability of occurrence within a specific period of time in a give area, of a potentially damaging natural phenomenon (Crozier, 1988). Tobin and Montz (1997) define natural hazard as the potential interaction between humans and extreme natural events. It represents the potential or likelihood of an event (it is not the event itself). The hazard exists because humans or their activities are constantly exposed to natural forces. Natural hazards are those triggered by climatic and geological variability, which is at least partly beyond the control of human activity (Palm, 1990)
Ball (1979) expands on the idea that “natural” disasters are not in fact natural but that they rely on an interaction between the natural world and the human society that inhabits it. There are social and economic conditions that influence where people are able to live and their ability to ward off the effects of environmental conditions. Therefore she suggests that there is a continuum of non-conflict disasters ranging from the acute to the chronic. The acute disasters are more immediately related to the activities of people including; nuclear accidents, toxic releases, or oil spills. These affect more industrialized nations initially, but will begin to have a greater affect on developing nations as they begin to industrialize without the environmental regulations to protect their population.

*Risk* is the actual exposure of something of human value to a hazard and is often regarded as the combination of probability and loss (Smith, 1996). Risk analysis is concerned with the probability of defined loss (Chapman 1994) and risk is the potential or likelihood of an emergency to occur. For example, the risk to a structure from an earthquake is high if it is built upon, or adjacent to, an active earthquake fault. The risk of damage to a structure where no earthquake faults exist is low. Mitchell (1990) defined hazard as the sum of risk, exposure, vulnerability, and response. Tobin and Montz (1997) describe risk as the product of the probability of occurrence and social vulnerability.

When large numbers of people exposed to a hazard are killed, injured, or structural damage occurs, the event is termed a *disaster*, although the threshold, which must be surpassed, to qualify as a disaster is often debated and therefore unclearly defined (Smith, 1996). Disasters are characterized by the scope of an emergency and an emergency becomes a disaster when it exceeds the capability of the local resources to
Disasters are defined as a hazardous event that has had a large impact on society. Unfortunately, there are no definitive boundaries to determine exactly when a threshold has been reached such that we can categorically say, “this constitutes a disaster” (Tobin and Montz, 1997).

Human populations have found themselves subject to a variety of hazards both environmental and technological. While hazards are experienced separately (flood, drought, hurricane, etc.), individuals can be exposed to a multitude of hazardous events throughout their lifetimes. Similarly, a place is frequented by many hazardous events throughout time. Unfortunately, the multiple hazard perspective is rarely adopted in assessing hazardousness or riskiness. Instead, the focus has been on the risk posed by individual hazards, which does not provide a sufficiently comprehensive understanding of the overall risk that exists at a given place: it can lead to gross underestimates of risk and hazardousness and may result in inadequate risk management (Tobin and Montz, 1997).

This work is largely based on the research of Susan Cutter et al. (2000) and Chris Emrich (2000) and is based in the concept of the hazardousness of place. (Burton, et. al 1993, Cutter 1996; Cutter et al 2000, Heinz Center for Science, Economics and the Environment 2002)
Individual Natural Hazards

Flooding

About 10 percent of the population of the United States is potentially exposed to some kind of flood threat, whether from small gully or major stream (Burton et al, 1993). A flood can be defined as the height, or stage, of water above some given point. Flood hazard is often related to the 100-year floodplain, which is the area covered by a flood with an average return period, or recurrence interval, of once in a century (Alexander 1993).

Humans have always had a close affiliation with the floodplain. This is due in part to the fertile soils that accumulate along the banks of the rivers as a result of flooding. The proximity to water was a benefit for both agriculture and manufacturing because of the constant supply of water and the ability to transport crops and finished products on the rivers. As a result many villages, towns, and cities formed along the river systems. The result of this is a balancing act between the risk of flooding and the benefits of living near the rivers.

Changes in sea level due to climatic conditions will change the effects of flooding. These changes will be due in part to global warming but also due to the modifications to streams and waterways to control flooding. These modifications have changed the way that siltation occurs and this will lead to increased coastal subsidence in some areas (Doornkamp 1998).
Sink Holes

Sinkholes occur in the Karst landscape that is common to Florida. Karst is a generic term which refers to the characteristic terrain produced by erosion processes associated with the chemical weathering and dissolution of limestone or dolomite, the two most common carbonate rocks in Florida. The rocks dissolve because they are exposed to acidic water. The slightly acidic rainwater becomes more acidic as it moves through decaying debris. The porous limestone of Florida allows this acidic water to percolate through dissolving some of the rock as it passes. The result of this breakdown in the rock results in caves, disappearing streams, springs, underground drainage and sinkholes (Florida Department of Environmental Protection, 2003).

A map of sinkhole type and distribution is shown in Figure 3. There are two regions of Hillsborough County that have a high potential for sinkholes in the northwest and central regions. The Hillsborough River Basin separates this region where sinkholes are less likely.

Sinkhole hazard has been mapped using the location of sinkholes as a point location and only the census block group that contains the sinkhole is potentially exposed to the hazard (Emrich 2000). An alternative method of analyzing the existing point data would be to create a density surface. Density surfaces are good for showing where point features are concentrated. Calculating density using GIS software spreads the point values over the surface. The magnitude at each sample location is distributed throughout a landscape, and a density value is calculated for each cell in the output raster. (ESRI 2002)
Figure 3: Sinkhole type and distribution in the Tampa Bay Region

Yellow – Bare or thinly covered limestone. Sinkholes are few, generally shallow and broad, and develop gradually. Solution sinkholes dominate.

Green – Cover is 30 to 200 feet thick. Consists mainly of cohesive and permeable sand. Sinkholes are few, shallow, of small diameter and develop gradually. Cover-subsidence sinkholes dominate.

Blue – Cover is 30 to 200 feet thick. Consists mainly of cohesive clayey sediments of low permeability. Sinkholes are most numerous, of varying size, and develop abruptly. Cover-collapse sinkholes dominate.

Pink – Cover is more than 200 feet thick. Consists of cohesive sediments interlayered with discontinuous carbonate beds. Sinkholes are very few, but several large diameter, deep sinkholes occur. Cover-collapse sinkholes dominate (Sinclair and Stewart, 1985).

Hurricane

About 30 million people in the United States are potentially exposed to hurricane wind hazard, and some 6 million are directly subject to the storm surge arising from a storm, which is more likely to cause loss of life. As many as two-dozen hurricanes may affect the East Coast per year, and from them winds of over 70 kilometers per hour may affect more than 5,000,000 square kilometers of land, or nearly one-quarter of the nation’s territory (Burton et al, 1993). Hurricanes are responsible for the most expensive and deadliest disasters in the United States of America so far (NOAA 1999).
The damage associated with hurricanes is a result of the combination of various components; wind, wind borne debris, waves, rain and storm surge. Storm surge is a result of low pressure associated with the hurricane combined with the wave effect from wind blowing on the water. This combined with the rainfall results in storm surge and coastal flooding.

**Technological Hazards**

*Transportation Spill*

Chemical accidents can occur anywhere that chemicals are manufactured, transported, stored, or used. Accidents are quite varied and range from rapid-onset events (1-30 seconds) such as explosions to expanding vapor events, such as a toxic clouds, with slightly longer onset times. All result in acute exposures (Cutter 1993a). A variety of methods have been used to determine the potentially exposed population and estimate their exposure. The paucity of specific detailed information about the frequency and concentrations of transportation spills requires some assumptions about exposure to calculate the potentially exposed populations. A worst-case scenario is to ignore the conditional distributions and use the product of the probability of a release and the extreme consequences of the incident to estimate the risk (List et al., 1991).

Another common method is to draw a band of fixed width around each transportation route and to use the number of persons living within this band as the potentially exposed population (Cutter et al. 2000 and ReVelle et al. 1991). An improvement on this method is to incorporate a Gaussian Plume model (Zhang et al. 2000). This method provides a more realistic estimation of the potentially exposed
population but is plagued with the problem of varying winds, which affect the Gaussian Plume model, and is computationally very difficult.

Others have used network analysis to determine the optimal route for transportation of hazardous substances (Leonelli et al. 2000). These methods involve the generation of a transportation network where each segment is given a probability of transportation spill. The interactions between this transportation network and the population density surrounding this network are used for a cost-benefit analysis to determine the optimal path for that transportation.

*Toxic Release Inventory*

In response to the release of toxic methyl isocyanate in Bhopal, India, which resulted in thousands of deaths, and a similar release in West Virginia, the United States Environmental Protection Agency (EPA) passed the Emergency Planning and Community Right-to-Know Act (EPCRA). The goal of this legislation was to provide information to the public about the types and amounts of chemicals which are released into the environment whether through the manufacturing or disposal process or through accidental releases (EPA 2002).

Section 313 of the EPCRA act requires that the EPA and states collect data on releases and transfers of certain toxic chemicals from industrial facilities, and make the data available to the public in the Toxics Release Inventory (TRI). The TRI program has expanded since its inception and now covers over 650 chemicals and seven new industry sectors have been added beyond the initial manufacturing sector. The industries that are required to report to the TRI include metal mining, coal mining, electrical utilities that
burn coal or oil, Resource Conservation and Recovery Act (RCRA) Subtitle C hazardous waste treatment and disposal facilities, chemical wholesale distributors, petroleum terminals and bulk storage facilities, and solvent recovery services. (EPA 2002) In the year 2000 the reporting rules changed; a new category of toxin was added to the TRI, persistent bioaccumulative toxic (PBT) and the threshold values for those PBT chemicals already on the list were lowered. These rule changes make it difficult to compare TRI reports prior to 2000 to those generated post 2000 reporting year.

