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AN ASSESSMENT OF POTENTIAL FOR ECONOMIC LOSS TO RESIDENTIAL PROPERTY IN UNITED STATES COASTAL COUNTIES FROM TROPICAL CYCLONES USING A GEOGRAPHIC INFORMATION SYSTEM

By

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ABSTRACT

Tropical cyclones pose a significant threat to life and property along coastal regions of the United States. As coastal development and populations increase, so too does the potential for unprecedented loss. Although close examination of the historical record indicates that U.S. tropical cyclone activity (tropical cyclones making landfall in the U.S.) has remained relatively constant through time, losses from these events have been climbing rapidly. With researchers now predicting an increase in major hurricane activity in the near future, it is possible that we are entering an era where multi-billion dollar losses are the norm rather than the exception. Utilizing a geographic information system (GIS), this study highlights those areas where coastal residential development is most concentrated. Overall, such areas likely face a greater potential for property losses from tropical cyclones relative to that of less developed areas. Coastal county residential property valuation data are coupled with historical tropical cyclone data and a ranking scheme is developed. Using this scheme, all first-tier 175 coastal counties (those with tidewater shorelines bordering the Gulf of Mexico, Atlantic Ocean, or other major estuarine water body) are then compared with one another in terms of their potential for future residential property loss based upon their level of economic exposure and their tendency for experiencing various intensities of tropical cyclones. Although the crudeness of the economic data utilized in this study precludes its use as a comprehensive loss estimation methodology, the study presents an innovative and pliable methodology that is

designed as a template that can be employed by local, state, and federal government agencies to support various tropical cyclone-related decision making activities.

INTRODUCTION

Early on the morning of August 24, 1992, the center of Hurricane Andrew roared across Dade county, Florida. The storm tracked east to west, its core entering the state just south of the city of Miami. At landfall, Andrew was classified as a category four hurricane on the Saffir-Simpson Hurricane Scale (See Appendix A). Packing sustained winds estimated at near 145 miles per hour, with gusts to 175, the storm wrought unprecedented destruction to property and ecosystems over the southern tip of Florida. In Dade county alone, the storm's tornado-like damage swath left 250,000 people homeless and otherwise disrupted the lives of hundreds of thousands of residents, many for years afterward.

Only four hours after Andrew's eye crossed Florida's Atlantic coastline, the storm's center exited the state over the Gulf of Mexico. Continuing on a more northwestward track, the storm made landfall again, this time as a weak category three hurricane in St. Marys Parish, along the south-central Louisiana coastline. Andrew was directly responsible for the deaths of more than 25 people and for monetary losses totaling nearly $25 billion (Mayfield *et al*. 1994). Consequently, Andrew became one of the most expensive natural disasters with respect to property loss in United States' history (Ayscue 1996). Many residents never could have imagined the caliber of destruction brought about by the passage of a single hurricane. Incidentally, Andrew was the first storm in the 1992 hurricane season - a season that was relatively slow to initialize and would end up producing only marginal activity and no other U.S. landfalling tropical cyclones.

In comparison, Hurricane Bret came ashore over Kenedy County, Texas on the evening of August 23, 1999. Although similar in size and strength to Andrew, Bret did comparatively little damage with final estimates totaling approximately $60 million (Lawrence and Kimberlain 1999). In addition, not a single death could be attributed to the storm. So why the large disparity? The reasons it appears, are rooted in county demographics. At the time Hurricane Andrew made landfall, the resident population of Dade County, Florida was nearly two million. In contrast, at the time Bret made landfall, the resident population of Kenedy County, Texas was less than 500. It was in fact, the least populated and least developed of all 175 counties used in this study. Under the notion that more people and more development equate to increased potential devastation from tropical cyclones, it is clear why damages were extraordinarily disparate between the two storms.

Hurricane Andrew was a wake-up call - a blatant reminder of our potential vulnerability to tropical cyclones. Many years had passed since the U.S. had witnessed such acute devastation from a single storm. Although relatively used to chronic damages from smaller storms, sixty-six years had passed since south Florida had been affected by an event of Andrew’s magnitude, thus few people realized the potential devastation wrought by these “meteorological monsters of the sea.” Surprisingly, despite the lessons learned from Andrew, we continue to increase our risk by continuing to populate and develop our nation’s coastlines.

This thesis utilizes a select set of economic indicators in an attempt to quantify and compare the relative potential for losses in coastal areas exposed to the tropical cyclone threat. This quantification is predicated on the assumption that a county's potential for losses is a function of both its amount of exposed property and past history of tropical cyclones. A ranking scheme is utilized whereby coastal county residential property valuation data and tropical cyclone climatology data are quantified, enmeshed, and used for comparisons between counties. The present analysis is an extension of the work of Whitehead (1999). Whitehead developed and employed a similar ranking scheme wherein coastal county wealth data and past hurricane frequency were combined and compared, however, the present work improves this work by considering not only historical hurricane frequency, but intensity as well. Moreover, it employs GIS to efficiently map out the relative exposure indices.

The study begins with a brief overview of the U.S. tropical cyclone problem. It then moves to a discussion of the nature of risk assessments including a look at some existing methodologies. It uses the State of Florida as a model of acute exposure and potential for vulnerability to tropical cyclones before focusing on the climatology of hurricanes affecting the U.S. coastline. Next, the study considers the concept, data, and method for assessing relative risk based on current levels of economic exposure coupled with past experience with tropical cyclones. Analysis, results, and discussion follow, including mention of using the present study as a template for future work.

1. THE PROBLEM

1.1 Societal Factors

Historically, coastal areas have shown a particular susceptibility to the catastrophic impacts of tropical cyclones. Between 1992 and 1997, 71 percent of the federally declared disasters in the U.S. occurred in coastal states or territories and were related to the effects of tropical cyclones (NOAA 1998). Furthermore, the destructive potential from tropical cyclone events continues to rise due to increasing development in coastal areas. Rapid, sprawling growth in coastal areas has the obvious consequence of increasing human exposure to natural hazards. Pielke (1997) states that although human losses from tropical cyclones have declined steadily during this century, “the *potential* for large loss of life remains significant.” This idea is supported by data from the U.S. Census Bureau (1997) indicating that the U.S. has an expansive and diverse coastline that supports a disproportionate percentage of the Nation’s population. Although the coastal counties account for only 20 percent of the total U.S. land area, they contain just over 50 percent of the U.S. population. During the last decade (1990-2000), 17 of the 20 fastest growing counties in the U.S. were located along the coast. In addition, 19 of the 20 most densely populated counties are classified as coastal, as are 16 of the 20 counties with the largest number of new housing units under construction (Census Bureau 1997). These data, juxtaposed with recent research that supports a return to more frequent major hurricanes in the Atlantic Basin (Gulf of Mexico, Caribbean Sea, and Atlantic Ocean) are cause for great concern among those responsible for the protection of life and property along and near our Nation's coastline.

Tropical cyclones affect people and property in widespread coastal areas and can radically alter the natural environment, particularly along the immediate coastline. In addition to concerns about public safety and health, there are compelling economic reasons to develop a better understanding of tropical cyclone impacts on coastal communities. The coastline now supports many communities' primary economic assets including fishing, civilian and military aircraft terminals, ports, resorts, large federal installations, refineries, oil rigs and chemical and metal processing plants, all of which have the potential to be threatened, impacted, or drastically altered by coastal hazards (Sugg 1967). Efforts to strengthen or protect these economic resources are often complicated by insufficient scientific information coupled with a wide range of confounding factors concerning and contributing to the overall vulnerability of the coasts. Among others, vulnerability factors associated with high risk areas include the underlying geologic framework of the coast, the patterns and characteristics of the built environment, and the socio-economic conditions. Developing a better understanding of these (and other) features and documenting their respective responses to hazard events will provide a rational and objective basis for making substantiated coastal resource management and planning decisions. This informational foundation is essential to help various local, state, and federal government agencies identify and prioritize the most appropriate and cost-effective coastal hazard mitigation strategies.

Massive development, much of it in the form of urban sprawl, has occurred in an environment of relative quiescence with respect to the occurrence of tropical cyclones

(Godschalk *et al*. 1999). Nearly every coastal county has experienced exceptional population growth over the past few decades. During the period 1990-2000, approximately one quarter (46) of the first-tier coastal counties used in this study (those with at least a portion of their land area bordering on the Gulf of Mexico, the Atlantic Ocean, or other major esturine water body such as the Chesapeake Bay) have experienced growth rates greater than 20 percent (Figure 1). It is not surprising that Americans are drawn to coastal locations. Living in close proximity to the Atlantic and Gulf coasts is

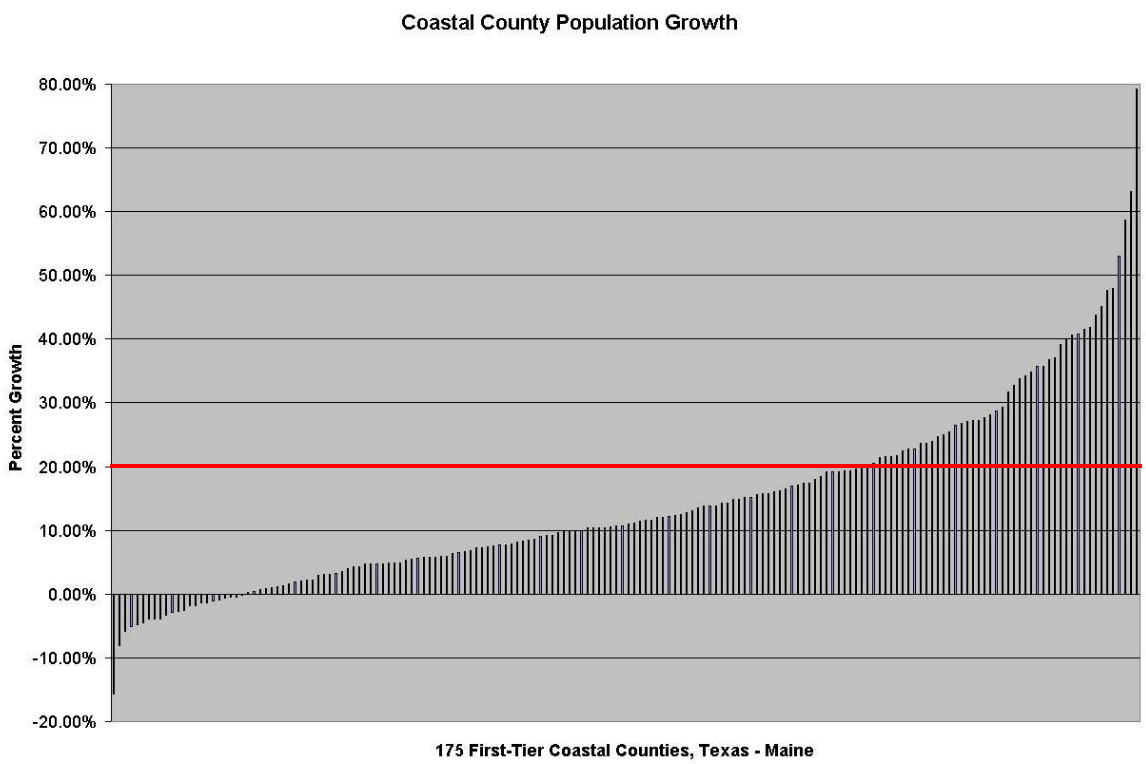

Figure 1. Percent Population Growth in Coastal Counties, 1990 – 2000.

highly desirable. Vacationers, investors and retirees, among others, striving to either rent, own, or develop coastal property flock to coastal locations in ever-increasing numbers. Interestingly, what these people may not realize, is that along with their choice to reside in coastal locations, they are choosing to place themselves at risk; they are in fact, accepting the risks inherent with the territory. Varley (1994) confirms these ideas when stating that, "vulnerability to tropical cyclones involves not only the risk of being impacted, but also the ability to exercise choice in locating in areas prone to tropical cyclones." Expanding on similar issues, Glantz (1978) writes, "adverse weather events themselves can be devastating for society, but their effects are often exacerbated by economic, political, and societal decisions made, in many instances, long before those events take place. For example, the amount of destruction attributed to a tropical cyclone may, in fact, reflect improper land-use planning by those responsible for such planning or by those who build in areas that are prone to hazards such as tropical cyclones, or both."

1.2 Natural Factors

That our society has become increasingly susceptible to the harmful effects of tropical cyclones is hardly debatable. Recent events highlight this notion and nearly every hurricane impacting the coast has left marked damage in its wake. Of the 49 billion dollar U.S. weather disasters that have occurred during the last 20 years (1980-2001), 15 (30 percent) were directly related to the effects of tropical cyclones. Total monetary losses from these 15 events totaled $75 billion (NOAA National Climatic Data Center 2001). While many individuals seek solace in blaming nature for the recent increase in damage, those familiar with tropical cyclone climatology have collected data that suggest otherwise. Analysis of the historical (and recent) data record indicates that the actual number of landfalling tropical cyclones is not increasing. In fact, their frequencies have remained relatively stable throughout the existing record. The U.S. has experienced an average of about 17 hurricane landfalls per decade since 1899 (Neumann *et al*. 1998). Additionally, Elsner and Kara (1999) note an annual average of 1.7 U.S. hurricanes over the period 1851-1996. Analyses of major hurricanes (category 3, 4, and 5 storms on the Saffir-Simpson Hurricane Scale), however, reveal variable patterns of activity, and data indicate that prior to the 1990s, a general decline in the number of major hurricanes striking the U.S. was observed (Kelly and Zeng 1995). In fact, between 1960 and 1992, only one major hurricane, Betsy in 1965, struck Florida, ironically the most hurricane-prone state (Ayscue 1996). Stated more generally, the second half of this century has seen a slight decrease in the number of major hurricanes striking the coastline of the U.S.

Research has shown that landfalling major hurricanes are responsible for a disproportionate amount of all damage incurred by tropical cyclones. Although only about 20 percent of hurricanes attain wind speeds high enough to be classified as "major", this 20 percent accounts for 80 to 90 percent of the damage incurred (Pielke 1997). This is of great concern to scientists, emergency managers, and planners alike as data trends hint at an increase in the number of major hurricanes, with activity perhaps returning to levels experienced during the middle decades of the 20th century (Elsner et *al*. 2000). Research reveals that while the period 1900 – 1942 saw 1.65 major hurricanes per year, the rate more than doubled to 3.57 major storms per year during the period 1943 – 1964 (Figure 2) (Elsner *et al*. 2000). From 1964 until 1994, the average annual number of major hurricanes per year decreased again to 1.67 storms. Since 1995, the Atlantic Basin has apparently returned to a rate similar to that experienced earlier in the 20th century, and has produced an average of 3.4 major hurricanes per year (Elsner *et al*.

