A Categorization Scheme for Understanding Tornadoes from the Human Perspective

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A CATEGORIZATION SCHEME FOR UNDERSTANDING TORNADO EVENTS FROM THE HUMAN PERSPECTIVE

by

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B.S., University of Wisconsin-Eau Claire, 2000
M.A., Kansas State University, 2006

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Geography
College of Arts and Sciences

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2011

Abstract

Given the recent recognition that not only physical processes, but social, political and economic aspects of hazards determine vulnerability and impact of an event, the next logical step would seem to be the development of classification systems that address those factors. Classifications for natural disasters, such as the Fujita Scale for tornadoes and the Saffir-Simpson hurricane scale, focus on the physical properties of the event, not the impact on a community. Pre-event vulnerability to a natural hazard is determined by many factors, such as age, race, income and gender, as well as infrastructure such as density of the built environment and health of the industrial base. The behavior of residents in the community, construction quality of shelters and warning system effectiveness also affect vulnerability. If pre-event vulnerability is to be determined by such factors, post-event impact should, at least in part, be as well. The goal of this research was to develop the Tornado Impact-Community Vulnerability Index (TICV) that utilizes variables such as the number of persons killed, economic impacts and social vulnerability to describe to the level of impact a tornado event has on community. As tornadoes that strike unpopulated areas are often difficult to classify, even in the traditional sense, the TICV will take into consideration only events that strike communities with defined political boundaries, or “places” according to the U.S. Census Bureau. By assigning a rating to the impact, this index will allow the severity of the storm to be understood in terms of its effect on a specific community and hence its impact, rather than an physically-based rating that gives only a broad, general indication of its physical strength.

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Dedication

To James and Joanne Stimers - the best parents a son could ask for.

CHAPTER 1 - Introduction

A single moment can retroactively flood an entire life with meaning.
Viktor Frankl

When the public tries to understand the severity of a particular hazard, it is useful to provide a measurement that expresses the movement away from everyday life, as recovery and adjustments to extreme events is not a part of the routine of a community (Kates 1996). By creating an index that describes impact on a community, this research aims to fill a perceived gap in how people gain an understanding of how tornado events impact communities. Voss and Wagner (2010) noted two topics that need to be addressed in terms of a community's adjustment to a disaster event:

1. The severity of the destruction caused by the event;
2. The spatial extent of disruption in the community.

Regarding the second topic, the spatial extent of a tornado's track (length and width) was not a part of the calculation process used herein although the intersection with a particular community was, representing the impact of an event as being distributed across the community as a whole. According to Form et al. (1956, 180), "Disasters usually affect entire communities or large segments of communities and are present when the established social systems of the community abruptly cease to operate." Voss and Wagner's first consideration, the severity of the damage coupled with the extent of disruption – described here as impact – is central to this research, and is a major criterion incorporated into the index and category scheme developed.

People strive to understand the physical world, including extreme events occurring within it. Scales used to measure extreme geophysical events in terms of strength have in large part focused on the physicality of the event. For example, the Richter scale (M_L) (Boore 1989) and moment-magnitude scale (MMS or M_W) (Singh and Havskov 1980) both provide a quantitative rating that allows people to understand the power of an earthquake based on physical characteristics. But like the Enhanced Fujita Scale (EFS), which estimates physical strength of tornadoes via wind speed estimates, the Richter and moment-magnitude scales do not give complete information concerning the severity of impact on a given area, although the qualitatively-based Mercalli scale for earthquakes accomplishes this goal to some degree (USGS 2011).

People, Communities and Understanding Natural Hazards

Humans have an inherent need to comprehend their physical surroundings, as well as to put atypical events into perspective (Davis et al. 1998). For those communities that have experienced a tornado the idea of them being “unusual” may not seem applicable to their reality. Grazulis (2001), however, claimed that any given home in the United States can expect to be hit by a tornado once every one-thousand years, and less than one percent of the U.S. population will ever find themselves in the path of a tornado. For those that do find their lives affected by a tornado event, the impact can range from practically none to severe and life-changing. As science constantly pushes forward in seeking to understand physical processes, it must also consider who and what physical processes affect: people and the communities in which they live.

First Realizations

Gilbert White defined natural hazards as interactions between people and nature (White 1974). Natural disasters are the manifestation of a potential hazard – when that potential hazard becomes real – with the end-result a physical impact on, and the people within, that area (Tobin and Montz 1997; Annan 2003). Impact comes in many forms, be it loss of property or structures, injury, emotional stress,[1] employment opportunities removed, difficulty in recovering from an extraordinary event or the loss of life. Gaining an understanding of the physical mechanisms that create and drive phenomenal weather events is undoubtedly important, but prior to the 1950s, understanding the social dynamics of the areas under threat from those phenomena received far less attention.

White's 1945 University of Chicago dissertation, Human Adjustment to Floods marked the beginning of a new chapter in hazard and disaster research. Early in his career, White noticed the so-called structural response to flood control was the focus; the building of dams to contain nature's fury. The social components that created underlying causes for the potential disaster received far less attention. As quoted in Hinshaw (2006, 134), White stated, "When I asked if they had ever considered looking into a floodplain to see what happened there, as distinct from computing the losses that would be experienced or averted, they said they weren't interested in that." Building to battle nature was of utmost concern while understanding who would be affected was a distant afterthought at best.

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[1] It is accepted within psychology and psychiatry literature that witnessing death, injury, destruction or otherwise being directly involved in a natural disaster event can lead to post-traumatic stress disorder (PTSD) as it satisfies Criterion A1 for that disorder as defined by the Diagnostic and Statistical Manual of Mental Disorders, Volume IV, 1994 (Middleton et al. 2002).

The First Tornadoes in the Americas

Natural disasters, including tornadoes, have been documented as far back as 77 AD in Pliny the Elder's Naturalis Historia. The first recorded tornadoes in the Americas occurred near the ancient Aztec cities of Tenochtitlan and Tlatelolco in August of 1521 (Fuentes 2010). Those events were described in the Spanish text Florentine Codex as, whirlwinds or severe winds (Sahagun 1970). What is most likely the first tornado record in Colonial America was written by Massachusetts Governor John Winthrop on 5 July 1643. A witness to the storm noted a swirling black cloud that made a great deal of noise and lifted trees from the ground (Bradford 1999). In an area now known to produce a low number of tornadoes annually, smaller funnels most likely went largely unnoticed from the late 1600s through the mid-1800s since the population was far less than it is today. Benjamin Franklin speculated about the nature of waterspouts in the mid-1700s, and several outbreaks were observed and recorded through the end of the century, but tornadoes were little studied in America until the 1830s. Three scientists, Robert Hare, William Redfield and James Espy, gave serious attention to the 31 May 1830 tornado that devastated Shelbyville, TN (Grazulis 1993, 2001). In 1847, physicist Joseph Henry initiated a program through the Smithsonian Institute to create a network of weather observers that would report via telegraph to Washington D.C. their findings for him to analyze. In 1862, Henry began compiling information from field observations on path length, width, location, direction, speed and shape of the funnel (Ludlum 1970). It is believed that these data were used to better understand the nature of the phenomena, but never used in an attempt to forecast tornadoes. It was also during the 1860s that William Ferrel, a mathematician and schoolteacher, became the first person to recognize the relationship between the rotation of the earth and the rotation present in tornado-producing thunderstorms (Grazulis 2001).

The Birth of Weather Forecasting

Observing turned to forecasting in 1870 when President Ulysses S. Grant directed military outposts to begin collecting meteorological information to be used for prediction, and to provide warning of approaching storms to mariners. From this, the precursor to the modern National Weather Service (NWS) was born (Bradford 1999). John Park Finley, a lieutenant with the U.S. Army's Signal Corps, engaged in data collection and attempted to forecast tornadoes from 1884 through 1886 as part of a test study. Finley was able to predict the onset of violent storms with a substantial degree of accuracy, but less so for tornadoes, and this caused him to fall into the poor graces of his superiors. The Chief Signal Officer even disallowed the use of the word tornado in forecasts for fear that it might instigate public panic, which he thought would injure more people than the tornado itself. Eventually, Finley was relegated to a desk job within the Signal Corps and the forecasting program was discontinued (Bradford 1999).

The Weather Bureau, placed under control of the Department of Agriculture in 1891, continued collecting data on storms, but did little research, and downplayed the need for tornado warnings, let alone forecasting. Gustavus Hinricks, the first State Climatologist of Iowa, even stated that tornadoes did not occur in Iowa during the summer months (Grazulis 2001), a gross understatement given our spatial understanding of tornado distribution in the U.S. today. These policies and lack of forecasting attempts surely harbor some of the blame for the massive loss of life that resulted from the 1925 Tri-State (MO, IL, IA) tornado which resulted in 695 lives; more than any other tornado in the U.S. before or since (Grazulis 1997). The 1935 Labor Day hurricane also reflects this lack of foresight. One of three Saffir-Simpson Category 5 hurricanes to make landfall on U.S. soil in the 20th century,[2] it took an estimated 409 lives (McDonald 1935). Had a warning been issued prior to the hurricane's arrival, the high death toll may have been avoided.

By the late 1940s and early 1950s, forecasting tornadoes was moving forward, and the directive to avoid use of the word tornado had vanished (Doswell 1993; Monfredo 2010). The first successful tornado forecast in the U.S. occurred on 25 March 1948 when meteorologists at Tinker Air Force Base in Oklahoma City, Oklahoma, noted similarities between the weather that day compared to five days prior, which had produced a costly tornado (Wagner 1999). It was in the early 1950s that Tetsuya (Ted) Fujita came to the United States and began studying at the University of Chicago. Going beyond the work of predecessors, Fujita (1978) recognized that convective cells that developed a radar signature in a shape resembling a bow frequently produced straight-line winds; a phenomenon we recognize as a bow echo (Weisman 2001). Downbursts, associated with bow and hook echoes, and carrying with them a great capacity to inflict damage via long paths of straight-line winds, were widely studied by Fujita (1985). The sudden downward rushes of air were quickly recognized to be a major hazard for aircraft, and Fujita's work in understanding the downburst has been applied to pilot training programs across the world (Wilson and Wakimoto 2001). Fujita also led the way in pioneering the use of satellite imagery to describe the motion of clouds (Menzel 2001),

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[2] Hurricanes Camille (1969) and Andrew (1992) made landfall in Mississippi and Florida respectively as Category 5s (National Hurricane Center 2010).

and produced a 70-year climatology of U.S. tornadoes, further aiding in the study of trends and frequency (Fujita 1987; Forbes 2001). Fujita's work spanned four decades and produced the most renowned portfolio of severe storm research academia or practical application had seen before or arguably since.[3]

Motion photography, instrumentation on aircraft, and experimental Doppler radar all continued push our understanding of tornadoes as well as forecasting ahead towards the end of the 1950s (Grazulis 2001). Doswell (1993, 558) described the 1960s-era of tornado research as the time it was first realized that large convective storms known as supercells were, "prolific tornado producers." Satellite-based meteorology was born in the 1960s, and the National Severe Storms Laboratory (NSSL) would begin to lead the field into a new era of forecasting methods and technology.

In the 1970s, the so-called "golden age of tornado research" (Grazulis 2001, 240), a nationwide Doppler network was established, computer mesoscale modeling began to show signs of promise (Weisman and Klemp 1984), and Dr. Fujita introduced the Fujita Scale to estimate tornadic wind speeds through after-event ground observations (Fujita 1971). The 3-4 April 1974 "Super Outbreak" (Corfidi et al. 2010) provided a massive laboratory from which the effects of F5-level damage could be studied. Today, Next Generation Radar (NEXRAD), a nationwide network of 159 Doppler radars, is widely used to forecast supercells likely to produce tornadoes, and computer modeling has become quite accurate up to three days from present. Dr. Joseph Friday, former director

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[3] A symposium honoring the life work of Fujita was held in Long Beach, CA, in January 1999. Several key figures in meteorology were invited to lecture on his many accomplishments. Their presentations were penned into manuscripts, and can be found in Bulletin of the American Meteorological Society 82(1): 9-118.

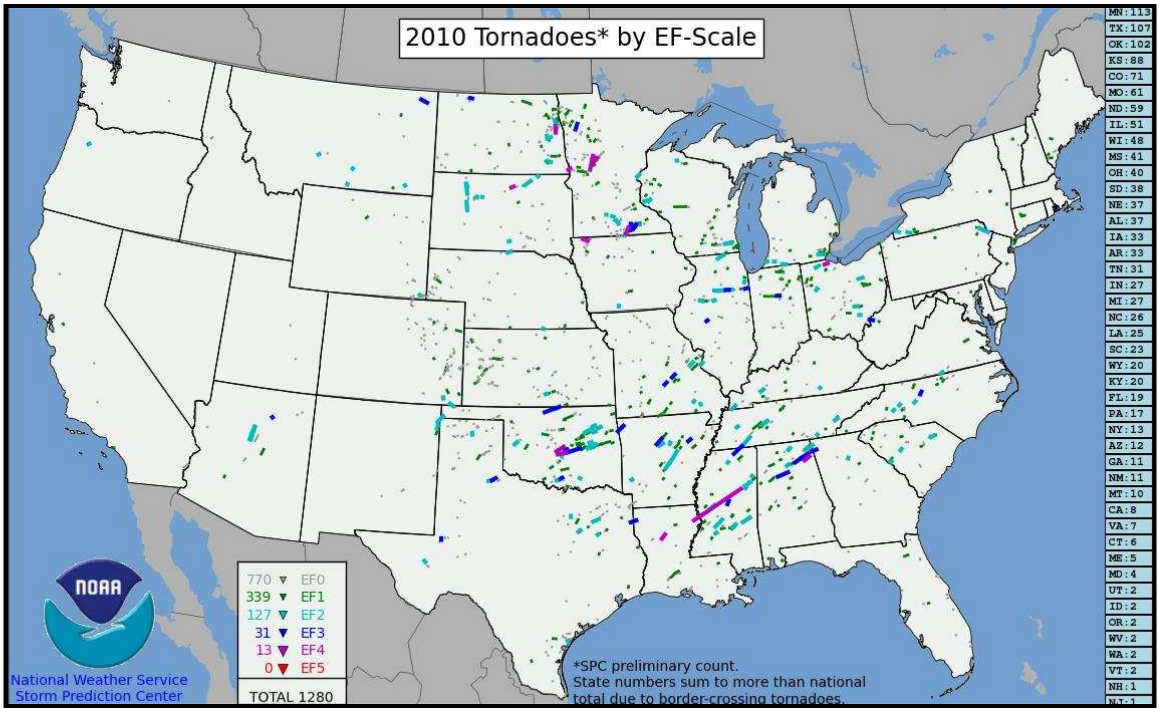
of the National Weather Service, stated that forecast modeling has hit what is known within meteorology circles as the “Hallgren Wall.” Up to twenty-four hours from present, computer models and human forecasts present roughly the same level of accuracy. Human forecasts add very little if any value to a computer model in the 24-72 hour period, and actually decrease the accuracy of computer models that span beyond 72 hours (personal communication, March 2011). Proprietary software developed by Baron Services ® uses radar signals in conjunction with mesoscale models to rate the immediate potential for a tornado to form out of a particular cell. The potential hazard is then ranked on the interval [0, 5], a scale called the Baron Tornado Index (BTI), and reported to the public via media outlets which have paid a user fee to Baron Services (Baron Services 2008).

A Brief Overview of Tornadoes in the U.S.

Over the course of a calendar year, the U.S. sees anywhere from 800 to 1,400 tornadoes (1,280 in 2010, Figure 1.1), but only a small fraction cause fatalities. Killer tornadoes struck 22 times and caused 45 deaths in 2010; with 58 on average per year in the 10 year period 2000–2009 (NCDC 2010a; SPC 2011), but fatalities from tornadoes actually have been steadily decreasing for over 50 years (Ashley 2007). Although the number of tornadoes reported each year, beginning in 1950, has been steadily increasing (Figure 1.2), it is believed to be a function of better detection and forecasting methods, increased population in the U.S., better awareness of tornadoes by the public and the recent advent of technology such as cellular phones and the Internet, rather than an increase in the actual number of events (Ray et al. 2003). The study of tornado distribution and frequency as well as the reliability of the National Oceanic and

Atmospheric Administration (NOAA) tornado record remains a key focus for researchers (for key publications in these areas see the work of Charles Doswell, Harold Brooks, Roger Edwards, Dan McCarthy, Joseph Schaefer and Stephanie Verbout).

Figure 1.1: U.S. tornadoes, 2010 (source: National Oceanic and Atmospheric Administration/Storm Prediction Center).



While tornadoes have occurred in every month of the year, an increase in frequency begins in March, peaks in May, then trails off through the end of the year with a second, but much smaller peak in November (Figure 1.3). This pattern can be generally linked to the northward shift of Arctic air, the northward movement of dry air from the southwest and northward movement of moist air from the Gulf of Mexico region; all of which occur in the spring. These three different air masses produce the conditions necessary for thunderstorm formation, which can result in tornadogenesis. However, it should be noted that peak time varies by location within the U.S., beginning earliest in the south and moving northward as the year progresses. The increase in solar heat also contributes to the higher frequency during spring and summer months. Because of this, there is no recognized tornado season for the U.S. as a whole, but varying seasons determined by geography. Time of day also plays an important role in occurrence, with more tornadoes forming in mid-to-late afternoon and evening than early morning or late evening and/or night (Figure 1.4). Thunderstorms gain energy from solar heat and the release of heat by condensing water vapor in the atmosphere, and these tend to be at their peak in the late afternoon.

Figure 1.2: U.S. tornadoes, 1950-2010 (source: National Oceanic and Atmospheric Administration/National Climatic Data Center).

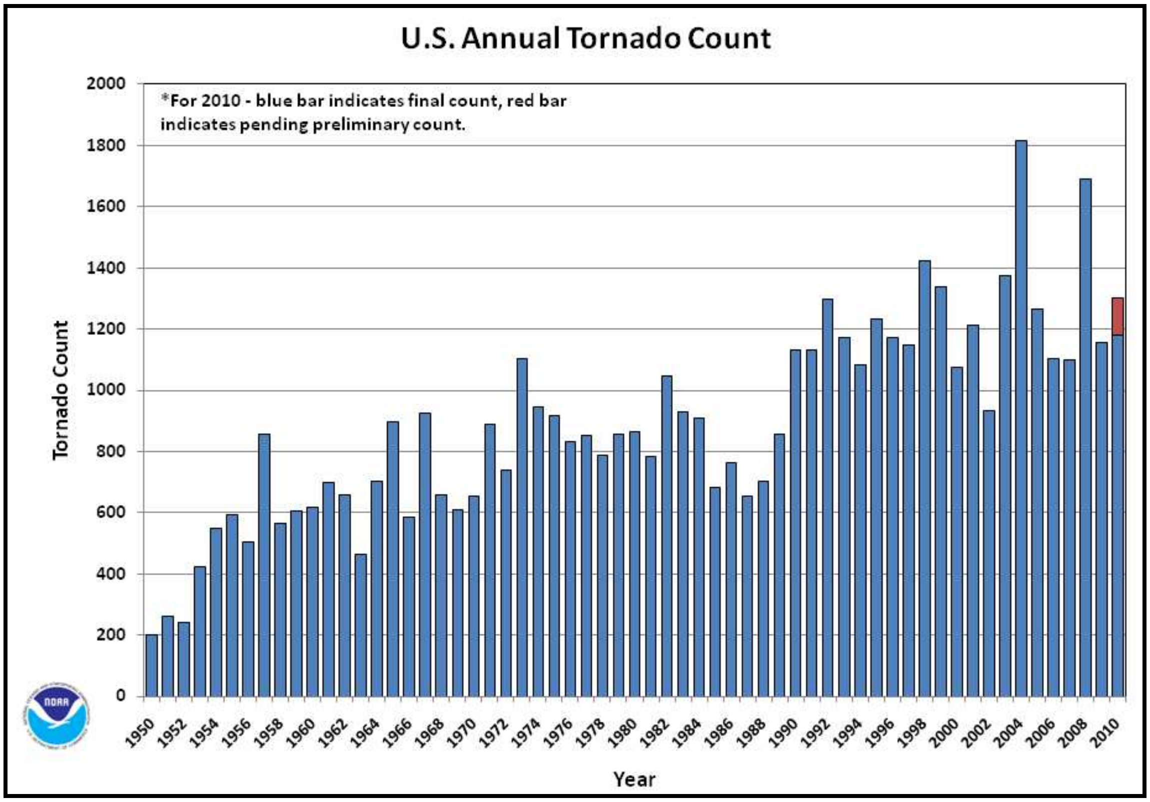


Figure 1.3: U.S. tornadoes by month, 1950-1999 (source: Oklahoma Climatological Survey).

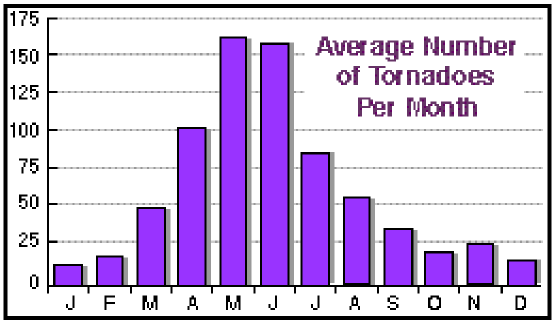
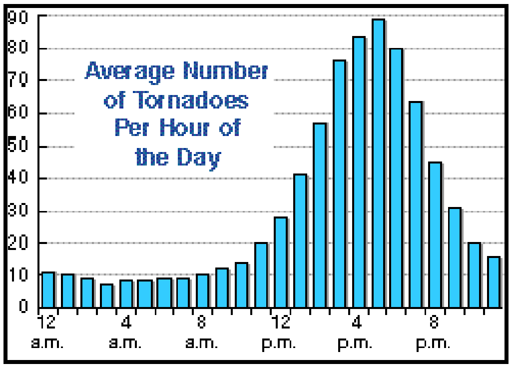


Figure 1.4: U.S. tornadoes by hour of the day, 1950-1999 (source: Oklahoma Climatological Survey).



Beyond the Physical

Tobin and Montz (1997) wondered why, if our scientific understanding of physical processes continues to increase, people continue to die from disasters. They went on to state that the losses stemming from a disaster do not result completely from the physical aspects of the phenomenon, but that the dynamics of the society impacted must also be considered. That sentiment was echoed by Cannon and Müller-Mahn (2010) who stated that disasters are socially constructed events, and that the results of a disaster are the product of the physical impact of the phenomena and the people affected. Hazard researchers frame this dynamic in the concept of social vulnerability, defined by Cutter and Finch (2008, 2301) as, “a measure of both the sensitivity of a population to natural hazards and its ability to respond to and recover from the impacts of hazards.”

After the 1906 San Francisco earthquake killed an estimated 3,000 people (USGS 2006), Abraham Himmelwright (1906, 13), a New York architect working for a firm hired to assess buildings in San Francisco after the event, wrote that, “Earthquakes are…natural phenomena and seldom cause loss of life, except indirectly, as when buildings collapse, etc." Himmelwright realized that people possess the ability to mitigate against mass losses by examining and altering the practices by which they construct the world around them. Nonetheless, the social influence on disaster impact remained largely in the background until the 1950s, when the notion of societal contributions to disaster magnitude began to receive serious attention in academia (for a seminal work concerning how societies respond to disasters, see Form et al. 1956). Since then, vulnerability studies have examined myriad factors that influence the degree to which people may be potentially harmed by natural or human-induced catastrophes.

Vulnerability study results generally produce measures of the potential for harm, and scales measuring natural disasters focus on the physical strength with which the phenomena strike; the coalescence of these two considerations as they relate to communities that are impacted by a natural disaster remains a lesser-studied topic. Cross (2001) stated that while the likelihood of a small community experiencing a natural disaster is less probable due to its smaller physical size, the amount of suffering and the level of impact are heightened. This is not to say that large communities are not impacted by disasters, but that they possess greater resources (or a greater adaptive capacity) to call upon for recovery, and the total community impact is lessened as the effects and response are distributed over a wider area (Gardoni and Murphy 2010).

The social make-up of the community must be considered, as it is the very people affected that must take on the burden of recovery. Most disasters are caused by geophysical systems that lay well beyond the boundaries of human control. Yet it is widely accepted that within our social institutions and structures the concept of vulnerability has an intangible hand in producing the immediate and on-going impact of an event (Nelson and Finan 2008; Cannon and Müller-Mahn 2010). Researchers now see that who we are may be just as important as Immanuel Kant's chorologic and systematic perspectives of where we are, and what happens there. Richard Hartshorne saw the where, what and how as geography's most central themes (Sack 1974), but it is now accepted that the who is critical in understanding how disasters impact communities.

Objectives

Ultimately, the primary objective of this research is to answer questions concerning how extent of damage, vulnerability of the population and size of a community relates to impact. Does an EF2 tornado impart the same impact in Sioux City, Iowa, as it does in Dallas, Texas? If a large EF4 skims the outer edge of Mobile, Alabama, does it impact that community in the same manner as an EF4 that runs the length of downtown Lincoln, Nebraska, on a football Saturday? A dataset that includes information on the physical aspects of tornado events from 2000–2009 in the coterminous United States was used to create and evaluate an index which sheds light on the human component of the tornado hazard.

Social metrics used here include the monetary damage done to a community and the number of fatalities resulting from the tornado. Injuries are not included since there is a vast spectrum of the severity of injuries; this is discussed further in Chapter Three. The Abbreviated Injury Scale (AIS) and Organ Injury Scale (OIS) rate injuries on a scale from one (minor) to six (unsurvivable) (Gennarelli 2008; AAST 2011). Minor injuries such as broken fingers are recorded in the Storm Prediction Center's (SPC) data the same as major injuries such as head trauma that may ultimately lead to death. As such, the SPC tornado record provides no description or coding which indicates the severity of an injury, and hence, the cumulative impact of injuries cannot be reasonably described based on the available data.

Data were collected from recognized government sources, namely the SPC and National Climatic Data Center (NCDC), and used within a geographic information system (GIS). Community/tornado track intersections were then linked to tabular data on deaths and monetary damage. A second aspect of the communities in question, the level of social vulnerability, was also considered. Indicators such as age, race, income and level of education for all U.S. communities were collected from the U.S. Census Bureau to serve as a baseline for constructing social vulnerability scores. Using this two-part dataset and the methods presented herein, index and category scores were calculated. These are meant to quantify impact on each community intersected by a tornado path during the study period. The goals of this research are to:

1. Present a method that combines an indicator of physical damage and human fatalities resulting from a tornado event with the pre-event vulnerability of a community into a single value and category score that describes to what level a community has been impacted by a tornado event;
2. Present a method (after Cutter et al. 2003) for calculating the vulnerability of U.S. communities;
3. Discuss the results across the U.S., by Federal Emergency Management Agency (FEMA) Regions, in order to point out the differing levels of vulnerability as well as the frequency of tornado occurrence within those regions;

4. Use the calculated TICV scores and categories for four selected communities across three FEMA Regions to discuss how the TICV can serve to effectively stand as an indicator of the level of impact for that community, illustrating how each community will view the event as unique to their set of circumstances.

Purpose and Importance of this Study

The main purpose of this dissertation is to create an index that will allow the public - those affected and those in charge of recovery - to understand the severity with which a tornado event has impacted a community. This index is developed based not only on the physical damage inflicted, but coupled with the social profile of the community. Studies such as the one undertaken here are important to the scientific community as its members further the understanding of how people interact with and are affected by both the natural and built environments.

The impact of a natural disaster is born of more that the physical damage to an area; impact also derives from the contribution of physical damage to the shift away from everyday life. High vulnerability to natural disasters can increase the impact of an event, as can the size of the community in which it struck; both of those factors are taken into consideration here. Conversely, lower levels of vulnerability can lessen the impact, as the community will have more resources to access in order to begin and sustain a successful recovery. Scales that focus on the physicality of disasters seek to increase understanding of physical processes, and through further understanding of those processes, advanced warning systems can be developed which can aid in mitigation against hazards.

This research examines hazards from a different perspective, and attempts to provide insight into how the populations of areas are affected by disasters. Furthering the knowledge base of the impacts on people and communities should be seen as equally important as furthering the knowledge of physical processes (Flanagan 2011). With an enhanced ability to relate impact to the characteristics of a community and its residents, decision-makers may be able to gain a better understanding of not only what types of communities are at heightened risk from natural hazards, buy why they may be impacted to a heightened degree. As will be shown in Chapter Two, Literature Review, there is currently no scale in place for tornado events that describes them from the point of view of impact on human populations. For the purpose of this work, this index will hereinafter be referred to as the Tornado Impact-Community Vulnerability Index (TICV), and the category scheme will be referred to as Tornado Impact-Community Vulnerability Index Categories, or simply Tornado Categories (TCs).

Structure of this Dissertation

Chapter Two provides a review of the literature relevant to this research, with topics including types of vulnerability and their relation to natural hazards. The review continues with an examination of several different indices concerning both societies in general and those specific to vulnerability to natural hazards. The literature review concludes with a discussion of indices and taxonomy of natural disasters as well as a discussion of Value of Life (VSL) studies.

Chapter Three begins with a description of the types of data used in this research and the sources for those data. As the need to transform the data gathered here into a usable format was intensive, a description of those methods, as well as problems encountered, is described. Those procedures are detailed for both GIS shapefile as well as tabular census data. Next, the methods used to construct the TICV and its core components (damage score and vulnerability score) are explained, which resulted in the TC scheme creation. Chapter Three concludes with a description of data retained as a result of the cleaning and formatting procedures, and finally, the study area is described. Traditionally, the study area for this type of research is described first. However, in this research, the study area of included tornado events was determined by the methods and procedures employed rather than the researcher (although the coterminous United States was selected by the author as the initial area of study, and is used in the vulnerability component construction). Because of this, the study area followed from the methods employed to determine that area, and is described last in Chapter Three.

Chapter Four describes the results by the ten FEMA Regions throughout the U.S., with those experiencing a higher frequency of tornado events described in more detail than those with lesser frequencies. The Discussion section of Chapter Four examines in closer detail the TICV and TC score for four events, and compares and contrasts them according to what the TICV and TC mean for each community. The idea that an index value cannot be seen as the ultimate explanation for an event is discussed in The Sense of Place and Loss section in Chapter Four, with special attention paid to how people and communities in general view place as an important aspect of life, and how people deal with losses stemming from a traumatic event. Chapter Four concludes with a discussion of potential practical applications of the TICV. In conclusion, Chapter Five summarizes the research as it is presented here, identifies the major findings of this research, discusses its limitations and outlines possible future directions for this topic. Appendices appearing at the end of the document list complete tornado event retention values for states included in this research, as well as a complete list of all communities in the dataset including summary statistics of the tornado event in each community and the TICV and TC calculated. The final appendix includes, for easy reference, a list of all acronyms used within the text.

CHAPTER 2 - Literature Review

When we were children, we used to think that when we were grown-up
we would no longer be vulnerable. But to grow up is to accept
vulnerability... To be alive is to be vulnerable.
Madeleine L'Engle

This chapter provides an overview of the literature concerning vulnerability and natural hazards, as well as a review of index-based measurements used to describe not only pre-event vulnerability, but post-event magnitude and impact. Vulnerability is a widely studied concept within fields of many social and natural sciences including sociology, psychology, health and medicine, politics, anthropology, geology and geography (Adger 2006; Eakin and Luers 2006).

Human beings, as well as the social and physical constructions that make up their world, are at risk from any number of potential hazards. Latent risk is all around us and apparent at all spatial scales (Birkmann 2006; Cardona 2006). From seemingly mundane tasks such as driving to the store for groceries to tests of humans versus gravity, for example, skydiving, there exists around us a near infinite set of possibilities for us to find harm, or for harm to find us. Some of those possibilities are simply unavoidable and some are not. But what puts us at risk? What makes us vulnerable to harm? For the skydiver, the risk is obvious; one should expect a greater chance of death if one leaps from an airplane flying 2,000 meters above the ground. For the homemaker stopping to buy food, some of the risks are also fairly obvious; traffic during the drive, a slippery floor or an armed assailant robbing the store while they shop. But as people go about everyday life within the communities in which they live, constructs across space and time such as access to resources, age and health of the population, density of the built environment and the types of houses in which people live all may increase or decrease the potential for the community as a whole to experience heightened or lessened effects from disasters (Lindsay 2003; Chang 2007; Cutter 2008; Sutter and Simmons 2010).

Vulnerability and Natural Hazards

In developing an index that suggests the extent to which a community has been impacted by a disaster, it is necessary to first discuss why one community may suffer more or less than another as a result of a natural disaster. Natural hazard researchers and other social scientists view the level to which a community may be affected in terms of vulnerability. The etymology of the word vulnerability indicates harm, as its Latin root means literally, “to wound.” An examination of the published literature concerning vulnerability reveals a wide range of definitions, but a common theme emerges; vulnerability is the degree to which a person or community is at risk for harm. In the context of this research, the potential harm stems from the naturally occurring phenomena of tornadoes. Geographers are perfectly suited to address this issue, since, according to Cutter (2001), “The vulnerability of people and places is an inherently geographical problem, one that necessitates a spatial solution.”

Thywissen (2006) identified 29 variations on the definition of vulnerability in the literature. While researchers are busy at work trying to quantify, describe and ultimately reduce vulnerability, there exists no universal definition for what the term means. Birkmann (2006, 14) cited the United Nations International Strategy for Disaster Reduction (UN/ISDR 2004) definition as one of the, “best-known;” as stated, vulnerability is defined by, “The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of a community to the impact of hazards." The UN/ISDR recognizes that vulnerability is tied to and affects communities, but unlike the United Nations Development Programme (UNDP) definition, it does not directly connect people to vulnerability. The UNDP (2004, 11) stated that vulnerability is, "…a human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard." This dissertation examines vulnerability at the community level, but recognizes that it is the aggregate vulnerability of the people within those communities that provides an indicator of vulnerability for the community as a whole.

Thywissen's (2006) glossary went on to list over two dozen more definitions of vulnerability from academic areas including social science, natural science, general science (termed multidisciplinary), disaster management and engineering. While engineering tends to provide quantitative-based definitions of vulnerability, most of the remaining definitions have a common general theme: vulnerability is a degree to which a person, group of people or some other larger areal unit are susceptible to harm from some external input. The UN/ISDR and UNDP, as well as Davidson (1997) and Bollin et al. (2003), identify four categories of vulnerability (which are further discussed below) that can contribute to the level of risk as mentioned above; these are:

1. Physical
2. Economic
3. Social
4. Environmental

Vulnerability is also seen as having a double structure: external and internal. Bohle (2001) noted that external sides of vulnerability include those that expose populations to shock and risk, but are not created or nurtured from within the group, such as physical threats; e.g., earthquakes, floods, tornadoes. The internal side of vulnerability is concerned with the ability of a population to cope with those external forces. Mitigation practices seek to reduce the impact of external forces by reducing vulnerability to them, and as such, constitute part of the internal dichotomy of the double structure.

Physical Vulnerability

The physical aspect of vulnerability is concerned with man-made infrastructure (Etkin 2003) as well as the physical presence of natural hazards such as landslides, earthquakes and volcanoes (Green and Rose 2005; Dominey-Howes and Papathoma 2007; Douglas 2007, Uzielli 2008). These considerations are usually examined alongside the placement of human populations to determine what tangible (physical) harm may come to people and infrastructure in a given area if an impending hazard physically manifests into a disaster. Hewitt and Burton (1971) noted that this concept connects humans and the built environment to the physical surroundings. People and property, therefore, cannot be separated from the physicality of hazard vulnerability; although social vulnerability (covered below) attempts to understand those relationships more thoroughly through the lens of human social considerations.

The focus of physical vulnerability studies includes the physical dimensions and features of disaster events such as duration (length of the event), seasonality (time of year the event occurs), frequency (how often the events reoccurs), rate of onset (how fast the event strikes), diurnal factors (time of day the event occurs) and magnitude (the physical strength of the event). Using those dimensions, as well as the geophysical or atmospheric structure and behavior of hazards and disasters, GIS modeling of potential impacts over given areas has become a major focus. The purpose of such modeling endeavors is to produce vulnerability and risk assessment maps for decision-maker and general population consumption (e.g., Zerger and Wealands 2004; Usul and Turan 2006; Vickery et al. 2006; Tarantino et al. 2007; Ebert et al. 2009; McLeman et al. 2010).

Economic Vulnerability

The economic aspect concerns attributes with a monetary value attached to them. These can include the value of land being used by people for some practical reason such as agriculture, the gross domestic product (GDP) of a nation or sources of import and export. The vulnerability of a community or nation in terms of economics is concerned with the nature of exogenous shocks that can render the location more susceptible to the effects of climate, environmental change, land use change or natural disasters (Bruguglio 2008). Cordina (2004) stated that the conditions that make a population more economically vulnerable can either result from inadequate economic growth or contribute to its continuance. Studies of this nature are often applied to import/export dynamics, the GDP and/or tourism economics of small nations or nation-states and small island developing states (SIDS), and have shown that increased risk and vulnerability negatively affects economic growth (e.g., Glezakos 1984; Guillaumont 1987, 2010; Bruguglio 1995; Meheux and Parker 2006; Turvey 2007; Boruff and Cutter 2007; Biswajeet 2010).

Social Vulnerability

When framing the discussion around topics such as age, ethnicity and race, physical and mental health, education, affluence employment and housing stock/tenure, (Cutter et al. 2003; Glavac et al. 2003; Mayhorn 2005; Sutter and Simmons 2010; Worts 2010), one is examining the concept of social vulnerability: how much in harm's way are we as a result of social factors in combination with the power of destructive natural events? Social vulnerability primarily concerns the determination of what social and demographic factors are thought to raise or lower a person's risk from harm due to a disaster. These factors, as listed above, compromise what Cutter et al. (2003) called the social profile of a community (also see Blaikie et al. 1994; Enarson and Morrow 1998; Buckle 2000; Putnam 2000; Tierney et al. 2001).

White (1945) and later Kates (1971) and Mileti (1980) were among the first to recognize the need to include the populations that inhabit areas at risk as well as the physical components of those areas. However, vulnerability studies have only become widely used within roughly the last fifteen years (Wisner et al. 2004). Increasingly studied in recent years, research has shown there are distinct groups of individuals that consistently exhibit higher or lower levels of vulnerability. The less affluent, the young, the elderly, persons who are physically or mentally disabled and require care from others, ethnic and racial minorities, immigrants (including non-native speakers), the unemployed, the unmarried and women are believed to have higher levels of vulnerability. Conversely, the affluent, post-adolescent to middle-aged males in good physical and mental condition, ethnic and racial majorities, indigenous persons (including native speakers), those gainfully employed and the married are believed to possess lower levels of vulnerability (Enarson and Morrow 1998; Putnam 2000; Wisner 2001; Cutter et al. 2003; Glavac et al. 2003; Handmer 2003; Turner 2003; Fothergill and Peek 2004; Wisner et al. 2004; Cutter and Finch 2008).

Social vulnerability is a complex concept, as levels can change over time if the conditions contributing to the system of vulnerable persons improve. For example, increased access to political capital, better housing and employment opportunities and increased institutional and structural systems put in place all may potentially reduce the level of vulnerability of individuals and groups (Cutter et al. 2003; Wisner et al. 2004). Measuring changes has been noted as problematic, however; according to Turner et al. (2003, 8076):

> Realworld data and other constraints invariably necessitate a ‘‘reduced’’ vulnerability assessment. Nevertheless, analysts must remain aware that vulnerability rests in a multifaceted coupled system with connections operating at different spatiotemporal scales and commonly involving stochastic and nonlinear processes.

The temporal and spatial scales are important to consider when undertaking vulnerability assessment. Data analysis performed at the national level may not accurately reflect a social profile at the sub-national (state, county or community) level, since there may exist unique sets of circumstances in localized areas that could yield different results at different scale, as demonstrated by Schmidtlein et al. (2008). This is referred to as the modifiable areal unit problem (MAUP) within the context of spatial analyses (Openshaw 1984). Albeit a complex and highly interrelated and interdependent concept, studies of social vulnerability will undoubtedly continue into the foreseeable future. The ultimate goal of any study of such nature is to better explain and help to alleviate the conditions that put populations in positions within society, both physically and socially, that may increase their level of vulnerability.

Environmental Vulnerability

Oluoko-Odingo (2011, 6) provided a definition of vulnerability that addressed environmental concerns; she stated that vulnerability is, "…the degree of loss resulting from a potentially damaging phenomenon or insecurity of the well-being of individuals or communities in the face of a changing environment." Environmental vulnerability studies largely examine the degree to which earth systems are put at risk due to climate and environmental, changing patterns of land use, sustainability and coupled human-environment systems (Turner et al. 2003; Eakin and Luers 2006). As human population continues to expand so too does the stress applied to natural systems. Increased use of land for farming, urbanization, pollution and land degradation all contribute to increased pressure on geophysical and atmospheric processes.

In terms of natural hazard and disaster research, the concept of environmental vulnerability becomes important in that degraded and over-worked natural systems that provide human populations with the basic necessities of life (e.g., access to food and water) may present increased levels of vulnerability to disasters. Not built of the social systems and institutions of humanity, should these physical systems cross thresholds where they can no longer provide for people, the resulting lack of access to resources may increase risk for those in already vulnerable situations. They may also place new sectors or groups of a population at risk, when they may have not been prior to the lost use of the natural system in question (Berkes et al. 2003; Chapin et al. 2004).[4]

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[4] For a lengthy review on vulnerability as it relates to environmental change see Adger 2006.

Models of Vulnerability

Developing conceptual frameworks, or models, for the study of vulnerability provides an overview of the complexity of the topic. Several models of vulnerability and related core components appear in the literature (e.g., Adriaanse 1995; Maclaren 1996; Cardona 1999; Bohle 2001; Bollin et al. 2003; Turner et al. 2003; Bogardi and Birkmann 2004; UN/ISDR 2004; Birkmann and Wisner 2005), but the Risk-Hazard (RH) model and Pressure-and-Release (PAR) models in particular have been identified by Turner et al. (2003) as the archetype for vulnerability analysis. The third model reviewed below, the Hazards-of-Place (HP) model, is also widely viewed as a seminal framework in vulnerability studies.[5]

Risk-Hazard Model

The purpose of the RH model is to explain the impact of a hazard as a direct result of a population's exposure to the manifested hazard (disaster) and the degree of sensitivity to the exposed population (Burton et al. 1993). The model is fairly straightforward, but possibly too much so. Turner et al. (2003) stated that, as the result of further study, the RH model has been shown to possess severe shortcomings. According to the authors, the RH model:

1. has no function that describes how the system described can lessen or increase impacts;
2. does not account for sub-system variation which could lead to a great deal of variation in the impact of a hazard;

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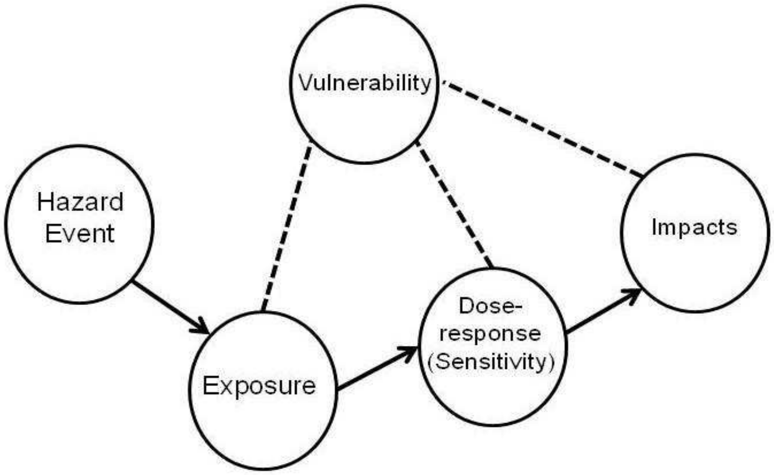
[5] According to the ISI Web of Knowledge, Cutter's 1996 paper Vulnerability to Environmental Hazards has been cited 138 times as of 11 February 2011.

3. does not allow for social considerations to affect levels of exposure.

In Figure 2.1, the dotted lines connecting vulnerability to the exposure, sensitivity and impact nodes are implicit in their relationship to those nodes. Vulnerability, as an input separate from the hazard, affects the exposure of the population, and the response ultimately figures into the level of impact experienced. The RH model represents a classic view of how hazards relate to impact.

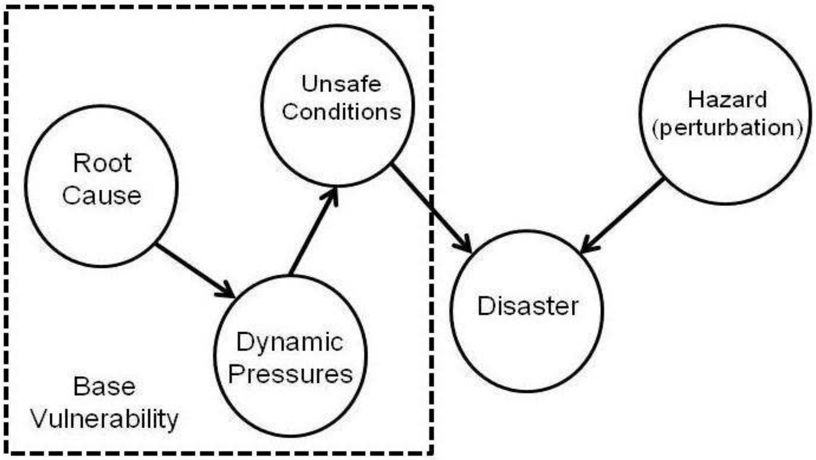
Figure 2.1: The Risk-Hazard Model (based on: Turner et al. 2003).



Pressure-and-Release Model

The PAR model, devised by Wisner et al. (2004, 50), places disaster at the "intersection of two opposing forces," the base (or progression of) vulnerability and the hazard (the perturbation, or disturbance of a previous state) (Figure 2.2). Labeled the root cause, dynamic pressure and unsafe conditions, vulnerability is, as with the RH model, separated from but related to the disaster event. The dynamic pressure is applied to a population from the root causes that ultimately create the unsafe conditions. The root causes are seen as being temporally or spatially distant, and most importantly include economic, demographic and political processes. They represent influences on the social characteristics of the community that may have been put in place several generations prior to present time, or are institutions which operate at a great physical distance from the community in question. Increased vulnerability stems from the root cause in the PAR. The release results from the reduction in the level of vulnerability through improved structural conditions within the community. The disaster impact then is a function of both pre-existing conditions within the population and the physical event itself.