Florida, according to the 2000 TRI Report, reported 1,974 reports accounting for over 400 million pounds of production and non-production waste materials generated. Florida was ranked 10th in the nation overall in waste production during that year. Hydrochloric acid was the largest airborne release while nitrite compounds resulted in the majority of surface water and land discharges. Methanol was the chemical that was most commonly disposed of using underground injection (EPA 2004).

Tampa Electric Co. Gannon Station was the third largest polluter in the state releasing over 17 million pounds of toxic material in 1999 and APAC Florida Tampa Plant was ranked tenth in top PBT emissions. (EPA 2004)

There are various techniques for estimating the extent of exposure due to toxic release. These include simple point locations, uniform buffers, buffers of various sizes, and overlapping buffers. Points are used for simple coincident analysis (Anderton et al. 1994 and Bowen et al. 1995). Buffer analysis involves creating a simple buffer around the points and the potentially exposed population is determined using this buffer. (Cutter and Solecki, 1996 and Glickman, 1994). Perlin at al. (1999) expanded on this idea and explored the effect of concentric circular buffers.
An alternative to the circular buffer model for air emissions is to simulate the dispersal of the gas as it vents into the environment. This plume model can be simulated using computer programs such as ALOHA (Areal Locations of Hazardous Atmospheres) or CHARM (Complex Hazardous Air Release Model). The plumes can be intersected with infrastructure maps and used by emergency planners for evacuation planning (Monmonier 1997). These plumes can also be integrated into a GIS and used for environmental equity analysis. (Chakraborty and Armstrong 1997) This method has been used to refine the circular containment analysis by using the plume model to estimate the limits of exposure (Chakraborty and Armstrong 2001, Margai, 2001 and Zhang et al. 2000). Chakraborty (2001) used this technique to create a “worst case scenario” where the overlapping variable buffers created by plume analysis were considered cumulative.

**Composite Hazard**

The cartographic, quantitative and analytical tools provided by a GIS have been used to quantify the exposure to a wide variety of natural and technological hazards, including; volcanic threat (Cronin, et al. 2000), coastal flooding (Thurmerer et al., 2000), hurricanes and storms (Hickey et al., 1999), and forest fires (Chuvieco and Congalton, 1989). These studies each address an individual threat independently assessing the exposure, the vulnerable populations and potential responses.

It was not until recently that these quantitative methods were incorporated in the study of multiple hazards. A small number of studies have begun the research into evaluating the threat posed by multiple hazards on vulnerable populations.
Weighted Linear Combinations

One method used to combine data sets together to generate a composite map involves the use of weighted linear combinations (Carver 1991 and Malczewski 2003). The main concept behind weighted linear combinations is that when combining together various layers into a composite map not all layers should have an equal representation, or weight, to the composite map. The most basic form of this analysis is to treat each component equally. Alternatively, various weights can be applied to each component of the composite model where each weighting factor is used to increase or decrease the importance of that component to the overall model. Malczewski (2000) raises some concerns with this technique including the assumption that the individual components are not auto-correlated and therefore redundant.

Examples of the application of GIS using linear-weighted combination include; regional planning (Eastman et al. 1995, Nijkamp et al. 1990) habitat evaluation (Pereira and Duckstein 1993) and site selection decisions (Fuller et al. 2003, Hobbs 1980; and Jankowski 1995). Recently, this technique has been used to assess social vulnerability (Lowry et al. 1995 and Rashed and Weeks 2003).
Social Vulnerability

According to Cutter at al. (2000) the rediscovery of “geography as human ecology” in the late 1970s contributed to a re-analysis of hazard research. Research began to explore how people and society response to natural disasters. This work culminated in *The Environment as Hazard* (Burton et al. 1978) which explored how communities responded to hazardous events around them. Since then a variety of methods have been developed to define and explain social vulnerability.

The hazard potential interacts with the underlying social fabric of the place to create the social vulnerability. The social fabric includes sociodemographic characteristics, perception and experience with risks and hazards, and overall capacity to respond to hazards. The social and biophysical vulnerability elements mutually relate and produce the overall vulnerability of the place. The fundamental causes of human vulnerability include a lack of access to resources, information, and knowledge (Cutter et al 2000).

A parallel and related development during this time period is the growth of the environmental justice movement. The concept of fairness in the distribution of environmental risks on the basis of race and income is commonly referred to as environmental justice or environmental equity. The perceived inequity in the distribution of environmental hazards has led to the rise of the environmental justice movement (Chakraborty et al, 1999). Researchers in the environmental justice movement developed a number of quantitative techniques to assess this inequality, basically quantifying the people who are potentially exposed to a risk.
Vulnerability is defined as the aggregate measure of human welfare that integrates environmental, social, economic and political exposure to a range of potentially harmful perturbations (Bohle, Downing, and Watts, 1994). Since losses vary geographically, over time, and among different social groups, vulnerability also varies over time and space. According to Cutter et al. (2003) there are three main tenants in vulnerability research: the identification of conditions that make people or places vulnerable to extreme events, an exposure model (Burton et al. 1993); the assumption that social vulnerability is a social condition, a measure of societal resistance or resilience to hazards (Blaikie et al. 1994 and Hewitt 1997); and the integration of potential exposures and societal resilience with a specific focus on particular places or regions (Cutter et al. 2000).

Vulnerability is based on the location that is inhabited and the types of building techniques that are used. The decisions about where to live and how to build are not prepared in a vacuum but instead are part of the overall “matrix of society’s culture”. Thus socially vulnerable communities may not be able to move or improve their building techniques thereby diminishing their vulnerability. These relationships between vulnerability, geomorphological hazards and building techniques can be explained by simple variables (Alexander, 1991).

There is little agreement on what the components are to social vulnerability and this has an impact on development policy (Dow 1992). However, many researchers have attempted to quantify social vulnerability based on information available through the United States Census Bureau. Clark et al. (1998) used factor analysis to simplify the multivariate data to examine social vulnerability in Revere, MA to flooding hazards. The method of developing a social vulnerability score and standardization methods were
developed by Cutter et al. (2000) and the same methods were used by Emrich (2000) for Hillsborough County.

Hazard exposure is primarily a factor of location, whereas, social vulnerability is dependant on the social characteristics of the community and is less dependant on location. Two groups of people could live in close proximity to a hazardous site, one rich with considerable resources the other poor with few opportunities. These groups are going to be exposed to the same hazard but have different capabilities to respond to that hazard. Thus they have different vulnerability.

There are a number of factors that contribute to social vulnerability including age, gender, race and socioeconomic factors. During time of crisis and socioeconomic change, kinship and community relations can be important to survival strategies in everyday life and adaptation to social change. When these relationships break down due to some disruption, recovery can be prolonged or even prohibited (Dershem and Gzirishvili 1998).

Total population is an important factor for vulnerability analysis because the more people located in a hazardous area results in greater potential exposure and more people to recover post disaster. Mileti (1999) states “as areas become more densely populated, they also become more exposed to hazards.” The greater population density and the more difficult it is to respond to hazardous events in terms of evacuation planning and disaster recovery.

Extremes of age can affect social vulnerability. The elderly may have mobility constraints or mobility concerns increasing the burden of care and lack of resilience (Cutter et al. 2000 and Hewitt 1997). The elderly are more likely to suffer from illness
and be dependent on the uninterrupted supply of medicine and direct medical care. These supplies can be interrupted during a hazardous event. They may be more socially isolated than the rest of the community and may not hear and/or be able to respond to emergency notification. They may suffer from a generally lack of mobility due to age or disease and therefore be dependent on caretakers to aid in their evacuation and recovery from hazardous events. The every young are dependant on family or other caretakers for food, shelter, and health issues. Therefore they may be disproportionately vulnerable to hazards.

Women can have a more difficult time during recovery than men, often due to employment, lower wages, and family care responsibilities (Blaikie et al. 1994; Cutter 1996; Hewitt 1997; and Morrow 1999). Women are generally disproportionately poor and they are more likely to remain with family members in emergencies to nurture, assist and protect them (Glass et al. 1980). Women also have difficulty during the recovery phase following a hazardous event because they normally have less economic means to promote that recover (Bolin and Bolton, 1986).

Race and ethnicity contribute because of the difficulty associated with language and cultural barriers that affect access to post-disaster funding and residential locations in high hazard areas (Bolin 1996 and Cutter 1995).

People rent for a variety of reasons. In some cases because they are either transient or do not have the financial resources for home ownership. They often lack access to information about financial aid during recovery. In the most extreme cases, renters lack sufficient shelter options when lodging becomes uninhabitable or too costly to afford (Heinz Center for Science, Economics, and the Environment 2000 and Morrow
Renters also often do not have insurance on their property and they tend to live a more economically tenuous lifestyle lacking the savings to cope with a hazardous event. Thus the rental community is generally going to have a more difficult time recovering from a hazardous event and is therefore more vulnerable.

2000 Census

The source of the data used to determine social vulnerability is the United States Census of 2000. In the United States Census 2000, blocks are the smallest unit tabulated. They are “bounded on all sides by visible features such as streets, roads, streams, and railroad tracts, and by invisible boundaries such as city, town, township, and county limits, property lines, and short imaginary extensions of streets and roads.” (U.S. Census 2001) Block groups, made up of clusters of blocks, are subdivisions of census tracts. The primary goal of establishing block groups is “to provide a geographic summary unit for census block data”. Each census tract contains a minimum of one block group and a maximum of nine block groups. Block groups must have between 600 and 3,000 persons (240 to 1,200 housing units), with an optimum (average) population of 1,500 (600 housing units). (U.S. Census 2001) Block groups are further aggregated into census tracts. Census tracts are small, relatively permanent statistical subdivisions of a county. When first delineated they “are designed to be homogeneous with respect to population characteristics, economic status, and living conditions.” (U.S. Census 2001) Census tracts must have between 1,500 and 8,000 persons. (U.S. Census 2001)
Census data are collected using two different questionnaire forms; the short and long form. The data collected using the short form is summarized in the Summary File 1 (SF1). SF1 contains 100-percent population and housing characteristics. The Summary File 3 (SF3) contains approximately 5,300 Census 2000 variables covering social, economic and household characteristics compiled from a sample of approximately 19 million housing units (about 1 in 6 households) that received the Census 2000 long-form questionnaire (Tetrad, 2004).