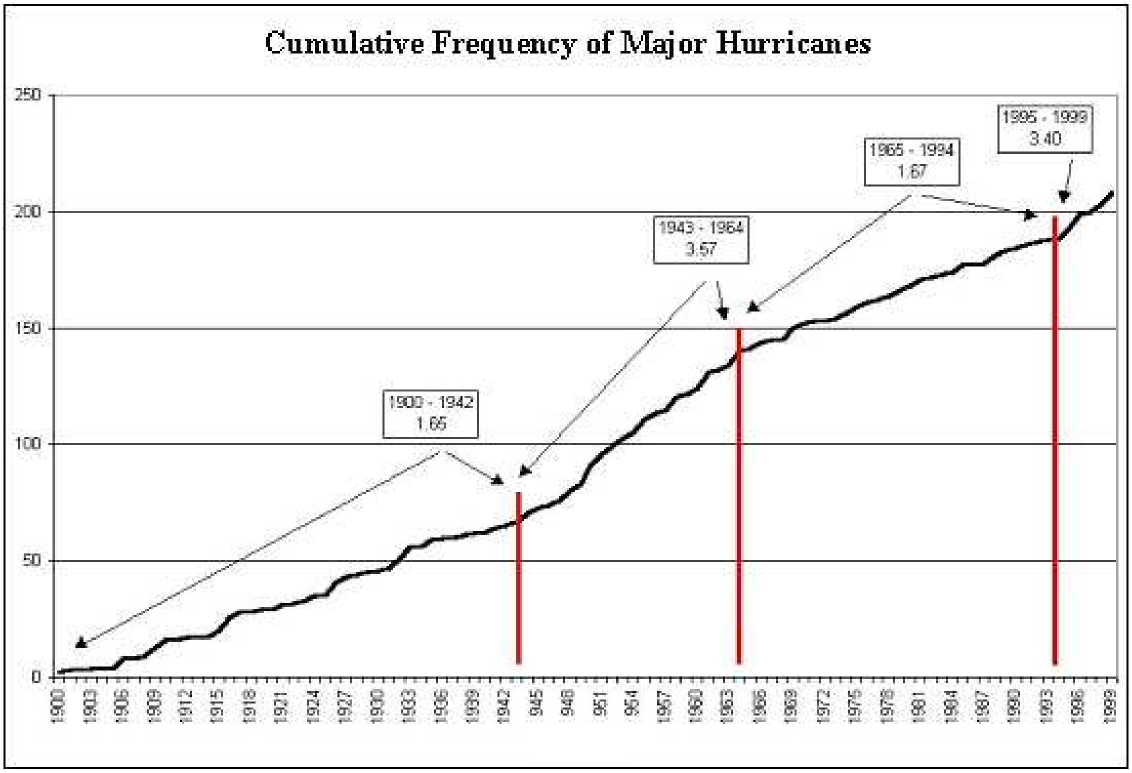

Figure 2. Cumulative Frequency of Major Hurricanes over the Entire North Atlantic. Source: Elsner *et al*. 2000

2000). These findings are frightening as major coastal development has occurred in the relatively quiescent interim of the mid 1960s through the mid 1990s. Increased numbers of landfalling major hurricanes coupled with increased development in hurricane prone coastal areas means that we may be facing an era where multi-billion dollar losses from tropical cyclones are commonplace.

These assumptions are supported by results from various studies which show that the increasing trends in losses related to weather and climate extremes (such as tropical cyclones) are *not* related to increases in the frequency of the events themselves. A study conducted by the International Panel on Climate Change (IPCC) (1996) found that, "overall, there is no evidence that extreme weather events, or climate variations, has [sic] increased in a global sense through the 20th century." Other studies have drawn similar conclusions. Kunkel *et al*. (1999) write that, "the increase in hurricane damage over recent decades has almost entirely taken place during an extended period of no upward trend in hurricane frequencies and intensities." In effect, this means that damage losses per storm are *increasing*. It appears, then, that changes in society, not nature are the primary factor explaining the increase in hurricane-related damage.

Thus, it is vital for society to be able to distinguish between adverse effects of weather events themselves which cannot be prevented and those that, in fact, have their origins rooted in political, economic, and social policies. This distinction also makes it possible to minimize such effects by adequately matching solutions to the correctly identified problems. Solutions to destruction by tropical cyclones may lie in improved land-use planning or, simply, in awareness of the risks of living in an area prone to tropical cyclones (Glantz 1978). After all, once a community understands its potential risks, officials will then have the knowledge necessary to improve planning for future events, including being better able to mitigate against future damages and becoming more prepared to respond following events (Heinz Panel 2000).

2. FLORIDA – COASTLINE AT RISK

Nicknamed, "the Sunshine State", Florida is perhaps the most desirable ingress destination of all eighteen coastal states. Unfortunately, the state could be re-named, "the Hurricane State" and the pseudonym would be no less appropriate since the state experiences more hurricanes than any other state in the U.S. Still, whether ignorant or merely apathetic to the risks, people immigrate to Florida in droves. According to U.S. Census Bureau reports, an estimated 15.4 million people now live in what is climatologically the most hurricane-prone state in the nation (Figure 3). Additionally,

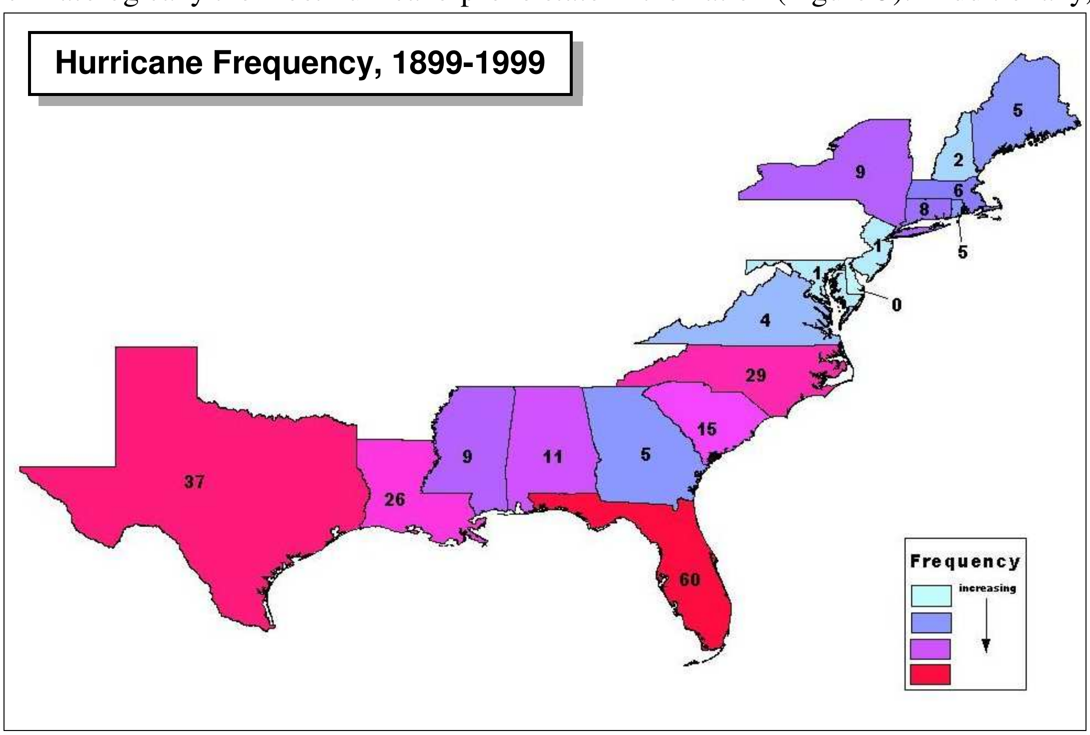

Figure 3. Frequency of hurricanes (direct hits, category 1-5) affecting each coastal state 1899-1999, according to the Saffir-Simpson Hurricane Scale. Source: Neumann *et al.* (1998), with updates.

Florida is the fastest growing coastal state with an increase in resident population of greater than 180 percent (Figure 4) over the period 1960 – 1990. By the year 2010, the state is expected to rank fourth in the nation in terms of absolute population growth (NOAA 1990). Florida is also the only state that is bounded by both the Atlantic Ocean and the Gulf of Mexico, possessing over 11,000 miles of tidal coastline, of which 1,160

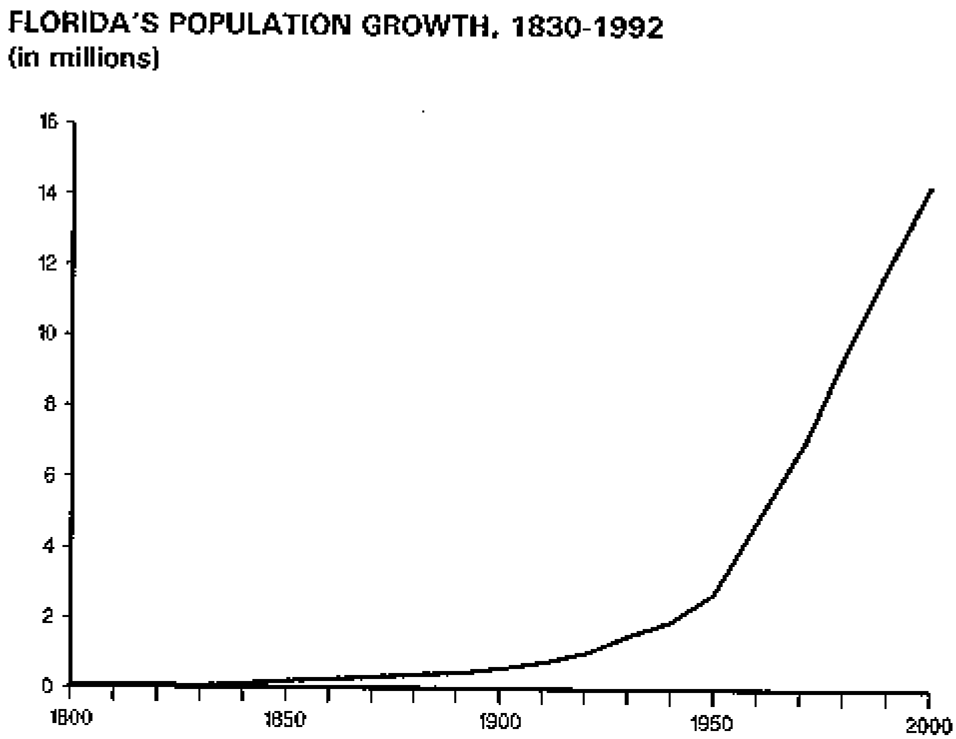

Figure 4. Florida Population Growth, 1800 – 2000 (est.). Source: Florida Game and Fresh Water Fish Commission.

miles are sandy beaches (O'Connell 1985). Although increasing its appeal to vacationers, retirees, and other sun-seekers, these features coalesce to contribute substantially to the state's overall vulnerability to tropical cyclones. The concentrated coastal development that results has the effect of dramatically increasing the potential for losses suffered as a result of impacts from tropical cyclones. Information gleaned from studies such as this one can lend assistance to those tasked with planning for and mitigating against such impacts as they attempt to focus their attention on certain areas, primarily those facing a greater potential for losses relative to other areas within a region.

Throughout history, Florida has had more encounters with hurricanes than any other state in the U.S. Nearly half (41 percent) of its storms are classified as major hurricanes, capable of causing extensive damage (Figure 5). In fact, one of the most

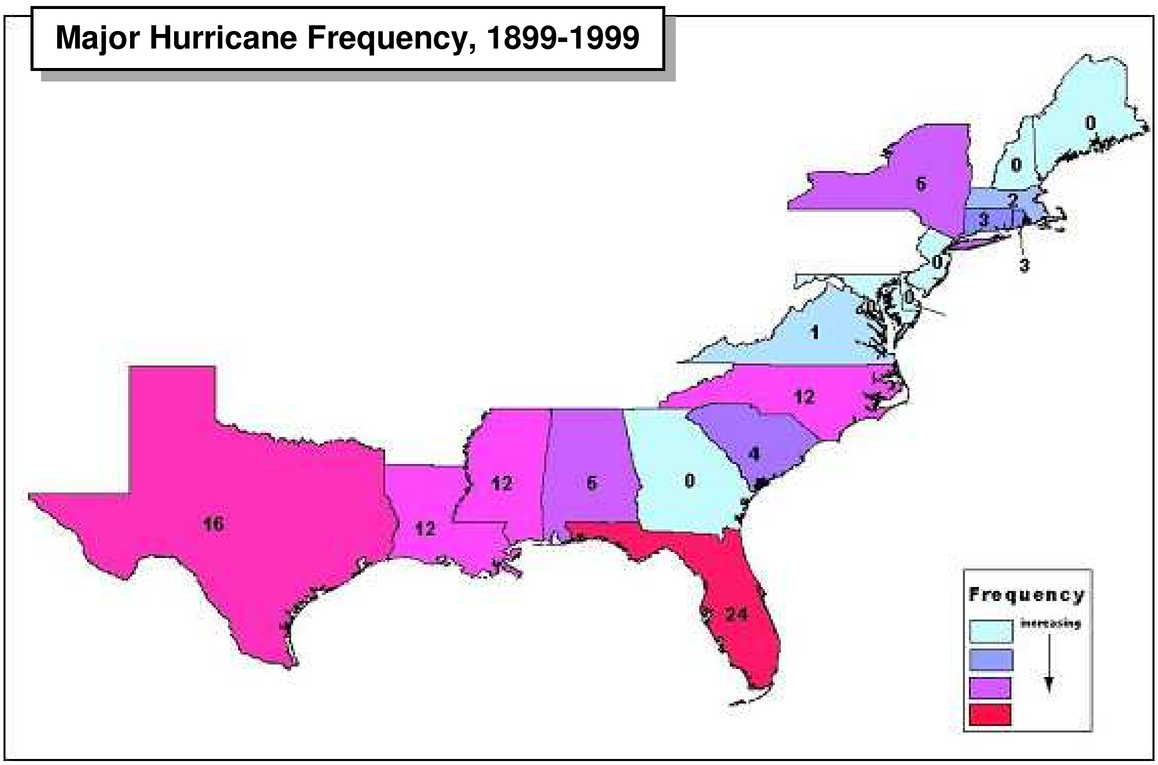

Figure 5. Frequency of major hurricanes (direct hits, category 3-5) affecting each coastal state 1899-1999. Source: Neumann *et al*. (1998), with updates.

devastating hurricanes ever to strike the continental United States hit Florida in 1926. Called the “Great Miami Hurricane”, it was directly responsible for killing hundreds of people and causing more than $100 million in damage in the city of Miami alone (Hebert *et al*. 1993). Taking into consideration, inflationary factors, coupled with a sharp growth in wealth in this area since 1926, researchers estimate that a similar storm, striking the same area today, would likely cause damages totaling nearly $70 billion (Pielke and Landsea 1998). Unfortunately, properties exposed to hurricanes extend well beyond Miami. In 1993, the total value of residential property within the state of Florida was near $900 billion. A continuation of this growth will result in totals approaching $1 trillion by the turn of the century (Lecomte and Gahagan 1998).