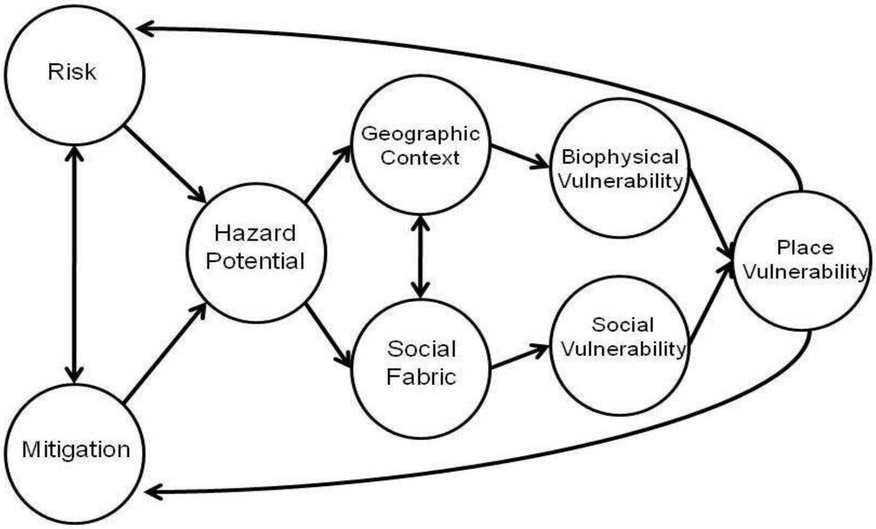
Figure 2.2: The Pressure-and-Release Model (based on Wisner et al. 2004).



Hazards-of-Place Model

Cutter (1996) developed the hazards-of-place (HP) model as a way to bring together physical (termed in her model biophysical) and social considerations of vulnerability (Figure 2.3). While each of these is centered around the potential for harm, they all approach how people and institutions are placed in positions of risk in different manners. For example, examining the physical vulnerability is a very different exercise than delving into the economic vulnerability of a given area; the two; however, are interrelated. Risk levels affect the mitigation strategies employed, but lack of mitigation increases risk. Both risk and mitigation work together to determine the potential harm from a hazard. This potential must be examined in terms of both the geographic context (where a disaster might occur) and the social fabric of the population at risk. This implies that both place and profile of a community must be considered when determining vulnerability.

Figure 2.3: The Hazards-of-Place Model (based on Cutter 1996).



The geographic context in connection with all previous nodes leads to the level of biophysical vulnerability while the social fabric leads to the level of social vulnerability. It is these two final nodes, location and characteristics of a place, that determine its vulnerability. The place vulnerability then connects back to risk and mitigation, in that depending on the level of that vulnerability, risk is either increased or decreased, and mitigation practices can be adjusted to lessen vulnerability. Cutter's HP model represents a complex and interdependent system where pre-event vulnerability is determined by myriad factors. Concepts such as vulnerability, when quantified, are often communicated using an index. The next section deals with the creation and use of indices regarding health, vulnerability and natural hazards and their impacts on society.

Indices

"The acid test for a new tool on how 'natural' and easy it is to understand and how well it integrates within existing theory, is whether it is accepted by those who need to use it, and how well it works in solving their problems" (Saaty 1980, 4). When developing his analytic hierarchy process (AHP), Saaty was primarily concerned with how to best decide what components are most appropriate to include in an analysis of some set of circumstances which may traditionally be viewed as difficult to quantify. Analysts can employ many different quantitative methods to determine a set of components suitable for use in the description of some natural or social phenomenon; the end result of such an exercise is likely to be an index (Nardo et al. 2008). According to Farell and Hart (1998), indices are most generally used to bring a quantifiable meaning to qualitative situations. This chapter continues with an overview of the use of indicators of vulnerability. In the two subsections that follow, selected indices dealing with society, vulnerability and natural hazards and disasters are reviewed and summarized in Table 2.4 with additional indices listed.

Indices Concerning Health, Vulnerability and Natural Hazards.

The following subsections review the literature focused on the creation of indices for not only vulnerability and hazards, which is the focus of this research, but on human health as well. Linsday (2003) stated that, the health of the human population in the area affected by a disaster is a major concern. Healthier populations are less vulnerable to the effects of a disaster, and are thus able to recover more quickly than those populations that are of poorer health. The review on health-related indices here is not meant to be comprehensive, since that area is not a primary focus here, but is nonetheless worth noting. The concept of population health relates to socioeconomic conditions and social environments (Zoller and Lessof 1998), and those considerations relate directly to the concept of social vulnerability.

The Air Quality Index (AQI)

One of the most well known indices used to measure large-scale phenomena and put it into terms applicable to people is the AQI. This indicator was initially developed as the Pollution Standards Index (PSI) by the United States Environmental Protection Agency (USEPA) in 1976 (Bishoi et al. 2009). Thom and Ott (1976) defined this index as one that reports the quality of surrounding air with respect to the health of people breathing in that air. The AQI uses the concentrations of five pollutants, carbon monoxide, nitrogen dioxide, ozone, particulate matter and sulfur dioxide. Pollutant values are converted into a single index value by a relatively simple piecewise linear function (Equation 2.1) that utilizes concentration (C) breakpoints and index (I) breakpoints above and below pre-defined thresholds (USEPA 2009).

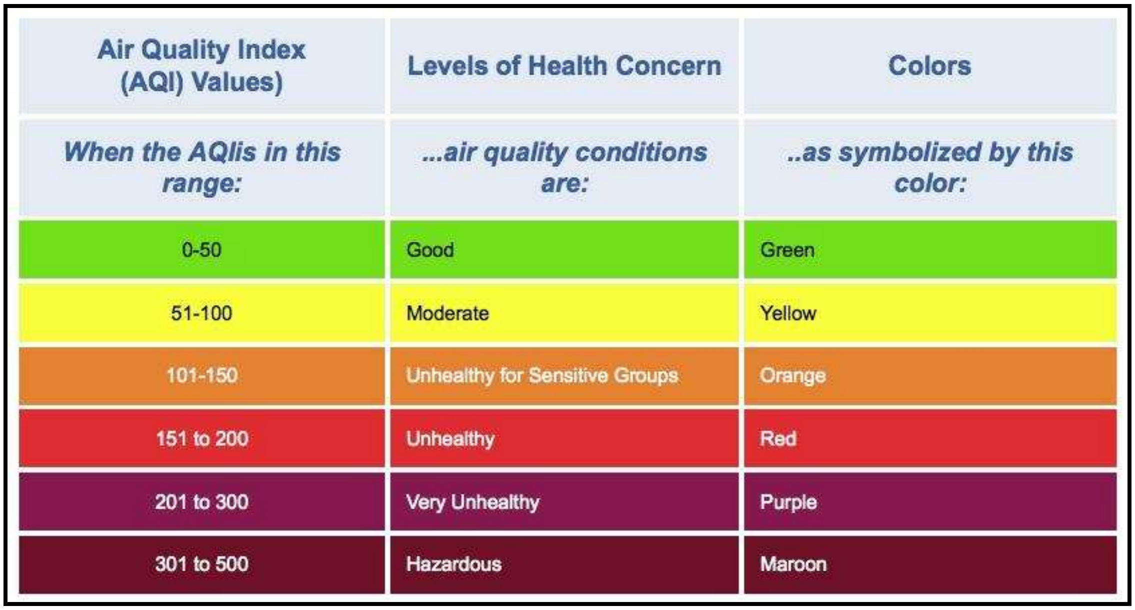
Equation 2.1: The Air Quality Index (source: USEPA 2009).

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low}$$

The purpose of the AQI is simply to inform a population as to the safeness of the surrounding air, and what some possible health effects (vulnerabilities) may be if polluted air at given levels is inhaled. The AQI is set on the interval [0, 500], with zero representing the least polluted air and posing lowest level of risk, and 500 representing hazardous levels of air pollution and the highest risk (Figure 2.4).

The AQI is calculated daily using data from over one thousand sensors, and as mandated by federal law, reported to the public for cities with a population of more than 350,000 (USEPA 2008). While different from the index developed herein in the respect that the AQI is collected at known locations on a routine basis, whereas the index developed in this research reports on events that do not by their very nature occur regularly, the AQI serves a similar purpose to the proposed TICV and TC: it is an information tool.

Figure 2.4: The Air Quality Index (source: USEPA 2008).



Air Quality Index (AQI) Values	Levels of Health Concern	Colors
When the AQIis in this range:	*...air quality conditions are:*	*..as symbolized by this color:*
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

There are many other indices targeted at ranking issues of human health,[6] one being the Body Mass Index (BMI), which is found by dividing a person's weight by their

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[6] A search of the Kansas State library's ISI Web of Knowledge using the term "index," within the document title then refining the search to medical and health related journals yielded a result of 34,175 articles as of 27 April 2011. Undoubtedly some articles

height squared (Keys 1972). Age is also taken into consideration, with children and teens commonly measured by the BMI-for-age scale (Must and Anderson 2003). While the BMI draws criticism as not fully explaining obesity in any particular individual (since considerations such as muscle mass can artificially inflate the BMI), it is the most widely used score to determine patterns of obesity across large populations. Obesity also can vary across cultures, which has led to the adaptation of the BMI on different scales for different countries.

The Influenza Epidemic Severity Index (IESI)

Created by Simonsen et al. (1997), the IESI examined deaths with flu as the underlying cause from 1972–1996 as well as deaths from all causes for the same period. Using a cyclical regression model, the authors fit the least-squares line through each annual data set and developed a range of deaths that could be attributed strictly to influenza and pneumonia. The authors broke this data into equal interval categories of the actual number of deaths, and this data was then transferred into categories that describe the severity of the outbreak, with category one representing a mild outbreak and category ten a severe outbreak. The AQI, BMI and IESI all serve to assign an index value to some aspect of human health and in the process, hopefully, allows the situation to be better understood.

The Social Vulnerability Index (SoVI)

Cutter et al. (2003) developed the SoVI with the intention of describing, at the county level, vulnerability to environmental hazards. Using 42 variables reduced from an

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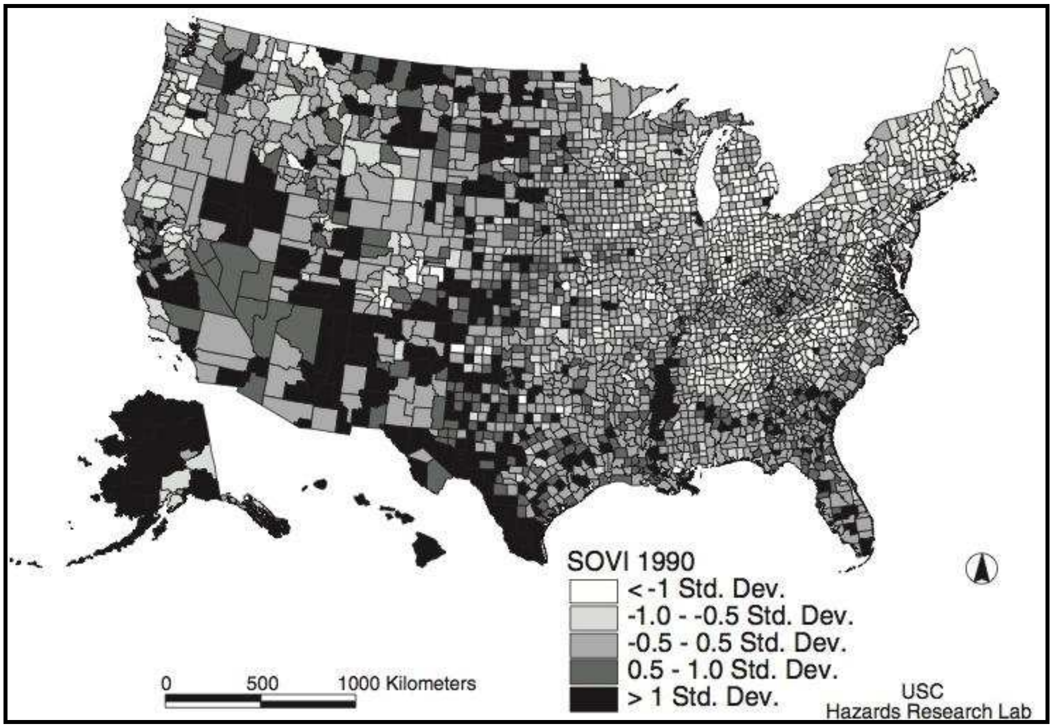
address the same index, but this serves to illustrate the ubiquity with which indices are used concerning human health.

original set of 250 by testing for multicollinearity, principal components analysis (PCA) was applied to discover what variables described the most variance within the dataset. The PCA produced 11 factors that explained 76.4 percent of the variance across all U.S. counties. The results showed that personal wealth (per capita income being the dominant variable) was the highest rated factor, explaining 12.4 percent of the variance in the dataset, followed by age at 11.9 percent and density of the built environment (number of commercial establishments per square mile) at 11.2 percent.

Figure 2.5: Comparative vulnerability of U.S. counties based on the Social Vulnerability Index (source: Cutter et al 2003).



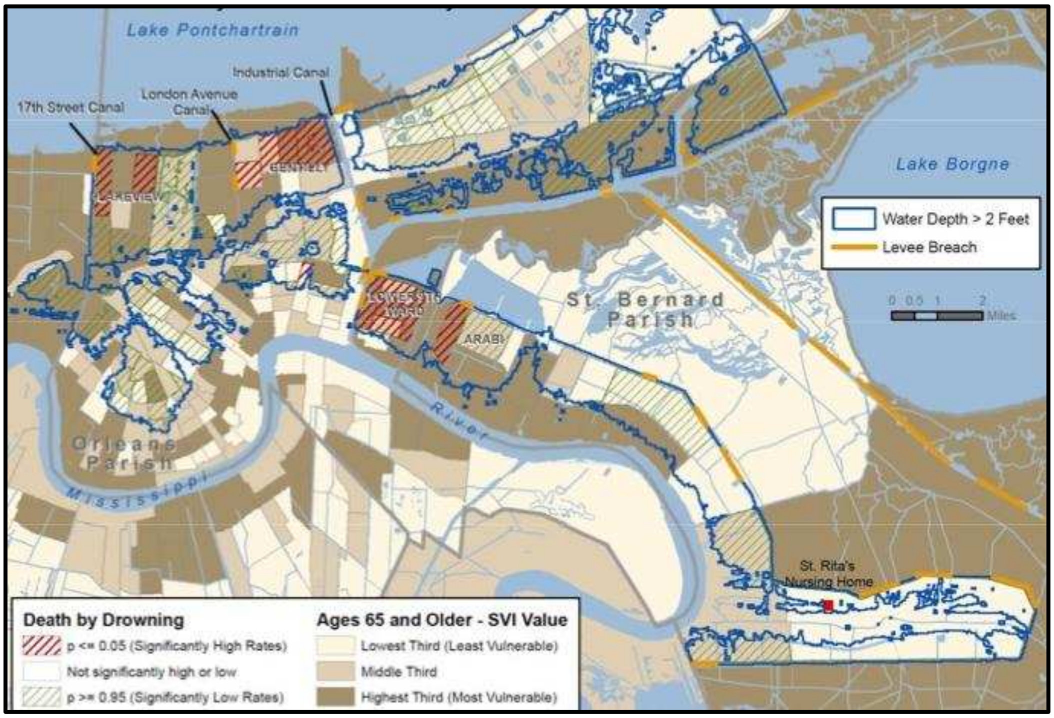
In order to produce the SoVI, the authors placed the factor scores for each county into an additive model that resulted in a composite index score of vulnerability for each county in the U.S., and displayed the results as a measure of standard deviation (Figure 2.5). Lower standard deviation equates to lower levels of vulnerability and higher standard deviation equates to higher levels of vulnerability. The results showed that counties with high density of the built environment, high degrees of racial and ethnic inequality and socially dependent populations all contributed to high levels of vulnerability in a given county. Conversely, counties on the low end of the SoVI all exhibited large populations of Caucasian, wealthy, highly educated persons in suburban (less densely populated) areas. Cutter et al. (2003) illustrated a collection of a wide range of variables narrowed down through statistical techniques, with the final result, the SoVI, producing a single value that described the potential for counties in the U.S. to be harmed by environmental disasters.

A Social Vulnerability Index (SVI) for Disaster Management

Flanagan et al. (2011), echoing White (1945) noted that through the twentieth century, disaster management has typically focused on structural and technological solutions. They further recognized that socioeconomic concerns were not given much attention within disaster management institutions until the 1970s. According to the authors, the concept of social vulnerability is more often than not ignored when mitigation practices are studied and implemented.

The HAZUS-MH (Hazards United States-Multi-Hazard) software package, first produced by FEMA in 1997, received an additional set of tools in 2009. The latest version includes the ability to incorporate social considerations in disaster risk mapping. Flanagan and his colleagues considered the domains of socioeconomic status, household composition and disability, minority status and language, and finally, housing and transportation census data at the tract level to construct the SVI. Their methods involved using 15 census variables that describe vulnerability in terms of the four domains listed above, and included all 65,081 census tracts in the U.S. The percentile rank for each tract was calculated, then a count (termed flags) of each individual variable with percentile ranks over 90 was found. The total number of flags was then used to identify census tracts that may have high vulnerability as indicated by a high percentile rank in at least one of the domains examined.

Figure 2.6: Katrina-related drowning deaths and Social Vulnerability Index for the elderly (source: Flanagan et al. 2011).



Their results were then imported into a GIS environment, and analyzed using the HAZUS-MH flood modeling package (Figure 2.6). They displayed the results of the SVI as applied to potentially vulnerable tracts overlaid on the hurricane Katrina flooding events, occurring in New Orleans, LA, in 2005. Their results, while not conclusive due to a lack of some necessary data elements concerning mortality rates among the elderly, do show that the elderly were disproportionately affected by flooding. The SVI shows that the intersection of physical considerations, social vulnerability and the appropriate

GIS techniques can provide a very different picture of a disaster event when the population dynamics of an area or community are considered.

The Hurricane Vulnerability Index (HVI)

Another application similar to the SoVI and SVI dealt with coastal vulnerability focused on the impact of hurricanes and storm surge associated with them. Dixon and Fitzsimmons (2001) examined the vulnerability of Texas Gulf Coast communities to hurricanes. Using Saffir-Simpson intensity categories for historical hurricanes as well as population and property value data for each county, the authors developed an additive model resulting in five categories of risk scores and five exposure scores; the HVI is then found by adding the two scores. This method illustrated an attempt to combine not only data on events that have already occurred, but to couple those data with the potential for harm to a county given the population and assumed worth of the property in that community, creating an index value that served to assign a measure of potential loss in the event of a hurricane.

The Coastal Vulnerability Index (CVI)

In a work similar to the HVI, Pethick and Crooks (2000) created the CVI by examining the vulnerability of coastlines through the work of several other studies from a geomorphological perspective. Often these changes are the result of a high energy input such as storm surge resulting from a hurricane, but also occur slowly over time with sustained erosional inputs. Coastlines will maintain an equilibrium with environmental conditions until some threshold is reached. However, many small scale changes in coastlines do not lead to morphological change since many of the perturbations apparent along coastlines are not large enough to instigate any large scale change. The authors examined factors such as exposure of cliffs, sand dunes, spits, beaches, estuaries and salt marshes in terms of their contribution to vulnerability of the coastal system as a whole.

Compared to the indices reviewed above, the CVI is relatively simple: vulnerability is equal to relaxation time divided by return interval of an erosion event, where relaxation time is the temporal lapse between a given erosional episode. The CVI results in an index on [1, 10] where one represents the least vulnerability and ten represents the greatest. Cliffs showed the lowest contribution to coastal vulnerability while salt marshes, spits and estuaries showed the highest. The authors claimed that recognizing vulnerability is necessary in order to monitor periodic changes in coastal systems, which can aid in determining which events can be attributed to natural change and which may be anthropogenically initiated. They go on to state that human-induced change is likely to have a greater and more immediate impact on those coastal landforms with higher CVI scores, and that careful study of the thresholds of each landform should be conducted.

The Disaster Risk Index (DRI)

Peduzzi et al. (2009) examined droughts, earthquakes, tropical cyclones and floods from 1980–2000 in the context of loss of life to create the DRI, which was used in the UNDP (2004) report Reducing Disaster Risk. According to the authors, the DRI was the first index to examine the connections between vulnerability, the threat of disasters and the level of a country’s development. Calculated for all countries where data was available, their index took into account probabilities of disasters occurring and population of areas likely to have been affected by the onset of such disasters. The DRI allows the end user to specify the weight that should be assigned to the variable concerning deaths, allowing it to remain flexible and useful for both developed and developing countries, where levels of vulnerability can markedly differ markedly. The authors stated that future iterations of the DRI should include measures of severity of the disaster in addition to risk probability.

A Resiliency Index

Cutter et al. (2010) measured the resiliency of southern U.S. counties in FEMA Region IV (the southeast) to natural disasters. In the context of environmental and hazards research, resiliency is largely viewed as the complimentary counterpart to vulnerability as it indicates the “systematic characteristics that make systems more robust to disturbances” (Turner 2010, 573). The resiliency indicator of the ability to withstand and recover from the impacts of such hazards as hurricanes, flooding, tornadoes and sea level rise was created from 36 variables, reduced from an original set of 50. Data reduction was achieved through examining correlation coefficients as well as Cronbach's Alpha[7] measure to reach a level of internal data consistency (Nardo et al. 2008). Indicators were placed into one of five categories describing resilience: social, economic, institutional, infrastructure and community capital. The data was then transformed using the linear scaling transformation (a.k.a. the Min-Max) method, to create an unweighted index value on [0, 1]. The authors chose an equal weighting scheme for simplicity and ease of understanding, and further found,

> no theoretical or practical justification for the differential allocation of importance across indicators. While methods exist for determining weights that are subjective or data

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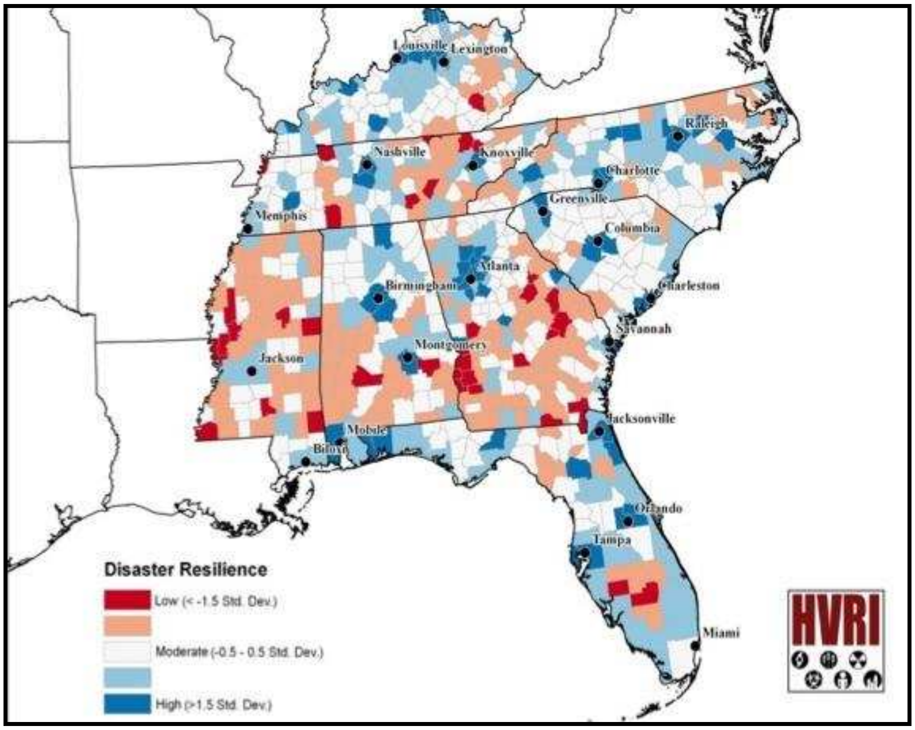
[7] Cronbach’s Alpha is used as a measure of the internal consistency of a dataset. The internal consistency of a dataset is said to be high when the correlations among the items in the set is high, which results in a higher Alpha statistic (Cronbach 1951).

> reliant, such weighting schemes do not always reflect the priorities of decision makers (after Etsy et al. 2005) (Cutter et al. 2010, 10).

The authors then mapped the full resiliency index using standard deviation cutoff scores (Figure 2.7) as well as each individual resiliency component scores. Results show that Mississippi, Alabama, Georgia and Tennessee all show mostly low to moderate resiliency, while Kentucky, North and South Carolina and Florida all show mostly moderate to high resiliency. The authors noted the urban-rural dichotomy, with metro areas displaying higher resiliency and rural areas showing lower levels, attributed to higher economic resiliency in the former. Their study further showcased the practical use for indicators aimed at population sensitivity to natural hazards and disasters.

Figure 2.7: Disaster resiliency in FEMA Region IV (source: Cutter et al. 2010).



Indices and Taxonomy Concerning Natural Disasters

Categorizing and indexing social characteristics of vulnerability to natural hazards represents only one part of the attempt to relate disasters to human populations. For purposes of cataloging events it becomes important for researchers to be able to refer to events in terms of their size and scope. As previously mentioned, tornado researchers among others now use the Enhanced Fujita Scale (EFS) to rank a tornado based on perceived wind speeds resulting from damage observations. The following sections review some of the more well-known scales, including the EFS, used in natural hazard and disaster research.

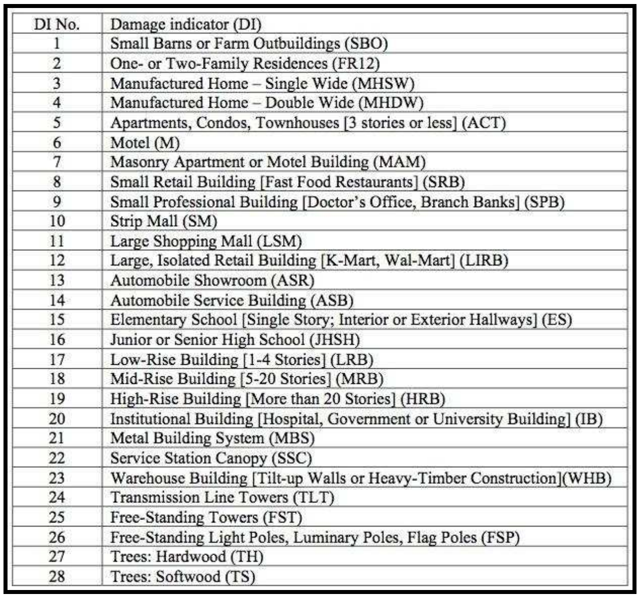
The Enhanced Fujita Scale

The original F-Scale, introduced by Dr. Theodore Fujita (Fujita 1971) has since been modified in order to correct for problems such as over-estimation of wind speeds inherent in the first version. Application of the F-Scale was widely accepted after its release (McDonald 2001) as the primary measure of a tornado's physical power, just as the EFS is today (Potter 2007; Doswell et al. 2009). However, the original F-Scale contained a high enough level of subjectivity and inconsistency to warrant restructuring it into the EFS; a problem Fujita (1992) himself recognized (United States Department of Commerce 1998; McDonald 2001; Edwards 2003; Guyer and Shea 2003).

Arriving at an EFS value begins by trained observers surveying the damaged areas following a tornado. Personnel first match the type of structure to a selection in a table of 28 Damage Indicators (DI) (Table 2.1). The DI table consists mostly of what type of building was damaged (e.g., strip mall, motel, metal building, high-rise), but also includes other structures (such as flag poles and towers), and two categories of trees, hardwood and softwood. Next, a table of Degrees of Damage (DOD) (

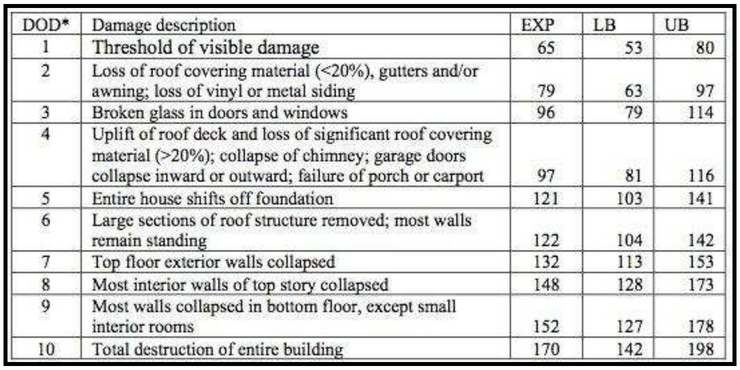
Table 2.2) specific to the DI is referenced, with observed damage fitting into a category ranging from one to ten. Each successive step upwards in the DOD table indicates more severe damage linked to higher wind speeds with the goal of estimating peak wind gust during a three second period. From the range of estimated wind speed, an EF value from zero to five is assigned (EF0-EF5) (Table 2.3).

Table 2.1: Damage Indicators (source: Wind 2004).



DI No.	Damage indicator (DI)
1	Small Barns or Farm Outbuildings (SBO)
2	One- or Two-Family Residences (FR12)
3	Manufactured Home – Single Wide (MHSW)
4	Manufactured Home – Double Wide (MHDW)
5	Apartments, Condos, Townhouses [3 stories or less] (ACT)
6	Motel (M)
7	Masonry Apartment or Motel Building (MAM)
8	Small Retail Building [Fast Food Restaurants] (SRB)
9	Small Professional Building [Doctor's Office, Branch Banks] (SPB)
10	Strip Mall (SM)
11	Large Shopping Mall (LSM)
12	Large, Isolated Retail Building [K-Mart, Wal-Mart] (LIRB)
13	Automobile Showroom (ASR)
14	Automobile Service Building (ASB)
15	Elementary School [Single Story; Interior or Exterior Hallways] (ES)
16	Junior or Senior High School (JHSH)
17	Low-Rise Building [1-4 Stories] (LRB)
18	Mid-Rise Building [5-20 Stories] (MRB)
19	High-Rise Building [More than 20 Stories] (HRB)
20	Institutional Building [Hospital, Government or University Building] (IB)
21	Metal Building System (MBS)
22	Service Station Canopy (SSC)
23	Warehouse Building [Tilt-up Walls or Heavy-Timber Construction](WHB)
24	Transmission Line Towers (TLT)
25	Free-Standing Towers (FST)
26	Free-Standing Light Poles, Luminary Poles, Flag Poles (FSP)
27	Trees: Hardwood (TH)
28	Trees: Softwood (TS)

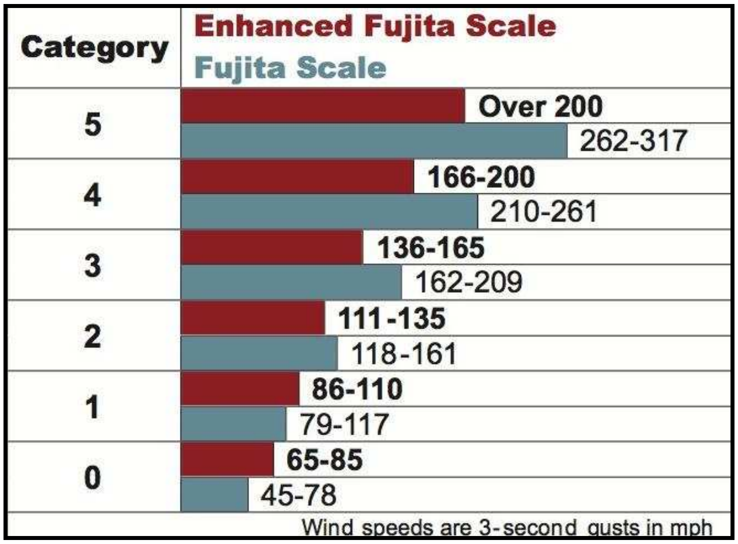
Table 2.2: Degrees of Damage for DI No. 2, FR12 (source: Wind 2004).



DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward or outward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Top floor exterior walls collapsed	132	113	153
8	Most interior walls of top story collapsed	148	128	173
9	Most walls collapsed in bottom floor, except small interior rooms	152	127	178
10	Total destruction of entire building	170	142	198

According to Doswell (2009) it remains questionable whether or not these additions meant to provide more specific damage criteria from which wind speeds can be estimated have resulted in a more accurate picture of the physical nature of tornado events. Doswell (2009, 561) stated that "the methods used for rating tornado intensity in the USA have been changing ever since the F-Scale was adopted” and further, "...the EF-Scale is only the latest episode in the story of that evolution.” While the EFS is the most widely used measure for tornadoes, there are other methods by which hazards, disasters and the impacts they can bring are quantified. The tornado taxonomy examined next, while not an index or measure of impact, illustrates the breadth of work undertaken to catalog and describe tornado events.

Table 2.3: The Enhanced Fujita Scale (source: Potter 2007).



Category	Enhanced Fujita Scale	Fujita Scale
5	Over 200	262-317
4	166-200	210-261
3	136-165	162-209
2	111-135	118-161
1	86-110	79-117
0	65-85	45-78

Wind speeds are 3-second gusts in mph

A Tornado Taxonomy

Recently, the work of Agee and Jones (2009) produced a taxonomy for tornadoes based on the type of convective system that produced the funnel. The classification was based on three types of vortices, Type I, II and III. Type I vortices are linked to supercells with mesocyclones, Type II tornadoes are generated by quasi-linear convective systems and Type III includes tornadoes produced by localized convective and shear vortices. The authors stated that their typing system may allow the NWS to more accurately produce more informative warnings. They further state that their taxonomy may provide a baseline by which the effects of climate change on tornado frequency patterns could be explained, as it is becoming increasingly clearer that human actions are inadvertently increasing both the frequency and intensity of climate-related hazards and disasters (Birkmann 2010; Cannon and Müller-Mahn 2010). However, in a reply by Markowski and Dotzek (2010) the authors made a case for the apparent difficulty in collecting the data necessary to implement such a taxonomic scheme. They further argued that problems in the U.S. tornado record[8] affecting the ability to study trends poses a much more pressing issue than the lack of a classification method of the detail proposed by Agee and Jones' 2009 taxonomy. This consideration is discussed in further detail in the Chapter Five section Potential Future Research.

The Outbreak Scale (O-Scale)

Another recent study created a classification system for severe weather events based on several data types concerning tornado outbreak days. Doswell et al. (2006) devised the tornado Outbreak Scale (O Scale), with outbreaks defined as seven or more tornadoes, and included the following data within the classification scheme:

1. Number of tornadoes;
2. Number of violent tornadoes (EF-4 and EF-5);
3. Number of significant tornadoes (EF-2 or greater);

---

[8] For a thorough review of the characteristic problems in the tornado record to which Markowski and Dotzek refer, see Evolution of the U.S. Tornado Database: 1954-2003 (Verbout et al. 2006).

4. The Damage Potential Index (DPI) (Thompson and Vescio 1998);
5. Path length;
6. Number of deaths;
7. Number of killer tornadoes (tornadoes that caused at least one fatalities);
8. Number of tracks 80 kilometers (50 miles) long or greater.

Doswell et al. (2006)

The index calculation is straightforward, and is arrived at by standardizing each outbreak date's variables described above by mean and standard deviation, and then applying a linear weighted average. The Doswell et al. (2006) study used deaths and number of killer tornadoes. In this regard, their study included human loss within the scale devised, similar to the work undertaken here. The final O Scale index values varied slightly at the high and low end, depending on the weight assigned to each variable (the authors assigned the weights arbitrarily depending on the perceived importance of each variable in the index calculation; a method they recognized as subjective), but ranged from a score of 2.768 for the 3 May 1999 outbreak (e.g., Brooks and Doswell 2002; Brown et al. 2002; Hamill et al. 2005) and 22.565 for the 3 April 1974 "Jumbo Outbreak" (Fujita 1974; Corfidi et al. 2010). The utility of the O Scale is flexible, in that weights can be changed to fit specific needs of different projects, and according to the authors it may aid in, "the effort to understand the meteorological differences, if any, between days producing major tornado outbreaks from those that produce primarily non-tornadic severe convective storms" (Doswell et al. 2006, 939). The authors also noted that not all significant meteorological events will result in significant impact on humans, and that conversely, a meteorological event that does impact humans may not be noteworthy; these sentiments underlie the TICV and TC.

The Northeast Snowfall Impact Scale (NESIS)

Kocin and Uccellini (2004) used data from thirty large-scale New England snowstorms from 1950–2000 layered on population density to create the NESIS. The NESIS is found by:

Equation 2.2: The NESIS.

$$\sum_{n}^{x}[n(A_n / A_{mean} + P_n / P_{mean})]$$

where

n = snowfall values divided by 10

A_n = mean area of snowfall greater than 10 inches

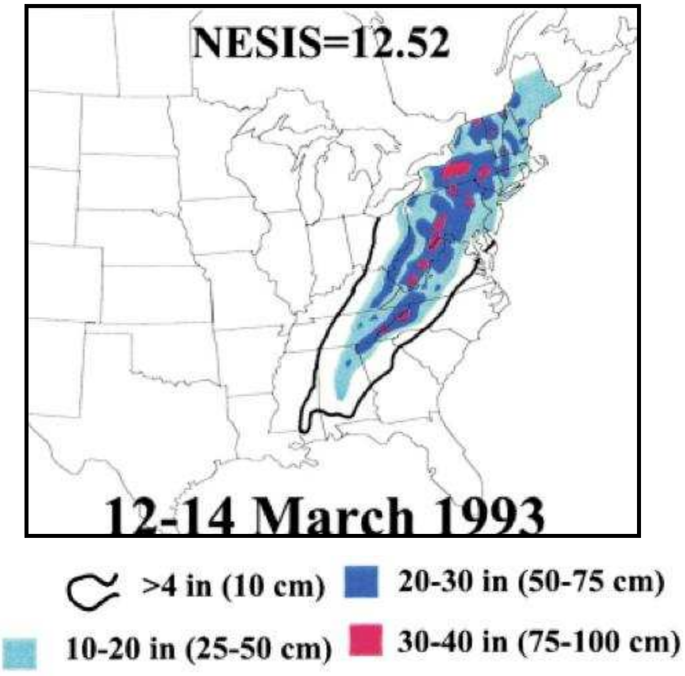
A_{mean} = mean area of snowfall over 10 inches over the 50-year study period

P_n = estimated 1999 census population living within A_n

P_{mean} = mean population for the 30 cases included in the 50-year dataset

NESIS values in the 50-year study set ranged from a low of 1.46 to a high of 12.52. Those data were then mapped within a GIS to display the spatial extent of the snowfall event (Figure 2.8). To fit the NESIS values onto a more meaningful rank structure, the authors calculated NESIS values for an additional 40 storms (bringing the dataset total to 70) and broke them into five categories of severity on [1, 5], with one as the lowest and five as the highest. The authors also added accompanying descriptions indicating the severity of each event. A category one event (NESIS = 1-2.499) was "notable," a category two event (NESIS = 2.5-3.99) was "significant," category three (NESIS = 4-5.99) was referred to as "major," category four (NESIS = 6-9.99) as "crippling," and finally, category five (NESIS ≥ 10) was labeled "extreme."

Figure 2.8: NESIS value and snowfall categories, March 1993 storm (source: Kocin and Uccellini 2004).



The NESIS, while using different methods than proposed for the TICV, is similar in intent. According to the authors (Kocin and Uccellini 2004, 178),

> The NESIS differs from the Fujita tornado scale and the Saffir-Simpson hurricane scale in that the NESIS focuses on the amount of snow that falls, mapped onto the population density that experiences the snow, rather than focusing on wind as the major impact agent. Furthermore, NESIS values are computed directly and provide an objective measure of the impact of a snowstorm on the population distribution.

The physical accumulation of snow is no doubt an important component to calculating an NESIS value, but clearly the authors goal was to produce values that have meaning in terms of the people a storm had impacted. The work of Kocin and Uccellini was continued by Squires et al. (2006) with the intent of producing an operational NESIS. One of the practical additions of their work was the spatial pre-processing of the data and the implementation of the Local Moran's I statistic, which was used to locate spatial clusters and identify trouble areas which were likely to have received more or less snow that reported by observation stations. They developed the Regional Snowfall Impact Scale (ReSIS) based on the NESIS methods, but with new means and thresholds defined for each of the 13 National Climatic Data Center (NCDC) climatic regions in the U.S. to better allow the scale to have real meaning in those regions.

The Disaster Impact Index (DII)

Gardoni and Murphy (2010, 619) created the DII to, "gauge the societal impact of disasters on the basis of the changes in individuals capabilities." In terms of the DII, the authors use the capability approach, which was developed by Sen (1989; 1993; 1999a; 1999b) and Nussbaum (2000a; 2000b; 2001), "to gauge the quality of life of individuals as a way of determining the overall level of development of societies" (Gardoni and Murphy 2010, 620). The capability approach attempts to measure well-being as it applies to a person's ability to function in a society. Health, access to shelter and property, mobility and level of education all contribute to a person's capability, and it is these factors among others that the authors took into account. The authors stated there are four criteria which capabilities must meet in order to gauge societal impact; these are:

1. Relevance: the capabilities considered must be related to the purpose of determining societal impact;
2. Importance: the capabilities considered must be of enough importance to justify wanting to mitigate against their loss in the future;

3. Influenceability: the capabilities considered must be responsive to policy change, in that future impact can be reduced;
4. Practical implementability: the capability-based index proposed should be practical in that it:
    a. uses the least number of variables as possible to reduce the amount of data that needs to be collected (parsimony);
    b. uses variables that are as unique from one another as possible (orthogonality).

(Gardoni and Murphy, 2010, 623)

Four capability groups were identified and corresponding indicators selected to represent each group. For the group termed longevity, the number of individuals killed served as the lone indicator. In the physical and mental health group, indicators included number of individuals injured, left homeless and left without adequate access to a water supply. For affiliation and mobility, the number of individuals unemployed due to the disaster as well as the ability to move about freely served as indicators. Finally, in the command over resources group, the lone indicator was direct economic losses resulting from the disaster.

In order to calculate the DII, the authors first determined the value for each indicator, then scaled those values onto [0, 1], where a value of zero indicated no value (no consequences, or no impact) for that indicator and a value of one indicated, "reasonable maximum consequences" (Gardoni and Murphy 2010, 629). However, the authors took no steps to quantify the upper bound of the interval for each indicator k, and as such, their definition of "reasonable maximum consequences" is unclear. In order to determine the maximum value for each indicator, the β-percentile of the indicators ranked value was used. This method was employed so that an outlier (unusually large event) would not set up an indicator whose maximum value is non-representative of the indicators across all disasters. The Indicator Index (II) is then determined by dividing the indicators actual value by the maximum value. The Disasters Index (DI) is then found by:

Equation 2.3: The Disaster Index.

$$\left[\frac{1}{n}\sum_{k=1}^{n} \mathrm{II}_k^{\alpha_k}\right]^{1/\alpha_k}$$

where

k = number of indicators

n = total number of IIs

a_k = the exponent used to taper the effect of IIs on the DI as the IIs increase in value

The DII is then found by:

Equation 2.4: The Disaster Impact Index.

$$\frac{\text{Disaster Index (DI)}}{n_s}$$

where

n_s = number of individuals in the population affected that are described by the DI

In agreement with Cross (2001) (as well as is argued in this research), the authors stated that, “The larger a society is, the smaller the actual impact of a disaster is for a given DI” (Gardoni and Murphy 2010, 631). In order to illustrate the DI and DII the authors compared two earthquake events, one in Pakistan in 2005, and one in Japan in 1995. Their analysis concluded that although the Pakistan earthquake was larger in magnitude (7.6 on the Richter scale) than the Japan earthquake (7.2 on the Richter scale), the Pakistan event scored a DI of 1.108 and a DII of 0.663 compared to the Japan event, which scored 0.725 and 0.577 respectively. Cost divided by gross domestic product (GDP) and the number of Pakistanis left homeless drove the DI and DII values higher than those of Japan, as Pakistan is considered a developing nation, having fewer resources to draw upon in the event of such a disaster.

A second analysis comparing the 1994 Northridge, CA, earthquake and the 2005 Katrina hurricane revealed that the two events scored similar DI and DII values; 0.401 and 0.154 respectively for the Northridge event and 0.597 and 0.208 respectively for the Katrina event. While hurricane Katrina killed far more people and did more monetary damage than the Northridge earthquake, the burden of Katrina was spread out over a larger population base than that of the Northridge earthquake, resulting in the comparable scores.

Although similar in intent to the TICV proposed herein, the DII values are derived from the Emergency Events Database (EM-DAT 2006), which details large-scale disasters, whereas the TICV was developed from NOAA tornado data, and is specific to tornado events (although it could, by design, be applied to any disaster event). The DII could potentially be scaled to smaller events than those outlined by the authors; however, the indicators used are not available for all disasters, including tornadoes (see McCarthy 2003). As such, the TICV provides an index and category value describing impact from a tornado event that the DII, by design, cannot. The DII seems well suited to describe impact of large events, and could even be used to describe very large-area, multiple-community tornado events (e.g., Jarrell, TX, 1997; Moore, OK, 1999), but operationally is too large in scope to be used to compare tornado events which are often on a far smaller scale than hurricanes, earthquakes and floods, as the TICV is proposed to do at the community level. Table 2.4 below summarizes the indices discussed in the preceding section, with the addition of several others not described in detail above.

Table 2.4: Summary of selected indices.