In order to visually represent the population density for Hillsborough County the population density for each census polygon was calculated by dividing the total population by the area of the polygon. The population density (individuals per acre) was calculated and the results for census tracts, block groups, and blocks are shown in Figures 4, 5, and 6 respectively. Note that regardless of the scale of aggregation the population density distribution remains the same.

It is evident that the most dense population is concentrated around the City of Tampa in the central portion of the county and extending north and west from there. The eastern size of the county is relatively sparsely populated except in the Brandon and Riverview to the south are areas that have experienced tremendous growth during the last decade. The 2000 Census for Hillsborough County reports a total population of 998,948 individuals, 48.9% (488,772) male and 51.1% (510,176) female. The racial and ethnic breakdown is shown in Table 1. Note that in the census data Hispanic is an ethnic group that includes a diversity of racial classifications. The age groups are summarized in Table 2. Hillsborough County is predominately white with African Americans being the largest racial minority and Hispanics making up the largest ethnic group.
Figure 4: Population density by census tracts for Hillsborough County, Florida
Figure 5: Population density by census block group for Hillsborough County, Florida
Figure 6: Population density by census blocks for Hillsborough County, Florida
Table 1: Summary of the racial totals for Hillsborough County, Florida (U.S. Census 2000)

<table>
<thead>
<tr>
<th>Group</th>
<th>Total</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Population</td>
<td>998,948</td>
<td></td>
</tr>
<tr>
<td>Caucasian</td>
<td>750,903</td>
<td>75.2%</td>
</tr>
<tr>
<td>African American</td>
<td>149,423</td>
<td>15.0%</td>
</tr>
<tr>
<td>Native American</td>
<td>3,879</td>
<td>0.4%</td>
</tr>
<tr>
<td>Asian</td>
<td>21,947</td>
<td>2.2%</td>
</tr>
<tr>
<td>Hawaiian - Pacific Islander</td>
<td>727</td>
<td>0.1%</td>
</tr>
<tr>
<td>Other</td>
<td>46,539</td>
<td>4.7%</td>
</tr>
<tr>
<td>Multi-Racial</td>
<td>25,530</td>
<td>2.6%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>179,692</td>
<td>18.0%</td>
</tr>
</tbody>
</table>

Table 2: Summary of age groups in Hillsborough County, Florida (U.S. Census 2000)

<table>
<thead>
<tr>
<th>Age Groups</th>
<th>Total</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 5</td>
<td>68,444</td>
<td>6.9%</td>
</tr>
<tr>
<td>Age 5 - 17</td>
<td>184,694</td>
<td>18.5%</td>
</tr>
<tr>
<td>Age 18 - 21</td>
<td>53,221</td>
<td>5.3%</td>
</tr>
<tr>
<td>Age 22 - 29</td>
<td>113,278</td>
<td>11.3%</td>
</tr>
<tr>
<td>Age 30 - 39</td>
<td>162,590</td>
<td>16.3%</td>
</tr>
<tr>
<td>Age 40 - 49</td>
<td>150,884</td>
<td>15.1%</td>
</tr>
<tr>
<td>Age 50 - 64</td>
<td>146,164</td>
<td>14.6%</td>
</tr>
<tr>
<td>Over 65</td>
<td>119,673</td>
<td>12.0%</td>
</tr>
</tbody>
</table>

The age distribution of Hillsborough County was also interesting. There is a common perception that Florida is largely a retirement community dominated by the elderly; however, this is not the case in Hillsborough County where only 12% is over the age of 65. It is interesting to note that the largest group is ages 5 – 11 due perhaps to the number of working families that are moving to Florida every year.

Hazards and Social Vulnerability

Exposure analysis examines the spatial distribution of social vulnerability. It requires information about the distribution and type of structures, property, and population that are subject to some hazard. The outcome of vulnerability/exposure...
analysis is some measure of loss in relation to the different measures of intensities or magnitudes of the hazard(s) concerned. Geographic Information Systems (GIS) are of particular assistance in developing exposure analyses because they provide methods to store, display and process spatial data (Chapman 1994) and have been used for a variety of studies.

A variety of methods have been used to estimate the population that is threatened by a hazardous event. These estimations are generated by overlaying a hazard map (a map which represents the area potentially exposed to some hazardous event like a hurricane or a flood) with a population density map. Demographic data are typically aggregated to some spatial resolution: the state, county, zip code, census tract, or census block group level, depending on the size and scale of the study area. The potentially exposed population is estimated using spatial coincidence of intersecting areas or centroid (the geographic center of a polygonal area) containment. This technique has the advantage of being very simple to calculate. One major problem with this technique is that it is so dependant on the specific geometry of the polygons. Thus it may overestimate exposure because only a small overlap can cause it to appear that an entire polygon is exposed. Likewise, the centroid containment is susceptible to the specific location of the centroid which is dependant on the shape of the polygon. Thus an area may be considered not exposed despite having the majority of the polygon contained in a hazard zone but the centroid for some reason is not contained.

Another approach for estimating the impact of a hazard is buffer containment. Assuming that the population is evenly distributed across the demographic unit, the potentially exposed population is calculated by comparing the area exposed to the area of
the entire unit. This ratio is used to calculate the number of people in the exposed area (the area that intersects with the hazard map) compared to the entire population of the block. If the hazard extends across several demographic units then the exposure is assumed to be the sum of the areas that are within the hazard zone. This method is also known as buffer containment when used in conjunction with buffers around points, lines or areas (Chakraborty and Armstrong 1997).

Many social vulnerability and environmental justice studies have been criticized because of the demographic aggregation method chosen for the analysis (Anderton et al, 1994 and Bowen et al, 1995). Census tracts were developed to facilitate the enumeration of the population ignoring the geographic variability with the enumeration units. Human settlement cannot ignore geographic features such as lakes, rivers, highways, and other obstructions that make up the mosaic of our landscape. Thus the assumption that populations would be distributed evenly across the census block is an incorrect one. The impact of simply removing the uninhabitable areas such as large water bodies and roads can have a tremendous effect on the population density within a census block (Monmonier and Schnell 1984). This research explores this concept by localizing population within census blocks utilizing land use data.

**Spatial Overlay Techniques**

It is important to examine how the selection of spatial overlay techniques affect the selected community because this research will involve the overlay of two polygon layers. There are a number of ways that this can be accomplished and which method is selected will have an effect on determining what the potentially exposed population is.
Spatial overlay techniques such as are described below were investigated by Chrakraborty and Armstrong (1997). They found that the potentially exposed population depends on shape of the buffer and the method used to select them. There are three primary methods on intersecting two polygon layers; polygon containment, centroid containment, and buffer containment.

**Polygon Containment**

This method of intersecting a hazard map with a social vulnerability map selects any polygon that is wholly or partially contained by the hazard map. The potentially exposed population is the sum of the population contained within each individual polygon. Emrich (2000) used this method of hazard analysis.

**Centroid Containment**

This method selects polygons based on the location of the centroid, the geometric center, of the polygon. In this method, if the centroid of the census polygon lies within the area of the hazard then that polygon is potentially exposed to that hazard. The total potentially exposed population is the sum of the population contained within each individual census polygon selected.

**Buffer containment**

Buffer containment uses a weighted average of the area of the intersected portion to the area of the whole polygon as a modifier to the population of the census block.

**Equation 1: Method of calculating the population affected using buffer containment.**

\[ P_f = \frac{A_t}{A_r} (P_s) \]
Where \( P_f \) is the final population and \( P_s \) is the starting population and \( A_i \) is the area intersected and \( A_t \) is the total area. Regardless of the selection method, the populations that fall within the affected zone are summarized.

**Cumulative Frequency**

One method of analyzing the results from each component of the hazard model is to examine the cumulative frequency graph. *Cumulative frequency* is used to determine the number of observations that lie above (or below) a particular value in a data set. The cumulative frequency is calculated using a frequency distribution table. The cumulative frequency is calculated by adding each frequency from a frequency distribution table to the sum of its predecessors. The last value will always be equal to the total for all observations, since all frequencies will already have been added to the previous total (Statistics Canada, 2003) An example of a cumulative percentage graph for the total population exposed to sinkhole hazards in Hillsborough County, Florida is shown (Figure 7). The data for this graph are shown in Table 3. The total percentage of exposed population increases as the hazard score increases. Note that 57.1% of the population is exposed to at least 0.25 sinkhole hazard score. Therefore 42.9% of the population is exposed to a greater hazard. Graphs of this type are used to examine the individual components of social vulnerability for each hazard as well as the composite hazard.
Figure 7: Graph showing a typical cumulative frequency distribution.