The juxtaposition of the fact that Florida is climatologically the most hurricane-prone state in the U.S. with research that suggests a return to increased major hurricane activity over the North Atlantic (Elsner *et al*. 2000), leads many to the assumption that in the near future, Florida may suffer considerable social and economic impacts. This conclusion alone is likely to spur local, state and federal emergency management officials into action. More and better information today will lead to better plans for reducing future losses (to both property and life) tomorrow.

3. RISK ASSESSMENTS AND LOSS ESTIMATION MODELS

Consistently gaining momentum within the arena of natural hazard planning, risk assessments and loss estimation models allow communities to identify, evaluate, and even model their respective risks to natural hazards. Loosely defined, risk assessments and loss estimation models are, "processes or applications of methodologies for evaluating risk as defined by probability, magnitude, and frequency of occurrence of a hazard event, exposure of people and property to the hazard, and consequences of that exposure" (FEMA 1995). They typically involve scientific, societal, and economic considerations and are the starting point for defining specific mitigation actions that communities can take to reduce economic loss and human impacts from natural hazards. Many communities seek to use these tools to improve their capabilities in mitigation, prediction and warning, emergency response, and disaster recovery (Hays 1991). Factors typically addressed by risk assessments include the location of buildings, facilities and infrastructure within a community, their degree of exposure to the physical effects of a natural hazard, and their vulnerability (potential to be damaged or destroyed) when subjected to the physical effects of a particular hazard or hazards. Issues addressed by communities seeking to lessen their overall vulnerability to hazards include the expected extent (areal and degree) of damage to buildings, facilities, and infrastructure at risk, the presence (or absence) and anticipated effectiveness of prior actions undertaken to control damage, deaths, injuries, economic loss and loss of function, and the social, scientific, and technical activities that can be undertaken in an attempt to reduce the vulnerability of existing buildings and infrastructure (Hays 1991).

Aside from the obvious, some important advantages of risk assessments and loss estimation models include providing a framework under which decisions can be made using scientific research rather than subjectively as well as allowing for regulations and strategies to be developed that are focused on the actual risks rather than on the risks perceived to be important by the public (Pielke, personal communication, 2001). With the ultimate goal of providing relevant information to the process of reducing a particular community's level of risk, risk assessments and loss estimation models aid decision makers in the allocation of resources between enforcement of building codes versus, for instance, evacuation planning (Pielke *et al*. 1997). This is an important distinction because what works and what is necessary in one location may be not be relevant in another community. With different communities invariably facing their own unique issues, interventions must be tailored to the characteristics and concerns of particular localities for their results to be deemed effective. In short, risk assessments allow for a more effective means for setting local, regional, and national priorities concerning the potential effects of hazard events.

3.1 Public Sector Approaches

The use of natural disaster modeling technologies including software and other computer-based risk assessments has increased in recent years partly due to the advent and continued evolution of software and computer technology coupled with an increase in disaster-caused damage (Kelly and Zeng 1996). One of the more widely publicized and freely distributed risk assessment methodologies available today is the Federal Emergency Management Agency's (FEMA) Hazards United States (HAZUS). Developed in conjunction with the National Institute of Building Sciences (NIBS), HAZUS is a nationally applicable, standardized loss estimation methodology and software application useful for estimating potential losses from earthquakes (FEMA 2001). The program "uses mathematical formulas and information about building stock, local geology, and the location and magnitude of potential earthquakes, economic data, and other information to estimate losses from a potential event" (Laatsch 2001). HAZUS also possesses the important capability of utilizing geographic information systems (GIS) technology to map and display various hazard characteristics and effects, as well as potential impacts upon the human and built environments. The HAZUS framework currently includes six primary modules including a hazard inventory and methods for calculating expected direct damage and direct and indirect economic losses (Laatsch 2001). It is designed to be applied throughout the nation by local, state, and regional planners with the results being used to plan and stimulate efforts to reduce risks from natural hazards.

Beyond earthquakes, FEMA and its partners are working to expand the program to address other hazards as well. A hurricane "preview" model is being developed for release in early 2003 to communities in Atlantic and Gulf Coast regions. This initial version will allow assessment of hurricane winds and computation of basic estimates of potential damage to residential, commercial, and industrial buildings. It will also allow estimation of direct economic losses. The hazard component of the HAZUS hurricane model will make use of an existing windfield model, which incorporates sea surface temperatures and calculates wind speeds as a function of central pressure, translation speed, and surface roughness. Development of the full wind model will continue after 2002, to increase the capability of the model to estimate indirect economic losses and impacts to lifelines as well as add the capability of assessing the effects of extra- tropical cyclones, tornadoes, thunderstorms, and hail (FEMA 2002). By addressing a wide range of damage affects (e.g., direct physical , induced, social, direct and indirect economic), the final HAZUS module will provide detailed estimates of expected losses from a wide variety of hazard events. The forthcoming HAZUS hurricane/wind model will be a valuable tool , useful in assessing localized vulnerability once more general, broad brush vulnerability assessment approaches (such as the one presented in this thesis) have been employed to identify more generalized areas of increased risk/vulnerability (C. Drury, personal communication, 2002).

Two additional studies contain more focused methodologies, geared toward assessing hazard risk at the local level. The National Oceanic and Atmospheric Administration (NOAA) recently completed a detailed study of New Hanover County, North Carolina focusing on potential vulnerability to hazards. The product is an informational aid designed to assist communities in their efforts to reduce hazard vulnerability through strategies relating to awareness, education, and mitigation. It contains a methodology that helps State and local governments determine and prioritize their locality's vulnerabilities to hazards. Physical factors such as the location of critical facilities and infrastructure relative to high-risk areas, the distribution of vulnerable populations such as the elderly, poor and under-insured, significant environmental resources, and the vulnerability of primary economic sectors are all included as issues for consideration (NOAA 1999). In addition, it serves as a foundational template for other communities seeking similar strategies for assessing risk and vulnerability to their own hazards.

A second vulnerability study, conducted by researchers at Florida State University (Boswell et al. 1999), attempts to quantify the public costs of varying intensities of hurricanes on a particular county in Florida. Although federal assistance monies are granted to localities following Presidential disaster declarations (as stated in the Stafford Act, Section 406 Public Assistance Program), local governments are required to fund a set proportion of their recovery efforts, with the ultimate amount directly linked to the degree of loss incurred. Local/federal cost-share is directly linked to the degree of damage, hence loss, sustained. Generally speaking, the greater the loss, the greater the influx of federal dollars into community governments, though local capital outlays can still be substantial, especially after exceptionally damaging storms. The methodology developed in the Florida State University study uses a variety of meteorological, socio-economic and physical data as inputs into a statistical model. The goals of that particular study include allowing policy makers to assess the implications of alternative federal and state policies for providing public assistance to jurisdictions that experience hurricane damage, as well as providing information needed to develop a contingency fund or other financial mechanism to assure that the community has sufficient funds available to meet its obligations following a disaster (Boswell et. al., 1999).

Although the second study is hazard-specific in its approach, the two studies parallel each other in that they both seek to incorporate as many variables as possible into their respective methodologies. While the first seeks to assist local officials with the location of potentially vulnerable areas, it does not attempt to quantify the potential costs associated with impacts on identified areas and facilities. The second study, however, is successful in quantifying potential loss and offers officials a method of estimating (in dollars) their degree of potential risk and vulnerability to hurricane impacts. Applying these (and/or other) methodologies concurrently in the same location would potentially yield the 'truest' measure of exposure, or amount of residential property present in hazardous areas, thus potential for loss possible.

3.2 Private Sector Approaches

While the FEMA and NOAA applications are "open source" and free to anyone who requests them, several private companies have developed or are in the process of developing their own loss estimation models. Due to the proprietary nature of these programs and procedures, however, few details about their models, data sources, or methods of analyses are available to the public. As a result, it can be difficult for interested organizations such as state emergency management or disaster planning offices to perform the meaningful evaluations of these programs that are often necessary prior to adoption and integration with planning or preparedness strategies.

Generally speaking, private sector tools are more robust than their public counterparts, usually containing more current and extensive datasets and more advanced engineering models at their core. Since most private companies charge significant fees for user access to their analysis tools, they can afford to maintain the data and science driving them. In contrast, public sector tools are usually borne out of a single and finite government funding initiative. Without additional monies for updates, these models can become obsolete after only a few years as advances in data and science are often not incorporated into the existing model.

Any discussion of existing private sector methodologies would not be complete without mention of the following companies and the respective tools they employ to estimate potential damage from tropical cyclones. In addition, mention of the these models is necessary to provide a context for the present methodology within the broader array of risk assessments and loss estimation models. Applied Insurance Research, Inc. (AIR), Applied Research Associates, Inc. (ARA), EQE International, and Risk Management Solutions, Inc. (RMS), have hurricane loss estimation models that they currently use to support clients primarily in insurance and finance. AIR's hurricane risk assessment model utilizes a complex computer program to estimate potential damage from landfalling hurricanes. The model develops and assigns specific meteorological criteria to each storm used in the simulation and then uses information about the sites at which properties in the impact area are located, including distance from the coast, surface terrain, topography, elevation, building code, and building practices to estimate potential losses (Clark 1997). ARA developed software designed to assess wind risk from tropical cyclones (HURSIM). HURSIM models various aspects of tropical cyclone windfields, taking into account the spatial variation of wind speeds, topographic effects, and the effects of surface roughness. Attesting to its validity, ARA claims that the HURSIM model was adopted without modification by the American Society of Civil Engineers (ASCE) and used to create national wind speed maps that are in turn used to form the basis for building design in the United States (ARA 2001). EQE International developed a similar software technology for calculating expected loss from tropical cyclones. EQE's USWIND model uses various storm parameters and simulations to compute expected annual loss rates for exposed portions of the U.S. East and Gulf Coasts (EQE 1999). Building portfolio data along with demographic, topographic, and meteorological data are used as inputs into the model in order to provide detailed and accurate damage curves that are used to estimate predicted losses from future events. Although developed independently of one another, all three models seek the same objective. They couple detailed, local-level data with highly sophisticated science and engineering in order to produce the most accurate estimates of loss from hazard events.

This thesis does not attempt to duplicate the methods or results of any of the aforementioned tools. Instead, it offers a broadly applicable, adaptable, and expandable methodology geared more towards state and local planning agencies who may lack sufficient resources to conduct focused loss estimation studies such as those afforded by methods developed by ARA, EQE, AIR, and others.

3.3 Issues

Depending upon the degree of specificity desired, loss estimation can be a complex, data-intensive approach to risk assessment. For example, for a user to be able to estimate concrete monetary losses to a particular community, it may be necessary to collect, construct, or import a detailed database of all buildings within the area of analysis, group them by type, and apply derived damage functions to each group. Most methodologies, such as those mentioned previously, include an engineering model to represent each aspect of measured or assumed risk, then combine them all with some sort of probabilistic model. In the case of tropical cyclones, such probabilistic models usually focus on hurricane return periods, or the probability, based on history, that a particular area will experience a certain intensity of wind over a given time period. Lacking sufficient resources (financial, technical, etc.), such highly detailed risk assessments, although extremely valuable, may eclipse the abilities of many state and local government entities. In the absence of significant external financial support, many smaller communities simply cannot afford to tackle the issue of hazard identification and analysis on a scale detailed and thorough enough for the results to be meaningful and effective. Instead, communities may seek grants, matches, or other funding alternatives to initiate various mitigation efforts. The first step in this process if for communities to prioritize their location with respect to their most hazardous areas. To accomplish this task, highly detailed risk assessments may not be necessary, at least not initially. Instead, state and local officials can employ more broad, composite methodologies to map out those areas where the hazards and infrastructure overlap.

When compared with most private sector approaches to risk assessment, the methodology used in this thesis is simple and demands far less input data and calculations. The present methodology is structured around a simple composite index model. Agreeably, private sector models, such as those mentioned previously, tend to capture details of risk consequences more realistically, however, they are often seen as "black boxes" (i.e., the math, science, and/or analyses techniques employed to generate results are not accessible to the public for evaluation). This has the effect of creating suspicion and hesitation on the part of many users, particularly those within the academic community. The present methodology is understandable for all users, yet it provides only a simple, first order representation of tropical cyclone risk. However, since the data needed to feed the methodology are easily obtained and freely available, studies such as this may be more feasible for states and even local communities who may lack the resources to complete highly detailed and location specific studies. Recognizing the fact that a growing number of agencies and organizations are finding it necessary to qualify and quantify their risks to hazards, this study seeks to empower those individuals with the tools needed to identify and analyze problem events and areas. Moreover, through the use of GIS, the results are presented in a clear, concise, understandable, and useful format. In time, it is hoped that the use of studies such as this one will lead to the development of innovative and effective planning opportunities, thereby granting communities the ability to mitigate the effects of potential events and lessen the chances that hazards become disasters.

4. TROPICAL CYCLONE CLIMATOLOGY

In this study, relative risk to tropical cyclones is quantified by examining residential property data coupled with experience with the hazard (climatology). Here, tropical cyclone incidence rates are estimated empirically from historical data. Therefore, we will first consider some general aspects of tropical cyclone climatology.

Tropical cyclones are defined as, "warm-core, nonfrontal, low pressure synoptic-scale systems that develop over tropical or subtropical waters and have a definite organized surface circulation" (Neumann *et al*. 1999). The term 'tropical cyclone' refers to all tropical systems as defined above, and includes subtropical storms and depressions, tropical depressions and storms, and hurricanes. The term 'hurricane', as it appears in this thesis, is used only when referring to those systems attaining hurricane force (60 second, 30 meter sustained winds greater than or equal to 65 knots).