Author(s)/Year	**Index or Scale Name and/or Phenomena Measured**	**Description**
Keys (1972)	Body Mass Index (BMI)	Weight divided by height squared
United States Environmental Protection Agency (1976)	Air Quality Index (AQI)	Concentrations of carbon monoxide, nitrogen dioxide, ozone, particulate matter, and sulfur dioxide in the air
Michel et al. (1978)	Oil Spill Vulnerability Index (OSVI)	Longevity of an oil spill in the absence of human intervention
Simonsen et al. (1997)	Influenza Epidemic Severity Index (IESI)	Deaths with flu as the underlying cause
Easter (1999)	Commonweath Vulnerability Index (CVI) for small states development	Impact of outside forces (natural or man-made) combined with resilience measured by gross domestic product
Pethick and Crooks (2000)	Coastal Vulnerability Index (CVI)	Exposure of physical coastal features to geomorphological change
Chen et al. (2001)	Soil Erosion Index Model (SEIM)	Environmental damage caused by soil erosion due to overdevelopment
Cutter et al. (2000)	Vulnerability to technological disasters	Examined the vulnerability of Georgetown, South Carolina, in terms of exposure to harm from technological disasters (e.g., railway, highway, and chemical facility accidents) as well as natural disasters (e.g., floods, earthquakes, and hurricanes).
Dixon and Fitzsimmons (2001)	Hurricane Vulnerability Index (HVI)	Hurricane vulnerability for the Texas Gulf Coast region using population and property data
Sullivan (2002)	Water Poverty Index (WPI)	Socioeconomic indicators and water availability estimates used to determine vulnerability to water shortages
Cutter et al. (2003)	Social Vulnerability Index (SoVI)	Demographic, economic, housing, and land-use variables

Author(s)/Year	**Index or Scale Name and/or Phenomena Measured**	**Description**
Belousova (2003)	Groundwater quality sustainability	Pollution damage, groundwater pollution, hydrogeochemical indices, pollution transport and mitigation, and leakage and aquifer interaction
Braganza et al. (2003)	Global climate variability and change	Five separate indices including global-mean surface temperature, land and ocean surface temperature contrast, inter-hemispheric difference in surface temperature, mean magnitude of the annual cycle in temperature over land, and mean meridional temperature gradient in the northern hemisphere mid-latitudes
Kocin and Uccellini (2004)	Northeast Snowfall Impact Scale (NESIS)	Snowfall data overlaid on population for the area affected
Esty et al. (2005)	Environmental Sustainability Index (ESI)	Health of environmental systems, reduction of environmental stress, reduction of human vulnerability, social and institutional capacity, and global stewardship
Doswell et al. (2006)	Outbreak Scale (O-Scale)	Classification for severe weather events based on data concerning tornado outbreak days
Rygel et al. (2006)	Social vulnerability to hurricane storm surges	Socioeconomic data and physical exposure to hurricane-generated storm surges
Spittal et al. (2006)	Earthquake readiness scale	Questionnaire responses concerning household preparedness used to construct a scale classifying level of readiness in the event of an earthquake
Squires et al. (2006)	Regional Snowfall Impact Scale (ReSIS)	Continuation of the work of Kocin and Uccellini (2004) applied to the 13 NCDC climatic in the U.S.
Ewing et al. (2007)	Local Housing Price Index (HPI)	Variance in mean housing prices in six MSAs affected by severe wind events and tornadoes
National Weather Service (2007, adapted from Fujita, 1971)	Enhanced Fujita Scale (EFS)	Physical damage caused by tornado events resulting in an estimation of wind speed and a classification for an event from EF-0-EF-5
Agee and Jones (2009)	Tornado taxonomy	Tornado taxonomy based on the type of convective storm that produced the funnel
Bowles (2009)	Heat stress classification	Accumulated high temperature, humidity, and recovery time data for 70 U.S. locations
Peduzzi et al. (2009)	Disaster Risk Index (DRI)	Disaster risk probabilities and population data used to calculate the potential for harm from floods, earthquakes, tropical cyclones, and droughts
Gardoni and Murphy (2010)	Disaster Impact Index (DII)	An index based on the capability approach to measure impact of large-scale natural disasters

Assessing the Value of Life

As part of the calculation methods described in Chapter Three, a value per fatality is assigned. Assigning a monetary value to the life of a human being may seem a macabre exercise in mathematical and statistical alchemy, and is certainly not a simple undertaking (Tobin and Montz 1997). However, government and industry routinely utilize empirical values in order to assess the value of risk-reducing measures and provide compensation to next-of-kin in the event of the loss of life. Value-Of-Life (VOL) studies have been conducted for the aforementioned purpose, and the results of such calculations are referred to as the Value per Statistical Life (VSL). According to Viscusi et al. (2000, 665),

> [The VSL] is a common measure used in court cases for compensating survivors, inasmuch as it is a reflection of the net economic loss to the survivors after the death of a family member. [T]his technique not only has appeared in the literature but also has been widely used by government agencies.

The structure of VOL studies involves survey questionnaires concerning the value a person places on risk-reduction. It utilizes numerous and complex statistical techniques and many variables, including occupation type and fatality rate in that occupation, age, gender, immigration status and health of the subject to name just a few. Accepted VOL formulas also incorporate monetary values such as loss of future earnings (a loss to the individual and his/her family), loss of tax revenue (a loss to society) as a result of death (Viscusi 1992; 2010), and the value attached to the progeny of a victim who has passed away (Kuhn et al. 2010). The VSL is considered an accurate and reliable method to determine compensation value for the loss of life, and presents an equally reliable measure to use in terms of lives lost as the result of a natural disaster (Viscusi 2009), as the VSL is not limited to any one specific cause of death, but rather myriad factors (Viscusi et al. 2000).

An argued limitation of the VSL by Robinson et al. (2010, 4) stated, "The VSL does not measure the value of a 'life' or an individual’s intrinsic worth; rather, it measures how individuals trade off income (or spending on other goods and services) and small risk changes." This limitation is recognized here; however, Robinson’s statement is nonetheless countered by recognized experts in the field, as cited above, that the VSL can stand as an indicator of the value of life when such an indicator is useful or required. In 2008 the harmonic mean VSL in the United States is seven million USD (Kniesner et al. 2010; Viscusi 2010). Harmonic means are used in datasets where all values are positive and each value represents a rate, thus the harmonic mean is the average of a set of rates. Harmonic mean is preferred over arithmetic or geometric mean in instances when a value is financial since the harmonic mean gives equal weight to all values, which eliminates the influence of outliers on the final value (Rielly and Schweihs 2004). The methods described in Chapter Three utilize this harmonic mean, and further describe the data used, calculation procedures for the TICV and describe the study area to which it was applied.

Summary of Literature Review

The concept of vulnerability is important to the study of natural hazards since the level of potential harm to a population is a major concern in understanding impact. While there are several areas of specific vulnerability studies, such as physical, economic and environmental, a focus for this work lies within the context of social vulnerability. Demographic factors such as age, race, education and income provide a social snapshot of a community. These data are commonly used to indicate the level of risk of a population when faced with some perturbation, such as natural or technological disaster. To relate the contribution of these considerations in a quantitative manner, researchers routinely report their findings via an index and/or a category value. Such indicators are widely used not only for the purpose of conducting research, but for informing the public about the level of potential harm or actual damage done by an anomalous event. This chapter has provided an overview of some of the more commonly known and used indices, and how they relate to our understanding of risk and severity.

As has been shown, there is an apparent void in the literature where vulnerability indicators are used in conjunction with economic data on damage done by a natural disaster. Only recently has the idea of examining physical impact of a disaster as a function of population been undertaken (e.g.; Kocin and Uccellini 2004; Gardoni and Murphy 2010; Flanagan et al. 2011). Impact needs to be examined in terms other than the physical strength of a geophysical event. Category values, such as the EFS for tornadoes, are often interpreted as an indicator of the of impact resulting from a storm, when by design are meant to relate some set of observed or empirically measured damage data to physical power. This misinterpretation thus provides an incomplete picture of the actual severity of the event. An index and category value that is designed to relate the level of impact based on the vulnerability of the population affected in addition to the monetary losses incurred is needed. Viewed from a different perspective, one where physical strength is not the primary focus, we may better understand how two storms of similar magnitude may impart two very different levels of impact on two unique communities when the social profile and size of those communities is considered. This perspective fits with the existing body of literature in that the purpose is to further our comprehension of the complex relationship between the natural world and its inhabitants.

CHAPTER 3 - Data, Methods, and Study Area

This chapter describes the types of data used in this research, as well as the sources from which those data were obtained. A description of the methods used to calculate the damage component, the vulnerability component and finally the overall TICV index and TC follows.

The coterminous United States was chosen as the overall study area due to the prevalence of tornado activity; however, states to be included in the index and category scheme development were determined by whether or not useable events had occurred in them. Those procedures are explained further in this chapter, and the results are presented in Chapter Four. As the states chosen resulted from the reduction of the initial dataset, the study area within the coterminous U.S. (states with usable tornado track data) is described following the descriptions of the data and methods used.

Data Extraction and Dataset Construction

Before calculating the TICV and TC, data needed to be collected from several sources. Procedures to extract data based on a temporal range, as well as spatial considerations, preceded the index calculation procedures. The spatial criterion was whether or not the tornado intersected a community. The 2000 population census was used to calculate the vulnerability component of the TICV. Tornado data from the years 2000–2009 were therefore included, as this time frame best matches the most recently published census. Additionally, SPC data on monetary damage is reported as a categorical variable prior to 1996 (Simmons and Sutter 2011), which essentially renders it useless for the purposes of this research, since an estimated damage figure in the form of a ratio variable was desired to more accurately indicate impact.

Data Sources and Software Employed

In order to construct the TICV and TC, two sets of data were used: tornado data and census data. First, data on the location and length of tornado tracks, their intersection with a community population and physical area of communities, the number of fatalities and the monetary damage done by an event were collected; those data indicate the physical impact of the event (Lindell and Prater 2003). Injuries were not included since there is a vast range of the effects of event on injuries (Jones-Lee et al. 1995). The Abbreviated Injury Scale (AIS) and Organ Injury Scale (OIS) rate injuries on a scale of one through six, from minor (1) to unsurvivable (6) (Gennarelli 2008; AAST 2011). The SPC tornado record provides no such description or coding which indicates the severity of an injury. Injury calculations are routinely included in mitigation cost-benefit analyses, and this inclusion is usually stated as avoided deaths rather than actual cost (or estimate of cost) of each injury (Cropper and Sahin 2009). It is unclear to what extent injuries impact a community after a disaster. Consequently the impact of an injury cannot be reasonably described based on the methods presented here as it would have introduced a component with a great degree of uncertainty as to its overall contribution to the index and category scheme.

Second, census data--including social, economic, housing and demographic characteristics (Table 3.2)--were collected for each of the 25,148 communities in the community shapefile; those data indicate a level of vulnerability to an event (Peduzzi et al. 2009). Data were collected from a variety of sources for this research, including the

SPC, the NCDC, the United States Census Bureau, the National Atlas, Internet-based news articles focusing on specific tornado events or outbreaks and personal communication (via email or phone) with county-level emergency management personnel (Drittler 2010; Crymes 2010; McGowen 2010; Williams 2010).

All GIS functions were performed using the Environmental Systems Research Institute's (ESRI) ArcGIS suite (ArcMap and ArcCatalog) 9.3; tabular data calculations were performed in Microsoft Excel 2007 and 2008, OpenOffice 3.0 and NeoOffice 3.0; statistical analyses were performed using Statistics Open For All (SOFA) 0.9.22, Statistical Program for the Social Sciences (SPSS) 18.0 and KyPlot 2.0.

GIS Shapefile Data

In order to assemble an initial base map, shapefile data containing U.S. states, 3,116 counties, and 25,148 communities was obtained from the National Atlas, henceforward referred to as the states, county (or counties), and community (or communities) shapefiles respectively.[9] Those data were imported into ArcMap and projected using Albers conic equal-area, North American Datum 1983. An equal-area projection was chosen to facilitate the spatial analysis of the vulnerability scores via the Moran’s I test as described further below. Equal area projections are best-suited for those types of spatial analysis, as they accurately preserve the area, and therefore, the distance between areas, which is essential to the Moran’s I statistic. Individual state maps and FEMA Region maps were re-projected into the Universal Transverse Mercator (UTM) zones appropriate for their respective locations to facilitate proper cartographic display.

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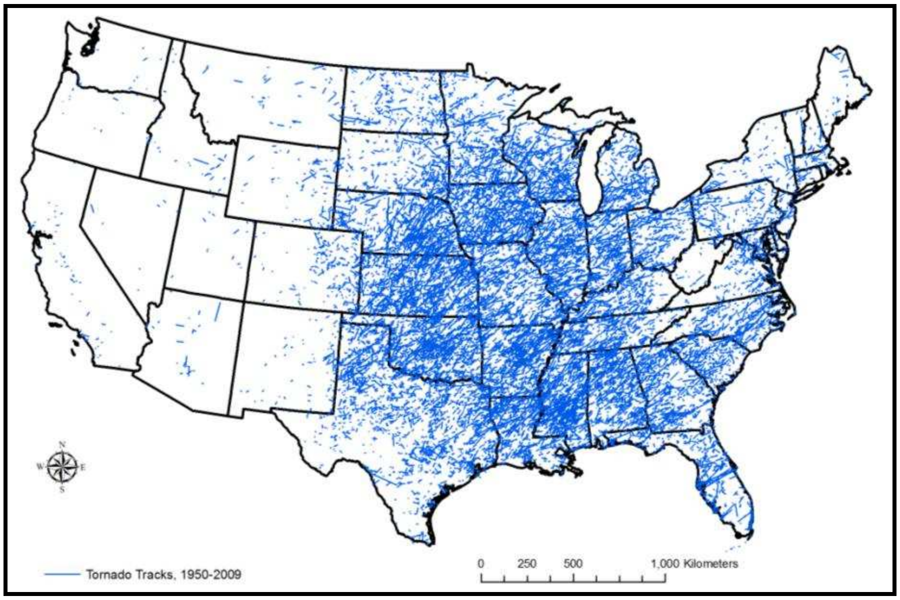
[9] All shapefiles used maintained the same name through all selection and exporting procedures which resulted in new files.

Initial Data Extraction and Reformatting

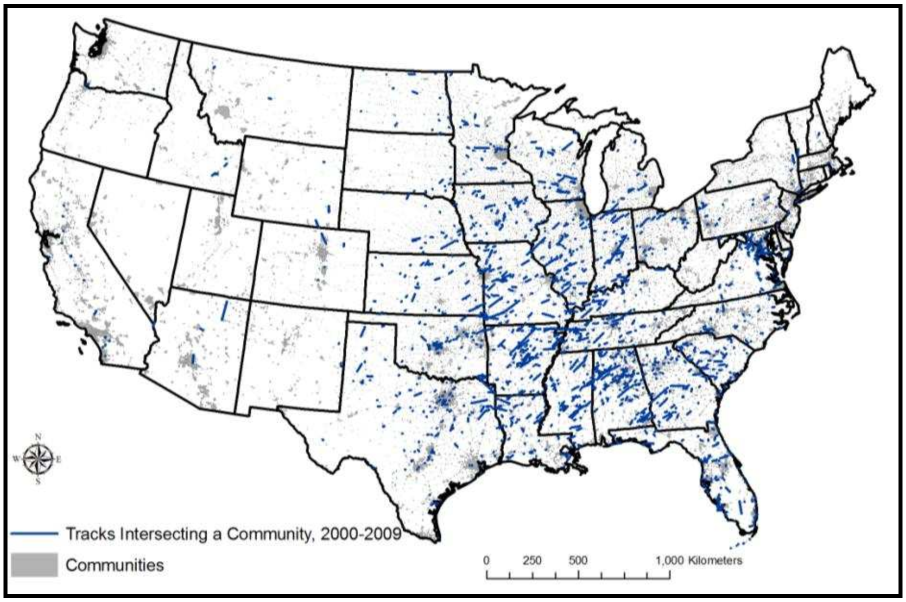
Within ArcMap, and from the states shapefile, a select by attributes function was performed, with the criterion set as all U.S. states except Alaska, Hawaii the U.S. Virgin Islands and the Commonwealth of Puerto Rico, and the result added as a new shapefile to the ArcMap document. The same procedure was performed on the community and county shapefiles, to produce new shapefiles containing only communities and counties within the coterminous United States. Point data containing the beginning and ending latitude and longitude of all tornado events (points) as well as line data for 26,431 U.S. tornado tracks (tracks) from 1950–2009 were obtained through the SPC's GIS data portal (SPC 2010) (Figure 3.1). Once downloaded and decompressed, the points and tracks shapefiles were imported into ArcMap. A select by attributes function was performed, with the selection criteria set as all tornadoes that occurred from 2000–2009; the result of 12,657 tornado events was added to the ArcMap document as a new shapefile named tracks, replacing the previous file of the same name.

Figure 3.1: Tornado tracks, 1950-2009.



The focus of this study was to apply the methods described in this chapter to only those tornadoes that passed through a community with U.S. Census-defined political boundaries (i.e., communities, referred to as places by the Census Bureau) that appear in the community shapefile described above. To reduce the initial tracks subset of 12,657 tornado events from 2000–2009 down to only those events striking communities, a select by location function was performed, with the selection criterion set as all lines from the tracks shapefile that intersected the community shapefile. This resulted in 1,885 community-intersecting tracks that were exported as a new shapefile and added to the ArcMap document (Figure 3.2).

Figure 3.2: Tornado tracks selected for use in this study.



The use of the methods described above presented a limitation involving the accuracy of the SPC points and tracks shapefiles and their intersection with the community shapefile, and a problem with tracks that passed through more than one community. Those two problems are referred to here as the point-line-polygon and the multiple-community-track-intersect problems, respectively. It was necessary to correct for these problems in order to properly prepare the dataset for use; these problems and their corresponding solutions are described below.

The Point-Line-Polygon Problem

In constructing the line to represent the tornado path, personnel at the SPC connect the beginning latitude and longitude point to the ending latitude and longitude point, resulting in a straight line between the two points for each tornado (Figure 3.3). For communities in which the estimated path represents the actual path (or very close to it), and the track passes through a community, the data is useable in situ (Figure 3.4).

In this dataset, the point-line-polygon problem occurred at locations where the line connecting the starting and ending latitude and longitude did not closely enough estimate the actual track of the tornado. For example, an actual track bent around a community, but the SPC-estimated straight-line path indicated that the track intersected the community when it actually did not (Figure 3.5), resulting in a track being included in the dataset when it did not actually intersect the community. Conversely, a track bent into a community, but the SPC-estimated straight-line path indicated it missed the community altogether, resulting in that community/track shapefile intersection not being included in the final dataset when it actually did intersect the community (Figure 3.6).

To correct as best as possible for instances illustrated by Figure 3.5, the NCDC Select-A-State dynamic database was used. This database permits a user to locate details on a specific tornado, including narratives on the event where they are available, by entering date and location information into a structured query language (SQL) form.

Figure 3.3: Path representation in the SPC dataset.

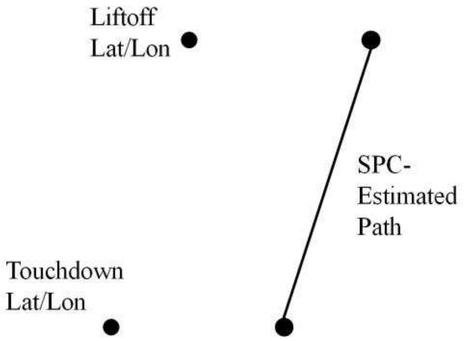


Figure 3.4: SPC estimated path mirrors actual path.

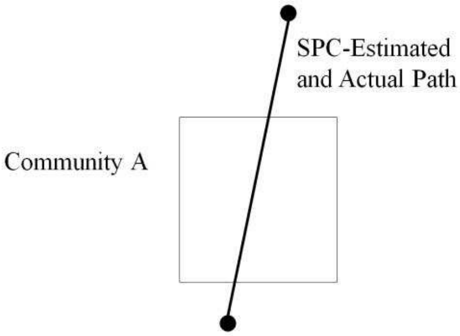


Figure 3.5: Actual path bends around the community.

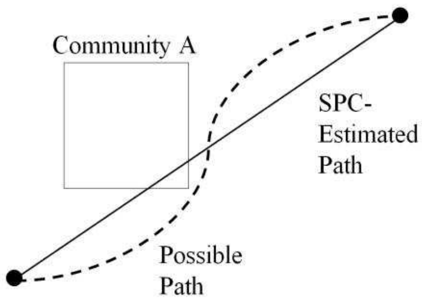
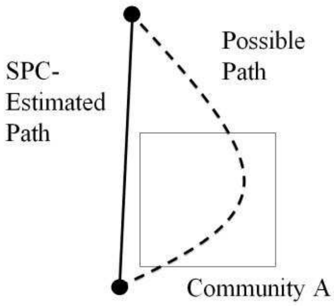


Figure 3.6: Actual path bends into the community.



Within the ArcMap document, and beginning in Washington state and transecting north-south/south-north and moving east through the ArcMap document, information for each of the 1,885 tracks were entered into the NCDC query form and the full record for each, including any narrative, was inspected and manually compared to the GIS data. By reading the NCDC record's text narrative, a determination was made as to whether or not an intersection actually occurred; i.e., did the path actually intersect the community or did it remain in an unpopulated area?. If it was determined that the path intersected the community, the record was flagged as "0" to indicate "usable."[10] If the record narrative indicated that the tornado remained in an unpopulated area and did not intersect the community, it was flagged as "2" to indicate "unusable." This process was repeated three times to ensure to the best of the author's ability that no tracks were misclassified.

For events similar to the representation in Figure 3.6, the only possible solution would have been to read each of the 10,772 narratives of the events not extracted from the initial 12,657 dataset of 2000–2009 events, flagged usable events as "0," and re-integrated them into the initially extracted dataset of 1,885 tracks. However, it was not a goal of this research to correct or validate the SPC tornado records beyond what was needed for inclusion in the final dataset, and from which the TICV values and subsequent category scheme was created. As Table 3.1 below and the Chi-squared test discussed in the Data Retention section show, the final count of usable tracks (981 usable, 904 unusable) was sufficient to apply the statistical and calculation methods described in the Calculation Methods section in this chapter.

The Multiple-Community-Track-Intersect Problem

This problem initially presented itself when the tracks shapefile was spatially joined (that is, the attributes of two separate shapefile tables linked by a common spatial attribute such as latitude and longitude) to the community shapefile, with the intended result to join the proper community population and physical area data from the community shapefile to each track in the tracks shapefile. However, in cases where the

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[10] “0” was used to indicate useable while “2” was used to indicate unusable. “1” was reserved, as is described below, to indicate tracks what were re-flagged from 2 to 1. This allowed for the final dataset to be coded as either 0 or 1 for useable, while those that remained flagged as 2 were eliminated altogether.

track intersected more than one community ("long-track"), the select by location tool produced erroneous results, randomly reassigning the attributes of the tracks and scattering them across various communities in the community shapefile. To correct for this, long-tracks were broken into individual segments, resulting in one segment passing through exactly one community, and flagged as "1" to indicate "track was segmented manually." The process used to segment long-tracks into individual tracks is illustrated in Figure 3.7, Figure 3.8, Figure 3.8 and Figure 3.10.

Figure 3.7: Long-track passing through communities A, B, and C, flagged as "1."

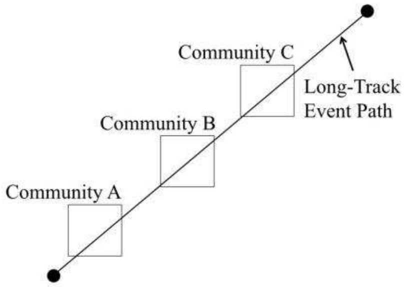


Figure 3.8: Original track duplicated.

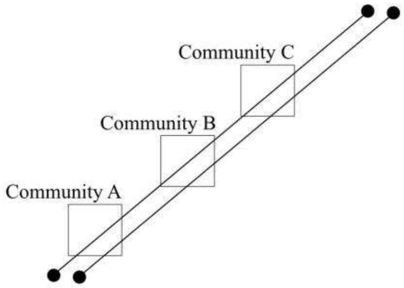


Figure 3.9: Original and duplicate tracks fit to communities A and B.

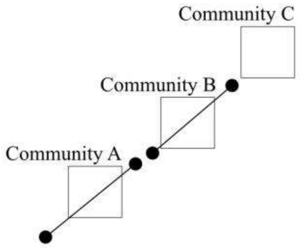
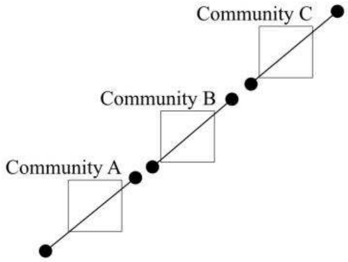


Figure 3.10: Track duplicated again and fit to Community C.



Since each new individual segment passing through exactly one community was created from the original long-track segment, all of the attributes of that segment were also copied in the new segment's attribute row by default. Each new segment's attribute row was manually edited, with NCDC data on damage in U.S. dollars, the number of fatalities, and EF-Scale (or F-Scale if the tornado occurred before 2007) added, and the segment re-flagged as "0," or "usable." Unfortunately, in some cases the NCDC database did not provide enough information to make a determination as to what data to add to each individual segment. In these cases, an attempt was made to contact via email or telephone the emergency manager or director for the county in which the community is located; a total of four county emergency managers were contacted. If the individual was able to locate the damage and fatality information requested, it was added to the proper segment's attribute table and the segment was re-flagged as "0," or "usable;" if the data was not available, that particular segment was re-flagged as "2," or, “unusable.” At this point, all tornado tracks in the dataset were associated with exactly one community; a one-to-one relationship. These procedures resulted in a final dataset (named USTOR2000) of 981 usable events that intersected a community (Table 3.1, Figure 3.11 and Figure 3.12).

Table 3.1: Summary of tracks identified as usable or unusable.

Initial track/community shapefile intersect (n=1,885)

Flagging key: 0 = usable, 1 = segmented manually, 2 = unusable

Initially Flagged as 0	904
Initially Flagged as 1 (long-tracks)	106
Initially Flagged as 2	875
New segments created from long-tracks and re-flagged as 0	77
New segments created from long-tracks and re-flagged as 2	29
Total usable tracks	981

Figure 3.11: USTOR2000.

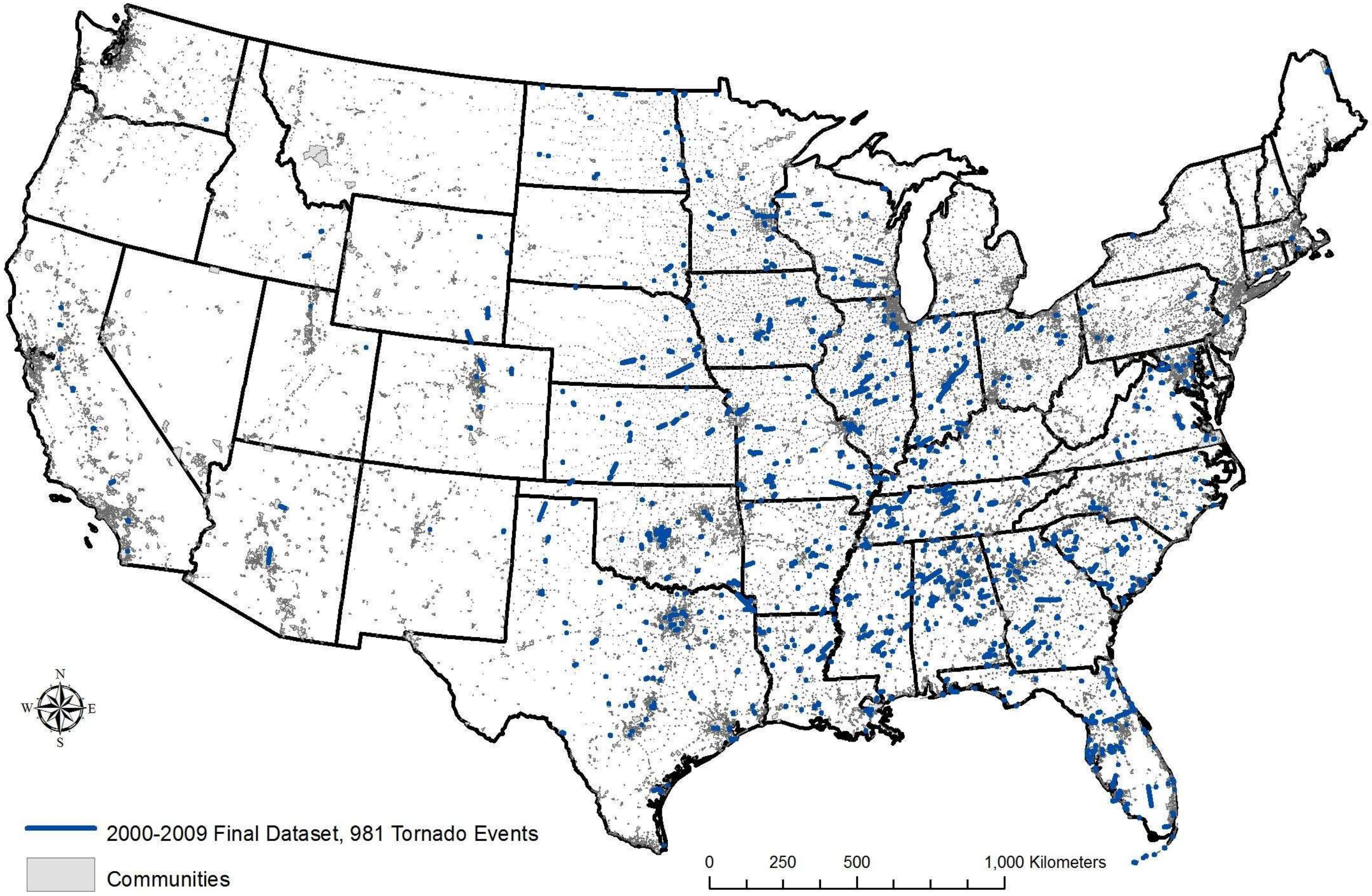
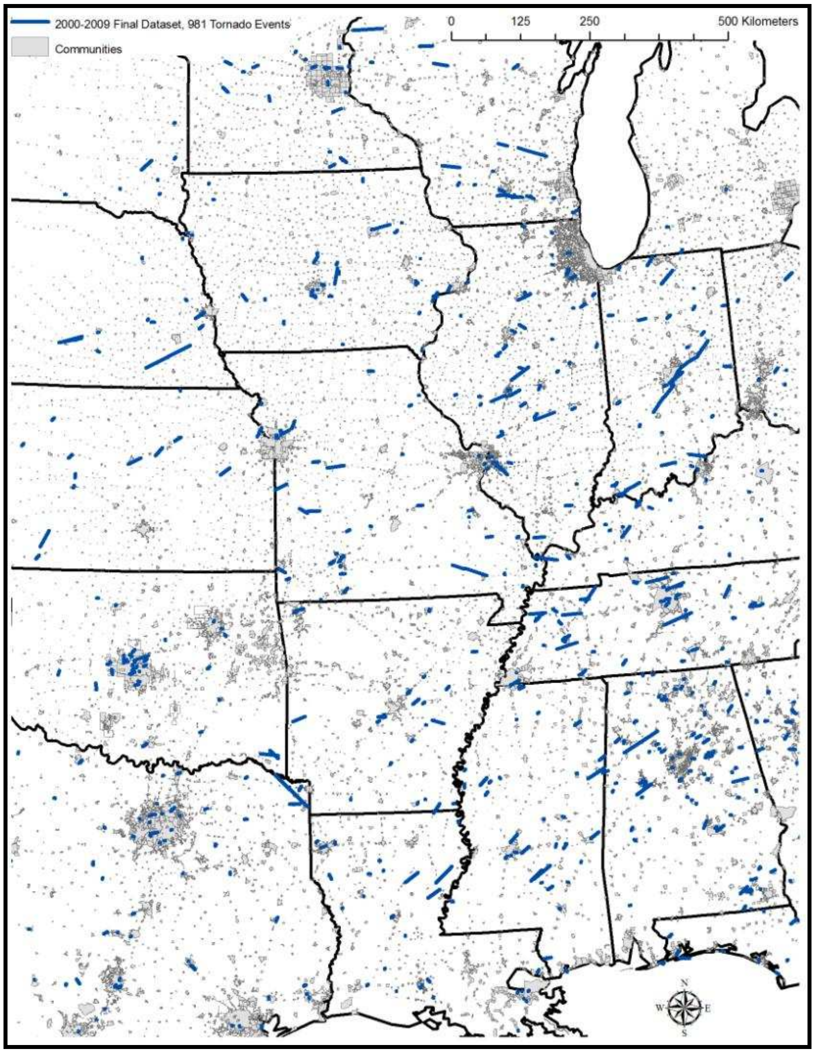


Figure 3.12: USTOR2000 through tornado alley.

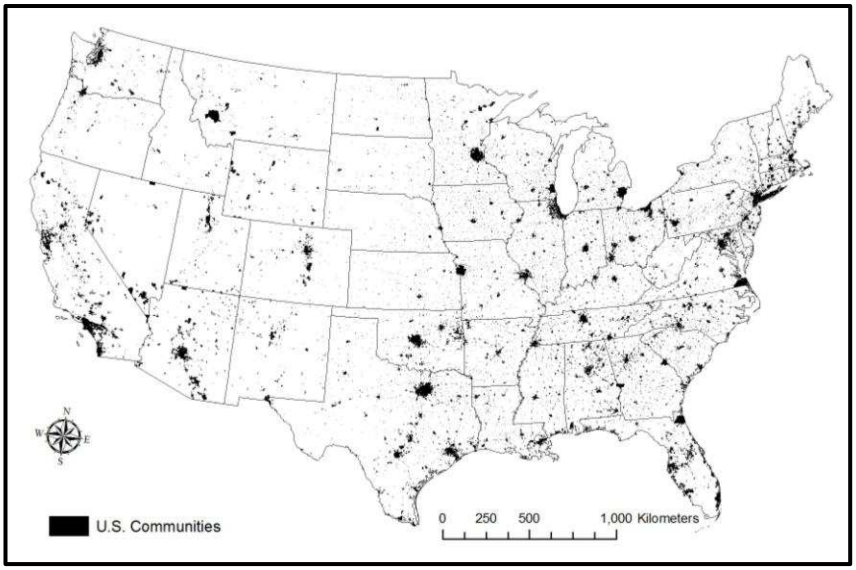


Data Retention

Through the course of the data extraction and cleaning methods, many tracks were eliminated from inclusion in USTOR2000 due to the location of the estimated path (unpopulated area paths), or lack of clear information as to whether or not the track actually passed through a community. Of the 12,657 tracks from 2000–2009, 981 from the originally extracted set of 1,885 were retained (see Appendix A, Table A.1), for an overall retention percentage in the U.S. of 7.75. Of the states with at least one track included, some states exhibited high retention values while some showed very low values. Colorado experienced 405 tornadoes during the study period, of which seven were retained, for a retention percentage of 1.73; the lowest of non-zero values. Kansas witnessed 1,121 tornadoes during the study period, yet only 20 events were retained; a percentage of 1.78. South Dakota showed the third lowest retention figures, with eight of 319 events included in USTOR2000, for a percentage of 2.51 (Appendix B, Table B.1).

The seemingly low retention percentages in these three states, among others, can be stated as a function of both frequency of tornado touchdowns and density of politically defined communities (Figure 3.13 displays U.S. communities in terms of their physical size for reference).

Figure 3.13: U.S. community size and distribution.



For example, a visual inspection of events occurring in Kansas revealed that a majority of the tornadoes from 2000–2009 struck in the western half of the state, and mostly in unpopulated areas (Figure 3.14). Tornado tracks that struck communities, where the data was useable, were included, while the remainders were not. The low retention percentage in Kansas is less a function of inadequate methods pertaining to track inclusion and more a function of the low population density and relatively few (and smaller) communities in much of the state and the geographical location of tornado tracks. A similar argument can be made for Colorado and South Dakota. Conversely, states such as Maryland (Figure 3.15), Florida, Tennessee and Indiana exhibit retention percentages of 18.82, 18.79, 18.41, and 16.96 respectively. These values are on the high end of the spectrum due to a larger number of events occurring in states with a higher density of communities.

To determine if the number of retained events per state resulting from these methods represented a statistically adequate sample of the original 12,657-count dataset (all U.S. tornadoes, 2000–2009), a chi-square test was performed. States with no observed events (seven total, see Table A.1) were removed before calculation because chi-square assumptions are based on no zero-value observations. The chi-square value of 314.23 exceeded the critical value of 73.40 (p = 0.001, df = 40) for the remaining 41 cases, indicating USTOR2000 was adequately representative of the initial dataset.

Figure 3.14: Tornado tracks in Kansas, 2000–2009.

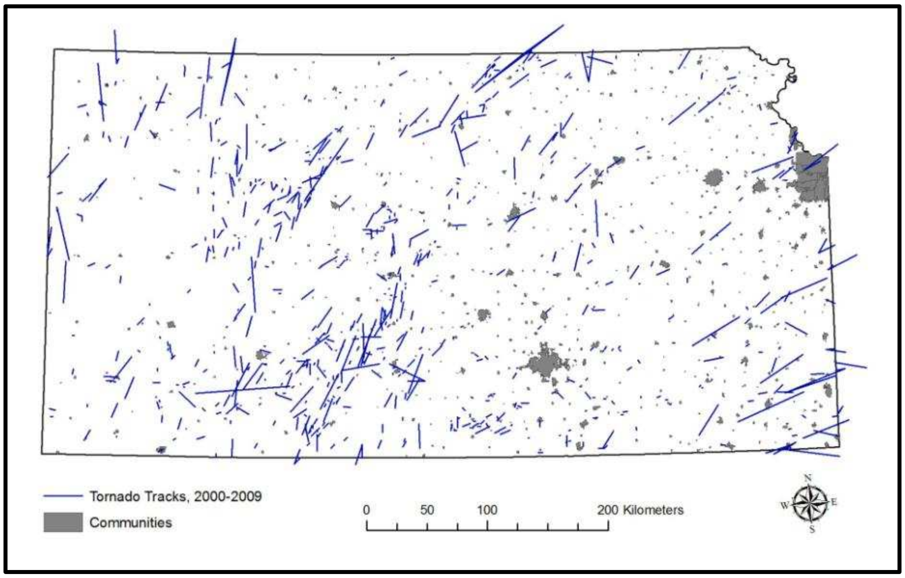
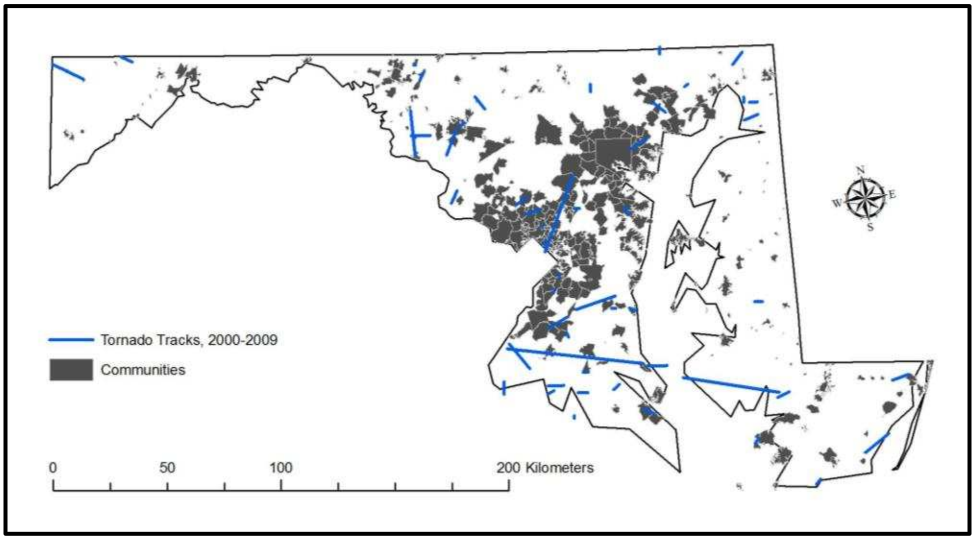


Figure 3.15: Tornado tracks in Maryland, 2000–2009.



Tabular Census Data

Census data were collected using the 2000 U.S. Census Download Center (Census 2010). The variables chosen to serve as indicators of vulnerability characteristics are routinely found in the literature (e.g., age, gender, race, income, housing type and tenure, education, marital status and employment) (Raphael 1986; Young 1998; Oliver-Smith and Hoffman 1999; Tierney et al. 2001; Wisner 2001; Burby et al., 2003; Cutter et al. 2003; Glavac et al. 2003; Handmer 2003 Wisner et al. 2004). Summary files one and three were accessed via the census download center, and 17 summary file tables downloaded. Using SPSS, 375 variables from those tables were placed in a correlation matrix, to identify variables that were highly correlated, and further identify a subset of variables to be used in constructing the community vulnerability score. A total of 19 variables were chosen to represent community vulnerability via correlation coefficients and the vulnerability literature as cited above. The variables were entered into a Microsoft Excel spreadsheet and either used as raw values or normalized per capita by population of the community, as percentages of the community population, or as density functions by the size of the community in square kilometers. Variables were then assigned descriptive names and imported into an SPSS table (Table 3.2).

The next section of this chapter details the calculation procedures employed in deriving the TICV and TC, including calculation of the damage score, the community vulnerability score and the combination of those two measures to produce the measures central to this research.

Table 3.2: U.S. Census summary files and tables downloaded, variables used and descriptive identifiers.

Summary File/Table	Table Description	Total Variables in Table	Variable(s) used	Identifier	Used as
SF1-H2	Urban and rural housing units	3	Total housing units	DENSSQKM	Density function
SF1-P3	Race	76	Percent African-American	PCTAFAM	Percentage
SF1-P11	Hispanic or Latino, total population	1	Percent Hispanic	PCTHISP	Percentage
SF1-P12	Sex by age, total population	53	Percent female Percent under 5 Percent over 65	PCTFM PCTUNDER5 PCTOVER65	Percentages
SF1-P13	Median age by sex, total population	3	Median age	MEDIANAGE	Raw values
SF1-P17	Average household size	1	Average number of people per household	AVGPPLHH	Raw values
SF1-P18	Household size, household type, and presence of own children under 16 years of age	19	Percent female householders, no husband present, with own children	PCTFMHHNHWC	Percentage
SF1-H4	Tenure (household)	3	Renter-occupied houses	PCTROH	Percentage
SF3-H30	Units in structure (housing types)	11	Percent housing units that are mobile homes	PCTMOBHH	Percentage
SF3-H76	Median value (USD), specified owner-occupied housing units	1	Median dollar value of owner-occupied houses	MVOOH	Raw values
SF3-P37	Sex by educational attainment, population age 25 years and older	37	Percent population over 25 with no high school diploma	PCT25NHSD	Percentage
SF3-P43	Sex by employment status, population age 16 years and older	17	Percent population unemployed, age 16 and older	PCT16UNEMP	Percentage
SF3-P50	Sex by occupation, employed civilian population age 16 and older	96	Percent population employed in the service industry	PCTSVCIND	Percentage
SF3-P52	Household income	18	Percent households earning $75,000 per year or more	PCTHH75K	Percentage
SF3-P53	Median household income	1	Median household income	MHHI	Raw values
SF3-P82	Per capita income	1	Per capita income	PCINCOME	Per capita
SF3-P87	Poverty status by age	18	Percent individuals below the poverty level	PCYPOVERTY	Percentage

Calculation Methods

Upon completion of the data extraction and cleaning procedures, the data were in the proper format to calculate the TICV. This was accomplished by:

1. Calculating the damage component, consisting of the number of fatalities and the monetary damage recorded for a community normalized by population;
2. Using principal components analysis to calculate a community vulnerability score for each community in the dataset;
3. Combining the previous two measures to calculate the TICV;
4. Using Jenks natural breaks to construct the TICV category scheme based on the array of TICV values.

The remaining sections in this chapter describe those procedures, concluding with a description of the study area within the coterminous U.S. (determined as described above). For analysis purposes, each of the tornado tracks included were associated with exactly one community. As such, the term “events” refers to one track/community intersection, and does not refer to the entire length of a track that may have struck multiple communities, as those were segmented into discrete units.

Damage Score: Fatalities and Monetary Damage

The number of fatalities and the monetary damage resulting from a tornado event make up the damage component (D) of the TICV. At least one fatality occurred in 61 (6.2 percent) of the 981 events in the dataset. To convert the fatality figure for an event to a monetary value, the number of fatalities resulting from a particular event was multiplied by the mean Value per Statistical Life (VSL) of seven million 2008 USD. The damage figure per event was available both in the tabular and GIS data taken from the SPC, although the figures reported in the SPC GIS shapefile attribute table were reported as categorical values (1=1,000,000 through 1,999,999 million dollars, 2=2,000,000 through 2,999,999 dollars, and so on). Because of this difference, the tabular SPC data, which reported a more accurately estimated ratio variable damage figure, was spatially joined to the GIS data to populate the damage column with that more accurate damage data. In the case of long-track events that were segmented into discrete tracks associated with exactly one community, the data were taken from the NCDC record and/or narrative, news reports, FEMA reports, county emergency managers or a combination of those sources. The damage figures were then adjusted for inflation to 2008 dollars in order to maintain temporal consistency with the VSL. The inflation-adjusted fatality figure was then added to the inflation-adjusted damage figure, and the sum normalized by the population of community c to arrive at D_c. This procedure is given by:

Equation 3.1: The damage component of the TICV.

$$D_c = [E_c + F_c(VSL)] / Pop_c$$

where

D_c = TICV damage component for community c

F_c = fatalities in community c

VSL = 2008 Value of Statistical Life constant of seven million USD

E_c = monetary damage done to community c

Pop_c = 2000 U.S. Census population of community c

Community Vulnerability Score

Principal Components Analysis

The census data collected for each of the 25,148 communities in the U.S. (see Table 3.2) was imported into SPSS. All U.S. communities were used to produce category breaks for vulnerability, into which the communities in USTOR2000 would fall. This allowed for the vulnerability of the communities in USTOR2000 to be represented by their vulnerability score (as explained below) as compared to all U.S. communities, rather than only the 981 within the TICV dataset. A principal components analysis (PCA) was performed using varimax rotation to produce a factor solution including only eigenvalues greater than one. Varimax rotation seeks to place each factor as close to orthogonal as possible to all other factors considered, and further produces high variable loadings on a single factor. Using eigenvalues greater than one is a standard method by which the most meaningful factor groups are included in the explanation of variance about the dataset as a whole (Kaiser 1958). The rotated solution produced 19 components in six factors that explained 71.05 percent of the total variance (Table 3.3).

Vulnerability Score Calculation

To calculate the vulnerability component for each community in USTOR2000, census data was extracted and placed into a new spreadsheet. The data were then arranged according to factor group from highest to lowest eigenvalue. Using the 25,148 communities as the rank array, which is the column of data by which an individual value is compared in order to determine its percentile position within that column, the percentile rank of each census datum for each community in the community dataset was calculated.

Table 3.3: PCA results.

Factors and Components	Factor Loading	Eigenvalue	Percent of Variance	Percent of Cumulative
1. Economic				
MHHI	0.943			
PCTHH75K	0.931	4.02	21.15	21.15
PCINCOME	0.929			
MVOOH	0.882			
PCTPOVERTY	-0.491			
2. Age				
MEDIANAGE	-0.896			
PCTOVER65	-0.869	3.26	17.17	38.32
AVGPPLHH	0.831			
PCTUNDER5	0.753			
3. Gender				
PCTFMHHNHWC	0.758			
PCTAFAM	0.738	1.93	10.14	48.46
PCTFM	0.515			
4. Employment				
PCT16UNEMP	0.818	1.55	8.17	56.62
PCTSVCIND	0.757			
5. Housing and Density				
DENSSQKM	0.767	1.42	7.48	64.10
PCTROH	0.606			
PCTHISP	0.475			
6. Housing and Education				
PCTMOBHM	0.669	1.32	6.95	71.05
PCT25NOHSD	0.628			

Four of the 19 components needed a further adjustment before proceeding with the TICV calculation: PCTHH75, MMHI, PCINCOME and MVOOH (see Table 3.2). In calculating the percentile rank for those variables, a higher rank (closer to 1) indicates higher vulnerability. However, an increase in percentile rank should indicate a decrease in vulnerability, not an increase. For example, higher MMHI (median household income) equates to lower vulnerability, an inverse relationship, whereas fifteen variables exhibit a direct relationship between their rank value and an increase in vulnerability. For those four components where an increased percentile rank score decreased the overall vulnerability score rather than increased it, the calculated percentile rank value was subtracted from 1.00 in order to invert the component (see Cutter et al. 2010; Flanagan et al. 2011).