Table 3: Table of sinkhole hazards and the cumulative percentage of exposed population

<table>
<thead>
<tr>
<th>Sinkhole Hazard</th>
<th>Total Pop</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.1%</td>
</tr>
<tr>
<td>0.13</td>
<td>32.7%</td>
</tr>
<tr>
<td>0.25</td>
<td>57.1%</td>
</tr>
<tr>
<td>0.38</td>
<td>73.1%</td>
</tr>
<tr>
<td>0.50</td>
<td>81.0%</td>
</tr>
<tr>
<td>0.63</td>
<td>88.7%</td>
</tr>
<tr>
<td>0.75</td>
<td>95.5%</td>
</tr>
<tr>
<td>0.88</td>
<td>99.4%</td>
</tr>
<tr>
<td>1.00</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
Chapter 3: Materials and Methods

Hazard Map

Hazard maps were created for each of the individual hazards used in this research. A variety of techniques were used to generate the individual maps based on the availability and type of data. The resulting individual hazard maps may have resulting hazard scores that span a variety of ranges depending on the source data and the techniques used to generate the individual hazards. It is necessary to make the ranges uniform in order to add the layers together. This is accomplished using a process known as normalization.

Normalization is used to take scores over a continuous range and convert them into a continuous fixed range of 0 to 1. The formula,

\[
X_{\text{nrm}} = \frac{x - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}}
\]

where \(X_{\text{nrm}}\) is the normalized value, \(x\) is the hazard score, and \(x_{\text{max}}\) and \(x_{\text{min}}\) are the maximum and minimum of the range of scores respectively, is used to perform this normalization. This technique is used for sinkhole, hurricane, transportation spill and toxic release.
Individual Natural Hazards

Flooding

Flooding in Hillsborough County, Florida was mapped using flood data acquired from the Southwest Florida Water Management District (SWFWMD 2000). This data set is the digitized Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) representing the hardcopy maps of 1988. The data set consists of polygons representing the various flood zones used by FEMA to represent the possibility of flooding (Table 1). The 100 Year Flood Zone was selected from this data set by selecting the areas attributed as being in Flood Zone A and AE.

Table 4: Flood zones in the FEMA/FIRM Maps (FEMA 2003b)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The 100-year floodplain where base flood elevations are not provided</td>
</tr>
<tr>
<td>AE</td>
<td>The 100-year floodplain where base flood elevations are provided</td>
</tr>
<tr>
<td>B</td>
<td>The 500-year floodplain</td>
</tr>
<tr>
<td>C and X</td>
<td>Area of minimal flood hazard</td>
</tr>
<tr>
<td>D</td>
<td>Area of undetermined but possible flood hazard</td>
</tr>
</tbody>
</table>

Sink Holes

The sinkhole hazard data were obtained from SWFWMD. The data are the reported sinkholes within the SWFWMD district area. The data collected on sinkholes prior to 1996 were collected by The Florida Sinkhole Institute. Most of the data collected during and after 1996 were collected by SWFWMD staff.

A density surface is created by moving a circular search radius over each cell within the output grid and calculating the number of points that are summarized to calculate a density value for each cell creates density maps. These calculations can be
created using simple or kernel estimations. In a simple density calculation, points that fall within the search area are summed and then divided by the search area size to get each cell’s density. In kernel density calculations the points that lie near the center of the raster cell are weighted more heavily that those near the edge. The result is a smoother distribution of values. For this research, the point data were used to create a density map kernel estimation (Bailey and Gatrell, 1996).

A density surface was created using Spatial Analyst in ArcMap using all the data for the whole state. One common problem with creating density surfaces is the “edge effect”. This occurs when the data are clipped prior to creating a density surface. The problem is that if a point is outside the study area then it is not used for the density surface. This will cause an underestimate in the density surface along the edge because of the points that were ignored. Therefore by generating the surface for the whole state and then clipping the resulting surface, it will minimize this edge effect. The input parameters were density type = Kernel, search radius = 10 km, area units = sq. km, and output cell size 200. The density type of kernel was selected because of the overall smoothing effect this has on the resulting data that is more consistent with naturally occurring areas. The search radius of 10 km was chosen because the modal densities results in a density similar to that predicted for the Gulf Coastal Lowlands (0-3 Sinkholes/km²) (Wilson, 1995). The output cell size was chosen to be approximately the same size as the smallest Census block groups.

The resulting grid was classified into 0.1 SH/km groups by generating contours using 0.1 intervals. The contours were clipped to the boundary of Hillsborough County
and polygons were built. The polygons were attributed with the number of sinkholes per kilometer (0 – 0.8) and normalized.

**Hurricane**

The hazardous components of the hurricane hazard considered for this project are wind, flooding, and storm surge. The data for hurricane hazard were obtained from Hillsborough County. These data were generated using The Arbitrator of Storms (TAOS) data in a SLOSH model. Each component was considered individually and the combination of these individual components resulted in a composite hurricane hazard map.

TAOS computes the wind field and other effects of a given storm based on the maximum wind, central pressure, radius of maximum winds, rainfall rates and a shape parameter (Watson and Johnson, 1999). The output of the TAOS model was a series of six data sets consisting of a continuous grid of values, a “raster”, with attributes describing a wide variety of effects of hurricane damage for hurricanes of each strength category (Tropical storm, Category 1 through 5). The term “raster” is used because the data represent a continuous distribution of values across the study area. The data were already in a vector format (a shapefile) and were further classified and normalized for use in the multiple hazard model. This research only used the Category 1 through 5 layers.

The historic record shows that the Tampa Bay area has been hit by eighteen recorded hurricanes between 1900-1996 including; six category one, three category two, six category three, two category four, and one category five hurricanes (NOAA 1999).
The sample size is not large enough to make predictions about the strength of any hurricane likely to impact Hillsborough County. Therefore, it was assumed for this research that each category of hurricane is equally likely.

**Wind Associated with Hurricanes**

The hazard posed by wind component is represented in the TAOS data set by the attribute WIND_SPD that is the estimated wind speed for each cell calculated from the TAOS model. To convert these continuous data into a vector map an additional column was added called HURRICANE. Each polygon was classified with the hurricane category represented by the wind speed in that polygon, thus a numerical value of “1” for “Type 1”, “2” for “Type 2”, “3” for “Type 3”, “4” for “Type 4”, or “5” for “Type 5” depending on the classification of the wind speed based on the Saffir-Simpson Hurricane Scale (Table 5). Thus each of the five layers had a new column HURRICANE with values from 1-5 which represented the category of hurricane.

Each of the five data sets were dissolved on the HURRICANE item to create a simplified data set. The resulting five dissolved data sets were then spatially overlaid (UNIONed) to create a composite wind hazard map for Hillsborough County. The sum of the total HURRICANE score was calculated for each cell in the composite wind hazard map. This was normalized using the method described above. (Equation 2)
<table>
<thead>
<tr>
<th>Category</th>
<th>Winds</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>74-95 mph</td>
<td>No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal road flooding and minor pier damage.</td>
</tr>
<tr>
<td>Two</td>
<td>96-110 mph</td>
<td>Some roofing material, door, and window damage to buildings. Considerable damage to vegetation, mobile homes, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of center. Small craft in unprotected anchorages break moorings.</td>
</tr>
<tr>
<td>Three</td>
<td>111-130 mph</td>
<td>Some structural damage to small residences and utility buildings with a minor amount of curtain wall failures. Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain continuously lower than 5 feet ASL may be flooded inland 8 miles or more.</td>
</tr>
<tr>
<td>Four</td>
<td>131-155 mph</td>
<td>More extensive curtain wall failures with some complete roof structure failure on small residences. Major erosion of beach. Major damage to lower floors of structures near the shore. Terrain continuously lower than 10 feet ASL may be flooded requiring massive evacuation of residential areas inland as far as 6 miles.</td>
</tr>
<tr>
<td>Five</td>
<td>Greater than 155 mph</td>
<td>Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away. Major damage to lower floors of all structures located less than 15 feet ASL and within 500 yards of the shoreline. Massive evacuation of residential areas on low ground within 5 to 10 miles of the shoreline may be required.</td>
</tr>
</tbody>
</table>

**Flooding Associated with Hurricanes**

The exposure to flooding was mapped using the output of the TAOS model contained in the same datasets, described above, by the attribute WATER_DP representing the depth of the water above Mean Sea Level. This value was rounded to the nearest whole number. The data set was then dissolved on the new DEPTH column resulting in a map representing the area potentially exposed to coastal flooding due to hurricanes.
The hurricane flood hazard was determined to occur at one foot flooding because this was the depth at which structural and electrical damage to the residences would occur (Emrich, 2000). The area inundated by one foot or greater was determined for each category of hurricane. This generated five hurricane flood hazard maps. These maps were spatially overlaid, the sum of the exposure for each category of hurricane was calculated, and the summary score was normalized.

**Storm Surge Associated with Hurricanes**

The storm surge component was a single vector data set that was attributed with a column called Category that represented the extent of the storm surge associates with each category. This data set was simply attributed with a new value classified such that Category 5 = 2, Category 4 = 4, Category 3 = 6, Category 2 = 8 and Category 1 and Tropical Storm = 10. Those areas that are flooded by a Category 1 storm are also flooded at any Category above it because of the cumulative effect of coastal flooding.

**Combined Hurricane Exposure**

Each component of the hurricane hazard was assumed to be of equal importance and therefore each was summed to create a total hurricane score. (Total Exposure = Wind + Flooding + Storm Surge). The total exposure was normalized to a score from 0 to 1.
Individual Technological Hazards

Transportation Spill

The transportation spill hazard was assumed to only occur on railroads or roads that were designated for the truck transportation by Hillsborough County. The truck transportation data set was obtained from Hillsborough County (2004) and the railroad data set was obtained from the Geography Network. (2004) A subset of the railroad data set was selected where the name column (FENAME) was not empty or “Abandoned Railroad”. These data sets were combined together to create a composite transportation data set. Constructing a one-half mile buffer around the railroads and major highways generated the hazard posed by accidental transportation spill.