North Atlantic tropical cyclone development tends to favor three broad regions with genesis location tending to oscillate between basins with the progression of the hurricane season (June 1st to November 30th). Early season storms (June and July) tend to have their origins in the Gulf of Mexico and the western Caribbean. Gulf storms characteristically form in the central or southern portion of the basin and quickly assume a northward motion. Caribbean storms generally form in the western end of the basin and assume a similar north to northeastward motion. Toward the middle portion of the season (August and September), as warm sea-surface temperatures spread north and east across the North Atlantic Ocean and upper tropospheric vertical shear relaxes, tropical cyclone formation occurs over the central and eastern Atlantic, often forming in the vicinity of the Cape Verde Islands. Such storms tend to move in a west to west-northwestward direction. Fortunately for the U.S., the majority of these systems tend to re-curve toward the north, around the western flank of the Bermuda High and often under the influence of upper-tropospheric westerlies over the North American continent (Elsner and Kara 1999). Finally, as sea surface temperatures cool, and westerly shear increases, late season storms (October and November) often find their origins returning to the western Atlantic basin.

Occasionally, tropical storms and hurricanes form outside the traditional hurricane season. May and December storms, although rare, occasionally occur. In fact, every month of the year has seen at least one tropical system, with mid-September being the most active portion of the season (Neumann *et al*. 1999). Complex geographical, oceanographical, and climatological factors are responsible for determining tropical cyclone incidence for any one location on the coast. Specifically, upper level wind patterns, ocean temperature, salinity, and atmospheric pressure values, as well as the location and relative stability of macro-scale climate features such as the Bermuda High and the Inter-Tropical Convergence Zone (ITCZ), are but some of the factors driving tropical cyclone formation and movement. Varying on seasonal, decadal, and even millenial time scales, these variables frequently conspire to alter tropical cyclone climatology (Elsner *et al*. 2000). It is therefore easy to understand why the occurrence of tropical cyclones varies considerably across temporal scales. According to data from the last 50 years, an average year will witness the formation of 10 (9.8) tropical storms, of which nearly 6 (5.7) will become hurricanes (Mayfield *et al*. 1994). Of those six hurricanes, two will achieve major hurricane status (Mayfield *et al*. 1994).

To some extent, geography helps explain the heightened vulnerability of certain regions of the U.S. mainland. Areas that jut out into the Atlantic and Gulf of Mexico are more likely to be affected by North Atlantic and Gulf tropical cyclones. Florida, eastern North Carolina, and Massachusetts are examples of areas that frequently find themselves in the path of tropical storms and hurricanes simply due to the seaward extent of their land area.

With a few exceptions (Hurricane Fran and some fast-moving Northeast hurricanes), strong winds associated with tropical systems tend to be significantly diminished once tropical systems move ashore, primarily due to the frictional effects of land-based obstructions (topography, forests, urbanized areas) and, more importantly, a loss of heat energy from the ocean's surface (Friedman 1975). For this reason, primary impact areas of tropical cyclones are found along coastal (or near coastal) regions. Yet, moisture from tropical cyclones occasionally merges with eastward-moving continental low pressure systems, producing copious amounts of rainfall inland from the coast. Tropical cyclone induced flooding has devastated communities located many hundreds of miles from the coast. Two of the most damaging tropical cyclones on record in the U.S. (Hurricane Agnes in 1972 and Hurricane Camille in 1969) caused significant damage well inland from the coast. Other recent examples including, Hurricane Hugo (wind and rain) in 1989, Hurricane Floyd and Tropical Storm Allison (flooding) in 1998 and 2001, respectively, and Hurricane Fran (wind) in 1996, reveal how the destructive forces of tropical cyclones can impact areas far from the initial landfall point.

Climate and geography may dictate a region's level of experience with tropical cyclones. However, an area frequented by such events is not inherently vulnerable to economic or human losses. For a particular county, area, or region to become vulnerable to the threat posed by such systems, property or lives must lie in the way. Unfortunately, for many coastal locations today, this is precisely the problem.

5. METHOD

Under practical considerations, the assessment of *relative* risk as outlined in this work is useful for establishing limited resource allocations and making high-level planning decisions while at the same time, raising awareness of tropical cyclone risk. In the present study, a particular county's potential for experiencing losses from tropical cyclones is viewed as being comprised of at least two variables; tropical cyclone climatology (frequency and intensity) and its amount (in dollars) of exposed property which, for purposes of this study, consists of residential property valuations gleaned from 1992 U.S. Economic Census data. We assume a location's level of risk to be proportional to its overall experience with the hazard and its degree of exposure, or level of residential property valuations. As a general rule, increasing exposure at a constant level of tropical cyclone activity will increase risk as will increasing the incidence at a constant level of exposure. The goal of this research is to estimate the relative potential for losses to residential property along the U.S. coastline as a way to predict which areas are at highest risk for loss while at the same time, offering improved visualization techniques to better illustrate that potential.

Frequency of tropical cyclones refers to the number of events experienced by a particular location and is determined by summing the total number of historical storms affecting an area over a given time period. For example, Florida has a high frequency of occurrence of storm events relative to that of other coastal states. In fact, Florida has the highest frequency rate of any coastal state, having experienced more than 200 tropical cyclones (including tropical depressions and storms and all categories of hurricanes) during the 20th century. Certain areas and even regions of the United States' East and Gulf coasts are affected by tropical cyclones on a more frequent basis than are others. The north-central Texas coastline, Southeastern Louisiana, South Florida, and Eastern North Carolina have a higher propensity for tropical cyclones than do other areas.

Tropical cyclone climatology is a combination of the frequency at which storms affect and area and their intensity. Pielke (1997) states, "climatology refers to the incidence of hurricanes – how many, how strong and where." Translating these ideas to measures of exposure and risk, a coastal location with a history of many tropical cyclone landfalls of which most are classified as weak events is assumed to possess a relatively low level of risk with respect to potential damage, with the converse being true as well. This can be illustrated by examining Monroe County, Florida and Dare County, North Carolina. While Dare County has historically been impacted by more tropical cyclones than Monroe County, the storms impacting Dare County are generally less intense than those affecting Monroe County (Table 1). Therefore, Monroe County is considered to possess a greater risk of stronger and potentially more damaging winds than Dare County in association with tropical cyclones. When coupled with data and research indicating that stronger storms, those possessing higher wind speeds, inflict greater damage on infrastructure than weaker storms. Therefore, when making comparisons between counties in the U.S., this study employs a composite measure of tropical cyclone climatology called 'weighted average occurrence' (WAO). WAO is calculated by multiplying a coefficient of damage potential to each tropical cyclone event in the historical record for each location. Since this metric considers not only tropical cyclone

Table 1. Tropical cyclone frequency comparison, by Saffir-Simpson classification for Monroe and Dare counties

County	State	TD	TS	H1	H2	H3	H4	H5	Total
Monroe	Florida	1	17	11	8	5	8	1	51
Dare	North Carolina	5	36	10	7	1	1	0	60

frequency, but intensity as well (and stronger storms tend to do more damage), it is felt that it is a more representative means of estimating a region's overall risk to the damaging effects of tropical cyclones when examining potential for residential losses.

5.1 Construction of a Coefficient of Damage

In most loss estimation models and in some risk assessments, vulnerability is typically expressed using a specific damage curve or some other function that relates the level or probability of damage to a certain degree of hazard. For example, the damage that strong winds cause depends on many factors such as sustained winds, wind gusts, duration of strong winds, direction of winds in relation to structural orientation, existence of projectiles that might break the building envelope, and various structural characteristics (Lambert 2000). Since it is difficult to know an individual structure's vulnerability by mere inspection, easily observed characteristics that are assumed to be related to vulnerability are often used to group structures. Structures are typically classified by structural type (e.g., wood frame, concrete block, reinforced and un-reinforced masonry), square footage, number of stories, age, etc. Finally, since structural characteristics, building practices, and lifestyles vary with location and time, vulnerability curves apply only to a specified geographical region and time period. Robust vulnerability models are usually developed by conducting surveys of structures and contents that are exposed to possible damage, fitting curves to empirical loss data, and/or using engineering judgment based on an understanding of structural behavior derived from experimental testing and computer modeling.

Since this study does not seek to model specific damage to individual structures, it employs a homogenous damage coefficient adapted from a scale developed and utilized by Pielke and Landsea (1999) in their study of normalized hurricane damage. The middle column in the table below (Table 2) indicates how they expect damage to increase as storm intensity increases. The values used in their study to estimate potential damage are intended to provide a blanket relative scale based on the median damage amount expected for each category of storm given that a category 1 hurricane is scaled as a "1" (Pielke and Landsea 1999). They use normalized 1995 median damage amounts for U.S. tropical cyclones from 1925 to 1995 taken from various sources including a NOAA Technical Memorandum assembled by Hebert et al. (1996) listing the deadliest, costliest, and most intense U.S. hurricanes of the 20th century.

Table 2. Damage coefficient values relating to storm intensity.

Saffir-Simpson Classification	Damage Coefficient developed by Pielke and Landsea	Damage Coefficient developed for this study
TD	0	1
TS	0	2
H1	1	3
H2	10	30
H3	50	150
H4	250	750
H5	500	1500

According to the scale developed by Pielke and Landsea, a category 2 hurricane results in 10 times the estimated damage as a category 1 hurricane while a category 5 hurricane results in 50 times that of a category 2 hurricane. They note that the value for a category 5 storm is highly speculative as only two category 5 events have ever directly affected the continental United States (Hurricane Camille, which came ashore along the Mississippi coastline in 1969 and the Labor Day Hurricane that struck the Florida Keys in 1935). It is interesting to note however, that the damage incurred from these two storms was virtually catastrophic (i.e., resulting in near total devastation). Mainly for this reason, it is felt that the damage scale developed for use in this analysis is sufficient in estimating the overall relative potential for damage presented by the various categories of storms studied. Since the Pielke and Landsea study focused on hurricanes only and ours extends to tropical storms, we found it necessary to adjust their scale somewhat to fit our data. It is important to note that although two categories were added to our scale (tropical depressions and storms), the resultant ratio remains the same in that a category five hurricane is capable of 500 times the damage of a category one hurricane, as measured by the Saffir-Simpson Hurricane Scale. Figure 6 is a graphical depiction of the third column of Table 2, representing the damage coefficient that was developed for and employed in this study.

Other studies published in this arena have arrived at similar conclusions. Unlike the Pielke and Landsea study, however, which is based on normalized median historical damage spanning an explicit time period, most studies use engineering methodologies and empirical wind damage curves in addition to claims data collected from the insurance industry to estimate potential structural failure from varying intensities of winds experienced in tropical cyclones. One such study, conducted by AIR, suggests that minimal increases in maximum wind speeds experienced in a major hurricane have the potential of doubling the degree of damage incurred in a storm event. Specifically, the study found that, "for major hurricanes, increases in maximum wind speeds of less than 15 percent could easily result in a doubling of losses" (Clark 1997). These findings are concurrent with the assumptions made in this thesis, namely that although damage tends to vary relative to the type of structure upon which the force is exerted, the wind damage curves are generally S-shaped in nature that is, damages tend to increase substantially

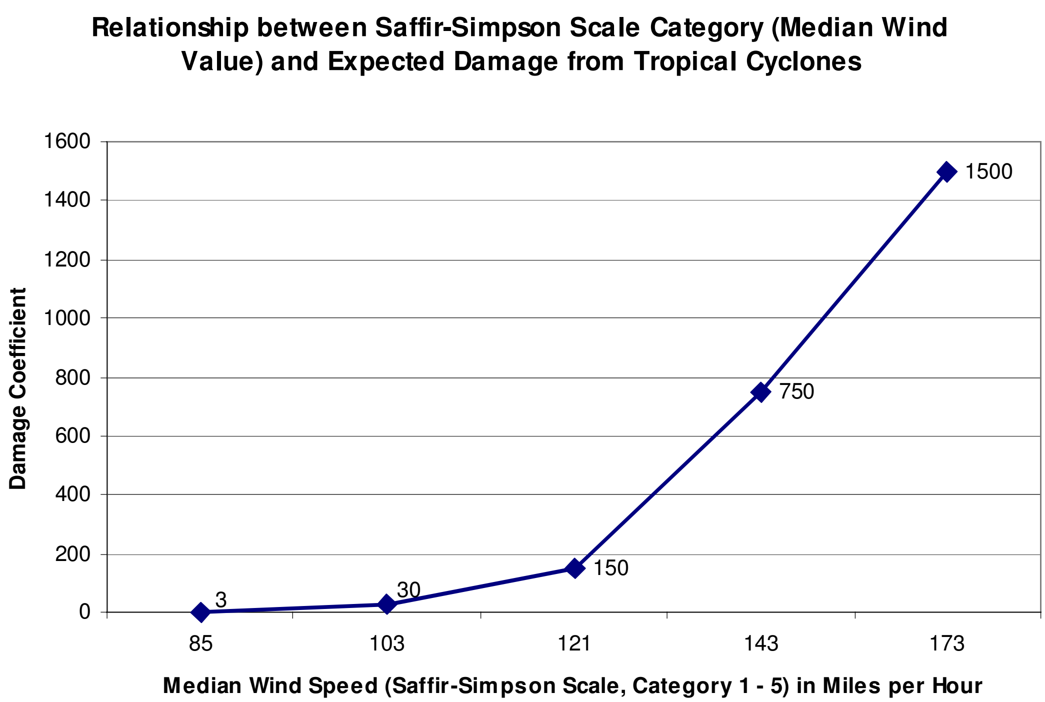

Figure 6. Relationship Between Saffir-Simpson Category (Median Wind Value) and Expected Damage from Tropical Cyclones.

with increasing storm intensity, eventually leveling off as the winds approach maximum values and structural damage approaches 100 percent. Contrary to that assumption, the curve depicted in Figure 6 above is not S-shaped. It demonstrates an expected exponential increase in damage as a function of increases in sustained wind speeds associated with tropical cyclones. However, a continuation of the line beyond the upper most value (>1500) would show the line leveling off. This is again congruent with research indicating that damages will peak once winds reach maximum potential velocity and structural damage becomes complete.