Each percentile rank value was then weighted, with the eigenvalue for the factor in which that component belonged serving as the weighting value. For each of the six factor groups, the sum of the weighted percentile ranks for each component within that factor group was found. Finally, for each community in the community dataset, the sum of each of the six factor group's weighted percentile rank sums was found, resulting in the vulnerability component for community c. This procedure is given by:

Equation 3.2: The vulnerability component of the TICV Index.

$$V_c = \sum_{k=1}^{6} \sum_{n=1}^{19} [\beta \mathrm{rank}(n_c)] \lambda_k$$

where

V_c = TICV vulnerability score component for community c

$\beta\,\mathrm{rank}\,(n_c)$ = percentile rank score of vulnerability component n in community c (percentile rank array = 25,148 U.S. communities, U.S. Census, 2000)

λ_k = principal components analysis eigenvalue for factor k

Tornado Impact-Community Vulnerability Index (TICV)

Using D_c and V_c calculated as described above, the TICV is given by: [11]

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[11] The square root of the product was used in order to transform the array of large numbers that grouped heavily towards zero.

Equation 3.3: The TICV.

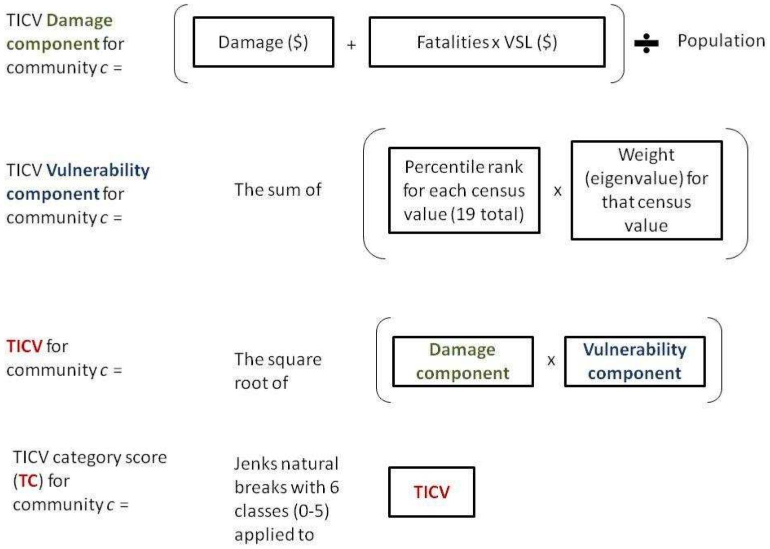
$$\mathrm{TICV}_c = \sqrt{D_c \cdot V_c}$$

where

TICV_c = the Tornado-Community Vulnerability Impact Index value for community c

The array of TICV values was then imported into the tracks shapefile attribute table in order to calculate the category break values, on [0, 5], where zero indicates the least impact and five indicates the most severe. Finally, Jenks natural breaks (Jenks 1967) was applied to the TICV column, defining the six TC categories. The calculation process is summarized in Figure 3.16.

Figure 3.16: Summary of the TICV and TC calculation process.



Study Area

The states included in USTOR2000 resulted from the data extraction procedures described above. Each “lower-48” state in which a useable tornado track occurred was included in the study area: this consists of 41 of 48 states, with Montana, Oregon, Nevada, West Virginia, Delaware, Rhode Island and Vermont excluded (Figure 3.17). The local Moran's I statistic is used in Chapter Four to identify clusters of vulnerable locations. As that statistic is based on location, comparing neighbors with similar characteristics, including Alaska and Hawaii would have caused the results to be artificially "pulled" towards those states. Due to their physical separation from the coterminous U.S., Alaska and Hawaii therefore were eliminated from consideration. It should be noted, however, that since the vulnerability score was calculated using percentile ranks for all communities in the coterminous U.S., that extent marks the study area as a whole, although not all states, as listed above, contributed tornado events to the dataset used in constructing the TICV and TC.

Figure 3.17: Study area.

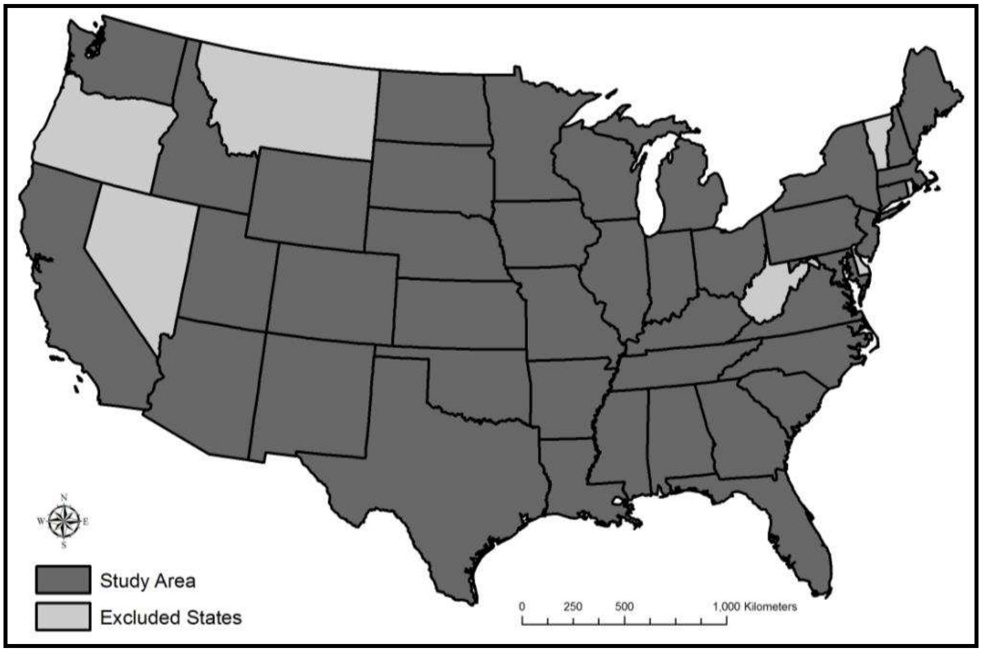


Figure 3.18: FEMA Regions used in Chapter Four.

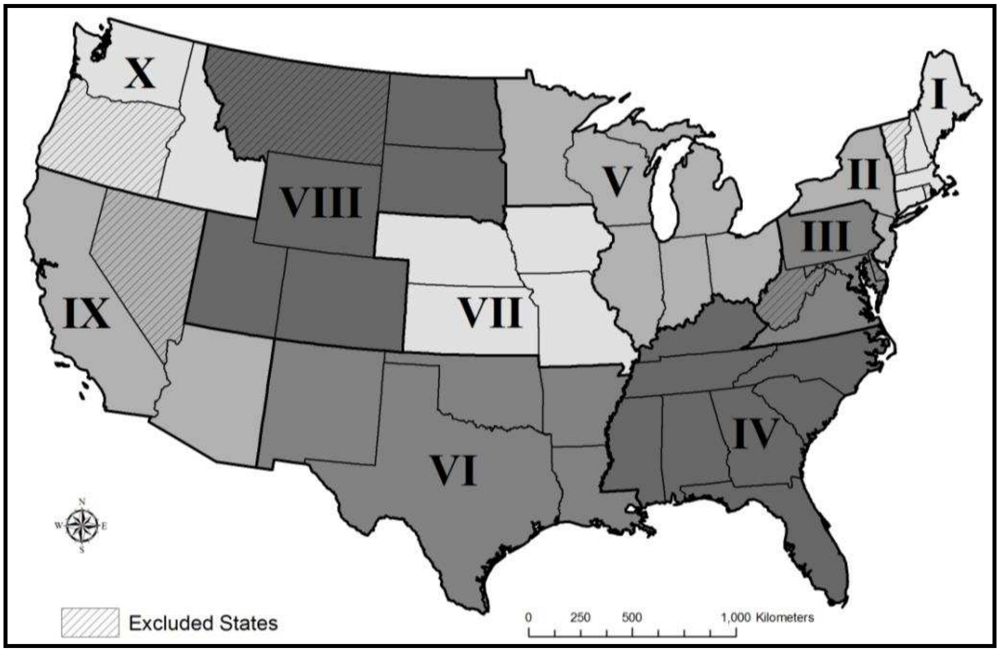


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Figure 3.18 displays the ten FEMA regions used in Chapter Four to identify smaller areal units which facilitate closer examination of tornado-community intersections. These regions were chosen for analysis as they represent the official regions used by FEMA and are easily recognized by decision makers who may wish to employ or further explore the TICV values and/or categories in those regions and their states. USTOR2000 could also serve as a baseline by which to measure change between the TICV and TC values based on the 2000 U.S. census with those based on the recent 2010 census. Finally, FEMA regions serve to delineate vernacular regions within the U.S. that are commonly thought to be relatively homogeneous in terms of the social profiles of communities (Newman 2006).

The dichotomy between urban and rural is much-studied and well-recognized within the context of geography (Woods 2005). Norton (1984, 103) stated that geographers have, “characteristically regarded rural and urban settlements as separate in order to facilitate research." Tornadoes that remained in unpopulated areas (not necessarily those that struck rural communities) were not considered in this research. Sherrib et al. (2010, 236) stated that, "'communities' are social constructs that need to be defined on a case-by-case basis," and the definition chosen here was that of communities designated as places by the U.S. Census and included in the U.S. communities shapefile. While damage can certainly occur to homes and businesses, and fatalities can occur as a result of a tornado outside of those politically defined aeral units, the impact is generally felt at the household level, which was considered too small a unit of analysis for the purposes of this research. Donner (2007) examined the relationship between rural (identified here as "unpopulated areas") tornadoes and fatalities (among other variables) and found that rural areas are less vulnerable to tornadoes, and fatalities occur with less frequency than in urban areas. Additionally, Simmons and Sutter (2011, 218) stated that, "the overwhelming proportion of casualties occur when tornadoes strike populated areas," and that, "tornadoes striking rural areas are less likely to result in damage" (224). The U.S. population has become increasingly urban and less rural (Cromartie 2001, 2002; McGranahan and Beale 2002, Harrington 2005), furthering the justification to focus on populated areas (communities) as the unit of study for this research. Finally, due to more open area and sparser populations, many rural tornadoes may even go completely unnoticed and unrecorded in the SPC database (Anderson et al. 2007).

CHAPTER 4 - Results and Discussion

This chapter presents the results of the calculation procedures used to arrive at the TICV and TC scores. Results for the damage component (raw damage values) and damage score (adjusted raw values) are presented first, followed by vulnerability scores and categories. The TICV and TC scores are discussed next, as well as their relationship to the Enhanced Fujita Scale. FEMA Regions I-X are used to frame regions for discussion.

An examination of the tornado events and associated TICV and TC scores across four separate communities is included here. These comparisons are made to highlight the unique effects different disaster events can have on communities. These examples also indicate that the TICV can not only serve as an indicator of the level of impact, but can better categorize communities hit hard by events that may not register high values on the EFS. The chapter concludes with the identification of potential practical uses for the TICV and TC.

TICV Components, Scores, and Categories

Damage Components and Scores

At least one fatality occurred in 62 (6.3 percent) of the 981 events considered in this study, with a mean occurrence of 0.23, and a maximum of 20 (Evansville, IN, 6 November 2005). The damage component[12] ranged from zero to $648M (Arlington, TX,

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[12] The damage component is the raw damage value, as calculated by the VSL times fatalities plus inflation-adjusted monetary damage.

28 March 2000), with an approximate mean of \$7 million, a median of \$75,000, a standard deviation of \$32.4 million, and a variance of over 10^8. Summary statistics thus are highly skewed by a few very high-damage events. The damage score[13] ranged from zero to 434,783 (Hallam, NE, 22 May 2004), with a mean of 2,292, a median of 7.98, a standard deviation of 18,015, and a variance of 324,883,758. Nearly one-third of the events in USTOR2000 (308 of 981; 31.4 percent) returned a damage score of zero, resulting in a Zipfian (power law) distribution[14] for both the raw damage component and the damage score (Figure 4.1). As noted by Brooks and Doswell (2001), property damages resulting from a tornado are harder to reduce than fatalities once a warning has been issued; people can move out of the way, structures cannot. Simmons and Sutter (2011, 213) further suggested that, "with winds that can exceed 200 miles per hour and the added force of tornado suction vortices, property damage is seemingly impossible to avoid." For this reason, the much higher percentage of damage occurrence compared to the incidence of at least one fatality becomes clear. The distribution of these findings are consistent with the relationship between tornado intensity and damage in the United

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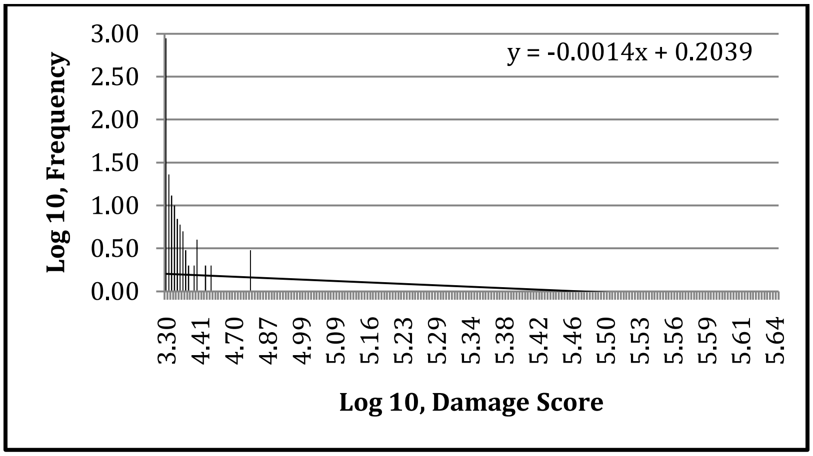
[13] The damage score is the damage component normalized by population of that particular community.

[14] Zipfian distributions, more commonly known as power law distributions, or the "80-20 rule," follow a pattern in which a large number of observed values fall within a small range of frequency for a given phenomenon. The frequency of damage scores here group heavily between zero and 250, yet range up to 434,783. This distribution follows the general pattern of the Zipf-Mandelbrot law, with a heavy left grouping and a long right tail. These distribution patterns are commonly displayed using log-log plots which are calculated using the base 10 logarithm of the values along each axis and re-plotting the result (another common display option is the quantile-quantile plot). Log-log plots display a linear pattern of frequency rather than a frequency where the phenomena under study is related to a value raised by some exponent. Non-linear results on a frequency graph are generally very difficult to interpret as they concentrate heavily on one side of the graph (Rapoport 1982; Popescu et al. 2010).

States, with stronger events generally producing greater damage (Brooks and Doswell 2001) and more frequently resulting in death (Simmons 2005; Ashley 2007) but occurring less frequently than weaker events (Dotzek et al. 2003; McCarthy 2003).

Figure 4.1: Log-log, damage score frequency.



Vulnerability Scores

The vulnerability scores displayed a normal distribution with a minimum score of 11, a maximum of 39 (Table 4.1), a mean of 24.77, a median of 24.99, a standard deviation of 5.53 and a variance of 30.65. The frequency histogram in Figure 4.2 was created using whole numbers 11 through 39 (inclusive) as frequency count categories for the array of vulnerability scores.

A Moran's I test was conducted based on the vulnerability scores and plotted using the Z-scores (measures of standard deviation) to spatially display any pattern among the communities and within regions included in USTOR2000 (Figure 4.3). Results show high levels of vulnerability (Z-score standard deviation >2.58) from east Texas (Dallas-Fort Worth metro area, Region VI) through deep southern states, including Arkansas, Louisiana, South Carolina, Mississippi, Alabama and Georgia (FEMA Region IV). The latter three also show mostly low to moderate resiliency, the inverse of vulnerability to natural hazards as described by Cutter et al. (2010) (Figure 2.3), which is in agreement with the high vulnerability scores shown here. As indicators of social vulnerability typically include race (minorities exhibit higher levels), poverty and income (the less affluent exhibit higher levels) and education (the less-educated exhibit higher levels) among others such as social class (Worts et al. 2010), it follows that areas with higher concentrations of African-Americans, Hispanics, the less-affluent and the less-educated will exhibit increased levels of vulnerability. Other areas with high Z-score values, indicating high vulnerability, include the Minneapolis-St. Paul, MN, metro area and surrounding suburbs, the Milwaukee WI-Chicago, IL, corridor extending to Madison, WI (Region V), and the Baltimore, MD, metro area (Region III); again, all areas with high concentrations of those considered to be more vulnerable to disasters.

Figure 4.2: Frequency of categorized vulnerability scores.

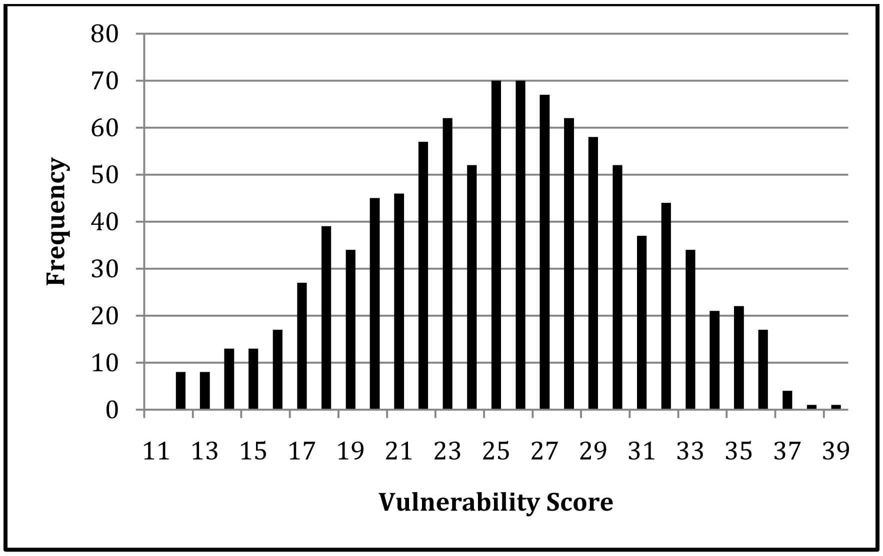
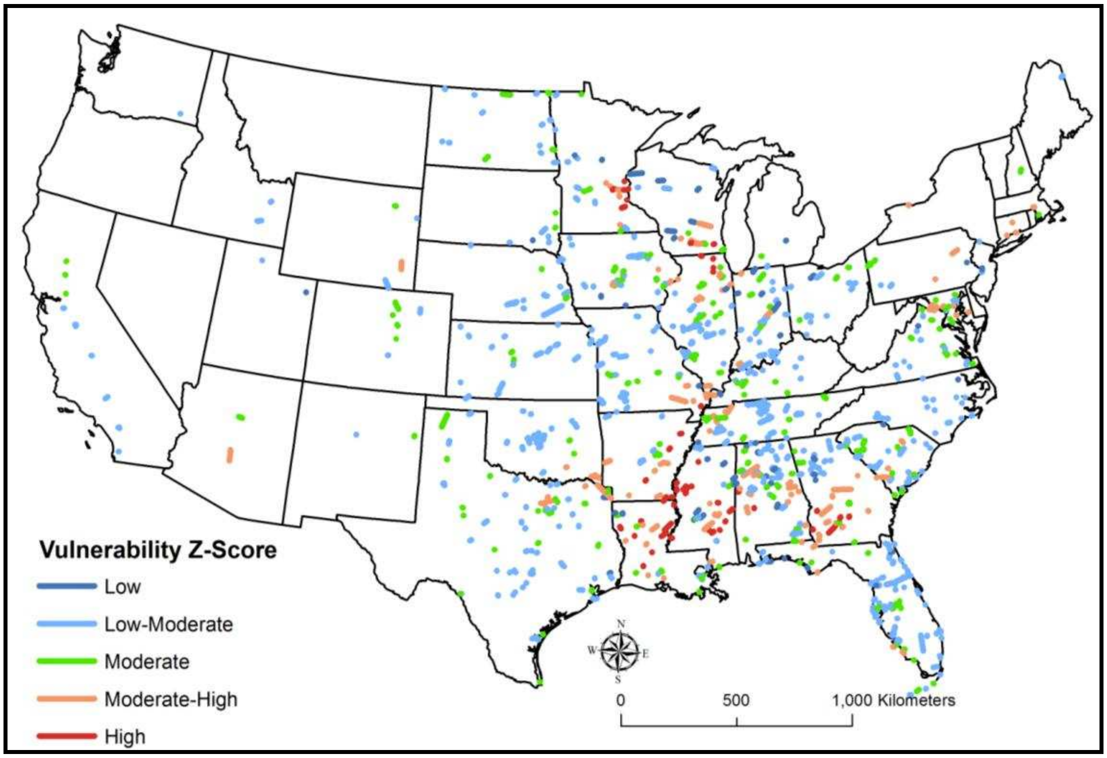


Table 4.1: Vulnerability scores and corresponding descriptors.

Vulnerability Score Range	Frequency	Vulnerability Level
11-18	139	Low
19-22	230	Low-Moderate
23-26	250	Moderate
27-30	211	Moderate-High
≥ 31	151	High

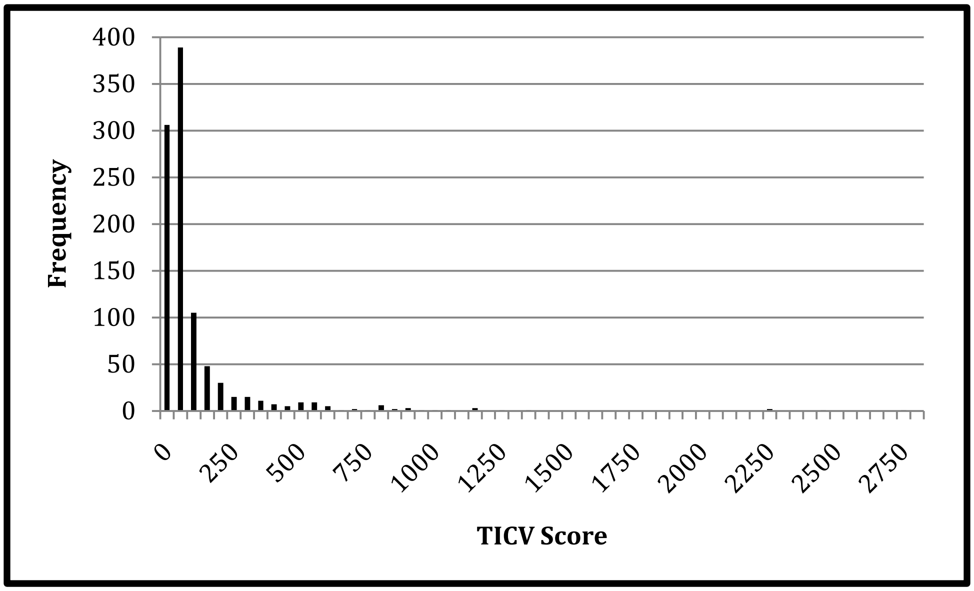
Figure 4.3: Community vulnerability by location of track-community intersection (tracks greatly enlarged for visibility).



TICV Scores

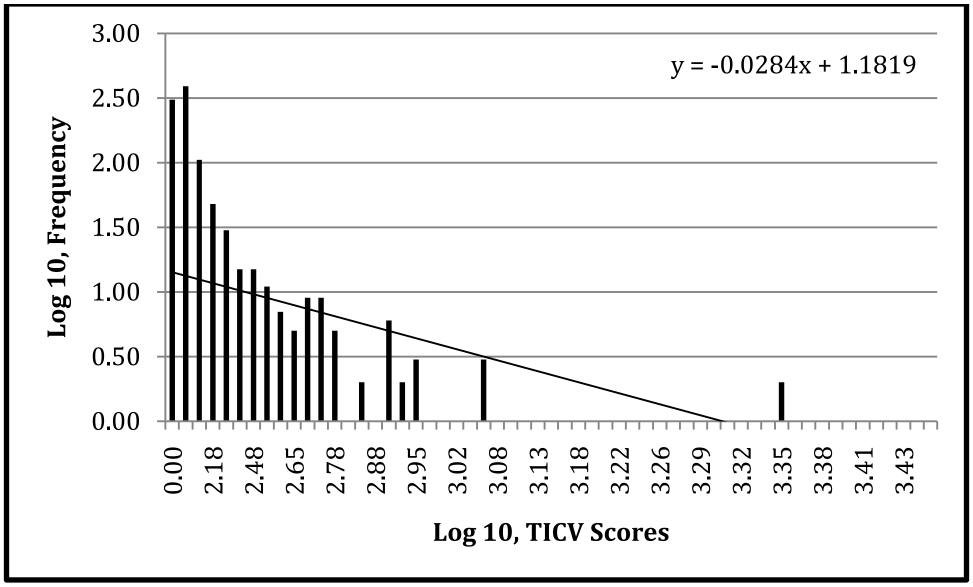
The TICV then resulted from the square root of the product of the damage and vulnerability scores. Scores ranged from zero to 2,743 (Hallam, NE, 22 May 2004), with a mean of 84.48, a median of 13.96, a standard deviation of 222.87, and a variance of 49,669. Figure 4.4 displays the frequency distribution of TICV scores, with those scores grouped heavily towards the low end, and comparatively few exceeding a score of 250. A log-log plot of TICV scores and frequency (Figure 4.5) shows a pattern similar to the damage score, again resulting in a Zipfian distribution.

Figure 4.4: TICV score frequency.



These results suggest that the TICV score is heavily influenced by the damage score, with the vulnerability score exerting a lesser influence. The standard beta coefficients resulting from a multiple regression analysis, with TICV score as the dependent variable and the damage and vulnerability scores as the independents support this suggestion. The damage score showed a β of 0.81 while the vulnerability scored showed a β of 0.09. A Spearman's test for linear correlation confirms this suggested influence, with r = 0.999 (p= 0.000) and r = 0.179 (p = 0.000) for TICV scores correlated to damage and vulnerability scores respectively. It could be argued that the vulnerability score is not a necessary component of the TICV; however, the concept of vulnerability as calculated by indicators such as those used here relate to the overall impact on the community post-event, and does influence the TICV score. Although its influence may be less than that exerted by the damage score, vulnerability nonetheless relates to the concept of community impact. Vulnerability analysis results such as these can be seen not as a measure of the direct physical impact, but rather the overall social profile of the community and that the physical impact is heightened by higher vulnerability.

Figure 4.5: Log-log, TICV score frequency.



TICV Categories

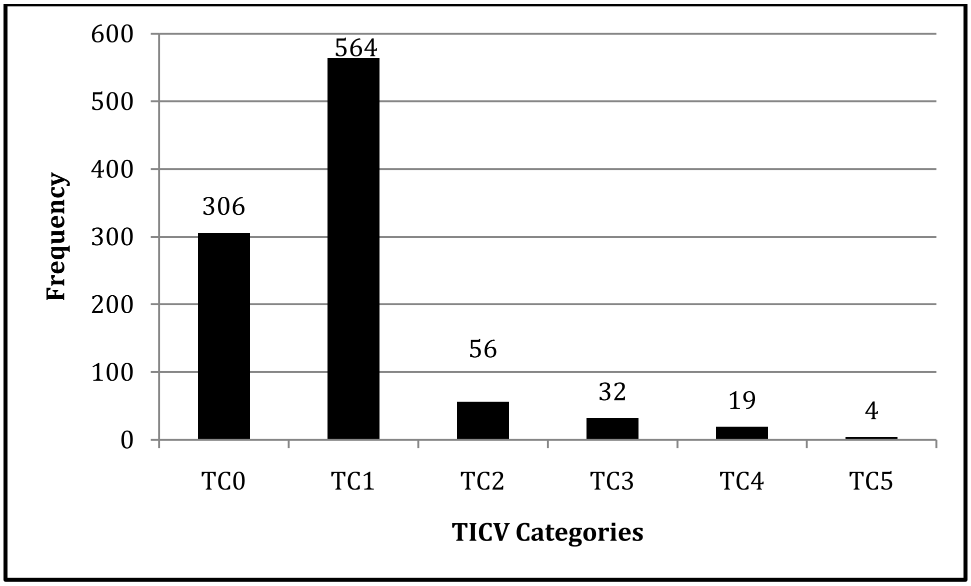
The creation of category schemes is well established and frequently employed (e.g., the EFS for tornadoes, the Saffir-Simpson scale for hurricanes, the Modified Mercalli scale for earthquakes and the AQI for air quality). The purpose of an index value is to provide a meaningful measure that can be easily interpreted (Booysen 2002;

Nardo et al. 2008). Grouping the TICV scores into discrete categories allows those measures to be better understood, since the initial scores were not distributed normally (Figure 4.5), thus displaying a grouping which presents itself as difficult to interpret quickly.

Table 4.2: TICV categories.

TICV Score Range	TICV Category	Impact Descriptor
0	0	None
1 - 181	1	Light
182 - 390	2	Moderate
391 - 720	3	Heavy
721 - 1,300	4	Severe
≥ 1,301	5	Devastating

Figure 4.6: Frequency of TICV categories.



The TICV scores were classified into six categories using Jenks natural breaks, which seek to minimize variance within a class and maximize variance between classes, to produce the TC (Table 4.2). The categories were fit onto [0, 5] (TC0, TC1,…,TC5).

The frequency of the categories show a similar distribution to the TICV scores, as should be expected, since the category breaks were based on those scores; the distribution also conforms to the Zipf-Mandelbrot Law (Figure 4.6).

TICV Score and Category Relationship to Fujita Scale

Since the EFS[15] is the standard scale by which tornado strength is rated in the U.S. (Potter 2007; Doswell et al. 2009), it seemed necessary to examine the relationship between the EFS and the TICV results presented here. Spearman's rho was used to correlate EFS values to vulnerability, damage and TICV scores, and to correlate the TC to the EFS in USTOR2000. The correlation between EFS and vulnerability scores was low, with r = 0.137 (p = 0.000), similar to the relationship between the vulnerability and TICV scores as shown above. Correlating the damage scores to EFS values produced a result of r = 0.535 (p = 0.000). A relatively high correlation should be expected, since the damage score consists of actual physical damage estimates, and wind speed estimates (EFS) heavily influences those data (Edwards et al. 2010). The correlation of the TICV to the EFS produced an interesting result, with r = 0.535 (p = 0.000); the same value exactly (to three decimal places) as the correlation between the damage scores and EFS values. These results suggest the damage score is the primary driver of the TICV.

The TC was compared to EFS values for each event in USTOR2000 to further examine the relationship between the two measures. Overall, the TC scores follows the traditional magnitude versus frequency pattern (Frequency α 1/Magnitude); with many events causing little or no damage (none to light impact) and few events causing

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[15] Although the EFS was not implemented until 2007, in order to maintain continuity it is used from this point on to refer to the Fujita Scale rating for all events in USTOR2000.

extensive damage (heavy to devastating impact). TC0 contains 306 of the 981 events (31.2 percent), and TC1 contains 564 of the 981 events; 57.5 percent, 88.7 percent combined between those categories. Table 4.3 displays the TICV category values compared to the number of EFS events that occurred in that category, as well as the percentage of the total (n = 981). TC0 consists of events resulting from EF-0 through EF-3 events, with no EF-4 or EF-5s resulting in a TC0 event. TC1 events resulted from EF-0 through EF-4s, with the plurality (and near-majority) resulting from EF-1 events (256 out of 564; 45.39 percent). TC2 events also resulted from EF-0 through EF-4 events, with the plurality resulting from EF-2s. TC3 events resulted from EF-1 through EF-4s, with exactly half occurring as a result of an EF-3. TC4 events resulted from EF-2 through EF-5 events, with the majority resulting from EF-3 tornadoes (10 of 19; 52.63 percent). Finally, TC5 events resulted from EF-3 through EF-5s, with two of the four resulting from an EF-4 event. The only EF-5 event in USTOR2000 resulted in the second highest TICV score, and one of only four TC5 events: Greensburg, Kansas.

Table 4.3: TICV category totals and corresponding EF-Scale.

TICV - EFS	**EF-0**	**EF-1**	**EF-2**	**EF-3**	**EF-4**	**EF-5**	**Totals**
TC0	179 (18.25%)	88 (9.00%)	29 (2.96%)	10 (1.01%)	0	0	306 (31.20%)
TC1	188 (19.16%)	256 (26.10%)	85 (8.66%)	29 (2.96%)	6 (0.61%)	0	564 (88.70%)
TC2	1 (0.10%)	10 (1.01%)	22 (2.24%)	19 (1.94%)	4 (0.41%)	0	56 (5.71%)
TC3	0	3 (0.31%)	9 (0.92%)	16 (1.63%)	4 (0.41%)	0	32 (3.26%)
TC4	0	0	4 (0.41%)	10 (1.01%)	3 (0.31%)	2 (0.20%)	19 (1.94%)
TC5	0	0	0	1 (0.10%)	2 (0.20%)	1 (0.10%)	4 (0.41%)
Totals	368 (37.51%)	357 (36.39%)	149 (15.19%)	85 (8.66%)	19 (1.94%)	3 (0.31%)	981

Simmons and Sutter (2011) stated that tornadoes, while generally not large enough to affect entire regions, can, however, devastate small communities. As defined by Fujita (1971) and Grazulis (1993), weak tornadoes (EF-0 and EF-1) generally produced events of lesser impact. However, in three cases, a weak tornado (EF-1) produced heavy impact. EF-2 and EF-3 tornadoes were powerful enough to have caused 15 of the 25 events (60 percent) rated at TC4 or TC5; the two highest categories resulting from these methods. No violent tornado (EF-4 or EF-5) resulted in a TC0 event. But in examining the EF-4 column, one sees that violent tornadoes of that magnitude caused a wide range of impacts; from light (TC1) to devastating (TC5). While the inverse relationship between magnitude and frequency can be seen in these results, Table 4.3 also displays exceptions. From this it can be concluded that a tornado does not have to be a violent EF-4 or EF-5 to have a severe or devastating impact on a community. Conversely, weaker tornadoes can inflict greater impact than their seemingly low EFS values (EF-1 and/or EF-2) may indicate.

The correlation between the TC and the EFS was found to be r = 0.533 (p = 0.000), indicating a similar relationship to the EFS as the TICV scores before category breaks were applied. Given the methods presented here, and that the TC was based on the TICV scores, this similarity in rho values was expected. In relation to the EFS, the correlation between that scale and the TICV scores and the TC indicated that while both scales provide an indicator of impact, the TICV and TC provide a different perspective of the event that the EFS, by design, does not. Larger tornadoes are generally linked to more damage and deaths (Brooks and Doswell 2001), so it follows that there should be a relationship between the two values. However, the purpose of this research was to construct an indicator that describes the impact of a tornado event from a perspective unique to the event and the community affected. While a correlation was found, it is not strong enough to support a claim that the EFS and the TICV are providing near-identical measures of the same event. This supports the presupposition that the TICV and TC, as an indicator specific to the social profile of, and tornado damage done to, an individual community is unique. Furthermore, these indicators can stand as separate from the EFS, as evidenced by weak tornadoes producing heavy impact and violent tornadoes producing light impact; the TICV and TC offer distinctive insight into the impact of a tornado event.

TICV Components, Scores and Category Results by FEMA Regions

Each regional section contains a summary table of the median, minimum and maximum values for the TICV components; a complete USTOR2000 results table appears in Appendix B, Table B.1. Within the following ten subsections of this chapter that follow, FEMA Regions I, II, VIII, IX and X are discussed first, due to the similarities among them in terms of low total numbers of events and range of TICV and TC scores. Discussion of FEMA Regions III through VII follow. Figure 4.7 displays all tornado tracks from 2000–2009 overlaid on FEMA Regions, and Figure 4.8 shows USTOR2000 by TC score overlaid on those same regions. Visually, it is clear that the majority of tornado events in the U.S. occur in FEMA Regions IV, V, VI and VII. The purpose of describing TICV values by region is to:

1. utilize known and recognizable regions to group what appear to be clusters of tornado tracks;
2. determine whether higher or lower levels of impact tend to group by those regions.

Figure 4.7: All tornado tracks, 2000-2009, by FEMA Region.

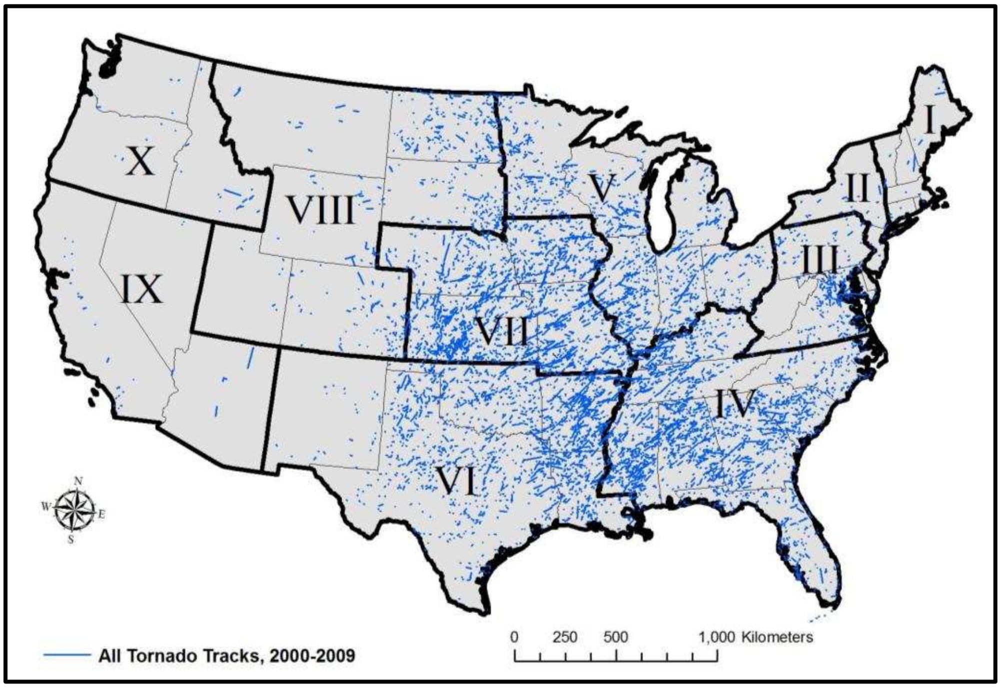
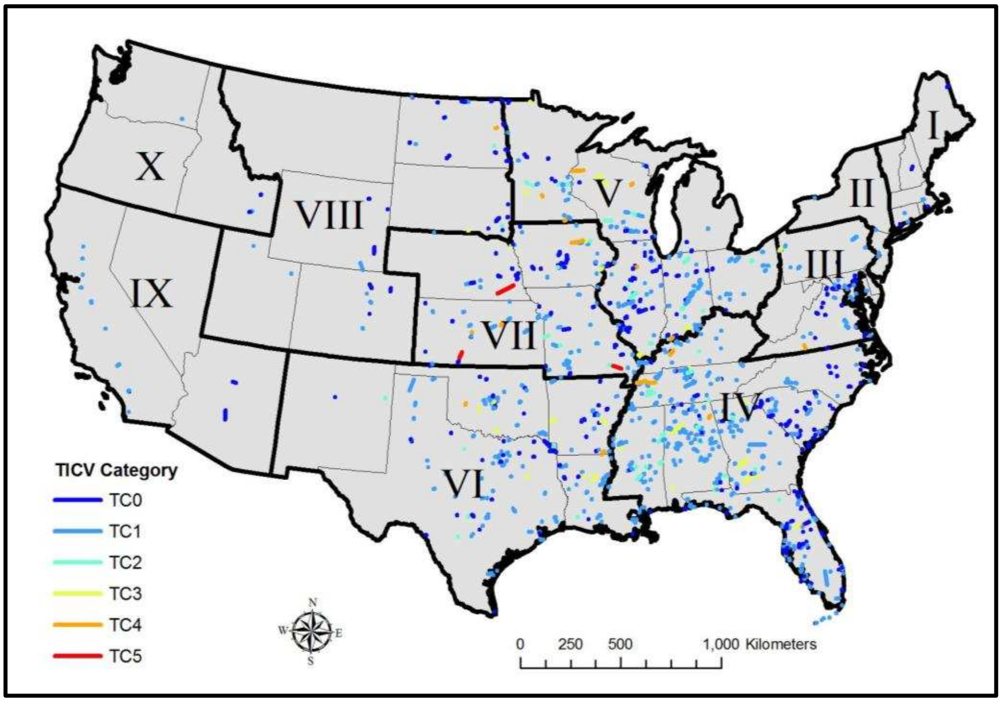


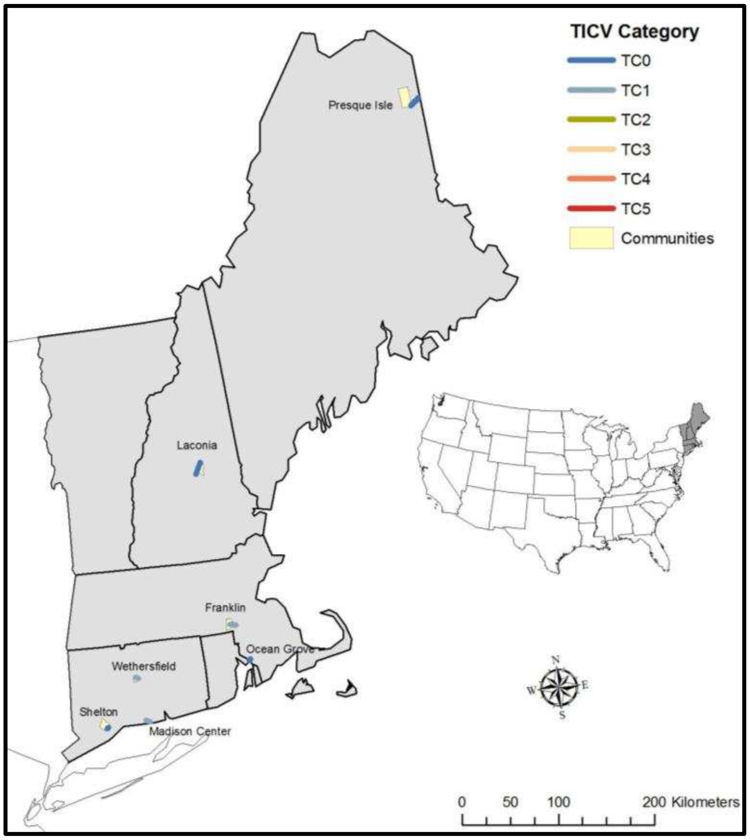
Figure 4.8: All USTOR2000 tracks, by FEMA Region.



FEMA Region I: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont

Tornadoes are relatively rare occurrences in the New England area (Figure 4.9), with a total of just 58 occurring in FEMA Region I from 2000–2009. In USTOR2000, there were only seven usable events total (12.07 percent retained), three in Connecticut, two in Massachusetts, and one each in Maine and New Hampshire (Table 4.4). There were no fatalities in this region, and damage was noted in just three of the seven events, ranging from $10,000 for a damage score of 4 (Shelton, CT, 31 July 2009) to $1,695,000 for a damage score of 57 (Franklin, MA, 21 August 2004).

Figure 4.9: FEMA Region I - CT, MA, ME, NH, RI and VT.



Vulnerability scores ranged from a minimum of 14, low, to a maximum of 26, moderate . A damage score of 57 resulting from $1.695M in damage to Franklin, MA, earned this event the highest TICV score in the region, at 28, TC1. Overall, four of the seven events were rated as TC0, with the remaining three rated as TC1. All events were either EF-0 or EF-1s. When considering all tornadoes, no event rated higher than EF2 on the EFS. Low to moderate vulnerability combined with relatively small damage scores resulted in low category ratings for communities in this region, indicating these communities can absorb events that result in relatively small damage amounts.

Table 4.4: FEMA Region I median, minimum and maximum component values, scores and category.

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
CT	3	Med.	0	10,000	4	17	8	1
		Min.	0	0	0	15	0	0
		Max.	0	750,000	28	19	22	1
MA	1	Med.	0	847,500	28	17	0	0.5
		Min.	0	0	0	14	0	0
		Max.	0	1,695,000	57	20	28	1
ME	1	Med.	0	0	0	26	0	0
		Min.	0	0	0	26	0	0
		Max.	0	0	0	26	0	0
NH	1	Med.	0	0	0	22	0	0
		Min.	0	0	0	22	0	0
		Max.	0	0	0	22	0	0
RI	0		--	--	--	--	--	--
VT	0		--	--	--	--	--	--
Region	7	Med.	0	0	0	19	0	0
		Min.	0	0	0	14	0	1
		Max.	0	1,695,000	57	26	28	0

FEMA Region II: New Jersey and New York

Events in FEMA Region II (Figure 4.10, Table 4.5) produced results similar to Region I. From 2000–2009 there were no fatalities stemming from 90 reported tornadoes, of which, only four were considered usable in this research (4.44 percent retained), two in New York and two in New Jersey. Damage estimates were at a low of $75,000 in both Hilton (25 July 2009) and Unionville (29 July 2009), NY, for damage scores of 12 and 139 respectively. The highest damage recorded was $1.17M in Trenton, NJ (23 September 2003), for a damage score of 13. Vulnerability scores ranged from 19, low-moderate, to 31, high.

The highest TICV score in the region (59, TC1) was attached to the Unionville, NY, event. Although a small community (population 536), the event scored as TC1 due to the extremely small damage amount and only a moderate level of vulnerability. All four of the events in this region were rated as TC1 events. Very few tornadoes occur in this region (218 from 1950–2009, with only 20 higher than F or EF2), and population centers (with the obvious exception of the New York metro area) are spread out sparsely over a wide area, which reduces the probability that a large-impact event will occur.

Figure 4.10: FEMA Region II - NJ and NY.

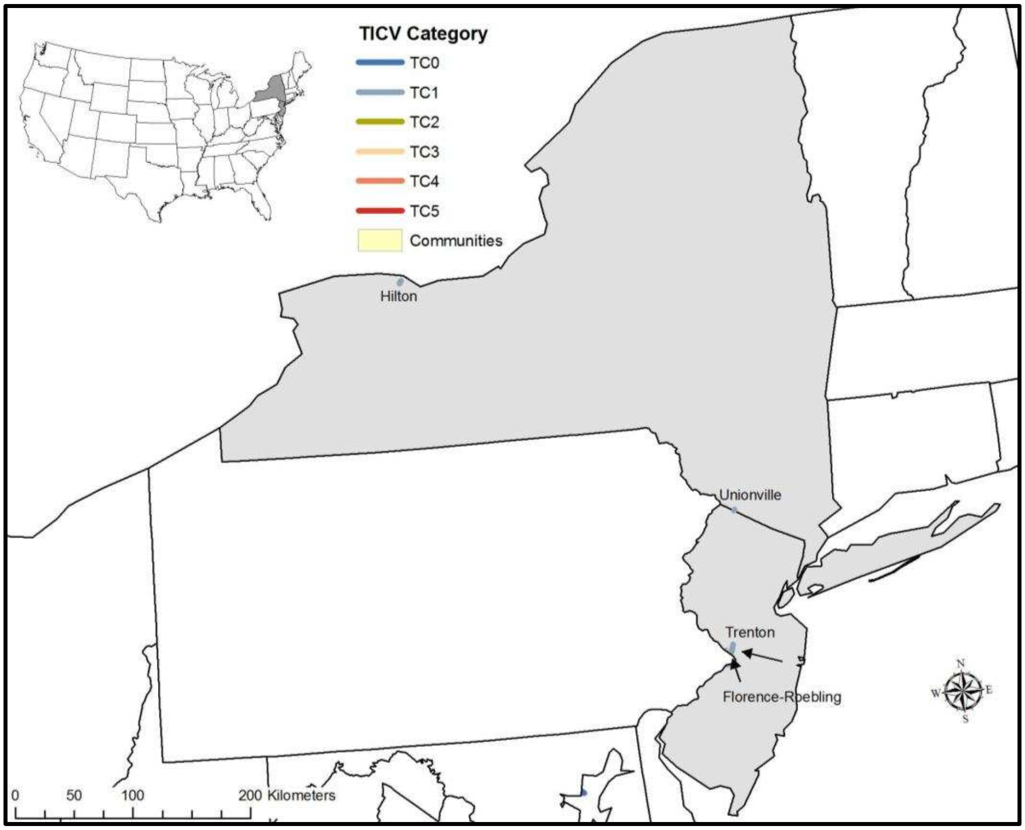


Table 4.5: FEMA Region II median, minimum and maximum component values, scores and category.