The hazard of transportation spill was assumed to be the same regardless of the mode of transportation, the volume carried or the frequency of the route used. However, it was assumed that an area could be receiving spills from overlapping regions. For example an area might have both a road and railroad paths near by, or it could be at the intersection of two roads and could receive a spill from either source. Therefore these areas are at a higher hazard than other areas. To represent this in GIS required creating overlapping one half-mile (1/2 mile) buffers and then summarizing the number of overlapping regions. The number of overlapping features was normalized.

Toxic Release Inventory

TRI data is reported for each year and the releases for each location are different for each year. To simplify the calculations only those sites that reported during the 2000
reporting cycle were used. The TRI data resulted from a search of The Right to Know Network (RTK, 2002) for any reported toxic release in Hillsborough County during the year 2000. This research focused only on the air emissions. The facilities were geolocated using the preferred latitude and longitude if available. The remaining sites were located using address matching in ArcInfo 8.0 and U.S. Census road data obtained from the U.S. Census department. There were a total of 56 reporting companies in the year 2000 and of these 44 of them were reporting toxic air emissions. The TRI reports both the volume and type of substance released at each location.

Airborne emissions are subject to the effects of the wind and other atmospheric conditions. Therefore the airborne emission does not expand uniformly around the point of release but instead forms a plume (generally an ellipse around the point of release). A plume was generated using the ALOHA model for each facility assuming the worst case (total release of the reported amount). The weather conditions were assumed to be the average over the year (Appendix 1). The largest plume was chosen to represent the greatest hazard posed by each site. The distance of the resulting plume was used to generate a circular hazard zone of the radius indicated by the plume.

The overlapping circular buffers were generated and the overlap regions were determined to be additive in the same way that overlapping regions were treated in the transportation spill example above. The number of potential exposures was assumed to be the sum of the number of the overlapping regions were normalized to values 0 to 1.
**Composite Hazard Map**

Overlying all five layers together created the composite hazard map. They had each been normalized to a scale of 0 to 1, which allowed the calculation of the total hazard score by adding the values for each normalized hazard. This resulting score was then normalized again and classified into 10 equal intervals.

**Social Vulnerability**

As we have seen there are three major components of social vulnerability in this study: population and structure, access to resources, and socioeconomic conditions. The data used to calculate these values were obtained from the 2000 Census Data. The TIGER census line data for this research were obtained from the Geography Network at all three levels of aggregation, tract, block group, and block. The TIGER line data were joined to census demographic data (Summary File1, SF1) obtained from the same site. In order to understand the implications localizing the population within the census block groups to the areas classified as developed, a modification of the technique developed by Monmonier and Schnell (1984) was used. The census data were used in conjunction with the Florida Land Use and Cover Classification System (FLUCCS) map for Hillsborough County obtained from the Southwest Florida Water Management District (SWFWMD). This land use data set was updated using the 1999 United States Geologic Service (USGS) Digital Ortho Quarter Quad (DOQQ) photography. The land use was classified at the first level using a modified Anderson Classification System developed by the Florida Department of Transportation. Table 5 summarizes the total land use of Hillsborough County.
Table 6: Breakdown of land use classifications in Hillsborough County, Florida

<table>
<thead>
<tr>
<th>FLUCCS</th>
<th>Description</th>
<th>Acre</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Urban and Built-Up</td>
<td>252,327</td>
<td>31.2%</td>
</tr>
<tr>
<td>2</td>
<td>Agriculture</td>
<td>196,380</td>
<td>24.2%</td>
</tr>
<tr>
<td>3</td>
<td>Rangeland</td>
<td>21,803</td>
<td>2.7%</td>
</tr>
<tr>
<td>4</td>
<td>Upland Forests</td>
<td>62,446</td>
<td>7.7%</td>
</tr>
<tr>
<td>5</td>
<td>Open Water</td>
<td>137,474</td>
<td>17.0%</td>
</tr>
<tr>
<td>6</td>
<td>Wetlands</td>
<td>118,067</td>
<td>14.6%</td>
</tr>
<tr>
<td>7</td>
<td>Barren Land</td>
<td>2,716</td>
<td>0.3%</td>
</tr>
<tr>
<td>8</td>
<td>Transportation</td>
<td>18,618</td>
<td>2.3%</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>809,831</strong></td>
<td></td>
</tr>
</tbody>
</table>

In order to implement this method it was necessary to determine if each populated census unit had land use classification for population (FLUCCS = 1). The census block was too small because when the blocks were spatially overlayed with the land use there was not a Urban and Built-Up code in each populated census block. It was found that the block groups were large enough to have an appropriate area in each block group using the same technique. For purposes of this research, it was assumed that only FLUCCS level 1 would be occupied.

The land use map was dissolved (adjacent polygons are merged if they are urban polygons) and the resulting data set was spatially overlaid with the census block group polygon data set. The population was distributed into the resulting polygons by multiplying the total population with the ratio if the residential polygon to the total residential area within the block group.

**Equation 3: Method used to calculate the weighted average population in each urban polygon**

\[ P_f = P_g \left( \frac{A_u}{A_g} \right) \]

The final population \( P_f \) is the sum of the population of the block group \( P_g \) times the ratio of the final urban polygon \( A_u \) to the area of the block group \( A_g \).
Calculating Social Vulnerability

There are many factors that can contribute to social vulnerability. This research used total population as an indicator of the overall vulnerability. The nonwhite, total female, age under 18 and age over 65 are representative of those populations that have differential access to resources. Finally, the rental population was used as an indicator of socioeconomic status.

In order to combine these components together it is necessary to normalize them to the same value. This was done by determining the ratio of each variable in each census block to the total number of that variable in the county and then dividing that result from the maximum ratio value normalized each vulnerability component. For example consider the population under the age of 18:

Equation 4

\[ \text{Age}_{18}^{\text{ratio}} = \frac{\text{Age}_{18}^{\text{block}}}{\text{Age}_{18}^{\text{county}}} \]

and

Equation 5

\[ \text{Age}_{18}^{\text{norm}} = \frac{\text{Age}_{18}^{\text{ratio}}}{\text{Max}(\text{Age}_{18}^{\text{ratio}})} \]

Spatially overlaying each individual vulnerability map and then summing the vulnerability scores for each vulnerability component created the composite vulnerability map. The scores were normalized using the same technique described for the hazard maps.
Hazards and Social Vulnerability

The goal of any hazard and vulnerability research would be to predict the exact exposure of each and every individual and to ascertain their social vulnerability. This would require having exact locations of everyone, very detailed hazard maps, and specific demographic and socioeconomic information about these individuals. This is not possible because of lack of data. However the data are provided at various spatial resolutions and there are several methods that can be used to select the potentially exposed population.

The hazard maps (both the individual and composite) are spatially overlaid with the social vulnerability map to determine the potentially exposed population. As discussed there are a variety of methods that can be utilized to determine the potentially exposed population. A case study was conducted using the 100 year floodplain and the census data to determine the best method of selection and level of aggregation of the social vulnerability data. The floodplain was chosen because it was a dataset that did not require any modification. The floodplain is an example of a vector dataset where an area is exposed or not depending on its position relative to that vector, therefore, it is an easy dataset to work with and to understand. Finally since one of the aggregation units that was tested was to locate the population within only those areas that had been mapped as urban, and since building restrictions make it more difficult to build in the floodplain, it was expected that the smallest exposed population would result from this analysis.

To determine the most effective method of spatially overlaying these two datasets, three methods were employed; polygon containment, centroid containment, and buffer containment. These methods were applied to four different methods of aggregating the
data, census tract, census block group, census block and the localized population using land use.

In the polygon containment method, any polygon that intersected the 100-year flood plain was potentially exposed to the hazard. The centroid containment is similar in that if the centroid of the polygon is contained within the 100-year flood plain then that polygon is considered at risk. The buffer containment method involves calculating the weighted average of the area that is contained within the 100-year flood plain as compared to the whole polygon (Equation 1).

Each of these four aggregation units were spatially overlaid with the 100-year floodplain as described above. The polygon containment method predicted the greatest exposure, centroid containment a smaller exposed population and buffer containment the smallest. The buffer containment is the best representation because it assumes that only the area exposed is affected and the population exposed is the proportion of the total population that would fit in the exposed area assuming an equal distribution. This aggregation method of locating the population within the urban landuse polygons resulted in the smallest exposure as was expected. The results of this analysis indicate that the centroid containment method used with the census block level of aggregation was the best method to use. This method is simple and can be conducted using a point coverage as opposed to a polygon coverage which results in smaller data sets and simpler calculations. This method was used for the remainder of the research.
**Weighted Linear Combinations**

One of the objectives of this research was to see how the variations in the hazard model affected the selection of potentially exposed population. The weighting factors used for weighted linear combinations are usually determined based on some component of the factors that are being combined. For example, in hazards research it might be frequency of the events, intensity of the event, or recovery time associated with the event. In this research, some very simple assumptions were made just to examine how the exposed population changed under different hazard scenarios.

Four different hazard model scenarios were created (Table 7). The first method is assuming that all hazards are equal. The second method assumes that the natural hazards were twice as important to determining the overall hazard. In the third, the technological hazards were twice as important. Finally, the flooding and storm surge components of the hurricane hazard were removed. Thus the wind component was the only one used in addition to all the other hazard scores. This was in keeping with Malczewski (2000) about independence of the layers. The 100-year flood zone, the hurricane induced flooding and the storm surge are really affecting the areas and therefore might be overrepresented in this analysis. The results of this analysis were summarized.

The first scenario where all hazard elements were weighted equally was examined in detail to understand how the potentially exposed population varied with each individual hazard. The sum of each of the components of social vulnerability used in this research was calculated for each hazard. The percent of potentially exposed population was calculated for each hazard score. The cumulative frequency (percentage) was calculated for each hazard. A cumulative frequency graph was created for each hazard.
and these graphs were examined to determine how the potentially exposed population varies depending of the source of the hazard both individually and for the combined hazard.