The first damage curves for wind load were linear relationships between a damage index (repair/initial cost) and wind gust speed. Holmes (1996) developed an analytical relationship between a damage index and gust wind speed for an ideally engineered structure. Holmes assumed that the structures consisted of many independent components, all of which possess the same probability distribution for strength and fail independently of one another. Stubbs and Perry (1996) define a damage ratio (repair cost/replacement cost) versus wind speed curves for each of nine building components (e.g., foundation, roofing, cladding). The component damage ratios are combined using a weighted average into a structural damage ratio. The weights are values representing the relative importance of each component to the full structure.

The Pielke and Landsea study (as well as this one) could be improved if statistically derived confidence levels and error bands were developed and integrated with the damage curves in recognition of the many sources of uncertainty at the various levels of analysis. Similar to studies focusing on earthquakes, a damage model comprising different vulnerability curves corresponding to different damage levels may be more appropriate for evaluating damages due to tropical cyclones. However, such improvements would require access to a wide variety of information that is not currently available to the research community. For example, it would require a willingness by insurance companies to share information about their portfolios, including building inventories and losses from past disasters. More comprehensive damage surveys (both in the U.S. and abroad, in regions that experience more frequent strikes from more intense tropical cyclones) will also be needed in order to provide the information necessary to develop improved damage models.

5.2 Exposure

In this study, building exposure merely represents the assessed value of residential structures within each coastal county. These exposure values, hereafter referred to as "wealth" were taken from the U.S. Census of Governments, Taxable property values and Assessment-Sales Price Ratios and is called, "Gross-assessed value before partial exemptions, total including state-assessed property." The United States Bureau of the Census, Census of Governments, states:

> "Taxable property values" are assessed values. Survey data reported here consist of aggregates of individual official determinations by more than 13,500 local assessors of the value, officially set in 1991 for 1992 tax purposes. Statistics for this report were obtained by contacting appropriate officials of each State… to obtain values officially assessed in 1991 for property subject to local general property taxation, for each State, individual county (or equivalent geographic area)…"

Four separate wealth components are used and consist of the following, according to the Census:

- Property: "This concept represents the legal interest of an owner in a parcel or thing. Property can be real or personal. Property itself may be tangible or intangible."
- Real Property: "Consists of land plus anything permanently attached to the land or legally defined as immovable. To the extent that 'real estate' commonly includes land and any improvements, the two terms can be understood to have the same meaning…"
- Personal Property: "Consists of every kind of property that is not real property."
- State Assessed Property: "That property for which the assessed value is set by a State agency, either for taxation by the local jurisdiction affected, or for State taxation. Most often, this term applies to utility property or property with special characteristics where the State preempts local authorities to achieve uniformity in assessments."

In examining the issue of coastal county residential building exposure, the analysis is approached as one of comparisons made between spatial extents (county, parish, boroughs, etc.) that vary in land area. Typically, as land area increases, so too does the amount of wealth present. To address this problem, a normalized value of wealth is used whereby county wealth is divided by county area, resulting in a measure of wealth per square mile. Although neither wealth nor population is uniformly distributed over county area, it is felt that this methodology is adequate for purposes of this study.

6. DATA AND TOOLS

6.1 Data Sources and Preparation

Data pertaining to historical tropical cyclone tracks were taken from the National Hurricane Center's HURDAT (HURicane DATa) data file. As described in Jarvinen *et al.* (1984), "the file contains dates, tracks, wind speeds, and central pressure values (if available) for all tropical cyclones occurring over the 97 year period, 1886 through 1983 and is updated annually." The data used for this study span 113 years, extending through 1999. Dates are listed in standard format (MM/DD/YYYY), with four positions provided per 24 hour period, corresponding to the official 6-hour advisories (0000, 0600, 1200, 1800 UTC) issued by forecasters at the Tropical Prediction Center/National Hurricane Center in Miami, Florida. Storm center locations are given in latitude and longitude, in tenths of degrees. Storm intensities are provided in maximum 1-minute, 10-meter surface wind speeds, in knots and central pressure values are provided in millibars.

Using a PERL script developed specifically for this study, a subset of the HURDAT data set consisting of all tropical cyclones (excluding subtropical storms) known to have either crossed or passed immediately adjacent to (i.e., at least a portion of the eyewall onshore), the United States coastline, is extracted based upon the XING=1 code in the data set. Therefore, the historical tropical cyclone track data plotted in this study are not representative of the entire historical record, rather they reflect only those storms whose centers (or at least a portion thereof) were known to have crossed the coastline of the U.S. Storms whose centers stayed out to sea are excluded from the analysis. The resulting database consisted of 360 tropical cyclones, of which 226 attained hurricane status (sustained winds greater than or equal to 74 miles per hour) with 107 of those events achieving major hurricane status (sustained winds greater than 110 miles per hour).

6.2 Geographic Information Systems (GIS)

This study uses Environmental Systems Research Institute's (ESRI) ArcView® GIS software, version 3.0. Although ArcView-specific terminology is used when discussing certain methodologies used in this study, the following discussion of GIS may be extended and is applicable to the majority of existing GIS software packages.

Computer-based GIS have been in use since the 1960s. Not until recently, however, has the technology become deeply rooted in mainstream society. The recent proliferation of GIS is due in part to rapid advances in computer and software technologies as well as to improvements in data capture, image processing, and digital mapping techniques (Papacostas *et al.* 1994). According to ESRI (1998),
"A GIS is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as queries and statistical analyses with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies." Additionally, a GIS stores

information about the world as a collection of thematic layers that can be linked together by geography.

Papacostas *et al*. (1994) expand on these ideas while explaining GIS in somewhat different terms. They write that, "GIS represents the synergy of geographic referencing, topology, and database methodology to define spatial and non-spatial data relating to objects in the real world." GIS data, generally in the form of points, polygons and/or lines, are linked to the records of relational databases that contain non-spatial descriptions of the objects' attributes (Papacostas *et al*. 1994). Interfacing spatial and attribute data has the effect of enhancing the visualization of the database contents within a geographical context. Perhaps the most powerful capability of GIS is that through spatial and non-spatial analyses and comparisons of existing thematic layers, new data are generated. Additionally, the functionality of a GIS can be extended by using the data maintained in the GIS, directly or indirectly, as inputs to other analytical or empirical models.

An example of how GIS has recently been incorporated into empirically-based tropical cyclone vulnerability analyses is The Arbiter of Storms (TAOS) project, a hurricane modeling technology developed by Charles Watson Jr. Currently in use by various local, state, and federal organizations (e.g., the Florida Division of Emergency Management), TAOS has the important capability of being able to ingest real-time tropical cyclone data and, through a series of meteorological and hydrodynamic modeling techniques, subsequently feeding the information into a GIS. Utilizing GIS, TAOS model results can be combined with other information, such as critical infrastructure or building footprints, to assess the vulnerability of settlements and other development to storm surge and wind effects. TAOS outputs are tropical cyclone impact analyses which include to wind and storm surge characteristics, and maximum wave height information, in addition others (C. Watson, personal communication, 2000).

7. ANALYSIS AND RESULTS

7.1 Tropical Cyclone Analysis

Two separate ArcView Avenue scripts were developed and are crucial to the bulk of the analyses present in this work. The first script uses the associated latitude/longitude pairs issued at each advisory to plot a series of points for each storm in the database (Appendix B). The resultant points are then joined with the data, emerging as a series of consecutive line segments. Called “advisory segments”, each point is encoded with all data issued at each advisory. This methodology is advantageous to more conventional, homogenous track analyses in that data relevant to each segment (or advisory) is encoded with each location. This allows for more detailed analyses at any or all points along the path of each storm.

The second script generated for this study is used to calculate tropical cyclone frequencies for each county (Appendix C). Although the script is capable of tabulating frequencies for any polygon (state, census tract, block group, equal area grid, etc.), county boundaries are used in this study. ‘Hits’ are then tabulated for all counties by taking each storm track (again, a series of consecutive line segments) and layering them over county polygons. The resulting database is a compilation of storm activity for each county in the U.S. encompassing the tropical cyclone record (U.S. landfalling storms) over the period used, 1886 – 1999, inclusive.

It is important to note that this study counts direct hits only. A county is classified as having experienced a direct hit when, “all, or part of the innermost core regions, or “eye,” of a hurricane (or tropical cyclone) moves over a county” (Jarrell *et al.* 1992).

However, since GIS uses a single point to represent the center of each storm, it is felt that some adjustment is necessary to account for the finite size of the core region of each storm. To solve this problem and in an attempt to determine an acceptable mean radius to maximum winds (RMW) value that could be used in this study, results from studies examining historical RMW data were consulted. Specifically, Hsu and Yan (1998) write, "if real-time hurricane data… are not available and a quick estimate [of the radius] is needed, the composite mean for all [radii] studied… 47 km may be used." Yet another study concluded that, center or "eye" diameter can fluctuate in size from 5 miles to over 120 miles, with most being approximately 20 to 40 miles in diameter" (Weatherford and Gray 1988). In accordance with these studies, a climatological mean 'buffer' of approximately 47 kilometers (29 miles) was added to either side of each line segment. This value represents an average RMW and is a symmetric buffer extending approximately 47 kilometers on either side of each storm track. Figure 6 uses a fictional hurricane track to illustrate this concept. It highlights the counties that are included as having been directly affected by a hurricane

whose center crossed four counties in south Florida. With RMW values generally extending only slightly beyond the width of the eye, it is felt that the RMW value used herein is representative of the bulk of landfalling storms. Technologies capable of measuring and collecting actual wind swath data, in a format compatible with GIS, have only recently been made available to those responsible for collecting and analyzing hurricane data and information. As a result, accurate wind swath data are only available since the early to middle 1990s.

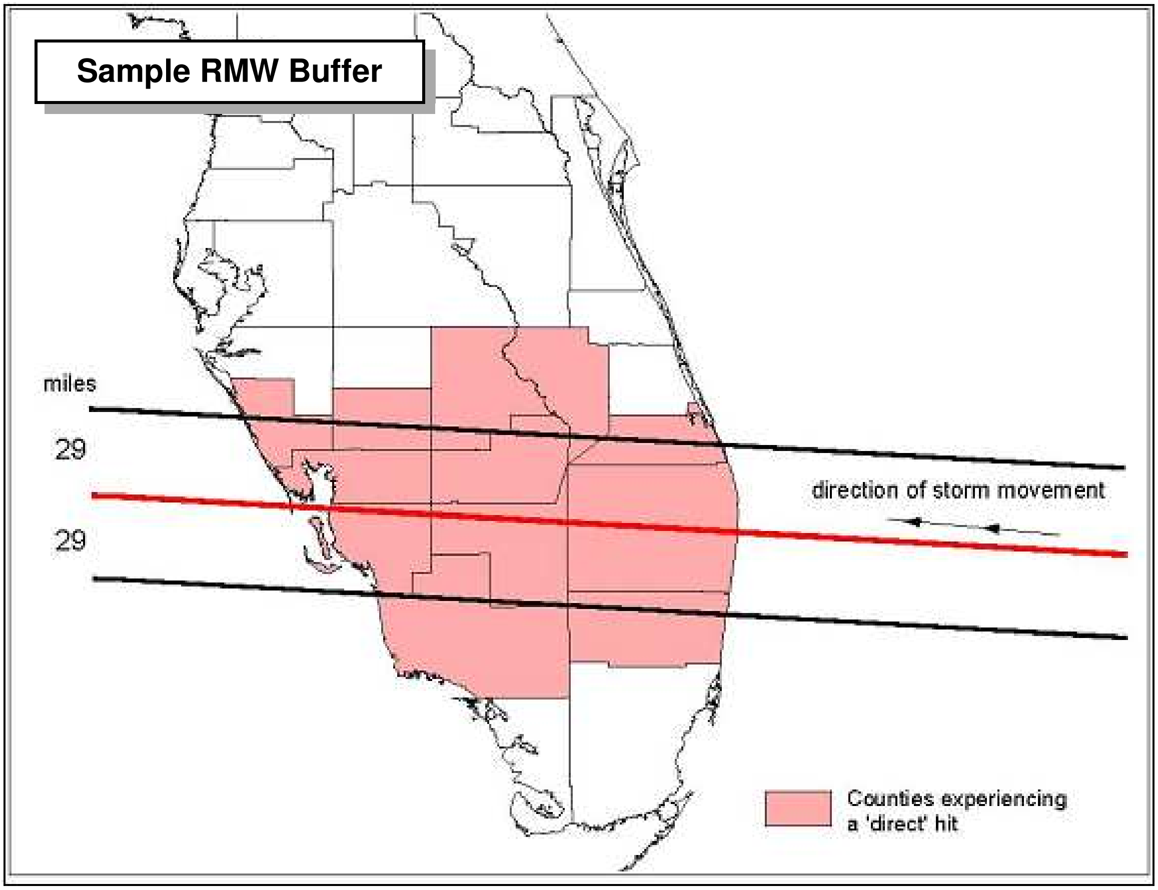

Figure 7. Sample Radius of Maximum Winds "buffer" used for this study.

Despite the fact that storms vary greatly in breadth and intensity and that using an average RMW will result in errors, in the absence of actual wind-swath data, this methodology is deemed appropriate for purposes of this study. The sensitivity of the results to minor adjustments in RMW was tested and found to be ineffectual in altering the overall results. An Atlantic Best Track reanalysis project is currently underway at the Atlantic Oceanographic and Meteorological Laboratory's Hurricane Research Division. The goal of this project is to append historical tropical cyclone windfield data, where available, to existing Best Track data (C. Landsea, personal communication 2000). Upon completion of this project, the existing dataset utilized in this project could be augmented through inclusion of these additional data.