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
NJ	2	Med.	0	936,000	50	26	31	1
		Min.	0	702,000	13	20	21	1
		Max.	0	1,170,000	86	31	42	1
NY	2	Med.	0	75,000	76	22	37	1
		Min.	0	75,000	12	20	16	1
		Max.	0	75,000	140	25	59	1
Region	4	Med.	0	388,500	50	23	31	1
		Min.	0	75,000	14	20	16	1
		Max.	0	1,170,000	140	31	59	1

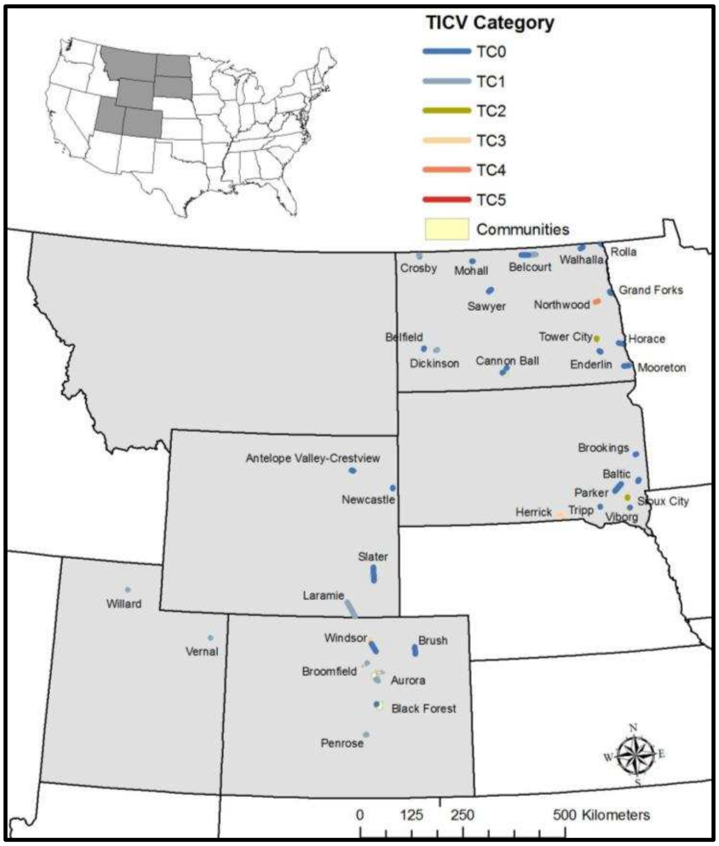
FEMA Region VIII: Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming

Covering a large geographical area, FEMA Region VIII (Figure 4.11) spans six states, and over 1.29 million square kilometers (about 498,100 square miles) across the northern continental interior and the western frontier. Within this vast region, 1,223 tornadoes struck during 2000–2009. However, given the vast land area and sparse population, it should not be surprising that a small percentage of usable events resulted from Region VIII. With the lowest percent retained among the ten regions, 3.35, only 41 tracks from the initial dataset appear in USTOR2000, and Montana entered no events into this record (Table 4.6).

Damage components ranged from zero to $59M (Northwood, ND, 26 August 2007), and vulnerability scores range from 11, low, to 33, high. TICV scores ranged from zero to 1,225 (Northwood, ND), and categories represented include TC0 through TC4. The lone TC4 event, which occurred in Northwood (8 August 2007), was one of only 17 F4 (or EF-4) events recorded in North Dakota from 1 January 1950 through 10 October 2010 (the latest date available as of this writing). Furthermore, it was only one of three EF4s to occur during the study period. The Northwood tornado was, by a factor of nearly two, the widest funnel ever in North Dakota, with a maximum width of 1,280 meters (1,400 yards). "This town is a mess. This town is a disaster. There's virtually nothing that hasn't been damaged" according to the community's emergency center manager (Tornado 2007, 2A). The NCDC (2010) narrative states:

> Northwood, in southwest Grand Forks County, had a population of about 1000 [959] people. 90 [sic] percent of the roughly 460 homes were damaged. One death occurred in a mobile home, with 18 other injuries reported. The death occurred in a trailer park on the north edge of town, where 19 total units were demolished. Just to the east of the trailer park, in the area that sustained the extreme damage, three businesses were hit particularly hard.

Figure 4.11: FEMA Region VIII - CO, MT, ND, SD, UT and WY.



Northwood, in 2010, is advancing through the recovery process, building a new $13M school to replace the one scrapped by the tornado, a new hotel, a new laundry, and RV park (Northwood 2010). Its rating of TC4 may appear to be too low, but its TICV score remained a little over half of what the Jenks breaks required to place it into the TC5 range. Other notable events in Region VIII include Herrick, SD (9 August 2002, TICV 577, TC3), and Windsor, CO (22 May 2008, TICV 476, TC3). The Windsor event was a segment in the 63 kilometer (39 mile) event referred to in the NCDC record as the Platteville Airport tornado. The community of 9,896 incurred $125M in losses and one fatality (Jaeger 2009); however, it displayed low vulnerability according to this analysis, with a score of 17 indicating a good resource base from which to initiate recovery.

Table 4.6: FEMA Region VIII median, minimum and maximum component values, scores and category (fatality totals noted in parentheses).

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
CO	7	Med.	0	1,130	0	20	2	1
		Min.	0	0	0	12	0	0
		Max.	1 (1)	132,000,000	13,338	29	476	3
MT	0		--	--	--	--	--	--
ND	19	Med.	0	0	0	25	0	0
		Min.	0	0	0	20	0	0
		Max.	1 (1)	59,000,000	61,522	33	1,225	4
SD	8	Med.	0	0	0	25	0	0
		Min.	0	0	0	19	0	0
		Max.	0	3,510,000	11,333	31	577	3
UT	2	Med.	0	13,000	7	22	9	1
		Min.	0	1,000	0	16	2	1
		Max.	0	25,000	15	28	16	1
WY	5	Med.	0	0	0	16	0	0
		Min.	0	0	0	11	0	0
		Max.	0	300,000	11	28	16	1
Region	41	Med.	0	0	0	24	0	0
		Min.	0	0	0	11	0	0
		Max.	1 (2)	132,000,000	61,552	33	1,225	4

FEMA Region IX: Arizona, California and Nevada

Well removed from what is traditionally considered tornado alley (Bluestein 2006), FEMA Region IX (Figure 4.12) recorded 134 events from 2000–2009, with 15 of those included here (retention of 11.19 percent). The damage component ranged from zero to $350,000 (March Air Force Base, CA, 22 May 2008) and TICV scores ranged from zero to 159 (also March AFB). Vulnerability scores ranged from 11, low, to 29, moderate-high. No events from Nevada were used, and within the two other states, Arizona's events all scored zeroes for the TICV and TC, and California recorded one TC0 and nine TC1s, all with very low TICV scores. Additionally, there were no events resulting in a fatality in this region (Table 4.7).

Figure 4.12: FEMA Region IX - AZ, CA and NV.

Table 4.7: FEMA Region IX median, minimum and maximum component values, scores and category.

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
AZ	4	Med. Min. Max.	0 0 0	0 0 0	0 0 0	12 11 22	0 0 0	0 0 0
CA	11	Med. Min. Max.	0 0 0	90,520 0 800,000	2 0 945	22 15 29	5 0 159	1 0 1
NV	0		--	--	--	--	--	--
Region	15	Med. Min. Max.	0 0 0	10,700 0 800,000	1 0 945	19 11 29	4 0 159	1 0 1

FEMA Region X: Idaho, Oregon and Washington

Region X (Figure 4.13) saw the third lowest number of tornadoes in the initial dataset (behind Regions I and II) at 104, of which, four were retained here for a retention percentage of 3.85. The damage component ranged from zero to $136,400 (Chubbuck, ID, 14 February 2000) and vulnerability scores ranged from 20, low-moderate, to 29, moderate-high. TICV scores ranged from zero to 46 (Dayton, WA, 16 January 2000). Categories were split evenly, with two events rated as TC0 and two as TC1. No tornado-related fatalities occurred in this region (Table 4.8).

Figure 4.13: FEMA Region X - ID, OR and WA.

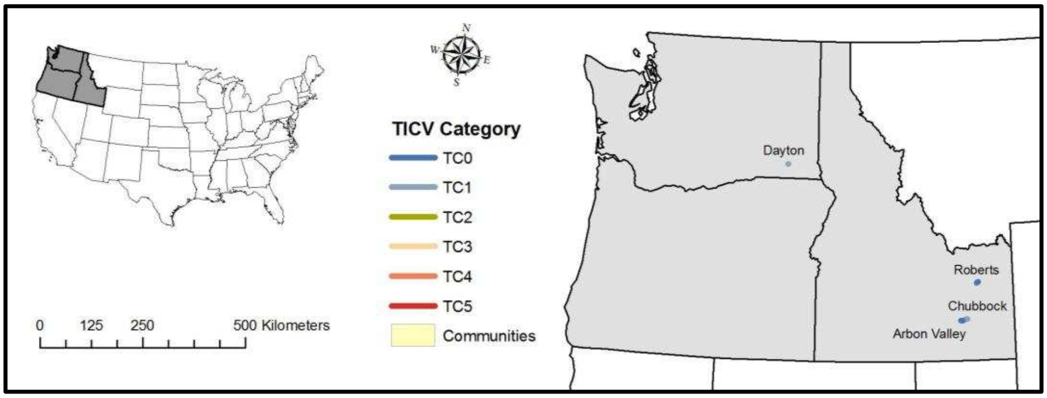


Table 4.8: FEMA Region X median, maximum and minimum component values, scores and category.

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
ID	3	Med. Min. Max.	0 0 0	0 0 136,400	0 0 14	23 20 27	0 0 1	0 0 1
OR	0		--	--	--	--	--	--
WA	1	Med. Min. Max.	0 0 0	124,000 124,000 124,000	46 46 46	29 29 29	36 36 36	1 1 1
Region	4	Med. Min. Max.	0 0 0	62,000 0 136,400	7 0 46	25 20 29	9 0 36	0.5 0 1

FEMA Region III: Delaware, Maryland, Pennsylvania, West Virginia and Virginia

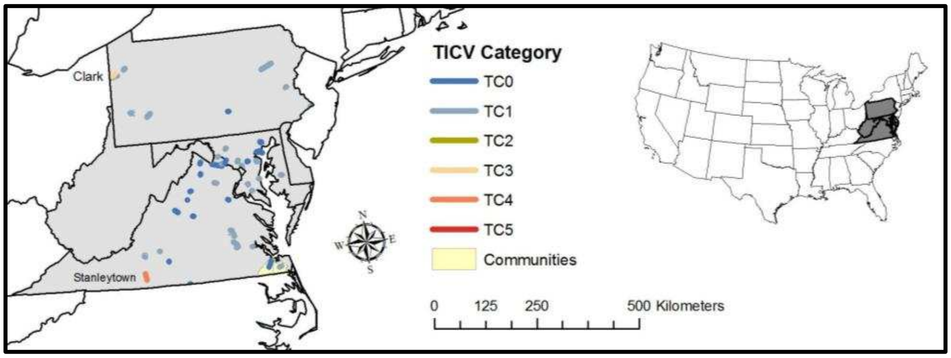
Region III (Figure 4.14, Table 4.13) witnessed a much higher occurrence of tornadoes than the previous five regions discussed, with 449 total events occurring during the study period. Of those, 47 were retained in USTOR2000 (10.47 percent), with the near-majority, 23 of 47, occurring in Virginia. The damage component ranged from zero to $60,794,000 (Stanleytown, VA, 17 September 2004), for a damage score of 40,128. Vulnerability scores ranged from 14, low, to 29, moderate-high.

TICV categories appearing in this region range from TC0 to TC4, with TC2 events absent. The TC4 event in this region took place in Stanleytown, VA (referred to in the NCDC record as the Fieldale tornado), on a very active tornado-day (43 events in Virginia). A damage figure of $53,800,800 was reported by the SPC, the tornado claimed no lives, and recorded a TICV score of 994; the highest in this region. No news articles could be located in order to elaborate on the impact and/or recovery of the area resulting from this event, but the NCDC (2010) narrative describes it as:

> A tornado [that] touched down near Fieldale at 1104 EST. The F1 tornado crossed U.S. Highway 220 turning over 2 tractor-trailer trucks and 2 passenger vehicles. All 4 drivers suffered minor injuries. The tornado damage patch widened to a quarter mile, and strengthened to F2 as it approached and struck a factory. At this location, around 40 vehicles were severely damaged or destroyed. The factory experienced significant damage. The tornado then proceeded north and entered a residential subdivision, but only minor roof and tree damage occurred here. The tornado path became intermittent as it continued north and the damage was limited to trees. The tornado crossed into Franklin County at 1114 EST.

The subdivision mentioned in the narrative is Stanleytown (population 1,515); the narrative indicates that only minor damage occurred in that area, with most of the damage occurring after the touchdown, one mile north of Fieldale (population 929). In this particular instance, the index does not appear to fit reality.

Figure 4.14: FEMA Region III - DE, MD, PA, WV and VA.



A second notable event in this region was the Clark, PA, tornado of 10 November 2002 (TICV 450; TC3). A small town of 633, Clark was struck shortly after the twister's touchdown at 7:54 EST. The NCDC (2010) narrative states:

> The tornado traveled northeast at 50 mph, crossed Route 18, then ripped into Clark. It crossed Shenango River Lake and tracked to New Hamburg, where it dissipated 8:02 PM. The tornado path was 7 miles long, about 500 yards wide at its maximum, in the town of Clark. Maximum winds estimated 155 mph. Majority of damage and all injuries occurred in Clark. Fifteen homes completely destroyed, 13 major damage, 29 had minor damage. One business destroyed; 1 suffered major damage. A large number of trees were snapped or toppled. Large truck was overturned. One van was thrown across Route 258. Several other vehicles were moved by the tornado or suffered considerable damage. Strongest tornado in Mercer county since May 31,1985.

Most of the damage occurred in the community of Clark, displaying an example of the TICV producing a result that can be applied directly to the community of record to better put the event into perspective. The record does not mention that the tornado claimed one life, an 81-year old man (Aid 2003). One fatality, in combination with the $1M in damages (adjusted to 2008 dollars, $1.19M) produced a damage component of $8.19M. The vulnerability score for Clark was 16, on the low end of the scale.

The Vindicator newspaper based in Youngstown, OH, described Clark as a "small Mercer County borough," and indicated that 12 homes were destroyed with over 100 more damaged (Aid 2003, B2).[16] The middle category (of non-zero events), a TC3 event represents an impact that, while not devastating or near-total (e.g., Greensburg, KS, and Hallam, NE), affected the community beyond the scale of minor damage to trees and buildings.

Table 4.9: FEMA Region III median, maximum and minimum component values, scores and category (fatality totals noted in parentheses).

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
DE	0		--	--	--	--	--	--
MD	16	Med. Min. Max.	0 0 0	23,550 0 6,420,000	1 0 530	19 14 26	5 0 97	1 0 1
PA	8	Med. Min. Max.	0 0 1 (1)	141,250 0 8,190,000	12 0 12,938	20 15 28	17 0 450	1 0 3
VA	23	Med. Min. Max.	0 0 0	1,130 0 60,794,000	0 0 40,125	22 17 29	0 0 994	1 0 4
WV	0		--	--	--	--	--	--
Region	47	Med. Min. Max.	0 0 1 (1)	10,400 0 60,794,000	0 0 40,125	21 14 29	2 0 994	1 0 4

FEMA Region IV: Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina and Tennessee

Region IV (Figure 4.15, Table 4.10) spans eight states in the southeastern U.S., and was home to 3,170 tornadoes during the study period. After removing unusable events, 392 tornadoes were considered here, for a retention percentage of 12.37. Damage component values ranged from a minimum of zero to a maximum of $323M (Enterprise, AL, 1 March 2007). Vulnerability scores ranged from 11, low, to 36, high. All six TICV

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[16] There sometimes are discrepancies between local reports and NCDC descriptions.

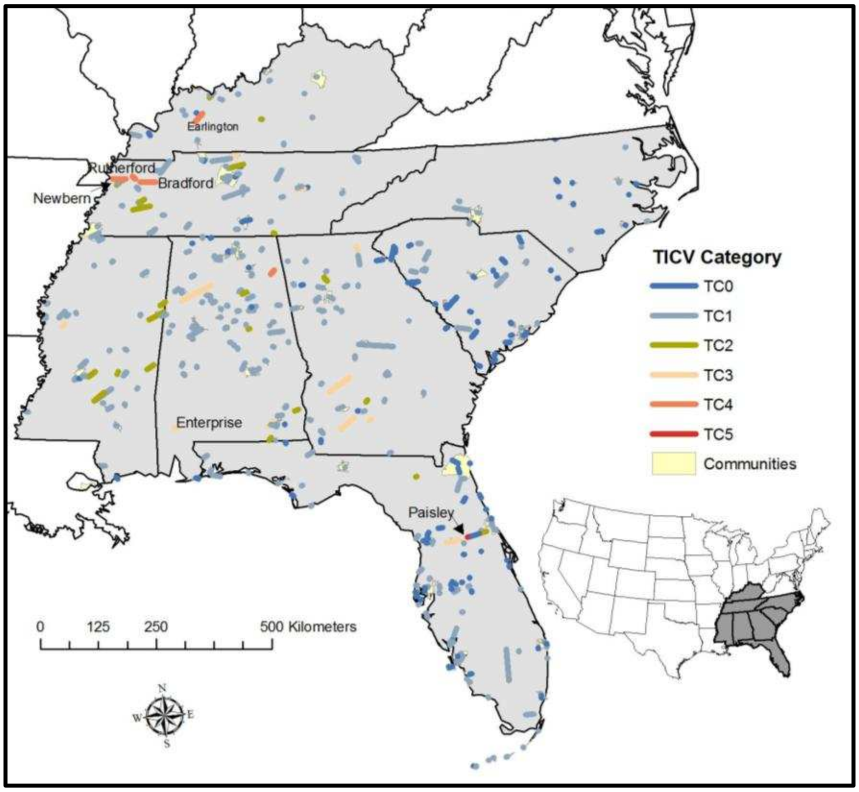
categories are represented in this region, including one of the four TC5 events in USTOR2000, Paisley, FL.

Touchdown occurred at 2:37 EST, on 2 February 2007, "in a rural area west southwest of Paisley," (NCDC 2010b). The tornado eventually laid down a 26-mile path that lifted and touched down three times, claimed a total of 13 lives (all persons in mobile homes) and caused close to $100M in damage overall. The path was segmented into four individual community-track intersections, striking the southeast corner of Paisley (population 734), Lake Mack-Forest Hills (population 989), West De Land (population 3,424), and De Land (population 20,904); it is the Paisley segment that warranted the TC5 rating, as $46M in damage and all 13 lost lives occurred as a result of the track-community intersection there. A visual inspection of the area using satellite imagery via Google Earth ® (Figure 4.15) revealed the presence of several mobile homes in Paisley, in the area through which the tornado tracked.

Figure 4.15: Mobile homes located at the southeastern corner of Paisley, FL (source: Google Earth 2010).

Additionally, Associated Press and local newspaper reports supported the fatality assignment (e.g., Ellis 2007; Florida Storm 2007; Long and Merzer 2007) thus the 13 fatalities were assigned to the attribute table entry attached to the community of Paisley. The Lake Mack-Forest Hills and West De Land segments rated TC0, as data could not be attached to those tracks, and the final segment, West De Land, rated a TC2, incurring $52M in damage, with an damage component of $54.08M and a damage score of 2,587.

Figure 4.16: FEMA Region IV - AL, FL, GA, KY, MS, NC, SC and TN.



Along with the Paisley event, there were several other tornadoes that caused a great deal of damage and were subsequently scored high on the TICV, including five TC4 and 11 TC3 events. Three of the five TC4 events were born of a single parent supercell over western Tennessee, striking the communities of Bradford, Newbern, and Rutherford on the same day, 2 April 2006, recording TICV scores of 1,300, 1,140 and

843 respectively. The Bradford event registered a damage component of $68.75M for a damage score of 61,769, and claimed six lives. The NCDC (2010) narrative states:

> This tornado was the second of two F3 tornadoes that affected Gibson County on April 2nd. The tornado touched down just south of the Obion and Gibson County line and tracked southeast. The tornado lifted just east of Rutherford near the intersection of China Grove Rd and Highway 105. The hardest hit area was the city of Bradford. There were six fatalities in Bradford along with forty-four injuries. Approximately two hundred fifty homes were damaged and seventy-five homes were destroyed. The Bradford Police Department was completely destroyed. Other businesses were also severely damaged.

Table 4.10: FEMA Region IV median, minimum and maximum component values, scores and category (fatality totals noted in parentheses).

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
AL	79	Med.	0	103,550	19	25	22	1
		Min.	0	0	0	14	0	0
		Max.	11 (29)	323,000,000	28,223	36	802	4
FL	106	Med.	0	13,000	0	24	3	1
		Min.	0	0	0	11	0	0
		Max.	13 (22)	138,840,000	189,155	35	2,223	5
GA	42	Med.	0	263,750	60	28	40	1
		Min.	0	0	0	14	0	0
		Max.	6 (11)	129,440,000	8,647	36	543	3
KY	19	Med.	0	169,500	105	28	56	1
		Min.	0	0	0	19	0	0
		Max.	0	79,360,000	20,491	35	857	4
MS	38	Med.	0	874,500	123	30	57	1
		Min.	0	0	0	14	0	0
		Max.	2 (2)	71,400,000	6,895	34	464	3
NC	15	Med.	0	0	0	24	0	0
		Min.	0	0	0	14	0	0
		Max.	0	2,340,000	243	32	74	1
SC	42	Med.	0	0	0	26	0	0
		Min.	0	0	0	13	0	0
		Max.	1 (1)	7,280,000	493	35	132	1
TN	51	Med.	0	585,000	64	26	43	1
		Min.	0	0	0	15	0	0
		Max.	16 (59)	133,400,000	61,769	32	1,300	4
Region	392	Med.	0	181,000	11	26	17	1
		Min.	0	0	0	11	0	0
		Max.	16 (124)	323,000,000	189,155	36	2,223	5

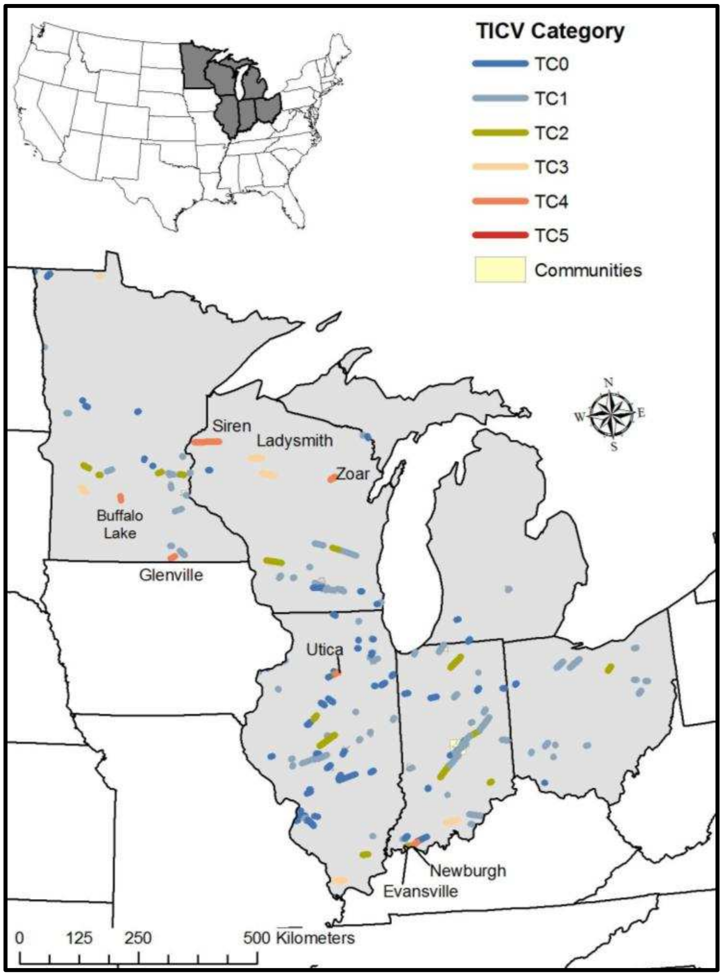
"The [Bradford] F3 tornado resulted in sixteen fatalities and 70 injuries. Seventy-one homes were destroyed and one hundred eighty-two were damaged" (NCDC 2010b), resulting in a damage component of $133.4M for a damage score of 44,645. Rutherford took $15M in losses, with two lives lost, for a damage component of $30.05M and a damage score of 23,624. These three communities all exhibit moderate-high levels of vulnerability, with Bradford's score at 27, Newbern's at 29 and Rutherford's at 30. Elevated levels of vulnerability in conjunction with heavy monetary losses and the accompanying loss of life resulted in these events being rated in the second highest TICV category, indicating tornadoes that did not completely devastate the communities, but yet caused widespread damage and imposed a severe impact on them (e.g., Clark 2006; Hall 2006; Schrade and Alligood 2006). Other notable TC3 events include Portland and Lake Tansi, TN, Camilia, GA, Lady Lake, FL, and Enterprise and Carbon Hill, AL. Notable TC2 events include Jackson and Gallatin, TN.

FEMA Region V: Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin

Region V (Figure 4.17), covering the upper Midwest, witnessed 1,776 tornadoes over the study period, of which 170 were retained for a percentage of 9.57. Damage components ranged from zero to $156,350,000 (Evansville, IN, 6 November 2005). Vulnerability scores ranged from 11, low, to 33, high. TICV scores ranged from zero to 1,110 (North Utica, IL, 20 April 2004). TC0 through TC4 events appear in this region, with only TC5 events absent (Table 4.11).

The North Utica, IL, tornado (highest TICV score in this region at 1,110, and categorized as TC4) caused a relatively little damage in dollars, $4M, compared to several other more destructive events in the dataset, but owes its high score to the size of the community, and the fact that eight lives were lost as a result of this storm. North Utica scored low-moderate (19) on the vulnerability scale, indicating a profile of a community with an increased capacity to recover from the event. This was a long-track event that was segmented into three tracks, with the first community-track intersection striking Mark, IL (population 491), with no data available for that specific segment it received a score and category of zero. Granville was struck by the second segment, resulting in a score of 259, category TC2, and North Utica was the third.

Figure 4.17: FEMA Region V - IL, IN, MI, MN, OH and WI.



Another TC4 in this region that resulted in the loss of life was the Siren, WI (18 June 2001, population 988) tornado, taking two lives, causing $10M in damage for a damage component of $26.2M, and a TICV score of 887. The town's tornado sirens failed to provide warning, but other mediums of information were still available, such as radio and television (Malhan 2001), and the town sheriff, who quickly drove around the small town warning people in person. According to the NCDC (2010) narrative:

> The tornado touched down at 806 pm local daylight time 1.5 miles east of Grantsburg and traveled east at an average speed of 40 mph through the village of Siren to the Washburn County line, then continued on to a point 3 miles west of Spooner. The path of the tornado averaged 1/8 to 1/4 mile, but reached its greatest width of mile as it approached Siren around 820 pm, where it did F-3 damage. Two people were killed by the tornado, and there were 16 injuries. Four hundred homes were destroyed, 200 in Siren alone, with 280 homes damaged, and 60 businesses destroyed or damaged. Most of the damage occurred in an 8-block area of Siren.

Table 4.11: FEMA Region V median, minimum and maximum component values, scores and category (fatality totals noted in parentheses).

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
IL	58	Med.	0	0	0	22	0	4
		Min.	0	0	0	11	0	0
		Max.	8 (10)	60,520,000	61,944	33	1,110	4
IN	38	Med.	0	1,215,000	65	23	40	1
		Min.	0	0	0	13	0	0
		Max.	20 (26)	156,350,000	32,011	31	786	4
MI	5	Med.	0	0	0	24	0	0
		Min.	0	0	0	22	0	0
		Max.	0	8,330,000	1,021	27	153	1
MN	30	Med.	0	300,000	29	19	20	1
		Min.	0	0	0	12	0	0
		Max.	1 (3)	39,100,000	33,888	29	870	4
OH	15	Med.	0	481,500	207	24	69	1
		Min.	0	0	0	14	0	0
		Max.	1 (2)	25,600,000	5,333	29	329	2
WI	24	Med.	0	758,475	54	20	35	1
		Min.	0	0	0	14	0	0
		Max.	2 (4)	29,750,000	26,518	29	887	4
Region	170	Med.	0	148,100	16	22	17	1
		Min.	0	0	0	11	0	0
		Max.	20 (45)	156,350,000	61,944	33	1,110	4

Other communities receiving high TICV scores and TC4 designations in this region include Glenville, MN (1 May 2001, population 720, TICV score 870), Buffalo Lake, MN (24 June 2003, population 768, TICV score 772), Zoar, WI (7 June 2007, population 124, TICV score 776), and Newburgh, IN (6 November 2005, population 3,088, TICV score 786). The Ladysmith, WI (2 September 2002), TC3 event is compared to three other events later in this chapter. A notable TC2 event in this region was the Evansville, IN (6 November 2005). A damage figure of $15M to a community of 121,582 is comparatively small, but the tornado claimed 20 lives, all in a mobile home park south of Interstate 164.

Within this region lies the longest track in the dataset, and the fourth longest when all 2000–2009 events are considered; the 112-mile Indianapolis tornado. This monster struck eight different communities causing a total of $103M in damages, but amazingly did not claim a single life. As per the segmenting procedure described in Chapter Three, this event was broken into eight discrete segments, one scoring as TC0, four as TC1, and three as TC2.

FEMA Region VI: Arkansas, Louisiana, New Mexico, Oklahoma and Texas

Region VI (Figure 4.18), covering the central southern U.S. recorded 2,846 tornadoes from 2000–2009, of which 183 were included here for a retention percentage of 6.43. Damage components ranged from zero to $648M (Arlington, TX, 28 March 2000), and damage scores range from zero to 42,554 (New Cordell[17], OK, 9 October 2001). Vulnerability scores ranged from 11, low, to 39, high. TICV scores ranged from zero to 1,117 (New Cordell, OK, 9 October 2001), resulting in categories TC0 through TC4 represented, with no TC5 events in this region (Table 4.12).

There were a total of two TC4s, eight TC3s, and eight TC2s in this region. As mentioned above, the highest TICV score resulted from the New Cordell, OK (population 2,867), event, a TC4. Despite several injuries, and one man remaining trapped in his car while it was tossed 250 feet, no fatalities occurred there (Plains Twisters 2001). The

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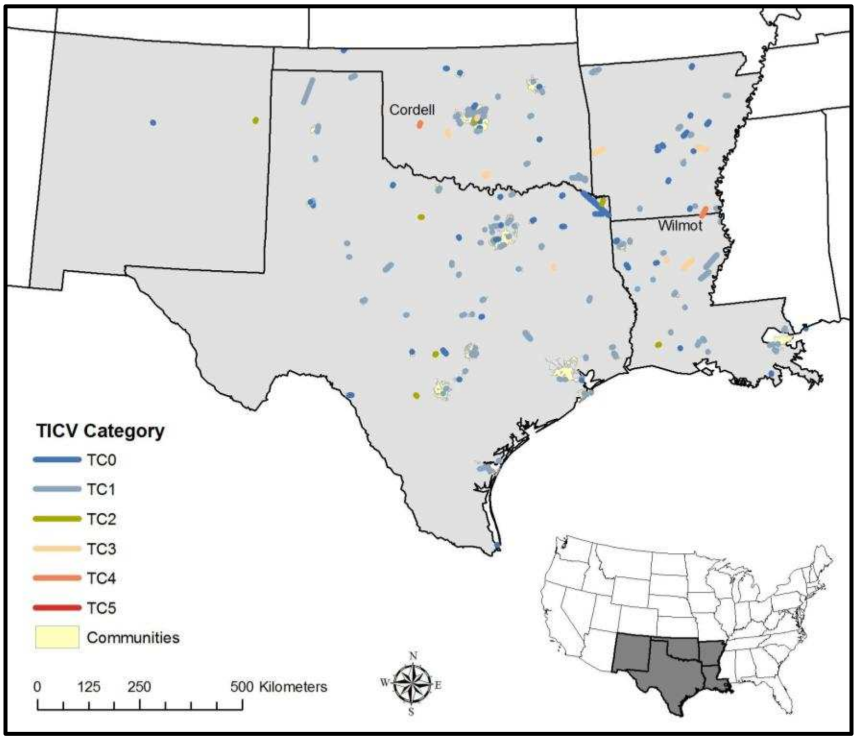
[17] The census lists this community as "New Cordell," but it is referred to as "Cordell" in all other sources located.

damage component, after adjusting for inflation, was $122M. According to the NCDC (2010) narrative:

> This tornado developed on the southwest side of Cordell, where a mobile home and metal warehouse were blown into a farmhouse. The tornado then moved through south, east and northeast portions of Cordell, including a business district and a large residential area. Most damage south of Main Street was rated F0 or F1. North of Main Street, the damage path widened to approximately 500 yards, with the tornado then inflicting widespread F1 to F2 damage up to 12th Street. Hundreds of homes were damaged in this area. As the tornado began to exit the northeast side of Cordell, F3 damage was sustained to several homes on 9th Street, just west of Crider Road. An F4 rating was considered; however, the structural integrity of most structures was at or below average, and was taken into consideration. Another interesting note is that several eye-witnesses reported that the tornado was widest and contained the most violent-looking winds at this time. The tornado eventually exited Cordell and dissipated 3.5 miles northeast of town.

Figure 4.18: FEMA Region VI - AR, LA, NM, OK and TX.



The only other event in this region to be rated as a TC4 occurred in Wilmont, AR (population 786), on 24 November 2001. This tornado caused $2M in damage, but received a damage component of $23.44M due to the three fatalities that resulted from the storm. "Heavy damage [was] reported," (Brown 2001, A1), and the NCDC (2010) narrative states:

> The tornado strengthened and widened as it approached the Wilmot area and was rated as an F3 with a maximum width of one half mile. The tornado destroyed 14 mobile homes and houses and caused extensive damage to five other homes in the vicinity of Wilmot. A church on the north side of Wilmot was completely destroyed.

Table 4.12: Region VI median, minimum and maximum component values, scores and category (fatality totals noted in parentheses).

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
AR	27	Med. Min. Max.	0 0 3 (6)	75,000 0 75,000,000	5 0 29,821	28 18 38	10 0 1,031	1 0 4
LA	29	Med. Min. Max.	0 0 1 (2)	300,000 0 12,650,000	32 0 8,927	29 18 35	27 0 525	1 0 3
NM	2	Med. Min. Max.	0 0 0	1,820,000 0 3,640,000	1,663 0 3,327	25 21 29	156 0 312	1 0 2
OK	39	Med. Min. Max.	0 0 8 (8)	113,000 0 245,700,000	3 0 42,553	25 17 36	8 0 1,116	1 0 4
TX	86	Med. Min. Max.	0 0 4 (5)	83,625 0 648,000,000	1 0 6,815	26 11 35	6 0 414	1 0 3
Region	183	Med. Min. Max.	0 0 8 (21)	100,000 0 648,000,000	5 0 42,553	26 11 38	11 0 1,116	1 0 4

Of the remaining TC3 through TC0 events, only six additional tornadoes resulted in fatalities; Lone Grove, OK (2/10/2009, eight fatalities), Olla, LA (23 November 2004, one fatality), Mena, AR (9 April 2009, three fatalities), Arlington, TX (28 March 2000, four fatalities), Corpus Christi, TX (24 October 2002, one fatality), and New Orleans, LA (13 December 2007, one fatality). The F4 tornado that struck Moore, OK (population 41,138), on 8 May 2003 was rated as a TC2. With a reported $210M in damage (damage component $245.7M), but no fatalities, the event received a TICV score of 368. Moore exhibits moderate vulnerability (23), thus possessing an ability to recover from a rather large event in terms of damage indicators. Furthermore, the event was spread out over several adjacent and discrete communities, with the high damage figure not attached solely to the community of Moore.

FEMA Region VII: Iowa, Kansas, Missouri and Nebraska

Region VII (Figure 4.18) logged 2,807 tornadoes during the study period, but only 118 of those were deemed usable for this research, for a retention percentage of 4.20. The damage component range from zero to $327M (Greensburg, KS, 4 May 2007), and damage scores ranged from zero to 436,783 (Hallam, NE, 22 May 2004). Vulnerability scores ranged from 14, low, to 34, high (Table 4.13). TICV scores ranged from zero to 2,743 (Hallam, NE), and all six categories are represented, including three of the four TC5 events in the dataset: Hallam, NE, Greensburg, KS, and Ellsinore, MO.

The 2004 Hallam (population 276) tornado ranks second in this dataset in path length at 87 kilometers (54 miles), behind only the Indianapolis track. It also recorded a maximum path width of 4,023 meters (4,400 yards), or approximately four kilometers (two and a half-miles); the widest ever recorded by the NWS (NWS 2004). The full track caused $160M in damage along its route, with the majority of the funnel’s time spent ripping through unpopulated areas. Had this enormous tornado tracked approximately 25 kilometers (15.5 miles) north it would have torn through Lincoln, NE, and at over four kilometers wide undoubtedly would have caused catastrophic devastation.[18]

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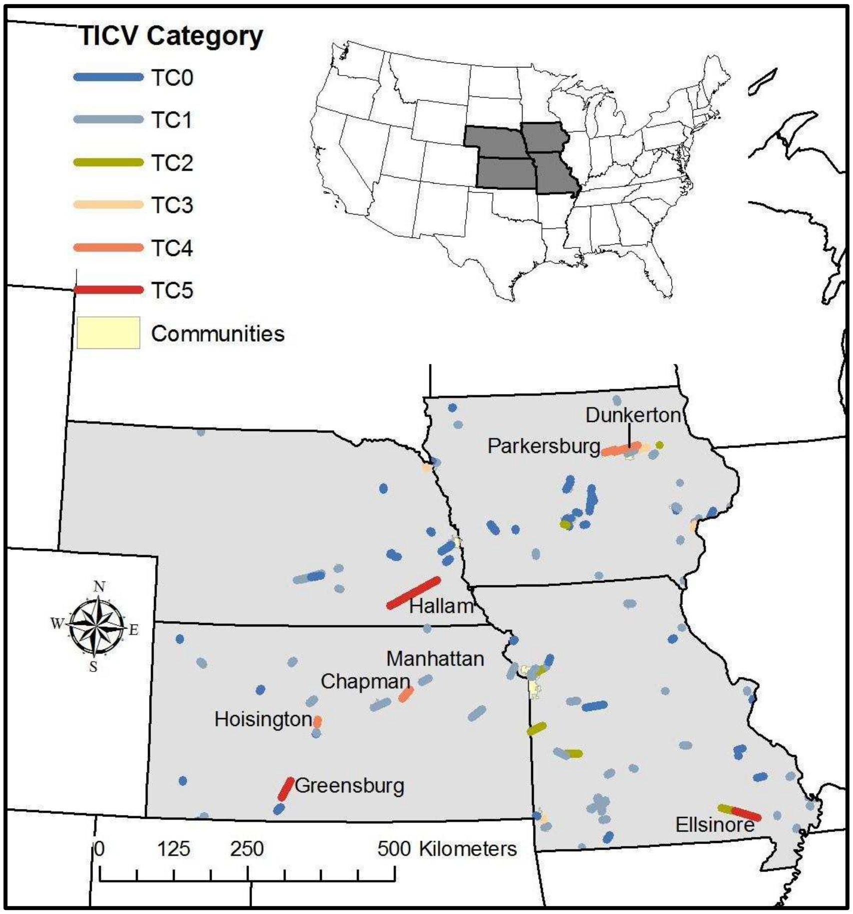
[18] Research on the hypothetical temporal and spatial transplant of tracks from one community to another was done by Rae and Stefkovich, (2000), "moving" the May 1999 Moore, OK, tornado onto the Dallas-Fort Worth, TX, metro area. According to the authors, the damage to the Dallas-Fort Worth area would be massive should a tornado the size of the Moore event occur in the Dallas-Fort Worth area.

Figure 4.19: FEMA Region VII - IA, KS, MO and NE.



The track intersected the southern tip of Wilber, but no clear damage figure could be found. Along its path, the tornado took one life. A damage figure of $100M was attached to the community, as estimated by subtracting the $60M in damages attributed by the NCDC to "agricultural" structures (2010), which were assumed to be in rural areas, from the $160M total. Newspaper reports culled from an Internet search consistently refer to the town as “flattened,” “almost totally destroyed,” “demolished,” “leveled,” and, according to FEMA official Mike Brown, "...about as bad as it gets" (WOWT 2004). The NCDC narrative indicates that approximately, "95 percent of the buildings in town were either destroyed or severely damaged" (2010). As a result, Hallam scored the highest TICV rating in the dataset: 2,743. Over six years later, the community is still in the process of recovering, with a new post office completed in 2009 (Laukaitis 2009) and other structures, such as a damaged cooling tower, replaced in late 2010 (NTV 2010).

Table 4.13: FEMA Region VII median, minimum and maximum component values, scores and category (fatality totals noted in parentheses).

State	Event Total	Median Minimum Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	TC
IA	39	Med.	0	10,700	1	23	5	1
		Min.	0	0	0	14	0	0
		Max.	7 (10)	66,000,000	34,939	29	930	4
KS	20	Med.	0	230,375	38	26	29	1
		Min.	0	0	0	21	0	0
		Max.	11 (13)	327,000,000	207,750	32	2,439	5
MO	43	Med.	0	428,000	82	25	44	1
		Min.	0	0	0	18	0	0
		Max.	2 (4)	70,200,000	147,520	34	2,213	5
NE	16	Med.	0	2,500	0	24	0	0.5
		Min.	0	0	0	17	0	0
		Max.	1 (1)	120,000,000	434,782	29	2,743	5
Region	118	Med.	0	100,000	16	24	20	1
		Min.	0	0	0	14	0	0
		Max.	11 (28)	327,000,000	434,782	34	2,743	5

The second of three TC5 events in this region hit Ellsinore, MO. The small community (population 363) was struck by the same tornado that shortly before passed through Van Buren, MO, (population 845, TICV score 217, TC2). The Ellsinore segment was rated with a TICV score of 2,213, and the community itself, pre-event, exhibited high vulnerability, with a score of 33. According to the NCDC, "Damage on the south side of Ellsinore was severe, where about 7 businesses were destroyed" (2010). News reports are not clear on how many homes were destroyed, but report that over 60 homes total were damaged in both Van Buren and Ellsinore (Tally 2002). The $45M damage total was collected from the Butler County Emergency Management Office. FEMA records are also unclear as to the extent of damage in the town, but indicate over $11.5M was made available to Butler and 39 additional counties after this and seven other tornadoes occurred that same day. Given the lack of news reports discussing the extent of damage and related recovery activities, which are commonly found in the media for very large events, it is questionable whether or not the Ellsinore tornado warrants a TC5 rating. The third TC5 event in this region, Greensburg, KS, is discussed in more detail and in comparison to three other events in the Discussion section.

Of the remaining events in this region, four were rated as TC4 and four as TC3. All four of the TC4 events resulted in at least one fatality each, with seven occurring in Parkersburg, IA (25 May 2008, TICV 930), one in Hoisington, KS (21 April 2001, TICV 790), one in Chapman, KS (11 June 2008, TICV 756), and two in New Hartford, IA (25 May 2008). Additionally, the Dunkerton, IA (11 May 2000, TICV 436, TC3) event resulted in one fatality.

Summary of Analysis by FEMA Region

FEMA Regions were chosen to facilitate discussion of these results as they represent boundaries that are recognized by emergency management officials. Additionally, in a vernacular sense, they represent regions of the coterminous U.S. that are recognizable by the layperson (e.g., the Deep South, Midwest, Great Plains). Table 4.13 summarizes the TICV components and scores by FEMA Region. Expressed as the geometric interval of median TICV value by state, Figure 4.20 shows most regions do not appear to be homogeneous in terms of the TICV and TC values. Regions, such as the Plains states, show similar median values (tornado alley is clearly visible), but Dixie alley in the southwest (FEMA Region IV) shows a wide range of median values, spanning all four classes presented by the interval method employed. Similar statements can be made for FEMA Regions I, II and III. While these regions serve a useful purpose in terms of allowing the Department of Homeland Security to efficiently govern the Federal Emergency Management Agency, they do not appear to accurately demarcate regions across the coterminous U.S. as a whole in terms of tornado impact as indicated by the index developed here.

Figure 4.20: Mean TICV values by state.

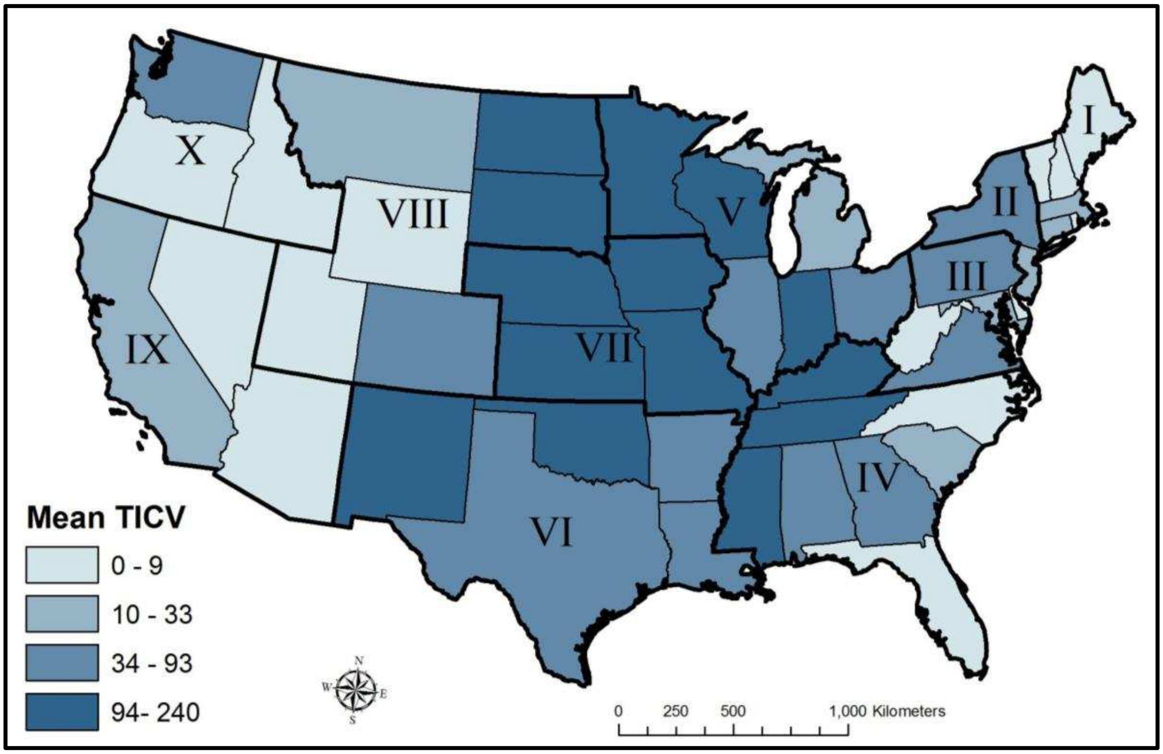


Table 4.14: Summary of TICV components and scores by FEMA Region (fatality totals noted in parentheses).