Table 7: Four scenarios for weighting the hazard map

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Method of Calculating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Weighting</td>
<td>All five hazards are weighed equally</td>
<td>Flood + sinkhole + hurricane + transportation + TRI</td>
</tr>
<tr>
<td>High Natural Hazard</td>
<td>Double the natural hazard scores</td>
<td>2 * (Flood + sinkhole + hurricane) + transportation + TRI</td>
</tr>
<tr>
<td>High Technological Hazard</td>
<td>Double the technological hazard scores</td>
<td>Flood + sinkhole + hurricane + 2* (transportation + TRI)</td>
</tr>
<tr>
<td>Eliminate Flooding</td>
<td>Drop the “triplicate” weighting by eliminating the flooding and storm surge component of the hurricane hazard</td>
<td>Flood + sinkhole + wind component of hurricane + transportation + TRI</td>
</tr>
</tbody>
</table>
Chapter 4: Results

Hazard Map

Individual Natural Hazards

Flooding

Figure 8 shows the result of the floodplain hazard mapping. Flooding is widespread and occurs in the river basins, swamps, and other low lying areas throughout Hillsborough County. The method used to delineate the flooding hazard results in a very clearly defined boundary typical of vector data. There is a clear line that represents the boundary between areas that are or are not predicted flood within the next 100 years. Thus any population that is in the 100-year floodplain would be potentially exposed to the flooding.

Sink Hole

Sinkholes are scattered throughout Hillsborough County but as shown they are not uniformly distributed (Figure 9). Instead they are clustered into two distinct areas. Comparing the density surface with the map of the geology of this region (Figure 3) provides some insight into why the sinkholes are clustered the way they are. The parameters used to generate the density map resulted in a map that is similar to the map of the underlying geology. The greatest sinkhole hazard is in the northwest and the eastern central portion of the county and a separation along the Hillsborough river basin.
Figure 8: Flooding hazard map of Hillsborough County, Florida (SWFWMD data)
Figure 9: Normalized Sinkhole hazard in Hillsborough County, Florida (SWFWMD data)
There are two major difficulties in mapping sinkhole hazard; lack of a complete dataset and the kernel used for the estimation. The sinkhole data unfairly biases the already developed region of the county because that area has been mapped in greater detail than other areas. Sinkholes that occur in undeveloped areas may not have been mapped, therefore this dataset is biased toward developed regions and underestimates the occurrence of sinkholes in undeveloped areas. However, the risk still exists in the undeveloped region but these sinkholes have not been mapped. Therefore using this method would overestimate the sinkhole hazard in some areas. The other issue of the variables used to generate the kernel estimations would require analysis beyond the scope of this research. An exhaustive study of a variety of input parameters could be conducted but this was not the purpose of this study.

Hurricane

The hazard posed by hurricanes is made up of several components. The components used in this research were wind, flooding, and storm surge. Different model runs were used to generate results for each category of hurricane. The resulting five datasets were classified according to the wind speed in each cell. The resulting five wind hazard maps were combined to create a composite wind hazard map. This map was normalized and the resulting map is shown in Figure 10. As expected the greatest wind hazard exists on or near the coast and diminished as the storm moves further inland. The banding typical of storms of this type is evident in this map.
The flooding component contributing to hurricane hazard is shown in Figure 11. As expected the majority of the flooding occurs along the coastal regions. Additional flooding occurs in low-lying areas in the northern and northeastern portions of the county and along the river basins. Figure 12 shows the storm surge component to hurricane hazards.

The composite hurricane hazard map is shown in Figure 13. As expected the greatest hazard is along the coast and the peninsula of Tampa. There are scattered spots where localized flooding has increased the hazard inland. It also shows that nearly everyone in the county is potentially exposed to some level of hurricane risk whether from wind, flooding, or storm surge. The vast majority of the population is only potentially exposed to wind hazard but the coastal regions are potentially exposed to all three hazard components and therefore are at considerably more hazard than those that potentially exposed only to the wind.

_Individual Technological Hazards_

_Transportation Hazard_

The hazard posed by transportation of toxic substances is shown in Figure 14. The greatest exposure is in downtown Tampa where a number of potential routes through the city are often used to transport toxic substances. This area has a small residential population but a very large working population. This is one of the downfalls of using Census data for hazard analysis because it only maps the location of the residential or “night time population” since most people work in other places than they live.
Figure 10: Map of the wind component for hurricane hazards for Hillsborough County, Florida. (Complied from TAOS SLOSH Hurricane Models)
Figure 11: Map of the coastal flooding component for hurricane hazards in Hillsborough County, Florida. (Complied from TAOS SLOSH Hurricane Models)
Figure 12: Map of the storm surge component to hurricane hazards in Hillsborough County, Florida. (Complied from TAOS SLOSH Hurricane Models)
Figure 13: Normalized total hazard due to hurricanes in Hillsborough County, Florida.
Toxic Release Inventory

The results of the TRI hazard mapping are shown in Figure 15. The location of some of the largest polluters is along Tampa Bay because proximity to the water provides both transportation of fuel and water for processing. Because of this the impact of toxic emissions is minimized to some extent.

Composite Hazard Map

The result of the composite hazard mapping project is shown in Figure 16. The data were classified into five equal intervals and reported as low, medium, and high hazard exposure. It appears that the major contribution to hazard in Hillsborough County is the wind component of the hurricane hazard. The flooding from the FEMA flood zones, hurricane induces flooding and storm surge are also apparent. The contribution of the sinkhole hazard is evident in the northwestern part of the county. The highest hazards occur near the Big Bend Power plant on Tampa Bay. This area is subject to flooding, wind, and toxic emissions. However, because of its location near the water it may pose less potential exposure than if it were located elsewhere.
Figure 14: Hazard due to transportation spills in Hillsborough County, Florida.
Figure 15: Airborne toxic emission hazard for Hillsborough County, Florida.
Figure 16: Normalized total hazard map where each hazard component is treated equally.
Social Vulnerability

The following maps (Figures 17 – 23) show the normalized social vulnerability maps for each vulnerability component. Note that the area south of Brandon and Mac Dill Air Force Base consistently ranked high in their vulnerability score. In fact those were the two most vulnerable locations.

The normalized total population map (Figure 17) shows that the most vulnerable census block due to total population is located in the south Brandon area. This polygon is consistently vulnerable for many of the vulnerability components (Figures 17, 18, 19, 21, 22). An investigation of the data reveals that this might be due to an aggregation artifact. The mean value for total population excluding the unpopulated polygons (e.g. Total Population not equal to 0) is 72.7 people per polygon and the standard deviation is 150. The total population for this polygon is 4943. This and the top 10 polygons are so much larger than the mean that they overpower the other polygons making the rest of the count appear less vulnerable than it really is. This polygon is the most vulnerable for total population, total female, total under 18, and total renter.

Figure 18 shows the normalized score for the not-white population. Again the very highly populated blocks overweigh the values of the other blocks. The same polygon in south Brandon has the highest overall score.

The total population for each vulnerability component is summarized in Table 8. The female population is distributed almost the same as the total population and is just a little greater than the overall population. Some of the largest variations are in the not white population. The areas of northern Hillsborough county are predominantly causation while areas in central Hillsborough county are more ethnically mixed.
variation in the distribution of the population that is vulnerable due to age is also evident. The preponderance of the over 65 population lives in southern Hillsborough county. The under 18 population more closely follows the total population distribution with the majority in the northwestern corner of the county and in the area around Mac Dill AFB. The renter vulnerability score was very low and largely concentrated in the northwest Hillsborough and Brandon areas.
Figure 17: Normalized score for total population component to social vulnerability in Hillsborough County, Florida. (U.S. Census data, 2000)
Figure 18: Normalized score for non-white population component to social vulnerability in Hillsborough County, Florida. (U.S. Census data, 2000)
Figure 19: Normalized score for under 18 population component to social vulnerability in Hillsborough County, Florida. (U.S. Census data, 2000)
Figure 20: Normalized score for over 65 population component to social vulnerability in Hillsborough County, Florida. (U.S. Census data, 2000)
Figure 21: Normalized score for female population component to social vulnerability in Hillsborough County, Florida. (U.S. Census data, 2000)
Figure 22: Normalized score for renter population component to social vulnerability in Hillsborough County, Florida. (U.S. Census data, 2000)
Figure 23: Normalized score for total social vulnerability in Hillsborough County, Florida
Table 8: Summary of at risk population

<table>
<thead>
<tr>
<th>Population</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>998,948</td>
</tr>
<tr>
<td>Not White</td>
<td>248,045</td>
</tr>
<tr>
<td>Women</td>
<td>510,176</td>
</tr>
<tr>
<td>Less than 18</td>
<td>253,138</td>
</tr>
<tr>
<td>Greater than 65</td>
<td>119,673</td>
</tr>
<tr>
<td>Rental</td>
<td>140,362</td>
</tr>
</tbody>
</table>

Methods of Selection

The methods used to determine the affected population can have a profound impact on the determining the potentially exposed population. To test how various aggregation units were selected using several different selection techniques, the U.S. Census data was intersected with the floodplain hazard map. The data were aggregated in four ways; census tracts, census block groups, and census blocks, and by uniformly distributing the population only in areas that were determined to be populated based on the land use map (Group/LU). Three methods were used to determine the potentially exposed population; polygon intersection, centroid containment, and buffer containment. The results of this analysis are summarized in Table 9.

The ideal condition would be to select exactly only those individuals that are exposed to this hazard. Therefore, the smaller potentially exposed population the closer the approximate of the truly exposed population. The polygon containment method dramatically overestimated the potentially exposed population regardless of the aggregations unit. The buffer containment resulted in the smallest number of potentially exposed individuals. Theoretically the areal interpolated group applied to the localized population using land use should have produced the smallest numbers because of
removing the population from the “non-urban” portions of the census block group. This is indeed the case and therefore could be assumed to be “ideal” for flooding hazard.