Using the HURDAT data and the ArcView scripts, we first consider the frequency of tropical cyclones by county. Figure 7 is a map showing the cumulative frequency of tropical cyclone events by county for the period 1886 – 1999. As expected,

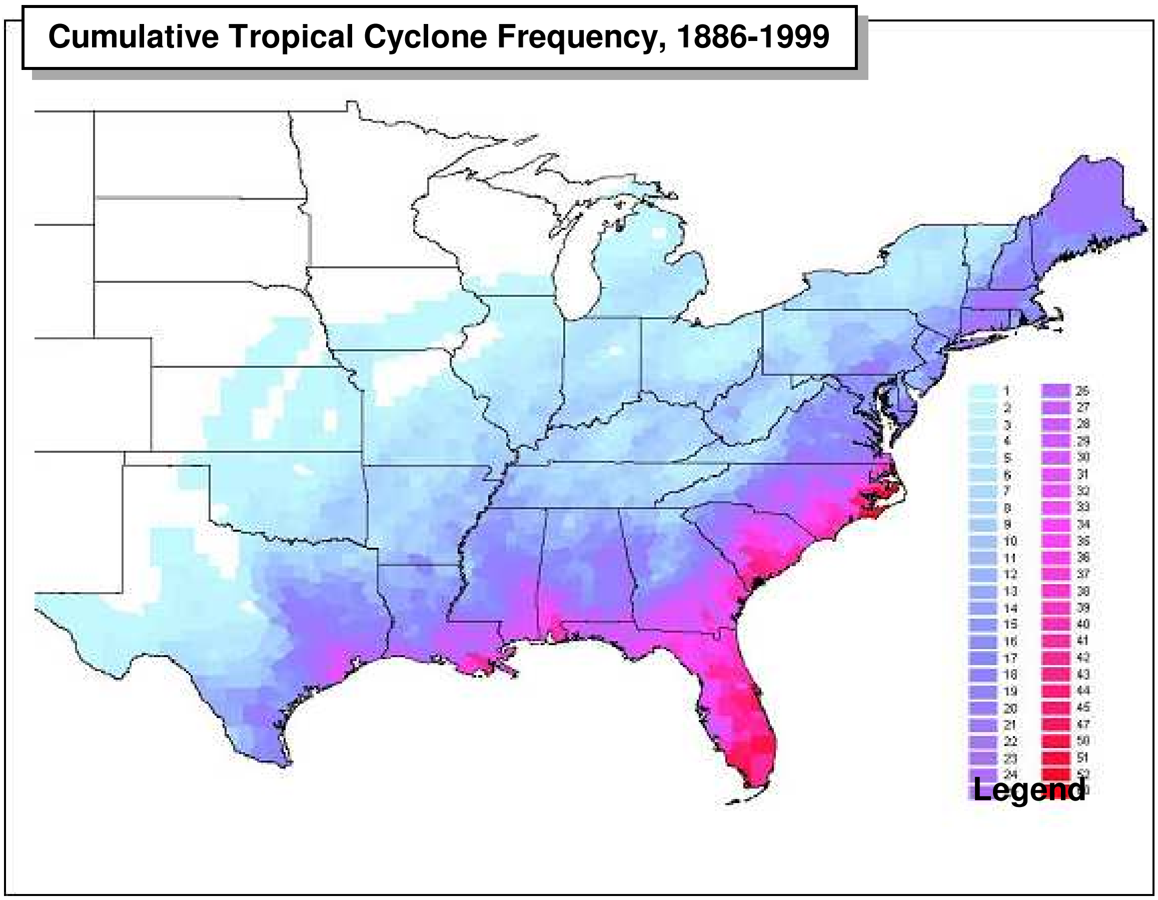

Figure 8. Cumulative U.S. Tropical Cyclone Frequency by County, 1886 – 1999.

tropical cyclone frequency is highest (red) along the coast and decreases inland. The Carolinas and Florida especially, stand out as areas experiencing high numbers of tropical cyclones. Over this same historical period, the Mid-Atlantic and the Northeastern U.S. have experienced fewer numbers of tropical cyclones. Interestingly, even the Midwest state of Indiana has witnessed the passage of several tropical cyclones over the past 113 years.

Although indirect hits were not addressed by this study, we are not suggesting that those fortunate counties escaping a direct hit by a tropical cyclone did not incur effects and/or damages as a result. Indeed, it is crucial that the public understands that even though the immediate center of a tropical cyclone may not pass directly through the county, the threat of damage and loss of life is still present. Experts frequently stress that, when tracking the motion of a tropical cyclone, far too much emphasis tends to be placed on the center of a storm.

Following the tabulation of tropical cyclone frequencies, WAO values (previously discussed to be a function of both tropical cyclone frequency and intensity) were calculated for each county. The calculation of WAO values was completed directly within ArcView, with the operations carried out within the theme's attribute table. Frequency totals for each category of storm (tropical depression through Category 5 hurricane) were multiplied by the corresponding damage coefficient values. The resulting figures were then summed and the total divided by the sum of the respective damage coefficients (2436). What is important to note is that the higher the WAO value, the greater the average intensity of the tropical cyclones that have passed through a particular county. Those counties possessing a high WAO value are assumed to be the ones with the greatest incidence of damaging hurricane effects (at least historically).

Figure 8 is a map showing the WAO for all counties in the U.S. As anticipated, since tropical cyclones weaken rapidly upon landfall, the largest values occur in counties

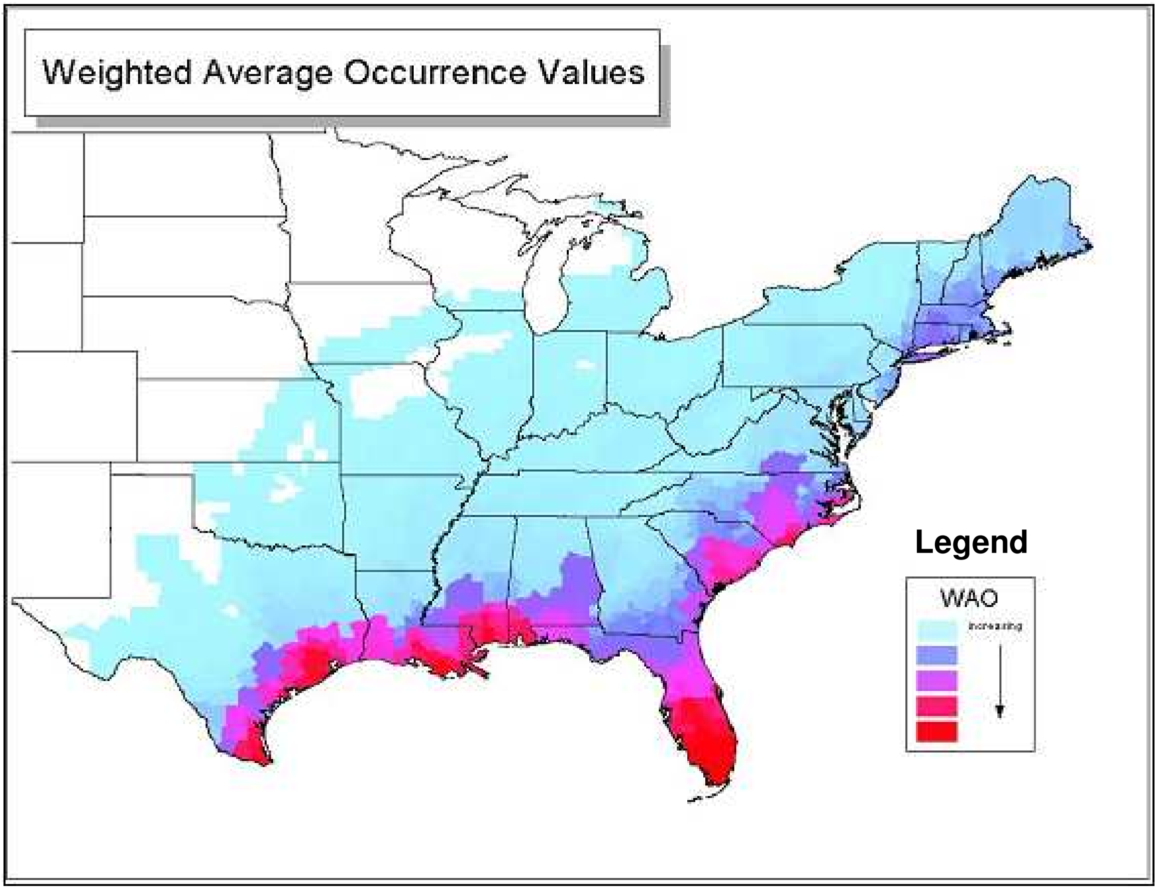

Figure 9. WAO Values by County.

immediately adjacent to the coast. In particular, south Florida and southeastern Louisiana are areas where historically, the strongest storms have occurred. Interestingly, the Mid-Atlantic region of Maryland, Delaware, and southern New Jersey have largely escaped the ravages of the most intense hurricanes.

The WAO focuses the hurricane problem with respect to wind and surge damages along the immediate coastline. For this reason, the areas chosen for the core analyses consists of all 175 first-tier Atlantic and Gulf coastal counties, extending from Cameron, Texas to Washington, Maine, as defined by the National Oceanic and Atmospheric Administration (NOAA) and by the U.S. Census. This narrow strip of land represents the area generally considered to be facing the greatest potential for damages from tropical cyclones since it typically experiences the brunt of these advancing systems. As previously mentioned however, severe damage can extend far inland from the coast and future analyses using similar methodologies may seek to include inland counties when addressing, for example, inland flooding hazards brought about by the passage of dissipating tropical systems.

7.2 Wealth Analysis

Wealth data normalized by county area are mapped in Figure 9 for the 175 coastal counties used in this study. Highest concentrations are shown in red and are found primarily in the northeast, in southern Florida, and along the northeast Texas coastline. Lowest concentrations of wealth are indicated in blue and are evident along the northern Gulf Coast and the Carolinas. Table 3 shows selected statistical characteristics of land area and wealth values for all counties included in the analysis. New York City possesses

Table 3. Statistical characteristics of land area and wealth values for the 175 coastal counties.

Statistic	**Land Area (square miles)**	**Wealth (thousands of 1991 $)**
Mean	642.18	$31,471
Median	581.51	4,830
Standard Deviation	442.51	92,692
Minimum	21.51 New York City	66 Cameron, LA
Maximum	2736.05 Washington, ME	811,117 New York City

the smallest area with slightly more than 21 square miles while Washington, Maine possesses the largest area with nearly 2800 square miles. Not surprisingly, the highest concentrations of wealth favor the Northeast. New York City, New York possesses the greatest concentration of wealth with more than $811 million per square mile. Cameron Parish, Louisiana possesses the least amount of wealth per unit area with just under $67,000. Table 4 lists the top and bottom ten counties possessing the highest and lowest

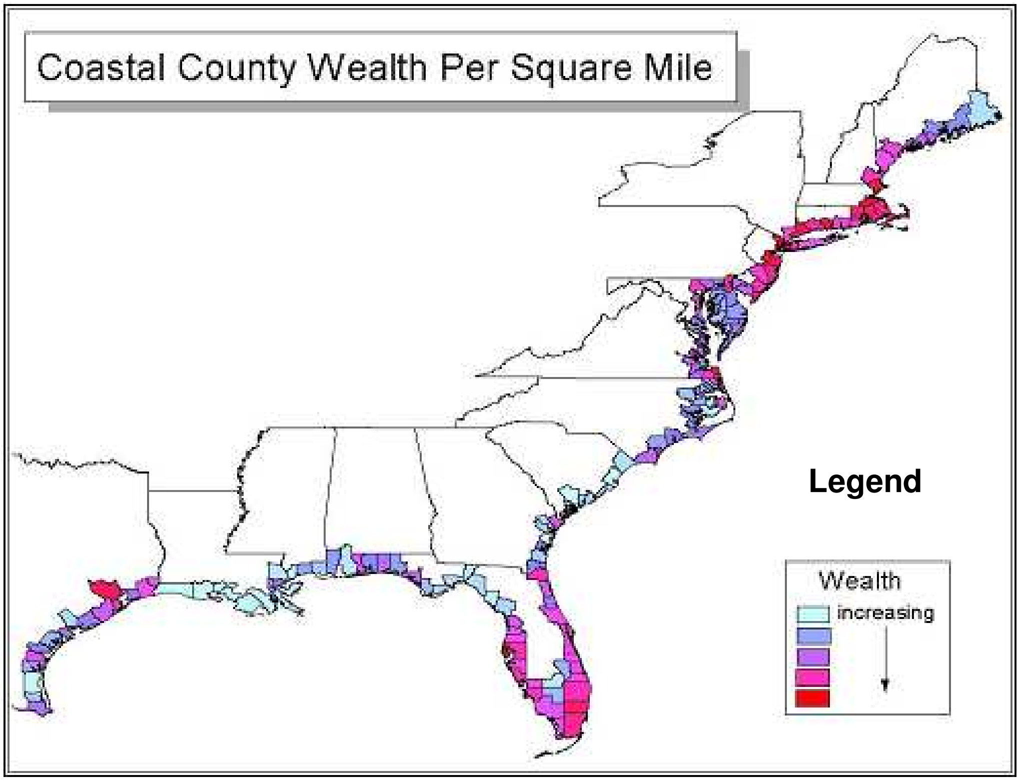

Figure 10. Coastal county wealth per square mile

amounts of wealth per square mile, respectively. Again, areas in the Northeast dominate the top of the list. Only one county in Florida, Pinellas, ranks among the top ten wealthiest counties. Conversely, areas along the Gulf coast in addition to a few counties in Georgia and South Carolina fall at the bottom of the list and represent those areas possessing the least amounts of wealth per unit area.

Table 4. Top and bottom ten rankings of wealth per square mile.