FEMA Region	Event Total	Median Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	Category
Region I	7	Med. Max.	1 1 (1)	0 1,695,000	0 57	19 26	0 28	0 0
Region II	4	Med. Max.	0 0	388,500 1,170,000	50 140	23 31	31 59	1 1
Region III	47	Med. Max.	0 1 (1)	10,400 60,794,000	0 40,125	21 29	2 994	1 4
Region IV	392	Med. Max.	0 16 (124)	181,000 323,000,000	11 189,155	26 36	17 2,223	1 5
Region V	170	Med. Max.	0 20 (45)	148,100 156,350,000	16 61,944	22 33	17 1,110	1 4

Table 4.14 Continued

FEMA Region	Event Total	Median Maximum	Fatalities	Damage Component (USD)	Damage Score	Vulnerability Score	TICV Score	Category
Region VI	183	Med. Max.	0 8 (21)	100,000 648,000,000	5 42,553	26 38	11 1,116	1 4
Region VII	118	Med. Max.	0 11 (28)	100,000 327,000,000	16 434,782	24 34	20 2,743	1 5
Region VIII	41	Med. Max.	0 1 (2)	0 132,000,000	0 61,552	24 33	0 1,225	0 4
Region IX	15	Med. Max.	0 0	10,700 800,000	1 945	19 29	4 159	1 1
Region X	4	Med. Max.	0 0	62,000 136,400	7 46	25 29	9 36	0.5 1

Discussion

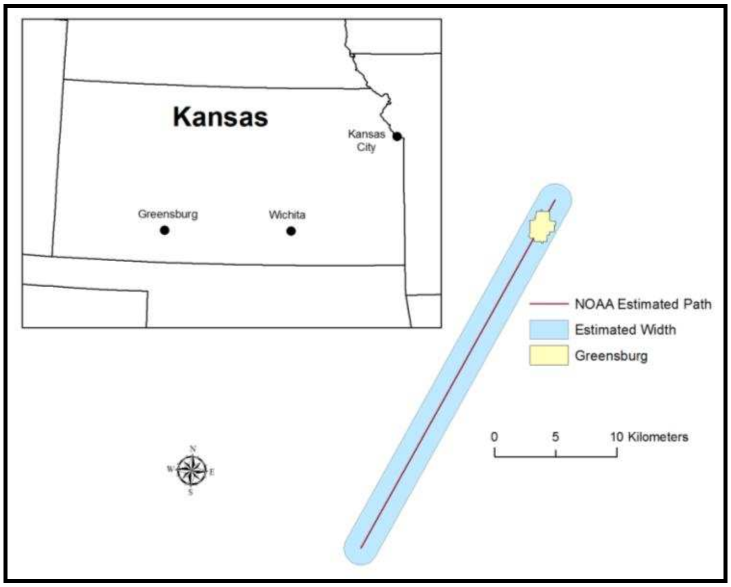
Comparing and Contrasting the TICV across Four Events: Greensburg, KS, 2007; Enterprise, AL, 2007; Ladysmith, WI, 2002; and Manhattan, KS, 2008

Three events were chosen for further examination due to the author's familiarity with those events (Greensburg, Ladysmith and Manhattan), and a fourth was added to include an event that occurred in a FEMA Region that displayed higher vulnerability scores than the regions housing the previous three. Further, all four events rate as strong (EF2-3) or violent (EF4-5) on the EFS, providing a backdrop to compare the difference between applying an EFS rating to describe community impact as opposed to the TICV.

The Greensburg, KS, Event

The period of 4–6 May 2004 saw a very strong and slowly advancing low pressure system over the central U.S. Eventually, this system produced a tornado outbreak lasting 56 hours and spawning 123 tornadoes over eight central states (NCDC 2010b). Over $260M in damage occurred, with 14 deaths. Unfortunately, the finger of blame for the majority of the damage and fatalities points to one single tornado: the Greensburg, KS, event.

Figure 4.21: Estimated width of the Greensburg, KS, tornado.



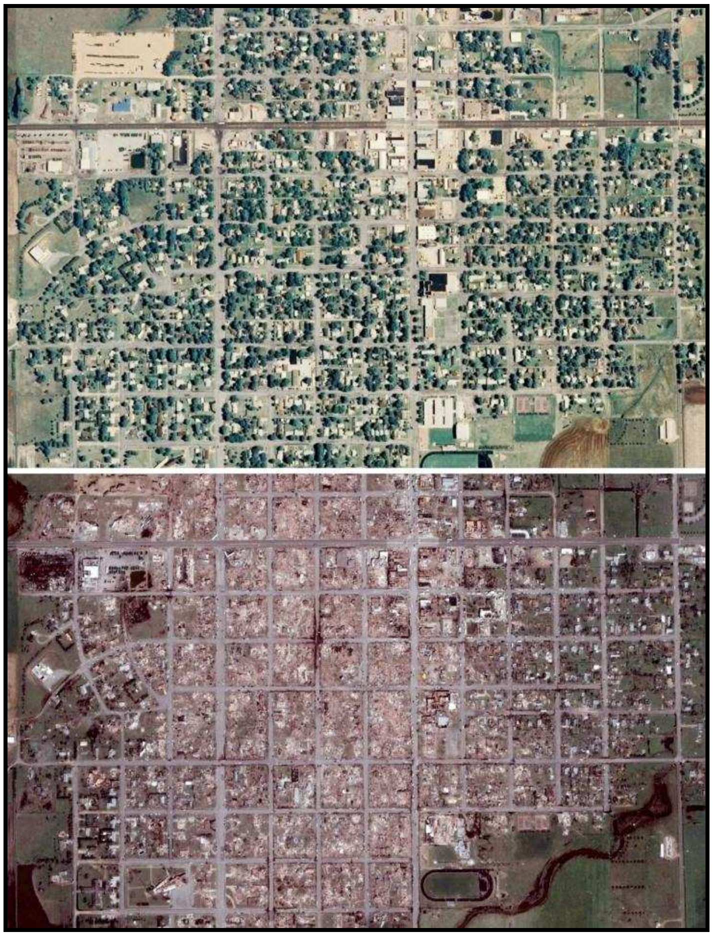
Beginning in Comanche county at 9:03 CST 4 May 2007, the tornado moved into neighboring Kiowa county, the location of Greensburg, and struck the town from the south at approximately 9:45 CST. According to the NCDC, the width of the funnel was 2,740 meters (3,000 yards), or 2.74 kilometers (1.7 miles) wide. A distance measurement in ArcMap revealed that Greensburg is approximately 2.1 kilometers (1.3 miles) across at its widest point and 1.1 kilometers (0.7 miles) across at its narrowest. Figure 4.21 displays a 2,740 meter buffer around the line representing the estimated SPC-derived path to illustrate the degree to which this tornado, for all intents and purposes, consumed the entirety of the community. Figure 4.22 displays before and after images of the community.

Total damage resulting from the event stands at $250M with 11 fatalities for a damage component of $327M. Greensburg placed in the moderate-high category for vulnerability, and received the second highest TICV score in the dataset (behind only

Hallam, NE) at 2,440, landing the event in the TC5 category. Much attention has since been paid to the event, but the NCDC (2010) summarized the immediate aftermath:

> This tornado destroyed nearly 95 percent of the town of Greensburg and despite adequate warning, unfortunately took the life [sic] of 11 people, some that were in basements. First responders arriving on the scene requested three refrigerated refer trucks thinking there would be hundreds of fatalities. In all, 961 homes and businesses were destroyed, 216 received major damage and 307 received minor damage. [H]azardous material was strewn everywhere. As of July 26th [2007], the debris was still not fully cleaned up. Two landfills were filled with debris from the town and this was even as most was burned. Hundreds of thousands of dump truck loads were taken out. It was estimated that approximately 400,000 cubic yards of debris was removed. The major highway running through town was closed for 1 full month. At one time there were over 150 law enforcement officers (from all over the country) present. Military was called in for debris removal and rebuilding.

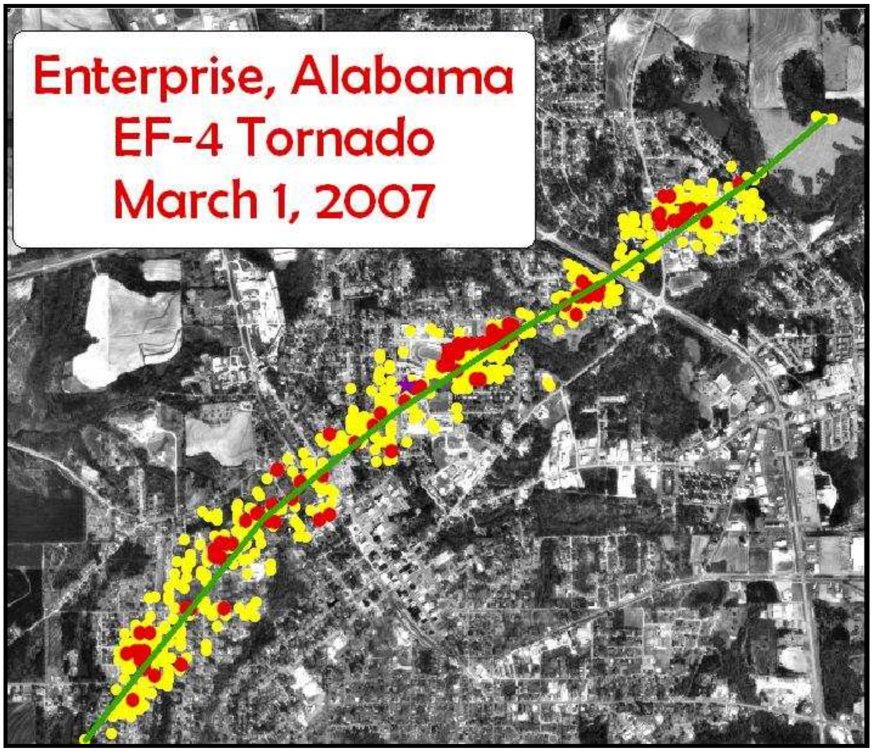
Figure 4.22: Greensburg before the tornado (top), and after (bottom) (source: Google Earth ®).



The Enterprise, AL, Event

At approximately 1:05 CST on 1 March 2007, a tornado entered Enterprise from the southwest, and moved directly through the community. The hardest hit area of the town was the high school, suffering major damage to the stadium, and partial collapse of the school's walls, which killed eight students seeking shelter inside. A FEMA official stated that, "the majority of the school is destroyed" (ABC News 2007). One additional death brought the toll to nine.

Figure 4.23: Enterprise, AL, tornado estimated path. Yellow circles indicate damage sites, while red circles indicate significant damage (source: NWS, Tallahassee, FL).



Overall, 239 homes were destroyed and over 900 homes suffered major or minor damage (NCDC 2010b). The Mayor of Enterprise, Kenneth Boswell, was quoted as saying, "It looks like ground zero, where there's just nothing left" (FOX News 2007). Figure 4.23 shows the NOAA/NWS estimated path of the tornado. The damage figure reported by the NCDC is $250M (although other sources place the number above $300M) for a damage component of $323M and a damage score of 15,252. Enterprise's community vulnerability score came in at 23 (moderate), and the TICV score at 596, rating this event as a TC3. As summarized by the NCDC (2010):

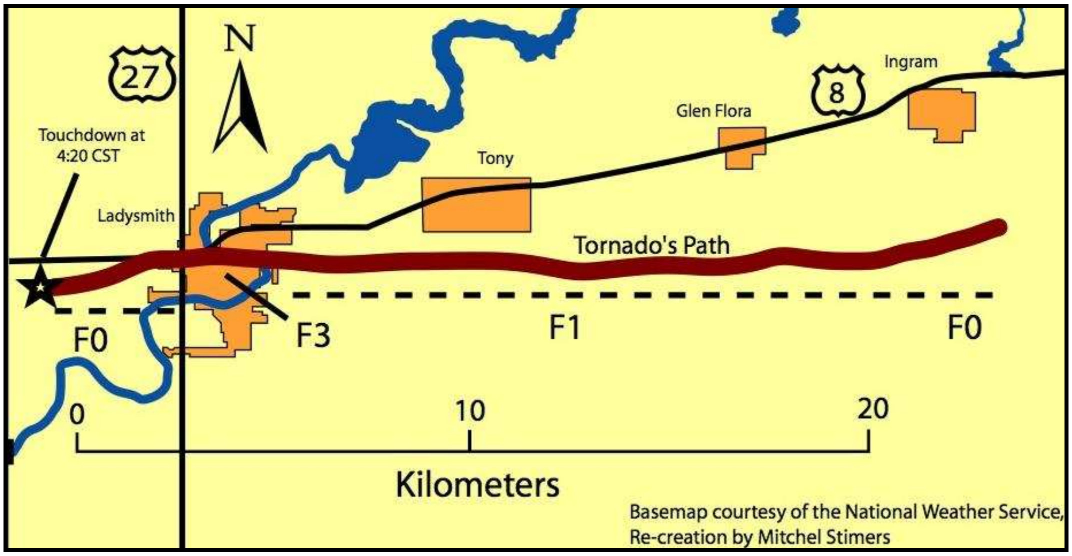
> The tornado then traveled northeast and quickly intensified as it moved into the Enterprise city limits. It severely damaged the high school just north of the downtown. Eight students were killed as walls collapsed on them while they took shelter in the interior hallways. Fifty more were injured. The football stadium was destroyed. Many vehicles surrounding the schools were overturned or tossed about. Several state roads were impassible due to debris and fallen utility poles and lines. The ninth fatality occurred where an elderly woman was standing behind a living room window of her home as the glass shattered. A nearby elementary school was heavily damaged with no deaths or injuries reported there. Damage near the high school and in northeast Enterprise reached low end EF-4.

The Ladysmith, WI, Event

Founded along the Flambeau River in the Wisconsin Northwoods as a railroad community in 1885, Ladysmith has since grown to a population of 3,932 as of the 2000 census. Up until 2002, a tornado had never passed through the town. But at 4:20 CST on 2 September 2002, a supercell produced a funnel that made contact with the ground just a few kilometers west of the entrance to the city (Figure 4.22).

Already on the ground before the warning sirens could be activated (Wisconsin 2002), and initially rated as F0, the tornado picked up strength as it moved east. It followed a path directly down Lake Street/Highway 8 (the main road through the city), growing from F1 up to F3 strength in the center of town, but began to weaken to F2 strength as it moved across the river, eventually exiting Ladysmith on the east end. The twister continued for another 15 kilometers (nine miles) before dissipating at F0 strength a few kilometers south of the town of Ingram; no other communities were struck by this event.

Figure 4.24: Estimated path of the Ladysmith, WI, 2002 tornado (source: Stimers 2003).

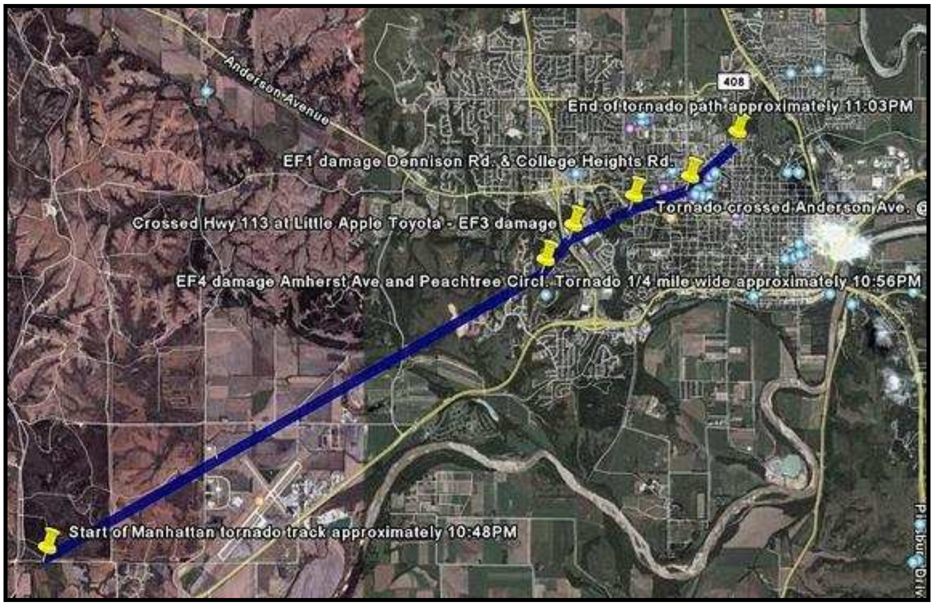


Basemap courtesy of the National Weather Service, Re-creation by Mitchel Stimers

In the heart of downtown Ladysmith and west into the residential section, an area approximately four blocks wide by 16 blocks long, major damage occurred. Within this small area 40 buildings were completely destroyed with another 159 damaged (NCDC 2010b). Luckily, no one was killed, and the total damage is recorded as $25M for a damage component of $29.75M, a TICV score of 471, TC3. Ladysmith scored 29 (moderate-high) on the community vulnerability scale. The NCDC (2010) provided this narrative of the event:

> The first tornadic supercell to rake Wisconsin this day started just west of Ladysmith and tore through the downtown before moving into rural parts of eastern Rusk County. Injury totals fluctuated at first, but Rusk County Emergency Management stated there were approximately 27 injuries, none more serious than a broken leg. The NWS performed a damage survey the next day, and the most severe damage, rated F3, was in downtown Ladysmith. In this area 4 blocks wide and 16 blocks long, 40 buildings were destroyed and 159 damaged.

Figure 4.25: Estimated path of the Manhattan, KS, tornado (source: Google Earth).



The Manhattan, KS, Event

Beginning approximately 21 kilometers (13 miles) southwest of the Manhattan city limits, the tornado moved into the community at roughly 10:56 CST on 11 June 2008 (Figure 4.25). A residential area suffered major damage as the tornado passed at EF-4 strength. Along its continued path, several businesses were severely damaged, with EF-3-level damage inflicted on the Kansas State University campus, including the Department of Engineering's multi-million dollar wind erosion laboratory, and a roof completely removed from a fraternity dormitory. The tornado continued through campus flipping vehicles, blowing out windows, and damaging trees. The funnel dissipated within the city limits at approximately 11:03 CST. No deaths resulted from the event, but damage in the amount of $66M was recorded, resulting in a damage score of 1,472. Manhattan scored low-moderate vulnerability, with a score of 22. The TICV score stands at 181, for a rating of TC1.

Four Communities, Four Unique Events

Just as each one of us represents a unique individual, with characteristics different from everyone else in the world, so too will no one community's experience with a tornado event be the same. Sherrib et al. (2010, 228) state that, "Clearly, not all communities react in the same way when faced with adversity. Just as individuals have the propensity to respond to stress in a variety of ways, so do communities." Barnett et al. (2008, 104) make the claim that, "Almost all vulnerability studies share an explicit concern for losses that directly relate to human welfare, in terms of damage to property, damage to livelihoods, forced migration, morbidity or mortality, for example." Nelson and Finan (2009, 108) argue that, "disasters are the result of larger social structures and processes," a position that is echoed in this research. Not only does the social fabric play a role in determining impact from a disaster, but the sheer physical size of the community (Cross 2001) in which that social fabric exists also plays an important role.

Manhattan, KS, is more than twice the size, in terms of population (44,831), when compared to the other three communities examined in this section, and ranked the lowest in terms of TICV and TC score of the four events discussed in this section. Described as "light impact," The TC1 rating for the Manhattan event is not informing the reader about the $66M in damage; it is making the statement that given this community's size and its low-moderate vulnerability score (22), the resources should be present to facilitate a recovery, as the Moran's I analysis (Figure 4.3) showed was the case for most of the communities in FEMA region VII.

Figure 4.26: EF-4 damage in the Amherst residential area, Manhattan, KS (photo by author, taken with homeowner's permission, on 12 June 2008; the morning after the tornado).

Damage from the event in this case was localized along a path that did not touch every business and home in the community. Friends and neighbors whose belongings, shelter, and mental state remained unscathed had the ability to come to the aid of others. Homes were opened to provide temporary shelter. As the immediate aftermath is tended to, the fact that the community possesses a lower degree of vulnerability than many others means rebuilding can commence, in most cases, almost immediately.

Reflecting on a visit to the Amherst residential neighborhood (Figure 4.26) in the spring of 2009, one year after the event, I noted that while some construction continued, the majority of homes had been repaired or rebuilt. Businesses damaged along the path were mostly repaired, and the Kansas State University campus showed practically no signs of the event, save a few trees with less-than-full crowns. The community is large, resilient, and can absorb and recover from the event quickly; therefore, the impact as a whole was light.

Consider the Manhattan event at TC1 in comparison to the Enterprise, AL, event at TC3. Although half the population at 21,178, Enterprise still possesses much in the way of resources from which to access in the case of a severe event. With a vulnerability score of 23, just above Manhattan's 22, it is considered here to fall into the next highest category: moderate social vulnerability. As stated above, the damage done to the community was widespread (Figure 4.27 and Figure 4.28), and with nine lives lost, a community of this size is sure to feel the impact both physically and emotionally.

A new high school opened in August of 2010, complete with two reinforced rooms capable of withstanding 200 mile per hour winds (EF-4 limit) (WCTV 2010). With a smaller population generally comes a smaller physical size (as is assumed in this research, with population standing as a proxy for size), and with that comes a greater probability that key resources could be taken out of the recovery loop immediately. Fewer buildings in which to house the newly rendered homeless and the possibility of key elements of infrastructure such as fire and rescue units and hospitals being damaged heightens the level of impact. The EFS rated both the Manhattan and Enterprise tornadoes as EF-4s, but given the description of each, clearly they cannot be seen as similar in terms of the impact on each individual community, as the TICV categories demonstrate.

Figure 4.27: Wreckage of the Enterprise High School, where eight children perished (source: New York Times).

Figure 4.28: Ikonos satellite image of the Enterprise High School, stadium and surrounding homes before the tornado (left) and after (right) (source: NASA Earth Observatory).


February 23, 2000

March 5, 2007

Ladysmith, WI, at 3,932, has less than one-fifth the population of Enterprise and less than a tenth the population of Manhattan. The tornado that ripped down the main street through town toppled 40 buildings and caused minor to severe damage to scores more as it exited the town moments later. Emergency crews from surrounding, and similar-sized towns, as well as larger surrounding metropolitan areas converged on the community almost immediately. And as is often seen in immediate post-disaster settings, altruism played a key role in first response, with many people in the community coming to help their neighbors (Caplan 1990). While thankfully no deaths occurred in Ladysmith, $25M in damage virtually shut down the community for weeks. The political aftermath also caused the Mayor to resign his office over the perceived poor handling of $400,000 in state relief funds, stating in an ill-received remark, “By the time we get done doling out the money, everyone will be mad at everyone else” (Ladysmith 2002, 5B). Impact, is seems, has the ability to reach beyond buildings left distorted by rotating winds.

I conducted research in the community regarding the state of recovery in both 2003 and 2004. By the latter of the two examinations, it was found that 26 percent of the damaged structures were still not repaired, with most of those located in the heavy-hit downtown area of central Lake Street and Miner Avenue (Figure 4.29 and Figure 4.30). By 2007 nearly all buildings damaged were repaired or replaced, and the town seemed to have made a near-full recovery; a half-decade later. However, as of December 2010, several lots remain empty in both the downtown area as well as in the neighborhood on the west end of the city. The TC3 rating applied to this event, in comparison to the previous two indicates a community that was initially hit hard by the storm, and recovery took some time, not unlike Enterprise, but in terms of size and resources available, worse off than Manhattan.

Figure 4.29: Progress in rebuilding after the September, 2002, Ladysmith, WI, tornado (source: Stimers 2004).

Figure 4.30: Heavily impacted neighborhood on the west end of Ladysmith, WI after the September 2002 tornado (source: NOAA).

Since the May 2007 tornado, the community of Greensburg has become something of a national celebrity. A television show produced by the Discovery ®

Network, Greensburg: A Story of Community Rebuilding, focuses not only on the rebuilding process, but on the drive to become the first Leadership in Energy & Environmental Design (LEED) Platinum certified community; a true "green" community (see Harrington 2010). But the massive twister that struck the small town has made rebuilding difficult. As of 2010, the landscape is still nearly devoid of trees, about half of the homes damaged remain unrepaired (Pless et al. 2010), and residents continue to struggle to put the town back together. However, many new and modern buildings are apparent in the town, such as the hospital, the Silo Eco-home, the "Business Incubator," and the new high school.

Figure 4.31: Four images from Greensburg, Kansas, 2009. The shell of a home (a), a still-empty lot (b), vacant business space (c), a view looking north from atop the Silo Eco-home (d) (photos by author, 10 June 2009).

Greensburg has become a laboratory for what a town can potentially become in terms of its impact on the environment. But the impact on the town and its inhabitants is the focus here, and that impact was devastating. Buildings devoted to human service, such as the hospital and city hall, were among those plucked away by the tornado. Most of the vehicles in town were ruined, and with 95 percent of the buildings destroyed and city government facilities gone, people were literally left with nowhere to go and no one to whom they could turn (Pless et al. 2010).

Since the event, approximately one-third of the residents have moved permanently (Barnhart 2010), further weakening the recovery effort. In revisiting Greensburg two years post-event, I noted that much of the town looked, and “felt” the same as it did during a visit about one month following the tornado. Long stretches of road through residential neighborhoods dotted with vacant houses, empty lots where houses and businesses once stood, and eerie images of stripped and skewed trees scattered throughout. The Greensburg tornado recorded the second highest TICV score, and resulting from that score and the Jenks breaks applied to the array of scores as a whole, easily landed in the highest TICV category: TC5. The impact descriptor for that category is “devastating,” and given the near-total destruction of the community, the massive federally-directed response to the scene, the out-migration of residents and the on-going recovery as of this writing, a TC5 rating should, to borrow a phrase from the U.S. Supreme Court, seem perfectly plausible to anyone with a rudimentary sense of reason.

When comparing this event to the Manhattan, Enterprise and/or Ladysmith tornadoes, the difference in the category levels becomes clear. Manhattan, rated at TC1, certainly felt the impact of the June 2008 tornado, but dispersed the recovery effort amongst the large population, and one year later, the vast majority of damage had been repaired. Enterprise and Ladysmith, both TC3s, were heavily impacted, and recovery took several years, but was nonetheless achieved (Ladysmith) or is well on the way to being achieved (Enterprise). This is not to say that those communities are not forever changed, but they have returned to what one could consider a usual day-to-day routine. Greensburg, as well as Hallam, NE, and Paisley, FL (two of the three other TC5s by this scale), were, in large part, quite literally ripped from the face of the earth. Enough was left to build again, and with support from surrounding communities as well as the intangible internal support structure of friends and neighbors that appears in the wake of a disaster, these communities remain. However, the impact of the devastating tornadoes that struck their cities lingers. “Levels of impact mean different things to different people in different situations” (Tobin and Montz 1997, 7). It is hoped that this rating scale can help put these events, and their different meanings into better perspective. Table 4.13 displays the summary statistics for these four events.

Table 4.15: Summary statistics for the four events examined above.

Community	Population	Date	EFS	Damage	Fatalities	Damage Score	Vulnerability Score	TICV	TC
Manhattan, KS	44,831	6/11/2008	4	$66M	0	1,472	22 (LM)	181	1
Enterprise, AL	21,178	3/1/2007	4	$250M	9	15,251	23 (M)	596	3
Ladysmith, WI	3,932	9/2/2002	3	$25M	0	7,566	29 (MH)	470	3
Greensburg, KS	1,574	5/4/2007	5	$250M	11	207,751	28 (MH)	2,439	5

The Sense of Place and Loss

Yi Fu Tuan (1977, 154), in discussing our sense of place, how we feel attached to our homeland or to our community, stated that,

> The city or land is viewed as mother, and it nourishes; place is an archive of fond memories and splendid achievements that inspire the present; place is permanent and hence reassuring to man, who sees frailty in himself and chance and flux everywhere.

Community provides us with a sense of security, a place to return to, a place we recognize. When tragedy strikes a place we hold dear, it is more than trees, high schools, playground equipment and houses that are destroyed. Those physical objects and coupled Platonic Forms represent people's childhood, a first home as a married couple, a tree planted with a favorite grandparent on Arbor Day; they represent memories and the tie felt to a location constructed by human hands. The "places" we label as communities are more than just the physical setting, they hold the human experience within them, and over time, a bond forms between people and the places they inhabit; "meanings are not inherent in the nature of things" (Stedman 2003, 672); we provide that meaning. Tuan (1977, 149) continued, stating, "Should destruction occur we may reasonably conclude that the people would be thoroughly demoralized, since the ruin of their settlement implies the ruin of their cosmos." Disasters can cause us to feel less attached to place, if it has sufficiently changed. The new place or the temporary arrangements made by those directing recovery efforts may simply not feel like home (Lewis 1979; Chamlee-Wright and Storr 2009).

Not everyone deals with loss in the same manner, just as not everyone holds the same memories born of their community. Bonanno (2004, 20) noted that for some people suffering losses resulting from a disaster is too much, and mental recovery cannot be achieved, while some, "suffer less intensely and for a much shorter period of time." Violent loss can bring about higher levels of psychological suffering when compared to death by natural causes (Davis *et al.* 1998). Bonanno (2004) further noted several studies that estimate the majority of the U.S. population will experience at least one traumatic event during the course of their lifetime (not necessarily a natural disaster). One can be sure that each person will process losses in their own personal manner.

After a destructive event, people will also try as best they can to find meaning, to make sense of the tragedy (Davis *et al.* 1998; Currier *et al.* 2006), to find some benefit from the experience, and in some cases, change their very identity and outlook on life (Gillies 2006). Extreme events bring trauma and loss, and these events often bring confusion and disorder; trying to find meaning in the event is a way for people to bring back some order to lives disrupted (Davis and McKearney 2003).

A mathematical formula applied to the circumstances of a traumatic event cannot be seen as a grand explainer, it cannot return childhood memories, it cannot rebuild a house, and it cannot re-plant a favorite tree. Indices such as the ones presented here should be taken for what they are; a quantitative representation of a highly qualitative event. While the TICV cannot console the bereaved in a time of great loss, hopefully it can aid in furthering the process of trying to make sense of a tragedy by putting that tragedy into better perspective in terms of the level of impact. As a CBS reporter noted (Grace 2002) after the Ladysmith, WI, event,

> The National Weather Service points out that this has been an unusually quiet tornado season. In an average year, by the first of September a thousand or so have touched down; this year it's been only half that many. That statistic doesn't mean much in Ladysmith, where picking up the pieces from the holiday storm will be a painful process.

Potential Practical Applications of the TICV

Lindell and Prater (2003) state that assessing the impact of a disaster on a community is important for three reasons:

1. Impact assessments can be used by community leaders in order to make a more informed decision as to how much (if any) external assistance may be needed;

2. Impact assessments can target specific sectors of the community to determine if the impact disproportionately affected certain people or businesses;
3. Impact assessments arising from previous events can be used as projection tools to better determine the effects of similar disasters on particular communities.

In the context of this research, the TICV may provide a useful tool for community leaders and/or emergency responders in the immediate aftermath of a tornado, so long as a government office, such as the city assessor, has access to an estimated damage figure. If fatalities are known to have occurred, they too could be used to calculate the TICV as described in this research, or eliminated if only the spatial extent of damage is desired. Even if the initial TICV and TC scores are revised at a later date, the immediate preliminary estimate may provide officials with a sense of the extent of the impact across the community. Lindell and Prater's second point may be beyond the capabilities of the TICV, as it was designed to relate impact information on a community level, not specific segments within a community. The TICV could, however, be modified to use estimated population via Landscan data to identify sub-sections of impacted communities.

The TICV scores and category scheme created here could be used to provide a baseline from which officials could then create hypothetical scenarios in which differing levels of impact occur within their communities to examine the range of TICV scores possible. By examining potential impact scores for communities with similar social profiles and population sizes, officials may be better able to anticipate the immediate need for assistance, as well as be better able to determine, by researching the recovery process of those communities, what may be in store for them in the event of a tornado. Future research, as discussed in the following chapter, may include relating TICV scores to recovery times, which would aid in any process of comparing events across similar communities. An application using one component of the TICV, the vulnerability score, may be able to inform officials of the potential for impact as well, as the vulnerability score provides an indication as to the degree to which the population is at risk from any wide-spread traumatic event, not only tornadoes. Finally, as calculated using PCA, the vulnerability scores may be compared across time (i.e., 2000–2010 census) to examine increases or decreases in patterns of community vulnerability.

CHAPTER 5 - Conclusion

Summary

Scales indicating the level of physical strength of natural disasters are commonly used to relay information such as estimated wind speeds, atmospheric pressure, energy released and overall size. What is less commonly reported is the impact a particular event carries with it and delivers to the communities struck, except for the usual news reports that describe the destruction with colorful language. As our understanding of the human factor as a key component to disaster impact has matured, the development of scales that attempt to quantify this impact has lagged behind, and for good reason; it is a difficult element to quantify. One individual's definition of "severe" may be markedly different from another's. These measures are nonetheless important, as they can be used to determine pre-event vulnerability, compared to past events to predict impact, examine trends over time, or used post-event to determine (or stand as an indicator to) actual impact.

In constructing the Tornado Impact-Community Vulnerability Index (TICV) and TICV Category values (TC) in this research, NOAA (SPC/NCDC) tornado data was entered into a GIS, and tracks intersecting community boundaries were extracted. Next, individual track records and their associated narratives (NCDC) were examined in order to make the best determination concerning the amount of damage that occurred, and where it occurred, and any fatalities associated with that event. If it was found that a track intersected a community but the damage or fatalities occurred in rural areas preceding the intersection, that track was removed from the dataset. Further, tracks that crossed into multiple communities were segmented into discrete events, with one segment intersecting exactly one community, in order to:

1. facilitate the spatial join feature within the GIS;
2. ensure that each community struck was treated as an individual entity, as per the stated goals of this research.

Tracks were then again inspected manually to check for errors, and then joined with the community data to produce the final tornado-based dataset to be used in calculating the TICV.

To construct the vulnerability component of the TICV, data were gathered for all census-defined places in the U.S. These data included information on age, race, education, housing stock (density, type), income and employment. The initial dataset was reduced by eliminating data elements that were highly correlated to one another, and choosing (based on Cutter et al. 2003) data that are generally seen as acceptable measures of social vulnerability. These data were then subjected to a principal components analysis and the resulting factor groups with their associated eigenvalues as weights used to indicate vulnerability among the communities in the tornado-based dataset discussed above.

The two components of the TICV are a measure of physical damage and fatalities (referred to as the damage component) and an indicator of social vulnerability (referred to as the vulnerability component). With a measure of each for each community in the dataset, the two were combined into a final measure, with the square root of that product resulting in the TICV score. With an array of 981 TICV scores, a Jenks natural breaks function was applied in ArcMap to determine the six-class category scheme for the TICV categories, with zero representing no impact, and five indicating devastating impact. TICV scores ranged from zero to 2,743 (Hallam, NE, 22 May 2004), for a category score of TC5. There were three additional communities that scored TC5: Greensburg, KS, Paisley, FL, and Ellsinore, MO. Results were examined across FEMA Regions, with some higher-scoring events described in greater detail.

Finally, the individual TICV values and resulting category values were compared across four communities from three FEMA regions: Greensburg, KS, Enterprise, AL, Ladysmith, WI, and Manhattan, KS. Through that discussion, it was contended that the TICV can serve as an adequate measure of the impact of a tornado event. Given that the TICV is sensitive to both the size of the community and pre-event vulnerability, and considering that it incorporates the level of physical impact, the TICV displays an index and category value that serves to aid in our understanding of the level to which a community has been impacted by a tornado.

Major Findings of this Research

Through the construction of the TICV and TC, several major findings emerged; these are enumerated below.

1. A tornado does not have to be physically strong or violent to impart major impacts on a community. While wind speed is undoubtedly an important factor in the amount of destruction that can occur, if a tornado strikes a populated section of town, killing several, or otherwise does a great deal

of monetary damage, then the wind speed rating becomes less of a concern than does the overall impact.

2. The damage component is the key driver of the TICV and TC. While higher instances of damage are, again, inextricably linked to more powerful events, overall impact is a major concern not only for those affected by the event, but for those directing recovery; weak tornadoes can have a strong overall impact.
3. The degree to which a community will be affected by a tornado is also determined, in part, by social vulnerability. While, as stated above, damage is the key driver, social vulnerability affects the ability of individuals and households to recover in the wake of a disaster.
4. States with a high occurrence of tornado events annually may not necessarily record a high number of events that directly impact a community. This was found to be a function of the density with which communities populate the state taken together with the frequency of tornado events.
5. Small communities are more likely to suffer a greater degree of impact than will larger communities, even if the events striking both communities are of similar physical strength. Small communities, especially those in rural areas, are often more vulnerable to hazards, and possess fewer resources from which to draw upon in order to initiate and sustain recovery.

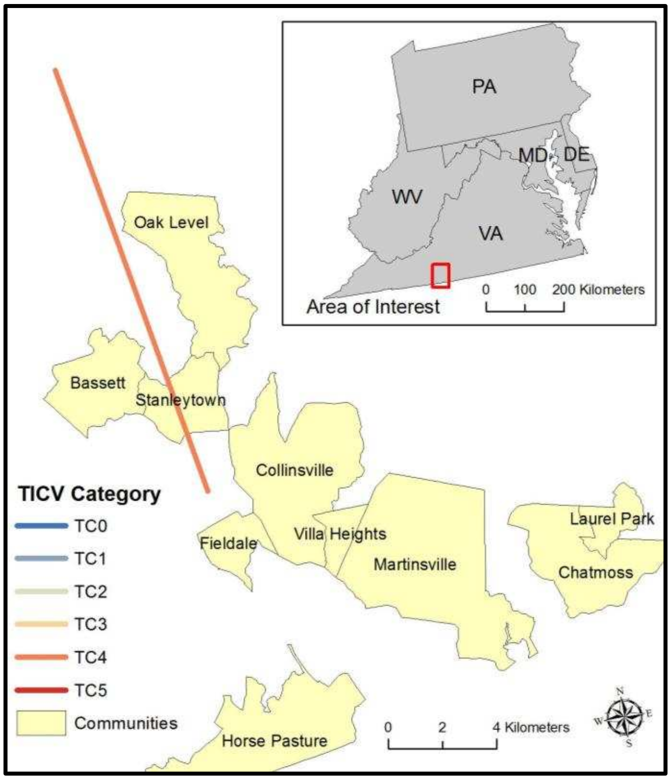
Limitations of this Research

Given the limited set of attributes contained within the SPC GIS data, track-community intersections may not adequately describe the actual event. For example, as described in the FEMA Region III section in Chapter Four, the Stanleytown, VA, tornado touched down outside the community of record (Fieldale) and did the most damage to a factory in the rural area between Fieldale and Stanleytown; however, the path as reported by the NCDC crosses the physical boundary of Stanleytown only, and therefore, the damage score, vulnerability score, and TICV ratings were based on the population of that community (Figure 5.1). A closer inspection of the location of the damaged areas may have revealed to what community those figures should be applied; however, that was not a feasible data selection option given the sheer number of tornado events from 2000–2009. Such an endeavor would require data collection involving not only the SPC and NCDC records available via Internet data portals, but personal communication with dozens or possibly hundreds of local and state authorities, as well as FEMA (for larger-scale events), in order to request individual records be inspected to obtain finer scale data for both the tornado's actual path as well as the locations of damage. Furthermore, as stated in Chapter Three, the purpose of this work was to use the USTOR2000 dataset to calculate and create the TICV scores and categories in order to present a method by which impact can be described, not to rectify the NOAA/SPC tornado record.

It is recognized that communities exist in the dataset which have been assigned scores that may not accurately reflect the impact on the community in which the tornado crossed, and as such, a certain degree of error is naturally present in the TICV scores and category break values, as is likely to exist in any study of this nature (Giannetti et al.

2009). The TICV, nonetheless, was constructed with the intention of providing a score and category rating to describe physical damage and impact as best as possible given the data available. A suggested use of the TICV for individual communities in this dataset, if the given damage figure is in question, and a community authority would like a more accurate measure, is to simply recalculate the score based on new data. With a method in place to make these calculations, future events could be scored in close temporal proximity to the actual events as they occur, resulting in a more accurate TICV value and category assignment. A comprehensive study into the details of each historical event (e.g., Grazulis 1993) in the NOAA tornado record may, in the future, yield a TICV baseline that is more accurate than the results presented here.

Figure 5.1: The Stanleytown (Fieldale), VA, tornado, 17 September 2004.



Potential Future Research

Future research using the methods presented here may include examining whether or not there is a relationship between the TICV score and the length of time required by a community to make a recovery from the event. This type of study could take the form of stating explicit definitions of what constitutes recovery, and the stages passed through along the way to full recovery, then comparing a measure for each stage of recovery to the TICV score for that event. In such a study, a closer examination of one or two individual communities could serve as examples of the recovery process as it continues.

A second avenue of future research may entail modifying the methods presented here as needed to create a scale by which tornadoes that remain in rural areas could be rated. Within this research, events in unpopulated areas were not considered, as they are seen as socially different from tornadoes that strike more densely populated and census-defined communities. A scale tailored specifically to rural events could provide a similar measure of impact as presented here.

A third possibility for continued research includes devising a method to include injuries into the TICV. As stated in Chapter Three, injuries can vary widely, and as such, were not included here. Injuries can, however, remove people from their usual functions in a community (if the injury is severe enough) and as such could constitute a loss to that community in some manner.

The release of the 2010 decennial U.S. provides a fourth possibility for continuing the examination of vulnerability as presented here. Using the same 19 indicators of vulnerability that resulted from the PCA in Chapter Three, a new array of vulnerability scores for 2010 could be derived and compared to those used here. PCA is a very useful method for comparing data across time, and such a study would provide an indicator of the increase or decrease of vulnerability among U.S. communities.

Finally, a fifth potential avenue of future research may be to use, in part, the results of this research in combination with a closer examination of the inconsistencies both within and between the SPC record and the NCDC record. Consistent data is important to researchers in that different conclusions could be reached depending on which dataset is employed. Given the simplicity with which the SPC presents the GIS shapefile data, and the lack of agreement on injuries, fatalities and damage values in some cases, an examination of the reliability of the data may be useful for future research efforts.

Conclusion

This research has shown that different communities can be impacted at different levels in the wake of a tornado. Although the inverse relationship between impact and frequency holds true here, it is concluded that EFS classifications do not always relay the level of impact realistically; the EFS is often times misinterpreted as an indicator of severity. Weak tornadoes can impart heavy impact on a community, and violent tornadoes can produce light impact.

The index presented here is intended to allow the level of impact from a tornado event to be described. While an index value cannot be seen as the final answer to the question of impact, it can be used to help put the event into context. Additionally, measures such as the TICV could potentially serve in a practical capacity, in that they could provide information that may be of use to emergency planners and other community officials should a disaster occur.

While some potential does exist to modify these methods, in its present form, the TICV can be seen as an indicator of severity, and as a measure of sensitivity as well. While many of the scores grouped in the lowest two categories (TC0 and TC1), the category values TC2 through TC5 show sufficient levels of increasing impact to allow them to be categorized in a more qualitative manner, as is shown by the category impact descriptors of moderate, heavy, severe, and devastating respectively. While these descriptors are qualitative measures, they serve to illustrate the use of an index of this nature; to make a difficult situation easier to understand through the application of research into the dynamics that make up such events.

The vulnerability scores presented here give insight into the level of risk these communities possess pre-event, and those, in concert with the physical impact of a tornado, provide a baseline measurement by which future events may be mitigated against. Additionally, the vulnerability score based on the 2000 census, may provide a baseline against the 2010 census by which changes in the level of vulnerability for these communities (or for all U.S. communities) could be estimated. Measures such as these can also provide a window into the advancement of issues of social justice, as social vulnerability can be used as an indicator of access to resources.

As our scientific understanding of phenomenal weather events continues to increase, the drive to understand the complex dynamics of societal-environmental relationships needs to continue as well. Should a tornado run through an abandoned town, one to which no one has property of value, or to which no connections to that place exist, then the impact on that “community” will be zero. However, with population increasing every day, and more and more people moving into non-rural communities, we are furthering the potential for tornadoes to move through built areas where property does matter, people are at risk for harm, and intangibles such as our attachment to place and community can be blown away in seconds. An index value cannot stop phenomenal weather events from occurring, but it is hoped that this research can provide a measurement by which communities, and the people within them, can gain an understanding of the level of impact of a destructive tornado.

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Appendix A - USTOR2000 Retention Values and Percentages.

Table A.1: Data exclusion and retention.