Table 9: Summary of the total population potentially exposed to flooding hazard using a variety of selection methods on four different aggregation areas

<table>
<thead>
<tr>
<th>Method of Selection</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tract Polygon Containment</td>
<td>848,221</td>
</tr>
<tr>
<td>Tract Centroid Containment</td>
<td>259,199</td>
</tr>
<tr>
<td>Tract Areal Interpolation</td>
<td>209,421</td>
</tr>
<tr>
<td>Block Group Polygon Containment</td>
<td>722,666</td>
</tr>
<tr>
<td>Block Group Centroid Containment</td>
<td>245,729</td>
</tr>
<tr>
<td>Block Group Areal Interpolation</td>
<td>211,092</td>
</tr>
<tr>
<td>Block Polygon Containment</td>
<td>470,651</td>
</tr>
<tr>
<td>Block Centroid Containment</td>
<td>222,547</td>
</tr>
<tr>
<td>Block Areal Interpolation</td>
<td>205,282</td>
</tr>
<tr>
<td>Group/LU Polygon Containment</td>
<td>665,272</td>
</tr>
<tr>
<td>Group/LU Centroid Containment</td>
<td>176,311</td>
</tr>
<tr>
<td>Group/LU Areal Interpolation</td>
<td>175,061</td>
</tr>
</tbody>
</table>

This method was labor intensive and resulted in a much larger dataset. There are 795 census blocks groups in Hillsborough County. The data set resulting from the spatial overlay of the census block group data with the dissolved land use data set the resulted in over 29,280 polygons (nearly a 36x increase). Of these 345 (43%) polygons remained undivided after the overlay and thus were entirely inside the urban area or entirely outside the urban area and thus were unaffected by this technique. This technique would be warranted in some applications such as insurance adjustment or evacuation planning it was not used for this research.

The results of the centroid containment are similar to the results from the buffer containment at each level of aggregation and are therefore selecting the same exposed population. This method improves with smaller aggregation units because smaller; the
smaller granular size, the closer the polygons fit the sinuous features of the floodplain and therefore the more accurate selection.

The best compromise for ease of use and computationally simplicity was centroid containment applied to census blocks. This was the easiest to use, resulted in small datasets and resulted in nearly the same potentially exposed population as the buffer containment. This was the method selected to use for the remainder of this research.

**Hazards and Vulnerability**

Weighted linear combination relies on taking the normalized base data and combining it using weighting values. Observing the changes in the outcome can help to understand how the potentially exposed population would change under various threat scenarios. The most basic combination where everything is weighted the same. The initial analysis looked into the details of this basic combination.

Each of the individual hazard components contribute to the overall potentially exposed population and each generate their own exposure envelope. Social vulnerability results from several components. The components of social vulnerability were graphed for each component of the hazard map and the composite hazard map.

**Individual Hazards**

**Flooding**

The cumulative frequency graph for exposure to flooding hazard is shown in Figure 24. This graph is a little misleading because there the model used for riverine
flooding is a discrete dataset. Therefore the population is either potentially exposed or not and there is no gradual change in the level of exposure as the graph shows. However, this graph shows that at zero hazard (the population living outside the floodplain) accounts for nearly 80% of the population. Therefore flooding only affects about 20% of the total population in Hillsborough County. It also shows that the 24% of the rental population is potentially exposed to flooding while only 15% of the non-white population is potentially exposed to flooding. This is perhaps indicative of the fact that many of the rental communities are located along the coast and rivers where flooding is more probable. These areas tend to be less racially mixed and therefore slightly less vulnerable than other area.

![Cumulative frequency graph showing the potentially exposed population to flooding hazard by the components to social vulnerability.](image)

**Sinkhole**

The cumulative frequency graph for sinkhole hazards is shown in Figure 25. This is a more typical example of a cumulative frequency map in that there are more
continuous values for the hazard. This graph shows that the potentially exposed population increases fairly rapidly to the point where about 50% of the population is potentially exposed at hazard levels between 20% and 30%. The rate of increase gradually diminishes from this point on until reaching 100%. The renter population is more potentially exposed to hazardous areas than the total population whereas, the age greater than sixty five are less affected. This is largely a cultural factor about this county.

The vast majority of the elderly population is located in the southern end of the county in residential communities that cater to the elderly (Figure 20). This area is well removed from the sinkhole hazards.

![Cumulative frequency graph showing the potentially exposed population to sinkhole hazard by the components to social vulnerability.](image)

**Figure 25:** Cumulative frequency graph showing the potentially exposed population to sinkhole hazard by the components to social vulnerability.
Hurricane

The cumulative frequency map for the normalized wind component (Figure 26) shows that nearly everyone in the county is potentially exposed to at least a 0.4 hazard score. The population age over 65 is more potentially exposed than the total population. The cumulative frequency graph for the normalized hazard coastal flooding hazard component (Figure 27) is very similar to the riverine flooding graph although it encompasses a larger area and therefore a larger population. The potentially exposed population demographics are the same as the riverine flooding.

Figure 27 shows the normalized hazard for the storm surge component of the hurricane hazard. It appears very similar to the riverine flooding map because it is virtually identical in area.

Figure 26: Cumulative frequency graph showing the potentially exposed population to the hurricane wind hazard by the components to social vulnerability.
Figure 27: Cumulative frequency graph showing the potentially exposed population to the hurricane flooding hazard score by the components to social vulnerability.

Figure 28: Cumulative frequency graph showing the potentially exposed population to the hurricane storm surge hazard score by the components to social vulnerability.
The cumulative frequency graph (Figure 29) for the composite hurricane hazard map shows how the components combine. The basic frequency created by the wind component was expanded by the cumulative effect of both the storm surge and flooding components. At lower levels of hazard (hazard <= 0.35) the under 18 population is most potentially exposed while the over 65 is the least. At higher levels (hazard > 0.35) the not white population is the least potentially exposed and the renter population is more potentially exposed.

*Individual Technological Hazards*

*Transportation Hazard*

The cumulative frequency graph (Figure 30) for this hazard shows that the vast majority of the population is unaffected by this hazard. Only about 10% of the population is potentially exposed at all. The least potentially exposed portion of the population appears to be the age less than 18.

*Toxic Release Hazard*

The cumulative frequency graph (Figure 31) shows that very few are potentially exposed the TRI hazards in Hillsborough County. Only about 10% of the population is potentially exposed at all. Of the potentially exposed population the least exposed is the age less than 18 and the most exposed is the renter population.

*Total Hazard*

The graph showing the components of social vulnerability and total hazard exposure (Figure 32) shows the same basic pattern as the total hurricane exposure graph
(Figure 29). It has been shifted down due to the influence of the extremely localized hazards (flooding, transportation spills and TRI). This graph shows that the renter community is still generally more potentially exposed to all the hazards used in this research than other vulnerable populations. It also shows that the over 65 age group is the least potentially exposed to hazards. This again is due to the preponderance of the population that lives in the Sun City area which is removed from many of the hazards.
Figure 29: Cumulative frequency graph showing the potentially exposed population to the total hurricane hazard by the components to social vulnerability.
Figure 30: Cumulative frequency graph showing the potentially exposed population to the transportation spill hazard score by the components to social vulnerability.

Figure 31: Cumulative frequency graph showing the potentially exposed population to the TRI hazard score by the components to social vulnerability.
Figure 32: Cumulative frequency graph showing the potentially exposed population to the total hazard score by the components to social vulnerability.
Total Hazard and Vulnerability

Figure 33 shows where the most vulnerable populations are in relation to the most hazardous areas. This map was prepared using three equal intervals describing the hazards and vulnerability. The resulting scores were used to create a hazard/vulnerability matrix. This map shows that many of the most vulnerable areas are also subject to moderate hazards. This is especially true of Mac Dill AFB and the areas of northwest Hillsborough County. The census block that is the most vulnerable fortunately is in a relatively hazard free area. There is one area in the Town and Country region of Hillsborough County that scored high in both hazard and vulnerability based on this classification.

The maps that show the effects of doubling the technological hazard and the natural hazard components of the overall hazard map are shown in Figures 34 and 35. The doubling of the natural hazard causes a larger area to be exposed to a higher hazard classification. This is primarily due to the coastal flooding and the FEMA flood zone increasing the risk along the shore. Doubling the technological hazards emphasized the impact of the toxic release scores around the Port of Tampa. Fortunately this is an area that is not very vulnerable because of the low population density in that area.

Figure 36 shows the impact of removing the duplicate weighting of flooding. Removing the duplicate flooding scores resulted in a general increase in the total hazard score. This is perhaps because the duplicate flooding was diminishing the impact of the other hazards and by removing it results in a more equal representation of each individual hazard.
Figure 33: Map showing the combination of the normalized total social vulnerability and the normalized total hazard.
Figure 34: Map showing the total hazard when the technological component (Transportation and TRI) is doubled.
Figure 35: Map showing the total hazard when the natural hazard component (flooding, sinkhole, and hurricane) is doubled.
Figure 36: Map showing the total hazard when the flooding is minimized.
Examining the cumulative percentage graph for high natural, high technological and equal weighting (Figure 37) shows the relationship between these three methods graphically. The doubling the technological hazard results in a generally less hazardous map while doubling the natural hazards creates a more hazardous map. This shows how various weighing factors can influence the overall hazard scores. Determining the appropriate weighting is important for any hazard analysis.