Rank	County	State	Rank	County/Parish	State
1	New York	NY	166	Dixie	FL
2	Suffolk	MA	167	Hancock	MS
3	Bronx	NY	168	McIntosh	GA
4	Hudson	NJ	169	Terrebonne	LA
5	Richmond	NY	170	LaFourche	LA
6	Bergen	NJ	171	Georgetown	SC
7	Kings	NY	172	Kenedy	TX
8	Queens	NY	173	Vermilion	LA
9	Pinellas	FL	174	Colleton	SC
10	Norfolk	MA	175	Cameron	LA

7.3 Calculating Relative Risk

An identical ranking methodology is applied to both wealth data and WAO values for each county. Wealth data normalized by county area are assigned a rank from highest (1) to lowest (175) in accordance with their position relative to other counties in the data set (ranking 1 (R1)). Counties are also ranked according to their WAO value (ranking 2 (R2)), with higher WAO values (those with a history of an active tropical cyclone climatology) assigned rankings closer to 1 and counties with lower WAO values assigned higher-order rankings. To help visualize the position of certain counties with respect to their associated relative vulnerability values, a scatter plot was constructed wherein the wealth ranks (R1) were plotted against the WAO ranks (R2) (Figure 10). In addition to the aforementioned, the points circled in red on the plot are those counties possessing both high WAO and high wealth values, indicating high risk. Conversely, points circled in blue represent counties possessing low WAO and low wealth values and are considered to be those areas with low levels of relative economic risk. Intuitively, these ideas make sense, as areas of the coastline experiencing both intense tropical cyclones

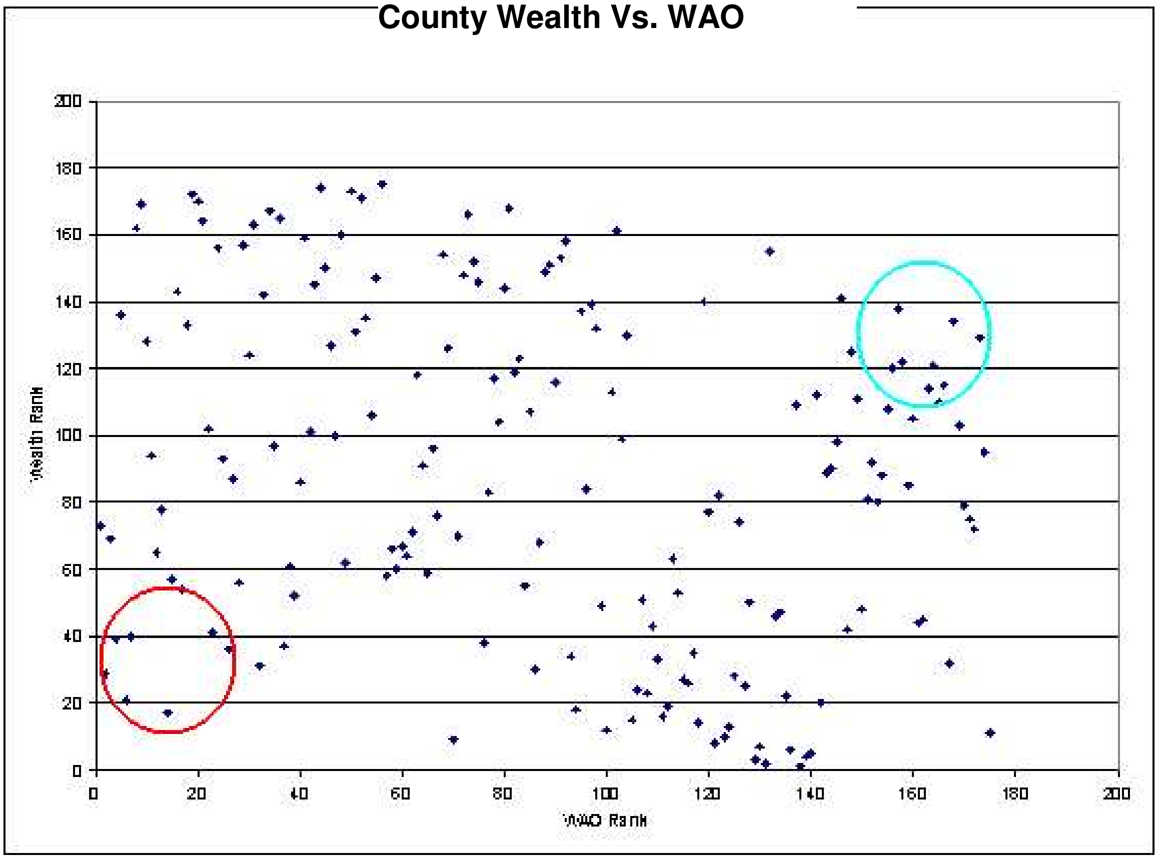

Figure 11. Scatter plot showing WAO ranking versus wealth ranking. Points circled in red indicate counties possessing both high wealth ranks and high WAO ranks, indicating high levels of vulnerability. Points circled in blue indicate counties possessing both low wealth rankings and low WAO rankings, indicating low levels of vulnerability.

and significant amounts of wealth to be potentially damaged or destroyed in a storm event, are those areas presumed to be the most vulnerable to losses.

In addition to the areas circled in blue and red on the graph, points located to the top left and bottom right of the graph represent counties possessing high WAO ranks and low wealth ranks, with the converse being true as well. Although emerging as being less vulnerable (according to the methodology used in this study), they face unique issues that set them apart from the type of risk measured in this study. Counties such as those located in New England and the panhandle of Florida may face a relatively low storm threat (reduced experience with tropical cyclones) while at the same time possessing high levels of wealth (residential property exposure). These counties are important from an emergency management perspective. In a similar manner, those counties falling to the bottom right of the plot also face unique issues related to tropical cyclone risk. These counties (e.g., Colleton County, South Carolina, Kenedy County, Texas) are those that on average, experience more frequent strong storms (enhanced climatology) but possess relatively low amounts of wealth (low building exposure). These are areas that must be closely monitored for future development as even moderate increases in wealth would translate to drastic increases in potential for loss.

Since risk, as it is used in this work, is considered to be an equally weighted combination of both exposure (wealth) and climatology (WAO), those counties possessing ranked values closest to (1,1) are considered to be the most vulnerable to potential destruction from tropical cyclones. In this way, a county possessing both an exposure ranking of 1 and a WAO ranking of 1 would be assumed to have the highest degree of potential for damage from tropical cyclones. The converse is true as well. A distance measure is calculated for each county using a simple geometric equation $rv_i = [\sqrt{(R1^2 + R2^2)}]^{-1}$ with the results equating to each county's risk situation relative to other counties in the data set. Each county in the database possesses a risk measure based upon its combined rank of exposure and tropical cyclone climatology. Upon completion of this step, a value of *relative economic risk* is appended to the coastal county theme's attribute table in ArcView and the results used to construct a map indicating the distribution of relative risk for potential damage from tropical cyclones (Figure 11). Red areas represent counties possessing high relative risk whereas blue areas are those possessing lower

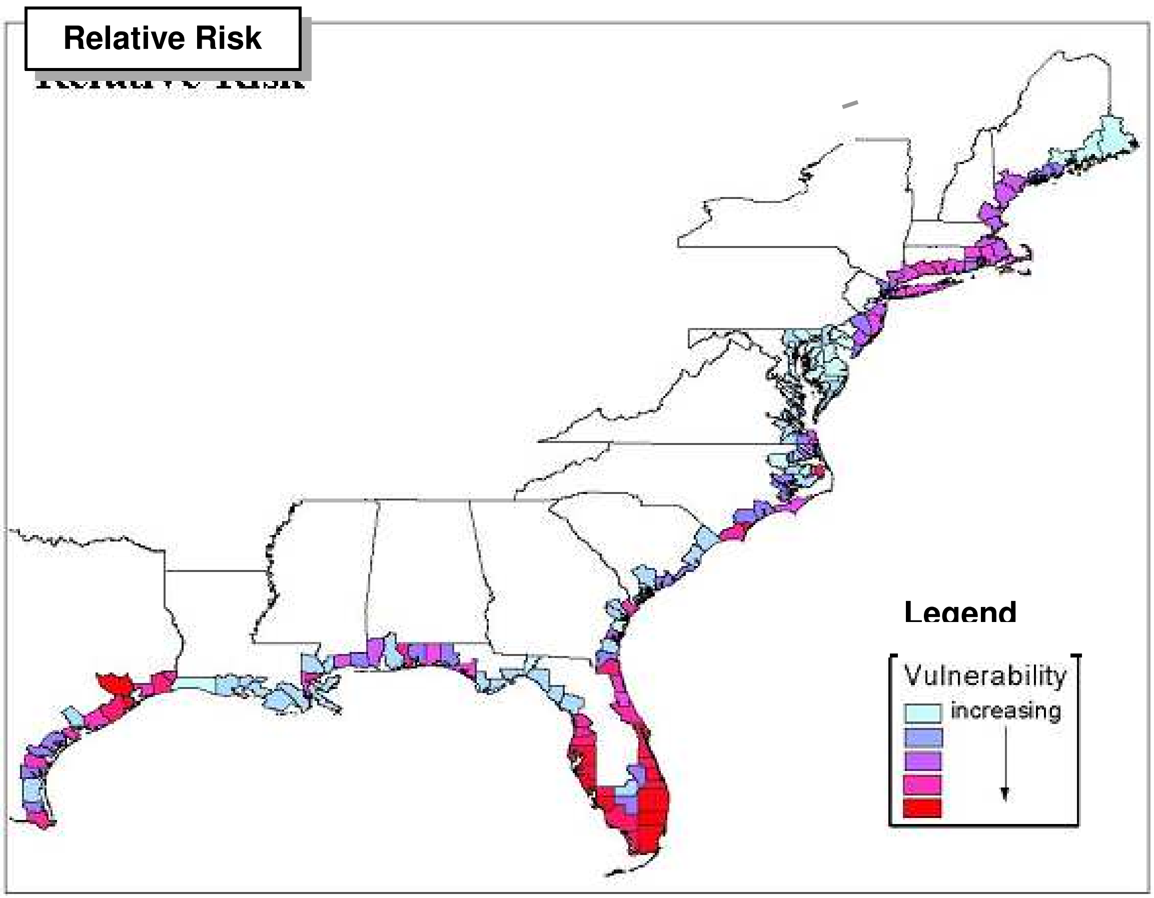

Figure 12. Coastal County Relative Risk

levels of relative economic risk. Not surprisingly, South Florida emerges as an area possessing concentrated levels of high relative risk. Additionally, the northeast Texas coastline and portions of extreme southeastern North Carolina stand out as well. Portions of the Gulf Coast, particularly Louisiana, the mid-Atlantic and the Northeast stand out as those areas possessing low levels of relative risk, with the exception of major metropolitan areas such as New York City. Table 5 lists the top and bottom ten counties possessing the highest and lowest relative risk, respectively. Florida dominates the list, as it contributes 70 percent of the ten wealthiest counties. Two counties in Texas and one in southeastern North Carolina make up the remainder of the list. Maryland demonstrates the lowest levels of relative risk, contributing 60 percent of the ten least exposed counties. Additionally, Virginia, Maine, and Delaware make up the remainder of the list. Maryland's placement on the list is most likely due to a combination of low levels of wealth and decreased tropical cyclone climatology figures.

Table 5. Top and Bottom 10 Rankings of Coastal County Relative Risk.

Rank	County	State	Rank	County	State
1	Broward	FL	166	Cecil	MD
2	Harris	TX	167	Westmoreland	VA
3	Dade	FL	168	Waldo	ME
4	Palm Beach	FL	169	Somerset	MD
5	Lee	FL	170	Kent	DE
6	Sarasota	FL	171	Washington	ME
7	New Hanover	NC	172	Queen Annes	MD
8	Galveston	TX	173	Dorchester	MD
9	Hillsborough	FL	174	Caroline	MD
10	St. Lucie	FL	175	Kent	MD

8. DISCUSSIONS AND FUTURE WORK

This study aims to facilitate a national, county by county comparison of the overall level of risk and potential for future losses from landfalling tropical cyclones based upon a comprehensive measure of tropical cyclone climatology. While the methodology potentially can provide some very useful information, several caveats should be noted to ensure that its inherent simplicity does not lead to misinterpretation or misuse. Users should have a basic understanding of the conceptual framework of tropical cyclone disaster risk on which the index is based, the indicators that comprise the WAO, and of the mathematical model that was used to construct the final risk index. It must also be clear that the reliability of the findings depend on the quality and complexity of the input data, that the results measure a subset of economic indicators (taken only from coastal county assessed residential property values) rather than overall expected economic loss, and that it assesses the relative risk of a particular county only as compared to other counties included in the study. With those characteristics duly noted, the methodology can serve as an important new tropical cyclone risk assessment tool.

The methodology utilized in this work is admittedly simplistic in nature and there is certainly room for further augmentation and improvement. A region's 'true' potential for damage from tropical cyclones is extraordinarily complex, consisting of many variables. The examination, collection, and integration of more variables related to vulnerability would certainly serve to improve and refine the results of this study. One should keep in mind however, that the inclusion of additional "vulnerability variables" will not necessarily increase a location's potential for damage from tropical cyclones. Instead, they often have the effect of clarifying or adding a level of specificity to the results. In fact, some may serve to lessen the degree to which any particular location is vulnerable. Mitigation measures such as enforced stricter building codes and insurance discounts, leading to structural enhancements as well as coastal setback lines and effective evacuation and emergency planning measures, might actually lessen a location's potential risk for losses from tropical cyclone hazards.

Although population exposure and vulnerability was not addressed in this study, it is well recognized as a significant component of potential tropical cyclone risk. Future studies may seek to adapt and apply the methodologies used herein to studying the vulnerability of coastal populations to tropical cyclones. The development and integration of a 'casualty potential index' is highly desirable and necessary for communities to adequately address the true complexity of the threat they face from tropical cyclones.

Perhaps the most beneficial applications of methodologies such as the one presented in this thesis and those discussed previously is the potential for inciting the development of community hazard awareness and preparedness. After all, simple awareness and general preparedness can go a long way toward keeping natural hazards from becoming disasters.