State	Initial Dataset	*USTOR2000* (Retained)	Total Removed	% Removed	% Retained
Alabama	596	79	517	86.74	13.26
Arkansas	460	27	433	94.13	5.87
Arizona	35	4	31	88.57	11.43
California	83	11	72	86.75	13.25
Colorado	405	7	398	98.27	1.73
Connecticut	15	3	12	80.00	20.00
Delaware	2	0	2	100.00	0.00
Florida	564	106	458	81.21	18.79
Georgia	365	42	323	88.49	11.51
Iowa	580	39	541	93.28	6.72
Idaho	44	3	41	93.18	6.82
Illinois	582	58	524	90.03	9.97
Indiana	224	38	186	83.04	16.96
Kansas	1,121	20	1,101	98.22	1.78
Kentucky	240	19	221	92.08	7.92
Louisiana	399	29	370	92.73	7.27
Massachusetts	10	2	8	80.00	20.00
Maryland	85	16	69	81.18	18.82
Maine	19	1	18	94.74	5.26
Michigan	139	5	134	96.40	3.60
Minnesota	419	30	389	92.84	7.16
Missouri	574	43	531	92.51	7.49
Mississippi	550	38	512	93.09	6.91
Montana	62	0	62	100.00	0.00
North Carolina	294	15	279	94.90	5.10
North Dakota	339	19	320	94.40	5.60
Nebraska	532	16	516	96.99	3.01
New Hampshire	4	1	3	75.00	25.00
New Jersey	14	2	12	85.71	14.29
New Mexico	78	2	76	97.44	2.56
Nevada	16	0	16	100.00	0.00
New York	76	2	74	97.37	2.63
Ohio	158	15	143	90.51	9.49
Oklahoma	462	39	423	91.56	8.44
Oregon	29	0	29	100.00	0.00

State	Initial Dataset	USTOR2000 (Retained)	Total Removed	% Removed	% Retained
Pennsylvania	107	8	99	92.52	7.48
South Carolina	284	42	242	85.21	14.79
South Dakota	319	8	311	97.49	2.51
Tennessee	277	51	226	81.59	18.41
Texas	1,447	86	1,361	94.06	5.94
Utah	24	2	22	91.67	8.33
Virginia	238	23	215	90.34	9.66
Vermont	7	0	7	100.00	0.00
Washington	31	1	30	96.77	3.23
Wisconsin	254	24	230	90.55	9.45
West Virginia	17	0	17	100.00	0.00
Wyoming	74	5	69	93.24	6.76
Totals	**12,657**	**981**	**11,676**	**92.25**	**7.75**

Appendix B - USTOR2000.

Table B.1: 981-count dataset, USTOR2000.

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
AL	Abbeville	2,987	11/5/2002	2	1	$3,000,000	$10,570,000	32	3539	336	2
AL	Adamsville	4,965	3/1/2007	1	0	$100,000	$104,000	21	21	21	1
AL	Alabaster	22,619	3/26/2009	0	0	$10,000	$10,000	18	0	3	1
AL	Alabaster	22,619	4/19/2009	0	0	$15,000	$15,000	18	1	3	1
AL	Albertville	17,247	9/22/2006	1	0	$90,000	$96,300	27	6	12	1
AL	Aliceville	2,567	4/6/2005	0	0	$50,000	$54,500	35	21	27	1
AL	Ashland	1,965	5/7/2003	0	0	$2,000	$2,340	32	1	6	1
AL	Ashville	2,260	12/16/2000	2	0	$125,000	$155,000	25	69	41	1
AL	Beaverton	226	2/6/2008	1	0	$50,000	$50,000	28	221	79	1
AL	Black	202	4/13/2009	0	0	$150,000	$150,000	28	743	145	1
AL	Blue Springs	121	1/11/2008	1	0	$70,000	$70,000	21	579	109	1
AL	Blue Springs	121	2/17/2008	1	0	$75,000	$75,000	21	620	113	1
AL	Carbon Hill	2,071	11/10/2002	3	4	$500,000	$28,595,000	35	13807	691	3
AL	Carrollton	987	5/6/2009	1	0	$50,000	$50,000	33	51	41	1
AL	Chelsea	2,949	2/27/2009	0	0	$5,000	$5,000	15	2	5	1
AL	Childersburg	4,927	4/8/2006	0	0	$30,000	$32,100	30	7	14	1
AL	Clanton	7,800	2/17/2008	0	0	$10,000	$10,000	29	1	6	1
AL	Clanton	7,800	9/16/2009	1	0	$150,000	$150,000	29	19	23	1
AL	Cordova	2,423	5/6/2009	1	0	$260,000	$260,000	36	107	62	1
AL	Dadeville	3,212	4/11/2007	1	0	$20,000	$20,800	31	6	14	1
AL	Daleville	4,653	11/25/2001	1	0	$3,000,000	$3,660,000	27	787	144	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
AL	Decatur	53,929	5/6/2009	2	0	$250,000	$305,000	27	6	12	1
AL	Demopolis	7,540	11/30/2006	1	0	$500,000	$535,000	29	71	45	1
AL	Dora	2,413	11/10/2002	1	0	$400,000	$476,000	32	197	79	1
AL	Enterprise	21,178	3/1/2007	1	0	$4,000,000	$4,000,000	23	189	66	1
AL	Enterprise	21,178	10/8/2008	4	9	$250,000,000	$323,000,000	23	15252	596	3
AL	Gardendale	11,626	4/8/2006	1	0	$500,000	$535,000	19	46	30	1
AL	Geneva	4,388	12/16/2000	2	1	$2,500,000	$10,100,000	31	2302	267	2
AL	Guntersville	7,395	2/6/2008	1	0	$0	$0	25	0	0	0
AL	Haleyville	4,182	4/7/2006	1	0	$2,000	$2,140	30	1	4	1
AL	Heflin	3,002	5/11/2008	1	0	$1,800,000	$1,800,000	28	600	131	1
AL	Highland Lake	408	3/15/2008	2	0	$960,000	$960,000	15	2353	191	2
AL	Hollywood	950	5/6/2003	0	0	$5,000	$5,850	26	6	13	1
AL	Hueytown	15,364	5/31/2004	0	0	$250,000	$282,500	21	18	20	1
AL	Huntsville	158,216	4/2/2009	0	0	$8,000	$8,000	21	0	1	1
AL	Jasper	14,052	5/6/2009	0	0	$850,000	$850,000	25	60	39	1
AL	La Fayette	3,234	11/15/2006	0	0	$50,000	$53,500	34	17	24	1
AL	Leeds	10,455	2/26/2008	1	1	$1,000,000	$8,000,000	23	765	134	1
AL	Lester	107	10/18/2004	0	0	$0	$0	19	0	0	0
AL	Level Plains	1,544	1/13/2006	0	0	$500,000	$535,000	22	347	87	1
AL	Lexington	840	10/18/2004	1	0	$5,000	$5,650	26	7	13	1
AL	Lincoln	4,577	8/31/2001	1	0	$75,000	$91,500	22	20	21	1
AL	Linden	2,424	5/10/2006	1	0	$24,000	$25,680	32	11	19	1
AL	Lineville	2,401	5/7/2003	0	0	$3,000	$3,510	33	1	7	1
AL	Madison	29,329	5/6/2003	0	0	$0	$0	16	0	0	0
AL	McIntosh	244	1/10/2009	1	0	$2,500,000	$2,500,000	26	10246	517	3
AL	Meridianville	4,117	5/6/2003	1	0	$100,000	$117,000	16	28	22	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
AL	Montgomery	201,568	11/15/2006	2	0	$500,000	$549,000	25	3	8	1
AL	Moundville	1,809	11/24/2001	0	0	$7,000	$8,540	31	5	12	1
AL	Northport	19,435	4/30/2005	0	0	$95,000	$103,550	23	5	11	1
AL	Oak Grove	457	11/24/2001	2	0	$800,000	$976,000	28	2136	246	2
AL	Oakman	944	12/10/2008	1	0	$215,000	$215,000	31	228	85	1
AL	Oneonta	5,576	9/22/2006	2	0	$1,500,000	$1,605,000	27	288	88	1
AL	Orange Beach	3,784	9/15/2004	0	0	$0	$0	20	0	0	0
AL	Orange Beach	3,784	9/15/2004	0	0	$0	$0	20	0	0	0
AL	Owens Cross Roads	1,124	5/3/2009	1	0	$30,000	$30,000	20	27	23	1
AL	Ozark	15,119	1/7/2007	0	0	$25,000	$26,000	30	2	7	1
AL	Ozark	15,119	4/14/2007	1	0	$250,000	$260,000	30	17	23	1
AL	Pell City	9,565	11/24/2004	1	0	$250,000	$56,500	22	6	24	1
AL	Pell City	9,565	2/26/2008	2	0	$500,000	$610,000	22	64	37	1
AL	Pinckard	667	10/8/2008	0	0	$0	$0	25	0	0	0
AL	Prattville	24,303	2/17/2008	3	0	$10,000,000	$10,000,000	21	411	94	1
AL	Redstone Arsenal	2,365	7/14/2004	0	0	$10,000	$11,300	24	5	11	1
AL	Riverside	1,564	11/24/2001	2	0	$0	$0	22	0	0	0
AL	Sand Rock	509	11/24/2001	2	2	$300,000	$14,366,000	23	28224	802	4
AL	St. Florian	335	4/7/2006	0	0	$0	$0	18	0	0	0
AL	Tallassee	4,934	4/25/2003	0	0	$45,000	$52,650	32	11	18	1
AL	Thorsby	1,820	4/3/2000	0	0	$50,000	$62,000	22	34	28	1
AL	Trinity	1,841	11/24/2001	2	0	$250,000	$305,000	17	166	53	1
AL	Tuscaloosa	77,906	12/16/2000	1	0	$100,000	$117,000	24	2	6	1
AL	Tuscaloosa	77,906	11/18/2003	4	11	$12,500,000	$92,500,000	24	1187	168	1
AL	Tuscumbia	7,856	4/7/2006	1	0	$125,000	$133,750	27	17	22	1
AL	Uniontown	1,636	10/13/2001	1	0	$110,000	$134,200	37	82	55	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
AL	Winfield	4,540	9/25/2005	1	0	$8,000	$8,720	26	2	7	1
AR	Benton	21,906	2/18/2000	1	0	$0	$0	23	0	0	0
AR	Benton	21,906	5/16/2003	2	0	$50,000	$58,500	23	3	8	1
AR	Benton	21,906	4/3/2008	2	0	$5,000,000	$5,000,000	23	228	72	1
AR	Bentonville	19,730	3/12/2006	2	0	$100,000	$100,000	21	5	10	1
AR	Bentonville	19,730	5/10/2008	1	0	$100,000	$107,000	21	5	11	1
AR	Bryant	9,764	5/16/2003	2	0	$0	$0	19	0	0	0
AR	Cabot	15,261	4/3/2008	1	0	$300,000	$300,000	19	20	19	1
AR	Cabot	15,261	9/13/2008	2	0	$2,000,000	$2,000,000	19	131	50	1
AR	Carlisle	2,304	5/2/2008	1	0	$1,000,000	$1,000,000	30	434	114	1
AR	Cherokee Village	4,648	11/1/2004	0	0	$0	$0	24	0	0	0
AR	Cotton Plant	960	12/18/2002	1	0	$0	$0	39	0	0	0
AR	Eudora	2,819	4/24/2003	0	0	$300,000	$351,000	37	125	68	1
AR	Fordyce	4,799	4/29/2004	1	0	$0	$0	33	0	0	0
AR	Hamburg	3,039	2/5/2008	1	0	$40,000	$40,000	32	13	20	1
AR	Harrisburg	2,192	5/16/2003	1	0	$50,000	$58,500	33	27	29	1
AR	Higginson	378	2/24/2001	1	0	$0	$0	28	0	0	0
AR	Humphrey	806	11/1/2004	0	0	$0	$0	32	0	0	0
AR	Little Flock	2,585	3/12/2006	2	0	$100,000	$107,000	23	41	31	1
AR	Lonoke	4,287	2/24/2001	1	0	$0	$0	30	0	0	0
AR	Magnolia	10,858	10/29/2009	1	0	$75,000	$75,000	30	7	14	1
AR	Mena	5,637	4/9/2009	3	3	$25,000,000	$46,000,000	32	8160	509	3
AR	North Crossett	3,581	2/24/2007	0	0	$0	$0	29	0	0	0
AR	Pine Bluff	55,085	10/29/2009	1	0	$400,000	$400,000	31	7	15	1
AR	Rogers	38,829	3/12/2006	2	0	$100,000	$107,000	22	3	8	1
AR	Stuttgart	9,745	5/10/2008	3	0	$75,000,000	$75,000,000	30	7696	478	3

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
AZ	Carefree	2,927	2/28/2003	0	0	$0	$0	12	0	0	0
AZ	Cave Creek	3,728	2/28/2003	0	0	$0	$0	14	0	0	0
AZ	Flagstaff	52,894	9/9/2003	0	0	$0	$0	22	0	0	0
AZ	Scottsdale	202,705	2/28/2003	0	0	$0	$0	16	0	0	0
CA	Durham	5,220	4/8/2005	0	0	$5,000	$5,450	16	1	4	1
CA	Elk Grove	59,984	2/25/2007	0	0	$2,000	$2,080	19	0	1	1
CA	Lathrop	10,445	4/8/2005	0	0	$10,000	$10,900	19	1	4	1
CA	March AFB	370	5/22/2008	2	0	$350,000	$350,000	27	946	160	1
CA	Merced	63,893	12/16/2002	0	0	$10,000	$10,700	29	0	2	1
CA	Merced	63,893	3/28/2006	1	0	$400,000	$476,000	29	7	15	1
CA	Perris	36,189	5/22/2008	0	0	$0	$0	28	0	0	0
CA	Poway	48,044	11/10/2000	1	0	$73,000	$90,520	16	2	5	1
CA	Rosamond	14,349	9/1/2007	0	0	$175,000	$182,000	23	13	17	1
CA	South Yuba City	12,651	5/9/2005	0	0	$85,000	$92,650	18	7	12	1
CA	Visalia	91,565	1/27/2008	0	0	$800,000	$800,000	24	9	15	1
CO	Aurora	276,393	6/7/2009	1	0	$500,000	$500,000	21	2	6	1
CO	Black Forest	13,247	6/20/2004	1	0	$0	$0	12	0	0	0
CO	Broomfield	38,272	6/7/2009	0	0	$25,000	$25,000	16	1	3	1
CO	Brush	5,117	7/12/2000	0	0	$0	$0	29	0	0	0
CO	Gilcrest	1,162	5/22/2008	3	0	$0	$0	22	0	0	0
CO	Penrose	4,070	6/15/2004	0	0	$1,000	$1,130	23	0	3	1
CO	Windsor	9,896	5/22/2008	3	1	$125,000,000	$132,000,000	17	13339	477	3
CT	Madison Center	2,222	7/31/2009	1	0	$10,000	$10,000	15	5	8	1
CT	Wethersfield	26,271	6/26/2009	1	0	$750,000	$750,000	19	29	23	1
FL	Apalachicola	2,334	10/27/2006	1	0	$1,000,000	$1,070,000	33	458	123	1
FL	Auburndale	11,032	8/12/2009	0	0	$0	$0	30	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
FL	Big Pine Key	5,032	8/18/2008	0	0	$1,000	$1,000	19	0	2	1
FL	Black Diamond	694	7/9/2005	0	0	$0	$0	11	0	0	0
FL	Bonita Springs	32,797	3/27/2003	0	0	$0	$0	18	0	0	0
FL	Boynton Beach	60,389	4/10/2007	0	0	$10,000	$10,400	25	0	2	1
FL	Brandon	77,895	7/9/2005	0	0	$40,000	$43,600	20	1	3	1
FL	Cape Coral	102,286	9/16/2007	0	0	$0	$0	22	0	0	0
FL	Cape Coral	102,286	8/16/2009	1	0	$4,000,000	$4,160,000	22	41	30	1
FL	Casselberry	22,629	5/19/2009	0	0	$0	$0	24	0	0	0
FL	Charlotte Harbor	3,647	6/29/2003	0	0	$30,000	$32,100	26	9	15	1
FL	Charlotte Harbor	3,647	6/21/2006	0	0	$50,000	$58,500	26	16	20	1
FL	Citrus Springs	4,157	3/29/2001	0	0	$0	$0	25	0	0	0
FL	Clearwater	108,787	5/22/2009	0	0	$0	$0	25	0	0	0
FL	Clewiston	6,460	8/13/2004	2	0	$50,000	$56,500	26	9	15	1
FL	Combee Settlement	5,436	5/12/2009	0	0	$0	$0	32	0	0	0
FL	Crescent Beach	985	6/12/2007	0	0	$0	$0	18	0	0	0
FL	Crescent Beach	985	4/13/2009	0	0	$0	$0	18	0	0	0
FL	Cudjoe Key	1,695	8/18/2008	0	0	$1,000	$1,000	15	1	3	1
FL	Davenport	1,924	8/13/2004	0	0	$0	$0	31	0	0	0
FL	Daytona Beach	64,112	12/25/2006	0	0	$50,000,000	$53,500,000	28	834	154	1
FL	De Land	20,904	12/25/2006	2	0	$2,500,000	$2,675,000	30	128	62	1
FL	De Land	20,904	2/2/2007	3	0	$52,000,000	$54,080,000	30	2587	281	2
FL	Dundee	2,912	4/15/2007	0	0	$250,000	$260,000	31	89	53	1
FL	Dunnellon	1,898	9/15/2004	1	0	$0	$0	27	0	0	0
FL	Eustis	15,106	9/20/2007	1	0	$6,200,000	$6,448,000	29	427	112	1
FL	Everglades	479	2/12/2008	0	0	$444,600	$444,600	20	928	137	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
FL	Flagler Beach	4,954	7/22/2007	0	0	$0	$0	21	0	0	0
FL	Fruit Cove	16,077	9/5/2004	0	0	$15,000	$16,950	14	1	4	1
FL	Graceville	2,402	9/25/2002	0	0	$0	$0	32	0	0	0
FL	Grand Ridge	792	3/20/2003	2	0	$500,000	$585,000	30	739	148	1
FL	Greater Carrollwood	33,519	6/30/2009	0	0	$20,000	$20,000	19	1	3	1
FL	Green Cove Springs	5,378	3/29/2001	2	0	$1,000,000	$1,220,000	26	227	77	1
FL	Gulf Breeze	5,665	9/15/2004	0	0	$3,000	$3,390	16	1	3	1
FL	Hernando	8,253	3/29/2001	0	0	$75,000	$91,500	28	11	18	1
FL	Hialeah	226,419	8/21/2001	0	0	$0	$0	31	0	0	0
FL	Hialeah	226,419	8/14/2008	1	0	$150,000	$150,000	31	1	5	1
FL	Highland City	2,051	4/23/2005	1	0	$250,000	$272,500	31	133	64	1
FL	Homestead	31,909	1/2/2002	1	0	$50,000	$59,500	32	2	8	1
FL	Hudson	12,765	3/4/2001	0	0	$250,000	$305,000	24	24	24	1
FL	Inglis	1,491	10/15/2002	1	0	$50,000	$59,500	27	40	33	1
FL	Islamorada, Village of Islands	6,846	9/10/2008	1	0	$120,000	$120,000	18	18	18	1
FL	Jacksonville	735,617	8/12/2004	2	0	$0	$0	23	0	0	0
FL	Jacksonville	735,617	7/14/2007	0	0	$0	$0	23	0	0	0
FL	Jacksonville	735,617	6/26/2009	0	0	$0	$0	23	0	0	0
FL	Key Largo	11,886	12/18/2009	0	0	$5,000	$5,000	21	0	3	1
FL	Key West	25,478	9/29/2008	0	0	$0	$0	19	0	0	0
FL	Lady Lake	11,828	2/2/2007	3	8	$52,000,000	$110,080,000	23	9307	465	3
FL	Lake City	9,980	3/7/2008	2	1	$4,000,000	$11,000,000	33	1102	190	2
FL	Lake Mack-Forest Hills	989	2/2/2007	3	0	$0	$0	29	0	0	0
FL	Lake Park	8,721	8/7/2003	1	0	$0	$0	28	0	0	0
FL	Lake Wales	10,194	8/13/2004	0	0	$0	$0	31	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
FL	Lakeland	78,452	6/24/2006	0	0	$0	$0	28	0	0	0
FL	Land O' Lakes	20,971	5/31/2005	1	0	$80,000	$87,200	18	4	9	1
FL	Largo	69,371	6/23/2005	0	0	$0	$0	26	0	0	0
FL	Lochmoor Waterway Estates	3,858	6/8/2004	0	0	$35,000	$39,550	18	10	14	1
FL	Marathon	10,255	6/24/2007	0	0	$2,000	$2,000	23	0	2	1
FL	Marathon	10,255	2/13/2008	0	0	$2,500	$2,600	23	0	2	1
FL	Mexico Beach	1,017	9/15/2004	0	0	$0	$0	22	0	0	0
FL	Miami	362,470	8/21/2001	0	0	$0	$0	31	0	0	0
FL	Miami Springs	13,712	8/21/2001	0	0	$0	$0	21	0	0	0
FL	Micco	9,498	8/19/2008	0	0	$420,000	$420,000	23	44	32	1
FL	Miramar Beach	2,435	9/25/2002	1	0	$550,000	$654,500	19	269	71	1
FL	Molino	1,312	2/17/2008	1	0	$750,000	$750,000	25	572	120	1
FL	Naples	20,976	3/27/2003	1	0	$50,000	$58,500	16	3	7	1
FL	New Smyrna Beach	20,048	2/2/2007	1	0	$6,000,000	$6,240,000	23	311	84	1
FL	North Fort Myers	40,214	6/8/2008	1	0	$100,000	$100,000	23	2	8	1
FL	Ocala	45,943	4/7/2005	1	0	$0	$0	28	0	0	0
FL	Ormond Beach	36,301	7/24/2009	0	0	$0	$0	20	0	0	0
FL	Paisley	734	2/2/2007	3	13	$46,000,000	$138,840,000	26	189155	2224	5
FL	Palatka	10,033	6/21/2005	0	0	$0	$0	36	0	0	0
FL	Palm Beach Gardens	35,058	3/31/2009	0	0	$75,000	$75,000	17	2	6	1
FL	Palm Harbor	59,248	8/12/2000	0	0	$500,000	$620,000	20	10	15	1
FL	Palmetto	12,571	6/18/2003	0	0	$2,000	$2,340	28	0	2	1
FL	Panama City	36,417	10/8/2008	0	0	$500,000	$500,000	27	14	19	1
FL	Pelican Bay	5,686	12/21/2007	0	0	$15,000	$15,600	12	3	6	1
FL	Pensacola	56,255	10/18/2007	1	0	$1,000,000	$1,040,000	25	18	22	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
FL	Port Charlotte	46,451	8/13/2004	0	0	$75,000	$93,000	26	2	7	1
FL	Port Charlotte	46,451	6/21/2006	2	0	$500,000	$535,000	26	12	17	1
FL	Port Orange	45,823	7/24/2009	0	0	$2,500,000	$2,500,000	23	55	36	1
FL	Riviera Beach	29,884	8/7/2003	1	0	$80,000,000	$93,600,000	29	3132	302	2
FL	Rockledge	20,170	8/6/2003	0	0	$0	$0	23	0	0	0
FL	Rockledge	20,170	10/23/2005	0	0	$50,000	$54,500	23	3	8	1
FL	Royal Palm Beach	21,523	7/2/2007	0	0	$0	$0	20	0	0	0
FL	Sanibel	6,064	6/13/2000	0	0	$0	$0	13	0	0	0
FL	Sanibel	6,064	8/13/2004	1	0	$0	$0	13	0	0	0
FL	Sharpes	3,415	4/14/2009	0	0	$0	$0	28	0	0	0
FL	South Bradenton	21,587	6/8/2004	0	0	$15,000	$16,950	31	1	5	1
FL	St. Pete Beach	9,929	6/8/2002	0	0	$500,000	$595,000	18	60	32	1
FL	Stock Island	4,410	12/18/2009	0	0	$10,000	$10,000	29	2	8	1
FL	Tallahassee	150,624	6/4/2009	0	0	$1,000,000	$1,000,000	23	7	12	1
FL	Tampa	303,447	7/27/2009	0	0	$0	$0	25	0	0	0
FL	Thonotosassa	6,091	7/8/2003	1	0	$20,000	$23,400	23	4	9	1
FL	Town 'n' Country	72,523	6/25/2000	0	0	$100,000	$124,000	23	2	6	1
FL	Town 'n' Country	72,523	6/5/2002	0	0	$150,000	$178,500	23	2	7	1
FL	Wauchula	4,368	7/9/2005	0	0	$50,000	$54,500	33	12	20	1
FL	West and East Lealman	21,753	7/9/2005	0	0	$0	$0	32	0	0	0
FL	West De Land	3,424	2/2/2007	3	0	$0	$0	24	0	0	0
FL	West Palm Beach	82,103	3/31/2009	0	0	$25,000	$25,000	24	0	3	1
FL	Westchase	11,116	6/5/2002	0	0	$0	$0	15	0	0	0
FL	Wewahitchka	1,722	3/7/2005	0	0	$75,000	$81,750	31	47	38	1
GA	Albany	76,939	12/16/2000	2	0	$750,000	$930,000	30	12	19	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
GA	Ashburn	4,419	12/15/2007	1	1	$1,300,000	$8,352,000	36	1890	263	2
GA	Atlanta	416,474	3/14/2008	2	1	$25,000,000	$32,000,000	22	77	41	1
GA	Baxley	4,150	11/5/2002	0	0	$200,000	$238,000	33	57	43	1
GA	Blakely	5,696	9/15/2004	0	0	$20,000	$22,600	35	4	12	1
GA	Brinson	225	8/29/2005	0	0	$0	$0	30	0	0	0
GA	Calhoun	10,667	5/1/2002	1	0	$3,000	$3,570	24	0	3	1
GA	Camilla	5,669	3/20/2003	3	6	$6,000,000	$49,020,000	34	8647	544	3
GA	Canton	7,709	5/6/2003	1	0	$10,000	$11,700	24	2	6	1
GA	Carrollton	19,843	2/26/2008	3	0	$7,000,000	$7,000,000	26	353	96	1
GA	Cedartown	9,470	8/29/2005	1	0	$50,000	$54,500	32	6	14	1
GA	Colquitt	1,939	9/15/2004	0	0	$125,000	$141,250	31	73	48	1
GA	Douglasville	20,065	3/7/2008	1	0	$2,000,000	$2,000,000	21	100	46	1
GA	Eastman	5,440	4/14/2007	1	0	$350,000	$364,000	30	67	45	1
GA	Eastman	5,440	4/15/2007	2	0	$500,000	$520,000	30	96	53	1
GA	Fitzgerald	8,758	4/13/2009	1	0	$200,000	$200,000	35	23	28	1
GA	Fort Valley	8,005	8/29/2005	2	0	$2,600,000	$2,834,000	34	354	110	1
GA	Gibson	694	4/10/2009	0	0	$4,000	$4,000	34	6	14	1
GA	Girard	227	12/28/2005	0	0	$0	$0	34	0	0	0
GA	Gumlog	2,025	4/10/2009	2	0	$0	$0	20	0	0	0
GA	Helen	430	8/29/2005	2	0	$3,000,000	$3,270,000	23	7605	418	3
GA	Lake Park	549	3/2/2007	0	0	$10,000	$10,400	27	19	23	1
GA	Lawrenceville	22,397	4/3/2000	1	0	$1,500,000	$1,860,000	21	83	42	1
GA	Lula	1,438	8/29/2005	0	0	$250,000	$272,500	26	190	70	1
GA	Macon	97,255	5/11/2008	2	0	$5,000,000	$5,000,000	31	51	40	1
GA	Marietta	58,748	4/8/2006	0	0	$150,000	$160,500	22	3	8	1
GA	McDonough	8,493	1/2/2006	1	0	$500,000	$535,000	24	63	39	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
GA	Palmetto	3,400	1/2/2006	2	0	$250,000	$267,500	27	79	46	1
GA	Reed Creek	2,148	8/26/2008	1	0	$0	$0	17	0	0	0
GA	Reed Creek	2,148	8/26/2008	0	0	$0	$0	17	0	0	0
GA	Richland	1,794	3/1/2007	1	0	$400,000	$416,000	35	232	91	1
GA	Rockmart	3,870	4/8/2006	2	0	$0	$0	29	0	0	0
GA	Senoia	1,738	1/5/2007	0	0	$45,000	$46,800	18	27	22	1
GA	Stockbridge	9,853	12/4/2005	0	0	$150,000	$163,500	21	17	19	1
GA	Summerville	4,556	4/10/2009	2	0	$900,000	$900,000	33	198	81	1
GA	Sumner	309	3/1/2007	2	0	$250,000	$260,000	28	841	154	1
GA	Sylvester	5,990	12/5/2005	1	0	$0	$0	33	0	0	0
GA	Tyrone	3,916	1/2/2006	2	0	$2,000,000	$2,140,000	15	546	90	1
GA	Winder	10,201	8/29/2005	0	0	$150,000	$163,500	26	16	20	1
GA	Woodstock	10,050	5/20/2008	1	0	$46,000,000	$46,000,000	17	4577	280	2
IA	Altoona	10,345	5/30/2000	1	0	$0	$0	20	0	0	0
IA	Ames	50,731	11/12/2005	2	0	$0	$0	19	0	0	0
IA	Anita	1,049	5/18/2000	0	0	$0	$0	27	0	0	0
IA	Aurora	194	9/6/2001	2	0	$300,000	$366,000	23	1887	209	2
IA	Baxter	1,052	5/22/2004	0	0	$0	$0	26	0	0	0
IA	Blue Grass	1,169	6/14/2001	2	0	$0	$0	18	0	0	0
IA	Colfax	2,223	4/11/2001	1	0	$0	$0	20	0	0	0
IA	Creston	7,597	9/11/2003	0	0	$250,000	$292,500	29	39	33	1
IA	Cumming	162	6/22/2007	2	0	$700,000	$728,000	17	4494	273	2
IA	Des Moines	198,682	10/2/2007	1	0	$0	$0	24	0	0	0
IA	Dunkerton	749	5/11/2000	3	1	$500,000	$7,620,000	19	10174	437	3
IA	Fruitland	703	6/1/2007	3	0	$15,000,000	$15,600,000	15	22191	573	3
IA	George	1,051	6/11/2008	0	0	$0	$0	26	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
IA	Independence	6,014	4/23/2001	0	0	$20,000	$24,400	22	4	9	1
IA	Independence	6,014	6/1/2001	1	0	$1,000,000	$1,220,000	22	203	67	1
IA	Iowa City	62,220	4/13/2006	1	0	$0	$0	20	0	0	0
IA	Iowa City	62,220	4/13/2006	1	0	$70,000	$74,900	20	1	5	1
IA	Le Claire	2,847	4/13/2006	1	0	$60,000	$64,200	19	23	21	1
IA	Martelle	280	8/19/2009	0	0	$5,000	$5,000	20	18	19	1
IA	Montrose	957	5/30/2004	1	0	$20,000	$22,600	24	24	24	1
IA	Muscatine	22,697	4/13/2006	0	0	$0	$0	24	0	0	0
IA	Muscatine	22,697	4/13/2006	0	0	$10,000	$10,700	24	0	3	1
IA	Muscatine	22,697	6/1/2007	3	0	$1,000,000	$1,040,000	24	46	33	1
IA	New Hartford	659	5/25/2008	5	2	$2,000,000	$16,000,000	23	24279	751	4
IA	Norwalk	6,884	6/22/2007	1	0	$0	$0	18	0	0	0
IA	Norwalk	6,884	6/22/2007	2	0	$300,000	$312,000	18	45	28	1
IA	Parkersburg	1,889	5/25/2008	5	7	$17,000,000	$66,000,000	25	34939	931	4
IA	Riceville	840	6/11/2004	0	0	$100,000	$113,000	25	135	58	1
IA	Seymour	810	10/2/2007	1	0	$100,000	$104,000	29	128	61	1
IA	Sioux City	85,013	3/30/2006	0	0	$0	$0	25	0	0	0
IA	Sioux City	85,013	7/6/2008	0	0	$100,000	$107,000	25	1	6	1
IA	State Center	1,349	9/5/2004	0	0	$0	$0	22	0	0	0
IA	Story City	3,228	11/12/2005	0	0	$0	$0	22	0	0	0
IA	Swan	121	5/18/2000	1	0	$0	$0	25	0	0	0
IA	Walnut	778	5/8/2004	1	0	$0	$0	25	0	0	0
IA	Waterloo	68,747	5/11/2000	3	0	$1,300,000	$1,612,000	26	23	25	1
IA	West Des Moines	46,403	9/6/2001	1	0	$0	$0	16	0	0	0
IA	Winfield	1,131	4/25/2008	1	0	$10,000	$10,000	26	9	15	1
ID	Arbon Valley	627	4/28/2003	0	0	$0	$0	21	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
ID	Roberts	647	6/1/2002	1	0	$0	$0	27	0	0	0
IL	Alexis	863	4/13/2006	1	0	$100,000	$107,000	25	124	56	1
IL	Bloomingdale	21,675	8/4/2008	1	0	$250,000	$250,000	15	12	13	1
IL	Bloomingdale	21,675	8/4/2008	1	0	$500,000	$500,000	15	23	19	1
IL	Bolingbrook	56,321	4/26/2007	0	0	$0	$0	17	0	0	0
IL	Bolingbrook	56,321	8/4/2008	1	0	$500,000	$500,000	17	9	12	1
IL	Cairo	3,632	5/6/2003	2	0	$300,000	$351,000	34	97	57	1
IL	Caseyville	4,310	6/10/2003	2	0	$0	$0	29	0	0	0
IL	Champaign	67,518	10/24/2001	1	0	$500,000	$610,000	22	9	14	1
IL	Colfax	989	6/15/2008	0	0	$50,000	$50,000	21	51	32	1
IL	Decatur	81,860	4/2/2006	1	0	$0	$0	27	0	0	0
IL	Dongola	806	4/28/2002	3	1	$5,000,000	$12,950,000	32	16067	720	3
IL	Dupo	3,933	6/10/2003	0	0	$0	$0	22	0	0	0
IL	Fairview Heights	15,034	4/2/2006	2	1	$0	$7,000,000	20	466	97	1
IL	Forest City	287	5/30/2003	1	0	$0	$0	23	0	0	0
IL	Galatia	1,013	4/28/2002	2	0	$3,500,000	$4,165,000	34	4112	372	2
IL	Germantown Hills	2,111	5/28/2003	1	0	$0	$0	14	0	0	0
IL	Gillespie	3,412	5/13/2009	0	0	$0	$0	26	0	0	0
IL	Glendale Heights	31,765	8/4/2008	1	0	$0	$0	18	0	0	0
IL	Granite City	31,301	4/10/2001	1	0	$5,000,000	$6,100,000	26	195	72	1
IL	Grant Park	1,358	4/20/2004	0	0	$0	$0	17	0	0	0
IL	Granville	1,414	4/20/2004	3	0	$4,000,000	$4,520,000	21	3197	260	2
IL	Herscher	1,523	5/18/2000	0	0	$0	$0	18	0	0	0
IL	Jacksonville	18,940	5/24/2004	2	0	$4,000,000	$4,520,000	26	239	79	1
IL	Joliet	106,221	5/30/2003	1	0	$60,000	$70,200	22	1	4	1
IL	Joliet	106,221	4/20/2004	1	0	$5,000,000	$5,650,000	22	53	34	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
IL	Lerna	322	6/6/2008	1	0	$0	$0	23	0	0	0
IL	Lily Lake	825	8/19/2009	0	0	$0	$0	12	0	0	0
IL	Lincoln	15,369	4/13/2006	0	0	$2,500,000	$2,675,000	26	174	67	1
IL	Loami	804	8/19/2009	2	0	$100,000	$100,000	23	124	54	1
IL	Manito	1,733	5/10/2003	2	0	$0	$0	21	0	0	0
IL	Mark	491	4/20/2004	3	0	$0	$0	21	0	0	0
IL	Monticello	5,138	10/24/2001	2	0	$2,200,000	$2,684,000	19	522	101	1
IL	Murrayville	644	5/26/2000	1	0	$44,000	$54,560	23	85	44	1
IL	North Utica	977	4/20/2004	3	8	$4,000,000	$60,520,000	20	61945	1110	4
IL	Oconee	202	6/20/2000	1	0	$0	$0	27	0	0	0
IL	Pana	5,614	4/2/2006	1	0	$0	$0	31	0	0	0
IL	Perry	437	9/30/2007	0	0	$0	$0	29	0	0	0
IL	Peru	9,835	5/30/2003	0	0	$0	$0	23	0	0	0
IL	Plainfield	13,038	4/26/2007	0	0	$100,000	$104,000	13	8	10	1
IL	Pontoon Beach	5,620	4/10/2001	1	0	$0	$0	26	0	0	0
IL	Roanoke	1,994	5/30/2003	2	0	$0	$0	19	0	0	0
IL	Rockton	5,296	5/30/2003	0	0	$0	$0	16	0	0	0
IL	Rossville	1,217	7/26/2006	1	0	$40,000	$42,800	25	35	30	1
IL	Shiloh	7,643	4/27/2002	1	0	$0	$0	17	0	0	0
IL	Shiloh	7,643	6/8/2009	2	0	$0	$0	17	0	0	0
IL	South Pekin	1,162	5/10/2003	3	0	$5,500,000	$6,435,000	24	5538	368	2
IL	Springerton	134	10/24/2001	0	0	$50,000	$61,000	29	455	115	1
IL	Springfield	111,454	3/12/2006	2	0	$0	$0	23	0	0	0
IL	Springfield	111,454	4/2/2006	1	0	$0	$0	23	0	0	0
IL	Springfield	111,454	8/19/2009	1	0	$200,000	$200,000	23	2	6	1
IL	Sugar Grove	3,909	5/28/2003	0	0	$0	$0	13	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
IL	Trenton	2,610	7/21/2006	0	0	$0	$0	19	0	0	0
IL	Williamsville	1,439	8/19/2009	3	0	$11,000,000	$11,000,000	18	7644	371	2
IL	Wilsonville	604	6/13/2005	1	0	$0	$0	25	0	0	0
IL	Wilsonville	604	6/13/2005	1	0	$0	$0	25	0	0	0
IL	Woodstock	20,151	6/19/2009	1	0	$75,000	$75,000	19	4	8	1
IN	Bedford	13,768	3/8/2009	0	0	$45,000	$45,000	27	3	9	1
IN	Bloomfield	2,542	2/5/2008	0	0	$0	$0	26	0	0	0
IN	Bloomfield	2,542	6/4/2008	1	0	$1,300,000	$1,300,000	26	511	116	1
IN	Boonville	6,834	11/6/2005	3	0	$0	$0	26	0	0	0
IN	Borden	818	5/27/2004	2	0	$1,000,000	$1,130,000	21	1381	169	1
IN	Brook	1,062	5/30/2004	0	0	$0	$0	27	0	0	0
IN	Burnettsville	373	5/31/2006	0	0	$0	$0	22	0	0	0
IN	Chesterton	10,488	8/19/2009	2	0	$1,500,000	$1,500,000	16	143	48	1
IN	Columbia City	7,077	3/8/2009	1	0	$500,000	$500,000	24	71	42	1
IN	Darmstadt	1,313	5/30/2004	0	0	$0	$0	13	0	0	0
IN	Darmstadt	1,313	5/10/2006	1	0	$1,200,000	$1,356,000	13	1033	115	1
IN	Decatur	9,528	8/28/2006	1	0	$0	$0	23	0	0	0
IN	Ellettsville	5,078	9/20/2002	3	0	$10,000,000	$11,900,000	25	2343	242	2
IN	Evansville	121,582	11/6/2005	3	20	$15,000,000	$156,350,000	27	1286	187	2
IN	Frankton	1,905	5/30/2004	0	0	$75,000	$84,750	22	44	31	1
IN	Georgetown	2,227	5/27/2004	1	0	$500,000	$565,000	17	254	66	1
IN	Greenwood	36,037	9/20/2002	3	0	$25,000,000	$29,750,000	20	826	127	1
IN	Hartford City	6,928	11/10/2002	1	0	$250,000	$297,500	28	43	35	1
IN	Holton	407	7/30/2004	2	0	$465,000	$525,450	31	1291	200	2
IN	Huntington	17,450	4/20/2004	0	0	$0	$0	24	0	0	0
IN	Indianapolis	781,870	9/20/2002	0	0	$0	$0	23	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
IN	Indianapolis	781,870	5/30/2004	2	0	$19,000,000	$21,470,000	23	27	25	1
IN	Indianapolis	781,870	6/12/2005	3	0	$40,000,000	$47,600,000	23	61	37	1
IN	Lawrence	38,915	9/20/2002	3	0	$0	$0	21	0	0	0
IN	Marengo	829	5/30/2004	3	1	$5,000,000	$12,650,000	30	15259	679	3
IN	Martinsville	11,698	9/20/2002	3	0	$15,000,000	$17,850,000	25	1526	196	2
IN	McCordsville	1,134	9/20/2002	3	0	$2,000,000	$2,380,000	14	2099	170	1
IN	Muncie	67,430	9/20/2002	3	0	$3,000,000	$3,570,000	29	53	39	1
IN	Nappanee	6,710	10/18/2007	3	0	$11,000,000	$11,440,000	20	1705	186	2
IN	Newburgh	3,088	5/30/2004	2	0	$2,500,000	$2,825,000	19	915	133	1
IN	Newburgh	3,088	11/6/2005	3	4	$65,000,000	$98,850,000	19	32011	787	4
IN	Pendleton	3,873	9/20/2002	3	0	$8,000,000	$9,520,000	18	2458	209	2
IN	Peru	12,994	5/30/2004	3	0	$6,000,000	$6,780,000	28	522	122	1
IN	Richmond	39,124	6/21/2000	0	0	$45,000	$55,800	28	1	6	1
IN	South Bend	107,789	10/24/2001	3	1	$3,000,000	$10,660,000	29	99	53	1
IN	Tennyson	290	11/6/2005	3	0	$0	$0	27	0	0	0
IN	Terre Haute	59,614	2/16/2006	1	0	$1,500,000	$1,605,000	28	27	27	1
KS	Bird City	482	3/28/2007	0	0	$0	$0	26	0	0	0
KS	Chapman	1,241	6/11/2008	3	1	$20,000,000	$27,000,000	26	21757	757	4
KS	Colby	5,450	8/7/2006	1	0	$125,000	$133,750	24	25	24	1
KS	Elwood	1,145	6/4/2005	0	0	$0	$0	32	0	0	0
KS	Great Bend	15,345	7/8/2008	0	0	$0	$0	29	0	0	0
KS	Great Bend	15,345	6/20/2009	0	0	$75,000	$75,000	29	5	12	1
KS	Greensburg	1,574	5/4/2007	5	11	$250,000,000	$327,000,000	28	207751	2440	5
KS	Hoisington	2,975	4/21/2001	4	1	$43,000,000	$59,460,000	31	19987	790	4
KS	Leavenworth	35,420	5/4/2003	1	0	$1,000,000	$1,170,000	22	33	27	1
KS	Liberal	19,666	5/15/2003	2	0	$6,000,000	$7,020,000	27	357	97	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
KS	Lyndon	1,038	5/8/2003	3	0	$1,000,000	$1,170,000	23	1127	162	1
KS	Manhattan	44,831	6/11/2008	4	0	$66,000,000	$66,000,000	22	1472	181	1
KS	Oketo	87	5/29/2004	0	0	$10,000	$11,300	24	130	55	1
KS	Protection	558	5/23/2008	1	0	$0	$0	28	0	0	0
KS	Russell	4,696	9/21/2006	1	0	$100,000	$107,000	30	23	26	1
KS	Salina	45,679	6/11/2008	3	0	$2,000,000	$2,000,000	25	44	33	1
KS	Stockton	1,558	6/9/2005	1	0	$300,000	$327,000	26	210	74	1
KS	Ulysses	5,960	10/26/2006	0	0	$0	$0	22	0	0	0
KS	WaKeeney	1,924	5/22/2008	1	0	$0	$0	27	0	0	0
KY	Burkesville	1,756	11/9/2000	1	0	$150,000	$186,000	36	106	62	1
KY	Clay	1,179	5/4/2003	2	0	$1,000,000	$1,170,000	25	992	158	1
KY	Earlington	1,649	11/15/2005	4	0	$31,000,000	$33,790,000	36	20491	858	4
KY	Eubank	358	4/10/2009	0	0	$40,000	$40,000	28	112	56	1
KY	Eubank	358	4/10/2009	1	0	$100,000	$100,000	28	279	89	1
KY	Hanson	625	6/1/2004	0	0	$0	$0	26	0	0	0
KY	Hardinsburg	2,345	6/12/2004	0	0	$100,000	$113,000	28	48	37	1
KY	Harrodsburg	8,014	2/6/2008	1	0	$1,000,000	$1,000,000	29	125	61	1
KY	Hendron	4,239	5/6/2003	1	0	$0	$0	20	0	0	0
KY	Hillview	7,037	10/18/2007	1	0	$35,000	$36,400	21	5	10	1
KY	Hopkinsville	30,089	8/4/2009	0	0	$35,000	$35,000	29	1	6	1
KY	Lexington-Fayette County	260,512	5/27/2004	3	0	$7,500,000	$8,475,000	20	33	25	1
KY	Louisville	256,231	1/2/2006	1	0	$250,000	$267,500	28	1	5	1
KY	Munfordville	1,563	5/11/2003	1	0	$100,000	$117,000	34	75	50	1
KY	Munfordville	1,563	11/6/2005	2	0	$2,100,000	$2,289,000	34	1464	222	2
KY	Owensboro	54,067	1/3/2000	3	0	$11,500,000	$11,960,000	27	221	78	1
KY	Owensboro	54,067	10/18/2007	3	0	$64,000,000	$79,360,000	27	1468	201	2

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
KY	Whitesville	632	9/22/2006	1	0	$75,000	$80,250	32	127	64	1
LA	Alexandria	46,342	12/9/2008	1	0	$300,000	$300,000	31	6	14	1
LA	Blanchard	2,050	10/29/2009	0	0	$0	$0	18	0	0	0
LA	Breaux Bridge	7,281	5/15/2008	1	0	$1,000,000	$1,000,000	31	137	65	1
LA	Cheneyville	901	9/3/2008	1	0	$40,000	$40,000	34	44	39	1
LA	Dodson	357	5/3/2009	2	0	$3,000,000	$3,000,000	31	8403	508	3
LA	Eastwood	3,374	10/29/2009	1	0	$1,000,000	$1,000,000	21	296	80	1
LA	Elton	1,261	10/22/2009	1	0	$600,000	$600,000	35	476	130	1
LA	Estelle	15,880	3/19/2008	1	0	$200,000	$200,000	23	13	17	1
LA	Fisher	268	3/30/2008	0	0	$15,000	$15,000	29	56	40	1
LA	Golden Meadow	2,193	9/25/2002	1	0	$0	$0	28	0	0	0
LA	Goldonna	457	5/10/2009	0	0	$0	$0	26	0	0	0
LA	Iowa	2,663	12/30/2002	1	0	$7,000,000	$8,330,000	28	3128	296	2
LA	Jonesboro	3,914	3/24/2009	1	0	$500,000	$500,000	35	128	67	1
LA	Jonesville	2,469	2/24/2007	2	0	$400,000	$416,000	36	168	77	1
LA	Kenner	70,517	2/2/2006	1	0	$750,000	$802,500	24	11	17	1
LA	Lafayette	110,257	5/15/2008	0	0	$50,000	$50,000	23	0	3	1
LA	Lafayette	110,257	5/15/2008	1	0	$3,000,000	$3,000,000	23	27	25	1
LA	Lake Providence	5,104	6/18/2007	1	0	$700,000	$728,000	36	143	71	1
LA	Mansfield	5,582	4/23/2000	2	0	$0	$0	36	0	0	0
LA	Metairie	146,136	5/16/2009	0	0	$15,000	$15,000	21	0	1	1
LA	Morse	759	10/16/2006	0	0	$0	$0	30	0	0	0
LA	Natchez	583	11/23/2004	0	0	$30,000	$33,900	33	58	44	1
LA	New Iberia	32,623	8/8/2008	0	0	$200,000	$200,000	33	6	14	1
LA	New Orleans	484,674	2/13/2007	2	1	$1,000,000	$8,040,000	29	17	22	1
LA	Olla	1,417	11/23/2004	3	1	$5,000,000	$12,650,000	31	8927	525	3