Figure 37: Cumulative frequency graph comparing three weighting methods.
Chapter 5: Conclusions

The goal of this research was to create a multiple hazard and social vulnerability model. This model was used to determine the extent of exposure to hazardous areas. The components of social vulnerable were examined for each individual component of the hazard model. The results show that the potentially exposed population varies not only in total numbers but also in demographic composition depending on which hazard is being considered. Recognition and utilization of this demographic variation could be used for disaster management, social improvement, and mitigation for exposure to hazards.

The multiple hazard map incorporated five components, flooding, sinkhole, hurricane, toxic release, and accidental toxic spills. Each component was responsible for different amounts of exposure. Some components such as flooding; flooding and storm surge due to hurricanes; transportation spills; and toxic release had minimal effect on the vast majority of the population. This is because the exposure was very localized around the source of the hazard. Sinkholes and wind due to hurricanes had potential exposure maps that showed potential exposure across most of Hillsborough County albeit at very low levels of exposure. It might seem reasonable to limit this research to only those hazards that have similar amounts of exposure. However eliminating any of them a priori would be a mistake because the combination of multiple hazards often reveals unanticipated results. For example, the interaction between the sinkhole hazard and the flooding due to hurricane combine together to create higher hazards in the north west
portion of the county. This area has a number of small lakes, formed perhaps due to sinkhole action, which would become flooded due to the rain that accompanies hurricanes.

This research was focused on the composite hazard and social vulnerability and therefore did not attempt and exhaustive examination of each hazard component. Each individual hazard component could be or has been mapped in other ways. The methods used to generate the exposure maps for each hazard were selected so that they would generate data in a manner that could be combined together into the composite hazard map. Much more research could be conducted into determining the amount of exposure resulting from each individual hazard.

The social vulnerability analysis consisted of six components; total population, total non-white, total age less than 18, total age greater than 65, total female population and total renter. Like the hazard analysis, this was not intended to be an exhaustive study of social vulnerability, but instead to show a representative subset of the components that contribute to social vulnerability. Additional components could be added to this analysis and would make a more complete picture of social vulnerability in this area.

There were some problems with the method used to normalize the components to social vulnerability due to the aggregation units chosen. Some very highly populated census blocks dramatically shifted the vulnerability calculations making the county as a whole seem less vulnerable. These highly populated census blocks were consistently in the top ten of vulnerable populations almost regardless of the vulnerable component that was being examined. These census blocks are areas that have experienced so much growth that they will probably be subdivided in the future. Because of this growth it
could be argued that they are indeed more vulnerable, but this may not be the case. The important fact is that the method used to normalize the social vulnerability is so susceptible to extremes in total population.

The important results from this work are deciding what methods are going to be used for spatial overlay. The results show how the total potentially exposed population varies depending on which method was used and how the data was aggregated. It is important to make these decisions early in the research and to be aware of the effects.

The use of cumulative frequency graphs for this type of hazard and vulnerability research was also very useful. It shows that there can be a tremendous variation in which vulnerable populations are exposed to various hazards. This information could be used for better emergency planning and relief following a hazardous event.

Finally, the weights used when combining various geo-spatial data layers together can affect the outcome of the analysis. The simplest method is to assume that all the weights are equal but this is not always the case. For example, hazardous events occur with different frequency and with variable intensity and duration. These could affect the weights used to generate the composite hazard maps and the potentially exposed population. Likewise perhaps not all the components of community vulnerability should be treated equally. It may be shown that some groups are more vulnerable than others and should be weighted differently.

**Use for this research**

There are many potential uses for this research including emergency planning and disaster response. It could be used for environmental justice analysis to show how
different vulnerable communities are exposed to a variety of hazards. It could also be used for urban planning by limiting development in very hazardous areas or requiring additional insurance in those areas. Tax incentives could be used to encourage vulnerable communities to relocate out of hazardous areas.

**Future Work**

The hazards selected for use in this model represent a small but significant subset of all the hazards that Hillsborough County is potentially exposed to. These hazards are representative of typical geographic data types (i.e. point, line, polygon, and raster). The techniques used to map the exposure from each individual data type could be used to incorporate additional hazards represented by similar data types. The more hazards that are incorporated into this type of research will lead to a more comprehensive understanding of the overall hazard exposure.

The temporal component of community vulnerability was touched on briefly in the discussion of the transportation hazard. In that analysis it was shown that the greatest exposure to transportation spills was in the downtown Tampa area because of the high concentration of transportation routes through that area. Fortunately this area has a very low residential population as revealed by the census data. This area is very dense in commercial and office space where thousands of people come to work every day. These “daytime” residents are not tabulated in the census data. This area also has a large number of hotels and cruise ships supporting thousands of tourists that visit the area every year.
The second major temporal component is the seasonal change in population. The population varies between August and January because of the number of winter vacation and residents that migrate into and out of this county every year. These people are generally not counted in the census data because they are recorded in their home locations.

The final temporal variation that could be incorporated into the community vulnerability model would be the temporal variation in the hazards themselves. Hurricanes and flooding due to rain have a distinct season in Florida. Incorporating this variation into the interaction between the transient and residential communities and the temporal distribution of the hazards would create a more realistic representation of the potentially exposed population.
Bibliography


ESRI (2002) ArcGIS 8.3 Help files


NOAA (1999a) Mitch: The deadliest Atlantic hurricane Since 1780. http://www.ncdc.noaa.gov/oa/reports/mitch/mitch.html Last Updated Monday, 25-Jan-1999 08:00:00 EST by Neal.Lott@noaa.gov, Sam.Mccown@noaa.gov, Axel.Graumann@noaa.gov, Tom.Ross@noaa.gov.


http://www.statcan.ca/english/edu/power/ch10/frequency.htm (Date modified: 2003-10-20)


Appendix: Sources of Toxic Release (2000)

Sum of all fugitive air and stack air emissions. The maximum for each site was selected. The total annual release was divided by four to simulate the potential release per quarter. The weather data is summarized below:

<table>
<thead>
<tr>
<th>Month</th>
<th>Wind Speed</th>
<th>Wind Direction</th>
<th>Cloud Cover</th>
<th>Temperature (°F)</th>
<th>Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>9</td>
<td>N</td>
<td>Clear</td>
<td>70.6</td>
<td>56</td>
</tr>
<tr>
<td>April</td>
<td>9</td>
<td>ENE</td>
<td>Partly Cloudy</td>
<td>82.2</td>
<td>46</td>
</tr>
<tr>
<td>July</td>
<td>7</td>
<td>E</td>
<td>Overcast</td>
<td>90.0</td>
<td>59</td>
</tr>
<tr>
<td>October</td>
<td>9</td>
<td>NNE</td>
<td>Clear</td>
<td>83.4</td>
<td>56</td>
</tr>
</tbody>
</table>

Cloud cover was estimated by from the probability of rain for each month. Temperature was calculated as the average temperature for each month in question. The time and date was assumed to be noon on the fifteenth of the month.

The ground cover is assumed to be open country in every case.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Chemical Reported</th>
<th>Chemical Used in ALOHA</th>
<th>Amount (lbs/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aloca Extrusion Inc.</td>
<td>Xylene</td>
<td>Xylene</td>
<td>230.8</td>
</tr>
<tr>
<td>Amalie Oil</td>
<td>Ethylene Glycol</td>
<td>Ethylene Glycol, Monoacetate</td>
<td>4.2</td>
</tr>
<tr>
<td>Ball Metal Beverage (1)</td>
<td>N-Butyl Alcohol</td>
<td>Tert Butyl Alcohol</td>
<td>2433.0</td>
</tr>
<tr>
<td>Cargill Fertilizer</td>
<td>Ammonia</td>
<td>Ammonia</td>
<td>1820.0</td>
</tr>
<tr>
<td>CF Industry</td>
<td>Ammonia</td>
<td>Ammonia</td>
<td>3356.6</td>
</tr>
<tr>
<td>Clorox Products</td>
<td>Chlorine</td>
<td>Chlorine</td>
<td>0.4</td>
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<tr>
<td>Col Met Inc</td>
<td>Glycol Ethers</td>
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<tr>
<td>Coronet Industry</td>
<td>Hydrogen Fluoride</td>
<td>Hydrogen Fluoride</td>
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</tr>
<tr>
<td>GAC Tampa</td>
<td>Asbestos</td>
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<tr>
<td>Gatsby Spas</td>
<td>Styrene</td>
<td>Styrene Monomer</td>
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<td>Gulf Coast Recycling</td>
<td>Lead Compounds</td>
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<td>14.0</td>
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<tr>
<td>Gulf Marine Repair</td>
<td>Zinc Compounds</td>
<td>NA</td>
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<tr>
<td>Industrial Galvanizers</td>
<td>Zinc Compounds</td>
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<tr>
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<td>Glycol Ethers</td>
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<tr>
<td>International Ship</td>
<td>Copper Compounds</td>
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<td>Johnson Controls</td>
<td>Lead Compounds</td>
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<td>Nitram, Inc.</td>
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<tr>
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<td>Styrene Monomer</td>
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<td>Ammonia</td>
<td>Ammonia</td>
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<td>Styrene Monomer</td>
<td>82.8</td>
</tr>
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<td>Valspar Corp</td>
<td>Ethylene Glycol</td>
<td>Ethylene Glycol, Monoacetate</td>
<td>2.1</td>
</tr>
<tr>
<td>Company</td>
<td>Chemical 1</td>
<td>Chemical 2</td>
<td>Value</td>
</tr>
<tr>
<td>------------------------------</td>
<td>--------------------</td>
<td>--------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Yuengling Brewing Co</td>
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<td>Ammonia</td>
<td>101.6</td>
</tr>
<tr>
<td>Ball Metal Beverage (2)</td>
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<td>Tert Butyl Alcohol</td>
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