APPENDIX A

Saffir-Simpson Hurricane Disaster Potential Scale

SS Category	Winds (mph)	Winds (kts)	Surge (ft)	Damage Potential
1	74-95	64-82	4-5	Minimal
2	96-110	83-95	6-8	Moderate
3	111-130	96-113	9-12	Extensive
4	131-155	114-135	13-18	Extreme
5	>155	>135	>18	Catastrophic

Source: Simpson (1974)

APPENDIX B

```
‘********************************
‘This script creates a new theme of one or several new hurricane tracks.  The track
‘segments are polyline features created from the input latitude and longitude, and each
‘line has a wind speed and pressure for it's from and to points.

theView = av.GetActiveDoc

ActiveThemes = theView.GetActiveThemes
 for each t in ActiveThemes
   t.SetActive(false)
end

EndofLine = FALSE
HurcDone = FALSE

afilename = FileDialog.Put(("c:\temp\HurcSegt.dbf").AsFilename,"*.dbf" ,"Output
Theme")
  if (afilename=nil) then
    exit
  end

  thePLFTab = FTab.MakeNew((afilename), PolyLine)

  fld1 = Field.Make("Year",#Field_BYTE,4,0)   'Year
  fld2 = Field.Make("Month",#Field_BYTE,2,0)   'Month
  fld3 = Field.Make("Day",#Field_BYTE,2,0)   'Day
  fld4 = Field.Make("BTID",#FIELD_BYTE,4,0)   'Best Track ID
  fld5 = Field.Make("Name",#FIELD_CHAR,12,0)  'From first line
  fld6 = Field.Make("Lat",#Field_DECIMAL,8,3)    'From First Advisory
  fld7 = Field.Make("Long",#Field_DECIMAL,8,3)   'From First Advisory
  fld8 = Field.Make("Wind_Kts",#Field_BYTE,3,0) 'From First Point
  fld9 = Field.Make("Pressure",#Field_BYTE,8,0)   'From First point
  fld10 = Field.Make("Wind_mph",#Field_DECIMAL,8,2)   'Calculate from Wind_kts
  fld11 = Field.Make("Cat",#Field_CHAR,2,0)   'Classification
  thePLFTab.AddFields({fld1,fld2,fld3,fld4,fld5,fld6,fld7,fld8,fld9,fld10,fld11})

tableName = FileName.make("C:\temp\hurcpnts.dbf")
```

```
thePtVTab = Vtab.MakeNew(tableName,dbase)

thePtTable = Table.Make(thePtVTab)
thePtTable.Setname("Attributes of hurcpnts")

  fLongitude = Field.Make("Longitude",#FIELD_FLOAT,8,4)
  fLatitude = Field.Make("Latitude",#FIELD_FLOAT,8,4)
  fWs = Field.Make("WindSpeed",#FIELD_BYTE,3,0)
  fPrs = Field.Make("Pressure",#FIELD_BYTE,4,0)
  fCat = Field.Make("Cat",#FIELD_CHAR,4,0)
  thePtVTab.AddFields({fLongitude,fLatitude,fWs,fPrs,fCat})

thePtVTab.SetEditable(true)

TrackFiles = FileDialog.ReturnFiles({"*.txt"},{"Text File"},"Select Hurricane Track File",
0)
  if(TrackFiles.Count = 0)then
    exit
  end
theTracks = LineFile.Make(TrackFiles.Get(0), #FILE_PERM_READ)
HowLong = theTracks.GetSize

DataLine = theTracks.ReadElt  'Read first line of file

While (theTracks.IsAtEnd.Not)  'Not End of File test

  If (dataLine.count > 31)then
    'Read Hurricane name and year
    IDNum = DataLine.Left(6).Right(4).Trim.AsNumber
    HurcName = DataLine.Left(22).Right(15)
    TheYear = DataLine.Right(4)

    'Read the first advisory point data

     DataLine = theTracks.ReadElt

     TheMonth = DataLine.Left(3).Right(2).AsNumber
     TheDay = DataLine.Left(6).Right(2).AsNumber
     TheFLat = DataLine.Left(18).Right(5).Trim.AsNumber
     TheFLong = DataLine.Left(12).Right(5).Trim.AsNumber*(-1)
     'To prevent zingers
       If (TheFLong > -7) Then
         TheFLong = theFLong - 100
       end
     FWindSpd = Dataline.Left(22).Right(3).Trim.AsNumber
     FPressure = dataLine.Left(28).Right(4).Trim.AsNumber
```

```
    FCat = DataLine.Right(1)

  Else
    TheTMonth = DataLine.Left(3).Right(2).AsNumber
    TheTDay = DataLine.Left(6).Right(2).AsNumber
    TheTLat = DataLine.Left(18).Right(5).Trim.AsNumber
    TheTLong = DataLine.Left(12).Right(5).Trim.AsNumber*(-1)
    If (TheTLong > -7) Then
       TheTLong = theTLong - 100
     end
    TWindSpd = Dataline.Left(22).Right(3).Trim.AsNumber
    TPressure = dataLine.Left(28).Right(4).Trim.AsNumber
    TCat = DataLine.Right(1)

    NYear = theYear
     If (theMonth < 10) then
       NMonth = "0" + theMonth.asString
     Else
       NMonth = theMonth.AsString
     End

     If (theDay < 10) then
       NDay  = "0" + theDay.AsString
     Else
       NDay = theDay.AsString
     End


     FixedDate = (NYear + NMonth + NDay)

       rec = thePLFTab.AddRecord
       theSegment = PolyLine.Make({{theFLong@theFLat,theTLong@theTLat}})

       thePLFTab.SetValue(thePLFTab.FindField("Shape"),rec,theSegment)
       thePLFTab.SetValue(thePLFTab.FindField("Year"),rec, theYear)
       thePLFTab.SetValue(thePLFTab.FindField("Month"),rec, theMonth)
       thePLFTab.SetValue(thePLFTab.FindField("Day"),rec, theDay)
       thePLFTab.SetValue(thePLFTab.FindField("BTID"),rec,IDNum )
       thePLFTab.SetValue(thePLFTab.FindField("Name"),rec,HurcName)
       thePLFTab.SetValue(thePLFTab.FindField("Lat"),rec,TheFLat)
       thePLFTab.SetValue(thePLFTab.FindField("Long"),rec,TheFLong)
       thePLFTab.SetValue(thePLFTab.FindField("Wind_kts"),rec,FWindSpd)
       thePLFTab.SetValue(thePLFTab.FindField("Pressure"),rec,FPressure)
       thePLFTab.SetValue(thePLFTab.FindField("Wind_mph"),rec,
(FWindSpd*6076.12/5280))
       If (FCat <> "*")Then
```

```
        thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,FCat)
      ElseIf (FCat="*") Then
        If (FWindSpd < 35) then
          thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,"TD")
        ElseIf ((FWindSpd >= 35) and (FWindSpd < 65)) then
          thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,"TS")
        ElseIf ((FWindSpd >= 65) and (FWindSpd < 84)) then
          thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,"H1")
        ElseIf ((FWindSpd >= 84) and (FWindSpd < 96)) then
          thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,"H2")
        ElseIf ((FWindSpd >= 96) and (FWindSpd < 114)) then
          thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,"H3")
        ElseIf ((FWindSpd >= 114) and (FWindSpd < 135)) then
          thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,"H4")
        ElseIf ((FWindSpd >= 135)) then
          thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,"H5")
        End
      Else
        thePLFTab.SetValue(thePLFTab.FindField("Cat"),rec,"!!")
      end


TheMonth = theTMonth
     TheDay = theTDay
     TheFLat = theTLat
     TheFLong = theTLong
     FWindSpd = TWindSpd
     FPressure = TPressure
     FCat = TCat

   End
   Dataline = theTracks.ReadElt
End

 PLTheme =FTheme.Make(thePLFTab)
  theView.AddTheme(PLTheme)
  PLTheme.SetName("New Hurricane Tracks")
  PLTheme.SetVisible(TRUE)

  theView.Invalidate
```

APPENDIX C

This script was used to calculate tropical cyclone frequencies for U.S. counties.

```
StartTime = Date.Now

theView = av.GetActiveDoc
If (theView.Is(View)) then

TheThemeList = theView.GetThemes

theCounties = MsgBox.ChoiceAsString(theThemeList, "Select the Polygon Theme",
"Select Theme") 'theView.FindTheme("Counties.shp")
theCntyFTab = theCounties.GetFTab
theCntyFTab.SetEditable(TRUE)
theCntyBMap = theCntyFTab.GetSelection

NewFieldsList = {}
  fHit = Field.Make ("Hit",#FIELD_LOGICAL, 0, 0)
  fWHit = Field.Make ("WHits",#FIELD_Byte,4,0)
  fDHit = Field.Make ("DHits",#FIELD_Byte,4,0)
  fLHit = Field.Make ("LHits",#FIELD_Byte,4,0)
  fEHit = Field.Make ("EHits",#FIELD_Byte,4,0)
  fSSHit = Field.Make ("SSHits",#FIELD_Byte,4,0)
  fSDHit = Field.Make ("SDHits",#FIELD_Byte,4,0)
  fTDHit = Field.Make ("TDHits",#FIELD_Byte,4,0)
  fTShit = Field.Make ("TSHits",#FIELD_Byte, 4, 0)
  fH1Hit = Field.Make ("H1Hits",#FIELD_Byte, 4, 0)
  fH2Hit = Field.Make ("H2Hits",#FIELD_Byte, 4, 0)
  fH3Hit = Field.Make ("H3Hits",#FIELD_Byte, 4, 0)
  fH4Hit = Field.Make ("H4Hits",#FIELD_Byte, 4, 0)
  fH5Hit = Field.Make ("H5Hits",#FIELD_Byte, 4, 0)
  fHitCnt  = Field.Make ("HitCnt",#FIELD_Byte, 4, 0)

  If (theCntyFTab.FindField("Hit") = nil) then
    NewFieldsList.Add(fHit)
  end
  If (theCntyFTab.FindField("DHits") = nil) then
    NewFieldsList.Add(fDHit)
  end
```

```
  If (theCntyFTab.FindField("WHits") = nil) then
    NewFieldsList.Add(fWHit)
  end
  If (theCntyFTab.FindField("LHits") = nil) then
    NewFieldsList.Add(fLHit)
  end
  If (theCntyFTab.FindField("EHits") = nil) then
    NewFieldsList.Add(fEHit)
  end
  If (theCntyFTab.FindField("SDHits") = nil) then
    NewFieldsList.Add(fSDHit)
  end
  If (theCntyFTab.FindField("SSHits") = nil) then
    NewFieldsList.Add(fSSHit)
  end
  If (theCntyFTab.FindField("TDHits") = nil) then
    NewFieldsList.Add(fTDHit)
  end
  If (theCntyFTab.FindField("TSHits") = nil) then
    NewFieldsList.Add(fTSHit)
  end
  If (theCntyFTab.FindField("H1Hits") = nil) then
    NewFieldsList.Add(fH1Hit)
  end
  If (theCntyFTab.FindField("H2Hits") = nil) then
    NewFieldsList.Add(fH2Hit)
  end
  If (theCntyFTab.FindField("H3Hits") = nil) then
    NewFieldsList.Add(fH3Hit)
  end
  If (theCntyFTab.FindField("H4Hits") = nil) then
    NewFieldsList.Add(fH4Hit)
  end
  If (theCntyFTab.FindField("H5Hits") = nil) then
    NewFieldsList.Add(fH5Hit)
  end
  If (theCntyFTab.FindField("HitCnt") = nil) then
    NewFieldsList.Add(fHitCnt)
  end

  If (NewFieldsList.Count > 0) then
    theCntyFTab.AddFields(NewFieldsList)
  End

theCntyBMap.SetAll
 theCntyFTab.Calculate("FALSE",TheCntyFTab.FindField("Hit"))
```

```
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("WHits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("DHits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("LHits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("EHits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("SSHits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("SDHits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("TDHits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("TSHits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("H1Hits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("H2Hits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("H3Hits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("H4Hits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("H5Hits"))
 theCntyFTab.Calculate("0",TheCntyFTab.FindField("Hitcnt"))

theTracks = MsgBox.ChoiceAsString(theThemeList, "Select the Track Theme", "Select
Theme")   'theView.FindTheme("New Hurricane Tracks")
theHurcFTab = theTracks.GetFTab
theHurcBMap = theHurcFTab.GetSelection

for each I in 1..2000

  theQuery = "([BTID] = "+I.AsString+")"
  theHurcFTab.Query(theQuery,theHurcBMap,#VTAB_SELTYPE_NEW)
  If (theHurcBMap.Count > 0)Then

    tempFTab = theHurcFTab.Export ( "c:\temp\AHurc".asFileName, Shape, TRUE )
    tempTheme = FTheme.Make(tempFTab)   '(SrcName.Make("c:\temp\AHurc.shp"))
    tempFTab = tempTheme.GetFTab
    TempBMap = tempFTab.GetSelection

    theView.AddTheme (tempTheme)
    tempTheme.SetName("Hurricane "+I.AsString)

wslist= { "H5", "H4", "H3", "H2", "H1", "TS", "TD", "SS", "SD", "E", "L", "W", "D"}
      for each c in wslist

Query2 = "([Cat] =" + c.AsString.Quote + ")"
       tempTheme.GetFTab.Query(Query2,tempBmap,#VTAB_SELTYPE_NEW)

if (tempBMap.Count > 0) then

         theCounties.SelectByTheme(tempTheme,
#FTAB_RELTYPE_ISWITHINDISTANCEOF,0.43, #VTAB_SELTYPE_NEW )
         theCntyBMap = theCntyFTab.GetSelection
```

```
Query3 = "([Hit] = False)"
        theCntyFTab.Query(Query3,theCntyBMap,#VTAB_SELTYPE_AND)

if( theCntyBMap.Count > 0) then
          theCntyFTab.Calculate("(["+ c.AsString + "Hits] + 1)",
theCntyFTab.FindField(c.AsString + "Hits"))
          theCntyFTab.Calculate("TRUE",theCntyFTab.FindField("Hit"))
        End

      End

     End 'for c
    theCntyBMap.SetAll
    theCntyFTab.Calculate("FALSE",theCntyFTab.FindField("Hit"))
    theCntyBMap.ClearAll
    if (theView.findTheme(tempTheme.AsString) <>nil)then
      theView.DeleteTheme (tempTheme)
    End

  End

End

theCntyBMap.SetAll
theCntyFTab.Calculate("[DHits]+[WHits]+[LHits]+[EHits]+[SDHits]+[SSHits]+[TDHits
]+[TSHits]+[H1Hits]+[H2Hits]+[H3Hits]+[H4Hits]+[H5Hits]",
theCntyFTab.Findfield("HitCnt"))
theCntyBMap.ClearAll

theCntyFTab.SetEditable(FALSE)

EndTime = Date.Now
MsgBox.Info("RunTime: "+(StartTime..EndTime).AsMinutes.AsString+" Minutes","")

Else
  MsgBox.Info("Active Document is not a view","")
End
```

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BIOGRAPHICAL SKETCH

Ethan Joel Gibney was born in Dayton, Ohio on August 17, 1971. Raised by his parents, Terry and Gloria, young Ethan was moved around from place to place until 1980, where the family finally settled in eastern Virginia. Ethan attended elementary school and junior high in historic Williamsburg, Virginia and later moved to Norfolk, where he attended Maury High School and then Old Dominion University (ODU). Earning his Bachelor's degree in Physical Geography with a concentration in natural hazards, Ethan began to focus his studies on hurricanes.

Having graduated from ODU and looking to expand his knowledge of the hurricane problem, Ethan looked to graduate studies in the geography department at the Florida State University (FSU) in Tallahassee for a challenging and rewarding intellectual experience. Ethan began his studies at FSU in August of 1998. After successful completion of his first year, he accepted a research assistant position working under the direction of hurricane climatologist and meteorologist Dr. James Elsner. The primary focus of their work was the problem of U.S. hurricane vulnerability.

Subsequent to the completion of his Master's degree, Ethan accepted a position with the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center in Charleston, SC, where his primary duties center around helping state and local coastal zone managers identify solutions to the cornucopia of problems associated with coastal hazards, particularly hurricanes and coastal storms.