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
LA	Sicily Island	453	11/8/2000	2	0	$15,000	$18,600	35	41	38	1
LA	Slidell	25,695	11/24/2004	2	0	$750,000	$847,500	23	33	28	1
LA	Westwego	10,763	12/15/2009	0	0	$3,000	$3,000	33	0	3	1
MA	Franklin	29,560	8/21/2004	1	0	$1,500,000	$1,695,000	14	57	29	1
MA	Ocean Grove	3,012	7/23/2008	0	0	$0	$0	20	0	0	0
MD	Charlotte Hall	1,214	5/7/2003	0	0	$25,000	$29,250	20	24	22	1
MD	Chesapeake Beach	3,180	6/4/2008	0	0	$400,000	$400,000	17	126	46	1
MD	Chillum	34,252	4/20/2008	1	0	$40,000	$40,000	26	1	5	1
MD	Dundalk	62,306	6/9/2009	0	0	$0	$0	25	0	0	0
MD	Essex	39,078	6/20/2009	1	0	$0	$0	26	0	0	0
MD	Frederick	52,767	6/6/2002	0	0	$15,000	$17,850	21	0	3	1
MD	Maryland City	6,814	6/21/2000	1	0	$0	$0	19	0	0	0
MD	Maryland City	6,814	7/10/2000	1	0	$0	$0	19	0	0	0
MD	Olney	31,438	5/27/2001	1	0	$500,000	$610,000	16	19	17	1
MD	Pleasant Hills	2,851	7/16/2007	0	0	$0	$0	16	0	0	0
MD	Pleasant Hills	2,851	6/20/2009	1	0	$10,000	$10,400	16	4	8	1
MD	Poolesville	5,151	9/17/2004	1	0	$0	$0	14	0	0	0
MD	Preston	566	6/4/2008	0	0	$300,000	$300,000	18	530	98	1
MD	Severna Park	28,507	9/28/2006	1	0	$6,000,000	$6,420,000	14	225	56	1
MD	St. Charles	33,379	4/20/2008	0	0	$50,000	$50,000	21	2	6	1
MD	White Oak	20,973	6/4/2008	0	0	$400,000	$400,000	21	19	20	1
ME	Presque Isle	9,511	5/31/2009	1	0	$0	$0	26	0	0	0
MI	Iron Mountain	8,154	9/30/2002	1	0	$7,000,000	$8,330,000	23	1022	154	1
MI	Lansing	119,128	8/24/2007	1	0	$300,000	$312,000	27	3	8	1
MI	Norway	2,959	9/30/2002	0	0	$0	$0	25	0	0	0
MI	Paw Paw	3,363	9/13/2008	1	0	$0	$0	22	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
MN	Austin	23,314	6/17/2009	2	0	$2,000,000	$2,000,000	26	86	47	1
MN	Benson	3,376	6/11/2001	2	0	$10,000,000	$12,200,000	27	3614	310	2
MN	Big Lake	6,063	5/9/2004	0	0	$0	$0	18	0	0	0
MN	Blaine	44,942	5/25/2008	1	0	$700,000	$700,000	17	16	16	1
MN	Brainerd	13,178	6/13/2001	2	0	$0	$0	30	0	0	0
MN	Buffalo Lake	768	6/24/2003	2	0	$15,000,000	$17,550,000	26	22852	773	4
MN	Clear Lake	266	5/30/2004	0	0	$0	$0	19	0	0	0
MN	Coon Rapids	61,607	9/21/2005	1	0	$700,000	$700,000	18	11	14	1
MN	Coon Rapids	61,607	5/25/2008	2	0	$5,000,000	$5,450,000	18	88	40	1
MN	Cottage Grove	30,582	8/19/2009	1	0	$100,000	$100,000	15	3	7	1
MN	Dent	192	6/18/2009	1	0	$0	$0	30	0	0	0
MN	Fergus Falls	13,471	6/14/2008	1	0	$100,000	$100,000	25	7	14	1
MN	Geneva	449	6/17/2009	0	0	$1,000	$1,000	20	2	7	1
MN	Glenville	720	5/1/2001	2	0	$20,000,000	$24,400,000	22	33889	871	4
MN	Granite Falls	3,070	7/25/2000	4	1	$20,000,000	$31,800,000	27	10358	526	3
MN	Hugo	6,363	5/25/2008	3	1	$25,000,000	$32,000,000	14	5029	268	2
MN	Lancaster	363	5/29/2002	0	0	$0	$0	23	0	0	0
MN	Lino Lakes	16,791	5/25/2008	3	0	$300,000	$300,000	13	18	15	1
MN	Marine on St. Croix	602	5/25/2008	0	0	$25,000	$25,000	12	42	22	1
MN	Marine on St. Croix	602	5/25/2008	0	0	$300,000	$300,000	12	498	77	1
MN	Marine on St. Croix	602	8/19/2009	0	0	$300,000	$300,000	12	498	77	1
MN	Minneapolis	382,618	8/19/2009	0	0	$500,000	$500,000	21	1	5	1
MN	Nielsville	91	8/29/2004	0	0	$1,000	$1,130	26	12	18	1
MN	North Branch	8,023	8/19/2009	0	0	$100,000	$100,000	17	12	15	1
MN	Northfield	17,147	5/9/2001	2	0	$9,000,000	$10,980,000	17	640	105	1
MN	Ottertail	451	6/20/2005	2	0	$0	$0	20	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
MN	Rogers	3,588	9/16/2006	2	1	$30,000,000	$39,100,000	12	10897	367	2
MN	Spicer	1,126	7/14/2009	1	0	$250,000	$250,000	22	222	69	1
MN	Warroad	1,722	8/5/2006	3	0	$20,000,000	$21,400,000	21	12427	515	3
MO	Amsterdam	281	3/12/2006	0	0	$400,000	$428,000	25	1523	194	2
MO	Berkeley	10,063	5/30/2004	1	1	$100,000	$7,113,000	31	707	149	1
MO	Bismarck	1,470	5/14/2009	1	0	$0	$0	32	0	0	0
MO	Branson	6,050	3/11/2006	0	0	$0	$0	25	0	0	0
MO	Buffalo	2,781	3/31/2008	2	0	$1,000,000	$1,000,000	33	360	109	1
MO	Chain-O-Lakes	127	9/2/2008	0	0	$5,000	$5,000	24	39	31	1
MO	Charleston	4,732	4/20/2002	1	0	$68,000	$80,920	35	17	24	1
MO	Desloge	4,802	5/12/2002	1	0	$0	$0	27	0	0	0
MO	Dexter	7,356	3/9/2006	1	0	$900,000	$963,000	32	131	65	1
MO	Ellsinore	363	4/24/2002	4	0	$45,000,000	$53,550,000	33	147521	2214	5
MO	Excelsior Estates	263	11/27/2005	1	0	$0	$0	30	0	0	0
MO	Excelsior Springs	10,847	11/27/2005	1	0	$1,200,000	$1,308,000	25	121	54	1
MO	Fulton	12,128	4/10/2001	1	1	$75,000	$7,091,500	22	585	113	1
MO	Gladstone	26,365	5/2/2008	2	0	$10,000,000	$10,000,000	20	379	86	1
MO	Highlandville	872	1/8/2008	1	0	$250,000	$250,000	26	287	86	1
MO	Jackson	11,947	5/6/2003	3	0	$12,000,000	$14,040,000	21	1175	159	1
MO	Joplin	45,504	6/30/2005	0	0	$0	$0	27	0	0	0
MO	Kansas City	441,545	5/11/2000	3	0	$4,000,000	$4,000,000	24	9	15	1
MO	Kansas City	441,545	5/4/2003	1	0	$5,000,000	$6,200,000	24	14	18	1
MO	Kansas City	441,545	5/2/2008	4	0	$31,000,000	$36,270,000	24	82	45	1
MO	Kirksville	16,988	5/13/2009	2	2	$5,000,000	$19,000,000	28	1118	175	1
MO	Lebanon	12,155	3/31/2008	2	0	$500,000	$500,000	29	41	34	1
MO	Liberty	26,232	5/4/2003	2	0	$60,000,000	$70,200,000	18	2676	221	2

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
MO	Monroe City	2,588	5/10/2003	0	0	$0	$0	30	0	0	0
MO	Neosho	10,505	3/31/2008	0	0	$100,000	$100,000	28	10	16	1
MO	Nixa	12,124	4/9/2009	0	0	$100,000	$100,000	23	8	14	1
MO	North Lilbourn	95	11/15/2005	1	0	$60,000	$65,400	35	688	155	1
MO	Palmyra	3,467	10/2/2007	0	0	$50,000	$52,000	27	15	20	1
MO	Redings Mill	159	4/15/2001	1	0	$2,000,000	$2,440,000	25	15346	616	3
MO	Republic	8,438	1/7/2008	1	0	$1,000,000	$1,000,000	25	119	54	1
MO	Republic	8,438	5/8/2009	2	0	$2,000,000	$2,000,000	25	237	77	1
MO	Roscoe	112	5/26/2004	2	0	$500,000	$565,000	24	5045	348	2
MO	Schell City	286	6/2/2008	0	0	$150,000	$150,000	33	524	131	1
MO	Sedalia	20,339	5/6/2003	0	0	$0	$0	31	0	0	0
MO	Springfield	151,580	1/8/2008	1	0	$50,000	$50,000	26	0	3	1
MO	Springfield	151,580	6/19/2008	1	0	$150,000	$150,000	26	1	5	1
MO	Springfield	151,580	2/10/2009	1	0	$200,000	$200,000	26	1	6	1
MO	Springfield	151,580	5/8/2009	1	0	$350,000	$350,000	26	2	8	1
MO	St. James	3,704	9/22/2006	1	0	$1,500,000	$1,605,000	31	433	116	1
MO	St. Louis	348,189	3/31/2007	0	0	$0	$0	30	0	0	0
MO	Van Buren	845	4/24/2002	4	0	$1,000,000	$1,190,000	33	1408	217	2
MO	Warrensburg	16,340	4/10/2001	1	0	$2,000,000	$2,440,000	25	149	61	1
MS	Abbeville	423	5/8/2008	0	0	$25,000	$25,000	22	59	36	1
MS	Bay St. Louis	8,209	8/12/2003	0	0	$0	$0	26	0	0	0
MS	Benoit	611	10/9/2009	0	0	$45,000	$45,000	35	74	51	1
MS	Brandon	16,436	4/24/2003	3	0	$50,000,000	$58,500,000	18	3559	256	2
MS	Byram	7,386	3/16/2002	1	0	$1,400,000	$1,666,000	17	226	63	1
MS	Caledonia	1,015	1/10/2008	3	0	$7,000,000	$7,000,000	22	6897	391	2
MS	Carthage	4,637	9/25/2005	1	0	$200,000	$218,000	30	47	37	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
MS	Columbus	25,944	11/10/2002	3	0	$60,000,000	$71,400,000	29	2752	283	2
MS	Greenville	41,633	9/24/2005	2	0	$680,000	$741,200	32	18	24	1
MS	Hattiesburg	44,779	10/17/2006	2	0	$700,000	$749,000	30	17	22	1
MS	Indianola	12,066	2/24/2007	1	0	$650,000	$676,000	32	56	43	1
MS	Isola	768	11/24/2001	3	0	$4,000,000	$4,880,000	34	6354	465	3
MS	Itta Bena	2,208	9/24/2005	1	0	$200,000	$218,000	34	99	58	1
MS	Jackson	184,256	9/25/2005	0	0	$0	$0	29	0	0	0
MS	Lake	408	3/3/2008	1	0	$1,200,000	$1,200,000	31	2941	304	2
MS	Laurel	18,393	3/15/2002	1	0	$3,300,000	$3,927,000	33	214	84	1
MS	Madison	14,692	11/24/2001	4	2	$12,000,000	$28,640,000	15	1949	171	1
MS	Magee	4,200	11/18/2003	1	0	$200,000	$234,000	32	56	42	1
MS	Magee	4,200	3/26/2009	3	0	$5,000,000	$5,000,000	32	1190	195	2
MS	Marion	1,305	12/16/2000	2	0	$2,100,000	$2,604,000	34	1995	262	2
MS	Moorhead	2,573	10/22/2007	1	0	$180,000	$187,200	35	73	50	1
MS	Mount Olive	893	4/6/2005	0	0	$5,000	$5,450	35	6	15	1
MS	Natchez	18,464	12/9/2008	1	0	$2,500,000	$2,500,000	32	135	66	1
MS	New Hope	1,964	11/10/2002	1	0	$15,000	$17,850	17	9	12	1
MS	Newton	3,699	12/19/2002	2	0	$1,000,000	$1,090,000	32	295	98	1
MS	Newton	3,699	9/24/2005	2	0	$1,000,000	$1,190,000	32	322	102	1
MS	Olive Branch	21,054	6/12/2009	2	0	$4,000,000	$4,000,000	17	190	57	1
MS	Olive Branch	21,054	7/30/2009	2	0	$6,000,000	$6,000,000	17	285	70	1
MS	Pachuta	245	4/6/2005	1	0	$40,000	$43,600	32	178	76	1
MS	Pearl	21,961	2/12/2008	1	0	$1,000,000	$1,000,000	26	46	34	1
MS	Philadelphia	7,303	8/29/2005	1	0	$15,000	$16,350	33	2	9	1
MS	Picayune	10,535	4/7/2003	1	0	$100,000	$117,000	31	11	18	1
MS	Sardis	2,038	3/9/2006	1	0	$500,000	$535,000	34	263	94	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
MS	Starkville	21,869	9/25/2005	1	0	$2,000,000	$2,180,000	24	100	49	1
MS	Tupelo	34,211	5/8/2008	3	0	$1,500,000	$1,500,000	23	44	32	1
MS	West Hattiesburg	6,305	12/10/2008	1	0	$700,000	$700,000	25	111	52	1
NC	Apex	20,212	9/27/2004	0	0	$0	$0	15	0	0	0
NC	Aulander	888	9/26/2008	0	0	$75,000	$75,000	32	84	52	1
NC	Charlotte	540,828	3/8/2005	1	0	$50,000	$54,500	20	0	1	1
NC	Clayton	6,973	9/14/2007	0	0	$0	$0	22	0	0	0
NC	Greenville	60,476	3/27/2009	1	0	$50,000	$50,000	24	1	5	1
NC	Jacksonville	66,715	5/7/2009	0	0	$0	$0	24	0	0	0
NC	Lillington	2,915	9/14/2007	0	0	$0	$0	25	0	0	0
NC	Lincolnton	9,965	10/16/2003	1	0	$50,000	$58,500	28	6	13	1
NC	Morehead City	7,691	5/11/2008	1	0	$30,000	$30,000	29	4	11	1
NC	Mount Holly	9,618	7/12/2003	1	0	$2,000,000	$2,340,000	23	243	74	1
NC	Plain View	1,820	3/27/2009	0	0	$0	$0	25	0	0	0
NC	River Road	4,094	7/17/2009	0	0	$0	$0	24	0	0	0
NC	Vanceboro	898	5/7/2009	0	0	$0	$0	29	0	0	0
NC	Watha	151	5/27/2003	0	0	$0	$0	23	0	0	0
NC	Whiteville	5,148	4/17/2006	1	0	$10,000	$10,700	29	2	8	1
ND	Belcourt	2,440	7/7/2008	3	0	$0	$0	32	0	0	0
ND	Belfield	866	6/6/2005	1	0	$0	$0	31	0	0	0
ND	Cannon Ball	864	6/26/2005	0	0	$0	$0	33	0	0	0
ND	Cannon Ball	864	6/26/2005	0	0	$0	$0	33	0	0	0
ND	Crosby	1,089	7/18/2003	1	0	$0	$0	29	0	0	0
ND	Crosby	1,089	6/11/2007	0	0	$75,000	$78,000	29	72	45	1
ND	Dickinson	16,010	7/8/2009	3	0	$20,000,000	$20,000,000	25	1249	178	1
ND	Enderlin	947	6/17/2007	0	0	$0	$0	23	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
ND	Grand Forks	49,321	5/20/2005	1	0	$0	$0	22	0	0	0
ND	Horace	915	7/10/2004	0	0	$0	$0	21	0	0	0
ND	Mohall	812	6/6/2004	0	0	$0	$0	26	0	0	0
ND	Mooreton	204	6/18/2009	1	0	$0	$0	23	0	0	0
ND	Northwood	959	8/26/2007	4	1	$50,000,000	$59,000,000	24	61522	1226	4
ND	Pembina	642	7/14/2003	0	0	$0	$0	17	0	0	0
ND	Rolla	1,417	7/7/2008	3	0	$1,000,000	$1,000,000	29	706	143	1
ND	Sawyer	377	6/12/2007	0	0	$0	$0	25	0	0	0
ND	Tower City	252	7/15/2007	1	0	$1,000,000	$1,040,000	23	4127	311	2
ND	Walhalla	1,057	6/23/2005	1	0	$0	$0	26	0	0	0
NE	Cody	149	6/21/2007	1	0	$75,000	$78,000	28	523	120	1
NE	Fremont	25,174	5/22/2004	1	0	$0	$0	25	0	0	0
NE	Gibbon	1,759	5/7/2005	0	0	$25,000	$27,250	27	15	21	1
NE	Grand Island	42,940	6/17/2009	0	0	$5,000	$5,000	26	0	2	1
NE	Hadar	312	5/21/2004	1	0	$0	$0	18	0	0	0
NE	Hallam	276	5/22/2004	4	1	$100,000,000	$120,000,000	17	434783	2743	5
NE	Hastings	24,064	8/22/2007	0	0	$20,000	$20,800	25	1	5	1
NE	Jackson	205	8/17/2001	2	0	$3,000,000	$3,660,000	19	17854	590	3
NE	Kearney	27,431	5/29/2008	1	0	$100,000	$100,000	24	4	9	1
NE	Kearney	27,431	5/29/2008	2	0	$11,000,000	$11,000,000	24	401	97	1
NE	Louisville	1,046	6/11/2008	1	0	$0	$0	19	0	0	0
NE	Omaha	390,007	6/8/2008	2	0	$0	$0	22	0	0	0
NE	Omaha	390,007	6/8/2008	2	0	$0	$0	22	0	0	0
NE	Shelton	1,140	5/29/2008	1	0	$0	$0	26	0	0	0
NE	Surprise	44	9/15/2006	2	0	$0	$0	30	0	0	0
NE	Ulysses	276	6/4/2008	1	0	$0	$0	26	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
NJ	Florence-Roebling	8,200	9/23/2003	1	0	$600,000	$702,000	20	86	42	1
NJ	Trenton	85,403	9/23/2003	1	0	$1,000,000	$1,170,000	31	14	21	1
NM	Cedar Grove	599	7/18/2009	0	0	$0	$0	22	0	0	0
NM	Logan	1,094	3/23/2007	1	0	$3,500,000	$3,640,000	29	3327	313	2
NY	Hilton	5,856	7/25/2009	0	0	$75,000	$75,000	20	13	16	1
NY	Unionville	536	7/29/2009	0	0	$75,000	$75,000	25	140	59	1
OH	Bethel	2,637	5/30/2009	0	0	$0	$0	28	0	0	0
OH	Brewster	2,324	6/22/2006	1	0	$450,000	$481,500	23	207	70	1
OH	Carlisle	5,121	7/11/2006	1	0	$200,000	$214,000	19	42	28	1
OH	Circleville	13,485	6/2/2001	0	0	$50,000	$61,000	25	5	11	1
OH	Fostoria	13,931	11/10/2002	2	0	$11,000,000	$13,090,000	29	940	166	1
OH	Jamestown	1,917	5/8/2008	0	0	$1,000	$1,000	25	1	4	1
OH	Macedonia	9,224	11/10/2002	2	0	$5,000,000	$5,950,000	14	645	95	1
OH	New Philadelphia	17,056	11/12/2003	2	0	$160,000	$187,200	25	11	16	1
OH	Polk	357	11/10/2002	2	0	$1,600,000	$1,904,000	20	5333	330	2
OH	Tiffin	18,135	11/10/2002	3	1	$12,800,000	$22,232,000	26	1226	178	1
OH	Twinsburg	17,006	11/10/2002	2	0	$5,000,000	$5,950,000	16	350	75	1
OH	Van Wert	10,690	9/20/2002	0	0	$0	$0	26	0	0	0
OH	Waynesburg	1,003	6/22/2006	1	0	$500,000	$535,000	27	533	119	1
OH	Wilmington	11,921	5/24/2001	0	0	$5,000	$6,100	25	1	4	1
OH	Xenia	24,164	9/20/2000	4	1	$15,000,000	$25,600,000	27	1059	168	1
OK	Agra	356	6/9/2004	1	0	$200,000	$226,000	30	635	137	1
OK	Anadarko	6,645	5/13/2009	2	0	$50,000,000	$50,000,000	35	7524	511	3
OK	Atoka	2,988	4/16/2002	1	0	$30,000	$35,700	35	12	20	1
OK	Bethany	20,307	5/9/2003	1	0	$10,000,000	$11,700,000	26	576	122	1
OK	Broken Arrow	74,859	4/22/2004	0	0	$0	$0	18	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
OK	Broken Bow	4,230	5/1/2003	2	0	$260,000	$304,200	36	72	51	1
OK	Choctaw	9,377	4/15/2003	1	0	$125,000	$146,250	19	16	17	1
OK	Coweta	7,139	5/13/2004	1	0	$100,000	$113,000	26	16	20	1
OK	Del City	22,128	5/8/2003	4	0	$160,000,000	$187,200,000	29	8460	498	3
OK	Edmond	68,315	2/10/2009	2	0	$0	$0	17	0	0	0
OK	El Reno	16,212	4/24/2006	1	0	$1,500,000	$1,605,000	26	99	51	1
OK	El Reno	16,212	5/8/2007	1	0	$3,000,000	$3,120,000	26	192	71	1
OK	Enid	47,045	4/25/2009	2	0	$0	$0	27	0	0	0
OK	Goldsby	1,204	5/7/2008	0	0	$15,000	$15,000	18	12	15	1
OK	Helena	443	9/7/2001	0	0	$0	$0	31	0	0	0
OK	Henryetta	6,096	5/16/2003	1	0	$100,000	$117,000	35	19	26	1
OK	Jones	2,517	11/10/2004	1	0	$1,000,000	$1,130,000	26	449	107	1
OK	Lone Grove	4,631	2/10/2009	4	8	$3,000,000	$59,000,000	28	12740	596	3
OK	McAlester	17,783	5/10/2008	0	0	$0	$0	28	0	0	0
OK	Minco	1,672	8/19/2007	1	0	$45,000	$46,800	25	28	26	1
OK	Moore	41,138	5/8/2003	4	0	$210,000,000	$245,700,000	23	5973	368	2
OK	New Cordell	2,867	10/9/2001	3	0	$100,000,000	$122,000,000	29	42553	1117	4
OK	Noble	5,260	5/7/2008	0	0	$10,000	$10,000	26	2	7	1
OK	Norman	95,694	6/12/2009	1	0	$0	$0	20	0	0	0
OK	North Enid	796	4/25/2009	2	0	$0	$0	19	0	0	0
OK	Oklahoma City	506,132	10/22/2000	0	0	$0	$0	24	0	0	0
OK	Oklahoma City	506,132	10/22/2000	0	0	$10,000	$12,000	24	0	1	1
OK	Oklahoma City	506,132	5/8/2003	0	0	$25,000	$26,000	24	0	1	1
OK	Oklahoma City	506,132	5/9/2003	0	0	$50,000	$50,000	24	0	2	1
OK	Oklahoma City	506,132	3/29/2007	1	0	$120,000	$148,800	24	0	3	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
OK	Oklahoma City	506,132	5/7/2008	2	0	$500,000	$585,000	24	1	5	1
OK	Oklahoma City	506,132	2/10/2009	1	0	$1,000,000	$1,000,000	24	2	7	1
OK	Oklahoma City	506,132	5/13/2009	3	0	$7,000,000	$8,190,000	24	16	20	1
OK	Tulsa	393,049	4/1/2006	1	0	$250,000	$267,500	24	1	4	1
OK	Tyrone	880	5/15/2003	0	0	$0	$0	28	0	0	0
OK	Union City	1,375	8/19/2007	1	0	$5,000	$5,200	19	4	8	1
OK	Warr Acres	9,735	5/9/2003	1	0	$20,000	$23,400	26	2	8	1
PA	Allentown	106,632	9/6/2008	1	0	$1,500,000	$1,500,000	29	14	20	1
PA	Clark	633	11/10/2002	2	1	$1,000,000	$8,190,000	16	12938	450	3
PA	Greensburg	15,889	12/1/2006	1	0	$75,000	$80,250	27	5	12	1
PA	Hermitage	16,157	4/28/2002	0	0	$150,000	$178,500	21	11	15	1
PA	Mountain Top	15,269	12/1/2006	2	0	$1,000,000	$1,070,000	16	70	34	1
PA	New Lebanon	205	7/21/2003	0	0	$15,000	$17,550	21	86	42	1
PA	Pittsburgh	334,563	8/9/2007	0	0	$100,000	$104,000	27	0	3	1
PA	Schlusser	4,750	6/21/2000	0	0	$0	$0	18	0	0	0
SC	Abbeville	5,840	4/10/2009	2	0	$1,000,000	$1,000,000	32	171	74	1
SC	Aiken	25,337	2/14/2000	0	0	$0	$0	22	0	0	0
SC	Allendale	4,052	3/15/2008	2	0	$2,000,000	$2,000,000	36	494	132	1
SC	Awendaw	1,195	6/13/2006	0	0	$1,000	$1,070	26	1	5	1
SC	Aynor	587	3/15/2008	0	0	$0	$0	27	0	0	0
SC	Beaufort	12,950	6/12/2001	0	0	$0	$0	19	0	0	0
SC	Bishopville	3,670	9/27/2004	0	0	$0	$0	34	0	0	0
SC	Charleston	96,650	4/8/2006	0	0	$0	$0	22	0	0	0
SC	Charleston	96,650	4/8/2006	0	0	$0	$0	22	0	0	0
SC	Cheraw	5,524	9/7/2004	1	0	$0	$0	33	0	0	0
SC	Clemson	11,939	8/26/2008	1	0	$0	$0	21	0	0	0

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
SC	Columbia	116,278	9/7/2004	0	0	$0	$0	22	0	0	0
SC	Conway	11,788	8/12/2004	0	0	$0	$0	27	0	0	0
SC	Denmark	3,328	3/15/2008	1	0	$0	$0	35	0	0	0
SC	Ehrhardt	614	9/7/2004	0	0	$0	$0	30	0	0	0
SC	Florence	30,248	5/14/2006	2	0	$1,300,000	$1,391,000	26	46	35	1
SC	Greenwood	22,071	4/10/2009	1	0	$200,000	$200,000	32	9	17	1
SC	Greenwood	22,071	4/10/2009	1	0	$300,000	$300,000	32	14	21	1
SC	Hampton	2,837	6/12/2001	1	0	$0	$0	28	0	0	0
SC	Hampton	2,837	7/1/2003	1	0	$0	$0	28	0	0	0
SC	Hanahan	12,937	9/28/2002	0	0	$0	$0	18	0	0	0
SC	Hanahan	12,937	6/27/2009	0	0	$150,000	$150,000	18	12	15	1
SC	Hardeeville	1,793	9/6/2004	1	0	$0	$0	32	0	0	0
SC	Laurens	9,916	1/13/2005	2	0	$2,000,000	$2,180,000	32	220	84	1
SC	Meggett	1,230	4/8/2006	1	0	$0	$0	17	0	0	0
SC	New Ellenton	2,250	3/4/2008	0	0	$0	$0	25	0	0	0
SC	North Augusta	17,574	9/25/2000	0	0	$0	$0	22	0	0	0
SC	Parris Island	4,841	6/12/2001	0	0	$0	$0	16	0	0	0
SC	Parris Island	4,841	6/15/2004	0	0	$0	$0	16	0	0	0
SC	Piedmont	4,684	11/11/2002	0	0	$0	$0	25	0	0	0
SC	Ravenel	2,214	5/14/2006	1	0	$0	$0	26	0	0	0
SC	Rembert	406	3/16/2000	0	0	$0	$0	34	0	0	0
SC	Simpsonville	14,352	11/11/2002	1	0	$250,000	$297,500	20	21	20	1
SC	Society Hill	700	9/7/2004	0	0	$10,000	$11,300	30	16	22	1
SC	Summerville	27,752	5/6/2003	1	0	$0	$0	22	0	0	0
SC	Sumter	39,643	9/7/2004	1	0	$0	$0	27	0	0	0
SC	Sumter	39,643	9/7/2004	2	0	$1,700,000	$1,921,000	27	48	36	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
SC	Tega Cay	4,044	9/7/2004	1	0	$5,000	$5,650	13	1	4	1
SC	Willington	177	11/11/2002	0	0	$0	$0	27	0	0	0
SC	Willington	177	3/15/2008	1	0	$0	$0	27	0	0	0
SD	Baltic	811	6/5/2008	2	0	$0	$0	20	0	0	0
SD	Bridgewater	607	9/16/2006	2	0	$0	$0	28	0	0	0
SD	Brookings	18,504	9/16/2006	0	0	$0	$0	21	0	0	0
SD	Herrick	105	8/9/2002	2	0	$1,000,000	$1,190,000	29	11333	578	3
SD	Parker	1,031	6/24/2003	2	0	$3,000,000	$3,510,000	25	3404	292	2
SD	Tripp	711	5/5/2007	0	0	$0	$0	32	0	0	0
SD	Viborg	832	6/24/2003	0	0	$0	$0	25	0	0	0
SD	Viborg	832	6/24/2009	1	0	$1,000,000	$1,170,000	25	1406	188	2
TN	Alcoa	7,734	6/2/2001	0	0	$200,000	$244,000	24	32	28	1
TN	Bartlett	40,543	6/12/2009	1	0	$25,000	$25,000	16	1	3	1
TN	Bradford	1,113	4/2/2006	3	6	$25,000,000	$68,750,000	27	61770	1301	4
TN	Brownsville	10,748	4/2/2006	2	0	$400,000	$428,000	32	40	36	1
TN	Clarksville	103,455	11/15/2005	2	0	$0	$0	24	0	0	0
TN	Clarksville	103,455	5/2/2008	1	0	$500,000	$500,000	24	5	11	1
TN	Collinwood	1,024	11/15/2005	2	0	$100,000	$109,000	29	106	55	1
TN	Cookeville	23,923	3/19/2003	1	1	$100,000	$7,117,000	23	298	83	1
TN	Crab Orchard	838	11/10/2002	1	0	$0	$0	27	0	0	0
TN	Crossville	8,981	4/7/2006	1	0	$4,000,000	$4,280,000	28	477	115	1
TN	Dyersburg	17,452	5/4/2003	0	0	$10,000	$11,700	29	1	4	1
TN	Dyersburg	17,452	5/4/2003	1	0	$1,000,000	$1,130,000	29	65	43	1
TN	Dyersburg	17,452	10/18/2004	2	0	$50,000,000	$58,500,000	29	3352	312	2
TN	Eastview	618	2/5/2008	1	0	$250,000	$250,000	26	405	110	1
TN	Fayetteville	6,994	10/9/2009	1	0	$30,000	$30,000	30	4	11	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
TN	Gallatin	23,230	4/7/2006	3	7	$69,000,000	$122,830,000	25	5288	365	2
TN	Goodlettsville	13,780	4/7/2006	3	0	$10,000,000	$10,700,000	20	776	124	1
TN	Jackson	59,643	11/10/2002	1	0	$50,000	$53,500	26	1	5	1
TN	Jackson	59,643	5/4/2003	1	0	$3,000,000	$3,570,000	26	60	39	1
TN	Jackson	59,643	9/22/2006	4	11	$30,000,000	$100,000,000	26	1677	209	2
TN	Jackson	59,643	2/5/2008	4	0	$100,000,000	$112,100,000	26	1880	221	2
TN	Kimball	1,312	11/14/2007	2	0	$2,500,000	$2,600,000	22	1982	207	2
TN	Lake Tansi	2,621	11/10/2002	3	4	$500,000	$28,595,000	27	10910	547	3
TN	Lynchburg	5,740	5/31/2004	1	0	$0	$0	21	0	0	0
TN	Lynchburg	5,740	8/20/2004	0	0	$0	$0	21	0	0	0
TN	Memphis	650,100	2/5/2008	2	3	$100,000,000	$121,000,000	28	186	72	1
TN	Mount Juliet	12,366	5/11/2003	1	0	$500,000	$585,000	16	47	28	1
TN	Murfreesboro	68,816	3/28/2009	1	0	$4,000,000	$4,000,000	21	58	35	1
TN	Murfreesboro	68,816	4/10/2009	4	2	$40,200,000	$54,200,000	21	788	129	1
TN	Nashville	545,524	2/13/2000	0	0	$0	$0	22	0	0	0
TN	Nashville	545,524	4/20/2000	1	0	$20,000	$24,800	22	0	1	1
TN	Nashville	545,524	5/26/2000	1	0	$100,000	$100,000	22	0	2	1
TN	Nashville	545,524	5/11/2003	1	0	$500,000	$500,000	22	1	4	1
TN	Nashville	545,524	4/2/2009	1	0	$500,000	$585,000	22	1	5	1
TN	Nashville	545,524	10/9/2009	1	0	$500,000	$620,000	22	1	5	1
TN	New Tazewell	2,871	4/3/2007	1	0	$425,000	$442,000	30	154	68	1
TN	New Tazewell	2,871	4/26/2007	1	0	$1,200,000	$1,248,000	30	435	115	1
TN	Newbern	2,988	5/4/2003	1	0	$25,000	$29,250	29	10	17	1
TN	Newbern	2,988	4/2/2006	3	16	$20,000,000	$133,400,000	29	44645	1141	4
TN	Paris	9,763	10/18/2004	1	0	$800,000	$936,000	32	96	56	1
TN	Paris	9,763	11/15/2005	2	0	$6,500,000	$7,085,000	32	726	153	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
TN	Ramer	354	5/31/2001	1	0	$100,000	$122,000	27	345	96	1
TN	Rutherford	1,272	4/2/2006	3	2	$15,000,000	$30,050,000	30	23624	843	4
TN	Sardis	445	4/7/2006	1	0	$40,000	$42,800	26	96	50	1
TN	Spencer	1,713	11/10/2002	2	0	$75,000	$89,250	30	52	39	1
TN	Springfield	14,329	5/4/2003	1	0	$3,200,000	$3,744,000	27	261	84	1
TN	Tracy City	1,679	5/30/2004	1	0	$30,000	$33,900	28	20	24	1
TN	Trenton	4,683	5/8/2003	1	0	$25,000	$29,250	30	6	14	1
TN	Walterhill	1,523	5/11/2003	3	0	$1,800,000	$2,106,000	17	1383	153	1
TX	Allen	43,554	4/10/2008	1	0	$10,000,000	$10,000,000	15	230	58	1
TX	Amarillo	173,627	10/23/2000	0	0	$15,000	$18,600	26	0	2	1
TX	Aransas Pass	8,138	9/29/2007	1	0	$250,000	$260,000	32	32	32	1
TX	Arlington	332,969	3/28/2000	0	0	$100,000	$104,000	21	0	3	1
TX	Arlington	332,969	4/3/2007	3	4	$500,000,000	$648,000,000	21	1946	202	2
TX	Austin	656,562	11/15/2001	0	0	$15,000	$18,300	20	0	1	1
TX	Austin	656,562	11/15/2001	0	0	$30,000	$36,600	20	0	1	1
TX	Austin	656,562	11/15/2001	1	0	$80,000	$97,600	20	0	2	1
TX	Austin	656,562	11/15/2001	1	0	$100,000	$122,000	20	0	2	1
TX	Beaumont	113,866	10/13/2001	1	0	$1,000,000	$1,220,000	28	11	17	1
TX	Beaumont	113,866	8/18/2009	1	0	$20,000,000	$20,000,000	28	176	70	1
TX	Belton	14,623	4/25/2008	0	0	$0	$0	28	0	0	0
TX	Benbrook	20,208	4/13/2007	0	0	$150,000	$156,000	19	8	12	1
TX	Brady	5,523	5/14/2008	0	0	$250,000	$250,000	36	45	40	1
TX	Bryan	65,660	10/12/2001	1	0	$60,000	$73,200	28	1	6	1
TX	Cactus	2,538	4/21/2007	2	0	$1,400,000	$1,456,000	31	574	134	1
TX	Canton	3,292	4/29/2006	0	0	$10,000	$10,700	28	3	10	1
TX	Canton	3,292	5/2/2008	1	0	$300,000	$300,000	28	91	50	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
TX	College Station	67,890	6/13/2003	0	0	$1,000	$1,170	23	0	1	1
TX	Colleyville	19,636	2/10/2009	1	0	$750,000	$750,000	12	38	21	1
TX	Colorado City	4,281	9/25/2003	1	0	$250,000	$292,500	35	68	49	1
TX	Cool	162	6/12/2009	0	0	$0	$0	27	0	0	0
TX	Copperas Cove	29,592	6/17/2007	0	0	$100,000	$104,000	26	4	9	1
TX	Corpus Christi	277,454	10/24/2002	0	0	$50,000	$50,000	26	0	2	1
TX	Corpus Christi	277,454	3/18/2008	1	1	$85,000,000	$108,150,000	26	390	101	1
TX	Corsicana	24,485	4/27/2009	1	0	$100,000	$100,000	31	4	11	1
TX	Cross Roads	603	4/24/2007	0	0	$40,000	$41,600	13	69	30	1
TX	Crowell	1,141	4/30/2000	0	0	$0	$0	35	0	0	0
TX	Dallas	1,188,580	4/13/2007	0	0	$50,000	$52,000	24	0	1	1
TX	Dayton	5,709	10/12/2001	0	0	$40,000	$48,800	27	9	15	1
TX	Del Rio	33,867	5/27/2004	0	0	$0	$0	32	0	0	0
TX	Del Rio	33,867	4/23/2007	0	0	$0	$0	32	0	0	0
TX	Denison	22,773	12/8/2008	2	0	$750,000	$750,000	29	33	31	1
TX	DeSoto	37,646	4/10/2008	0	0	$1,000,000	$1,000,000	21	27	23	1
TX	Detroit	776	6/10/2009	0	0	$0	$0	34	0	0	0
TX	Douglassville	175	4/23/2000	2	0	$0	$0	22	0	0	0
TX	Elbert	56	4/30/2000	1	0	$200,000	$248,000	22	4429	309	2
TX	Flower Mound	50,702	4/24/2007	1	0	$100,000	$104,000	14	2	5	1
TX	Galveston	57,247	7/5/2007	0	0	$30,000	$31,200	28	1	4	1
TX	Galveston	57,247	8/30/2009	1	0	$500,000	$500,000	28	9	16	1
TX	Grand Prairie	127,427	3/28/2000	3	0	$0	$0	23	0	0	0
TX	Greenville	23,960	5/2/2009	0	0	$0	$0	27	0	0	0
TX	Harper	1,006	5/1/2007	0	0	$0	$0	28	0	0	0
TX	Haslet	1,134	4/17/2007	0	0	$15,000	$15,600	12	14	13	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
TX	Hico	1,341	3/30/2002	0	0	$75,000	$89,250	32	67	46	1
TX	Hitchcock	6,386	4/18/2009	0	0	$50,000	$50,000	31	8	16	1
TX	Hondo	7,897	10/12/2001	2	0	$20,000,000	$24,400,000	29	3090	300	2
TX	Houston	1,953,631	6/21/2008	0	0	$110,000	$110,000	25	0	1	1
TX	Johnson City	1,191	11/16/2004	0	0	$0	$0	27	0	0	0
TX	Killeen	86,911	5/25/2007	1	0	$50,000	$52,000	27	1	4	1
TX	Laguna Heights	1,990	11/7/2008	0	0	$0	$0	35	0	0	0
TX	Laughlin AFB	2,225	5/27/2004	0	0	$0	$0	22	0	0	0
TX	Leary	555	4/10/2008	2	0	$1,000,000	$1,000,000	28	1802	224	2
TX	Lewisville	77,737	6/10/2009	1	0	$200,000	$200,000	19	3	7	1
TX	Lubbock	199,564	5/29/2006	0	0	$0	$0	27	0	0	0
TX	Lubbock	199,564	4/17/2007	0	0	$0	$0	27	0	0	0
TX	Lubbock	199,564	5/14/2008	0	0	$75,000	$78,000	27	0	3	1
TX	Lubbock	199,564	8/26/2009	0	0	$100,000	$100,000	27	1	4	1
TX	Lufkin	32,709	12/23/2009	3	0	$10,000,000	$10,000,000	29	306	94	1
TX	Lumberton	8,731	10/28/2002	1	0	$100,000	$119,000	20	14	16	1
TX	McGregor	4,727	3/30/2007	0	0	$50,000	$52,000	31	11	18	1
TX	McGregor	4,727	6/25/2007	1	0	$500,000	$520,000	31	110	58	1
TX	McKinney	54,369	4/10/2008	1	0	$2,000,000	$2,000,000	17	37	25	1
TX	New Boston	4,808	5/14/2003	2	0	$0	$0	34	0	0	0
TX	New Boston	4,808	11/29/2009	1	0	$0	$0	34	0	0	0
TX	New Braunfels	36,494	11/15/2001	0	0	$0	$0	24	0	0	0
TX	Perryton	7,774	4/6/2001	1	0	$500,000	$610,000	25	78	45	1
TX	Poynor	314	12/29/2006	1	0	$2,000,000	$2,140,000	25	6815	415	3
TX	San Angelo	88,439	4/9/2008	1	0	$6,000,000	$6,000,000	28	68	43	1
TX	San Antonio	1,144,646	7/15/2007	1	0	$50,000	$52,000	27	0	1	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
TX	San Marcos	34,733	1/13/2007	1	0	$50,000	$52,000	27	2	6	1
TX	Seabrook	9,443	6/3/2009	0	0	$0	$0	15	0	0	0
TX	Shoreacres	1,488	3/30/2002	3	0	$350,000	$416,500	14	280	62	1
TX	Snyder	10,783	4/23/2008	1	0	$20,000	$20,000	31	2	8	1
TX	Stafford	15,681	11/17/2003	2	0	$300,000	$351,000	20	22	21	1
TX	Stephenville	14,921	12/29/2006	0	0	$15,000	$16,050	27	1	5	1
TX	Stonewall	469	10/12/2001	3	0	$1,000,000	$1,220,000	26	2601	259	2
TX	Tulia	5,117	4/21/2007	2	0	$2,000,000	$2,080,000	30	406	111	1
TX	Tuscola	714	3/4/2004	2	0	$800,000	$904,000	23	1266	171	1
TX	Whitesboro	3,760	4/9/2008	0	0	$0	$0	29	0	0	0
TX	Wichita Falls	104,197	4/10/2001	1	0	$150,000	$183,000	26	2	7	1
TX	Winnsboro	3,584	5/14/2008	1	0	$0	$0	28	0	0	0
TX	Wylie	15,132	3/30/2007	0	0	$500,000	$520,000	18	34	25	1
UT	Vernal	7,714	8/6/2009	0	0	$1,000	$1,000	28	0	2	1
UT	Willard	1,630	5/3/2009	0	0	$25,000	$25,000	17	15	16	1
VA	Bedford	6,299	4/28/2002	1	0	$1,000,000	$1,190,000	29	189	75	1
VA	Charlottesville	45,049	5/13/2000	1	0	$0	$0	24	0	0	0
VA	Chesapeake	199,184	5/4/2009	0	0	$10,000	$10,000	19	0	1	1
VA	Chester	17,890	8/30/2004	0	0	$5,000	$5,650	19	0	2	1
VA	Claremont	343	4/28/2008	1	0	$74,000	$74,000	21	216	68	1
VA	Colonial Heights	16,897	4/28/2008	1	0	$2,000,000	$2,000,000	21	118	50	1
VA	Elkton	2,042	8/2/2008	0	0	$0	$0	24	0	0	0
VA	Fredericksburg	19,279	9/17/2004	0	0	$0	$0	22	0	0	0
VA	Front Royal	13,589	9/17/2004	0	0	$0	$0	26	0	0	0
VA	Hurt	1,276	7/17/2009	1	0	$0	$0	25	0	0	0
VA	Laurel	14,875	6/15/2001	0	0	$5,000	$6,100	19	0	3	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
VA	Leesburg	28,311	11/5/2003	0	0	$200,000	$234,000	17	8	12	1
VA	Lovettsville	853	5/25/2004	0	0	$1,000	$1,130	17	1	5	1
VA	Richmond	197,790	9/8/2004	0	0	$5,000	$5,650	26	0	1	1
VA	Roanoke	94,911	6/3/2008	0	0	$350,000	$350,000	28	4	10	1
VA	Stanley	1,326	6/3/2009	1	0	$0	$0	30	0	0	0
VA	Stanleytown	1,515	9/17/2004	2	0	$53,800,000	$60,794,000	25	40128	994	4
VA	Suffolk	63,677	6/1/2001	1	0	$0	$0	22	0	0	0
VA	Verona	3,638	5/9/2003	0	0	$0	$0	21	0	0	0
VA	Virgilina	159	4/28/2008	1	0	$0	$0	24	0	0	0
VA	Warrenton	6,670	5/7/2003	1	0	$12,000	$14,040	21	2	7	1
VA	Winchester	23,585	9/17/2004	2	0	$0	$0	23	0	0	0
WA	Dayton	2,655	1/16/2000	1	0	$100,000	$124,000	29	47	37	1
WI	Clear Lake	1,051	6/11/2005	0	0	$0	$0	25	0	0	0
WI	Fitchburg	20,501	5/30/2003	0	0	$0	$0	16	0	0	0
WI	Fitchburg	20,501	8/18/2005	3	0	$0	$0	16	0	0	0
WI	Fort Atkinson	11,621	8/13/2002	0	0	$5,000	$5,950	21	1	3	1
WI	Fort Atkinson	11,621	8/18/2005	1	0	$355,000	$386,950	21	33	26	1
WI	Gilman	474	9/2/2002	2	0	$3,900,000	$4,641,000	24	9791	489	3
WI	Kenosha	90,352	1/7/2008	0	0	$0	$0	23	0	0	0
WI	Kenosha	90,352	6/19/2009	1	0	$7,900,000	$7,900,000	23	87	45	1
WI	Ladysmith	3,932	9/2/2002	3	0	$25,000,000	$29,750,000	29	7566	471	3
WI	Lake Koshkonong	1,219	8/18/2005	1	0	$30,000	$32,700	14	27	19	1
WI	Madison	208,054	6/23/2004	1	0	$1,500,000	$1,695,000	18	8	12	1
WI	Markesan	1,396	6/23/2004	3	1	$675,000	$7,762,750	21	5561	340	2
WI	Merrimac	416	8/18/2005	0	0	$5,000	$5,450	22	13	17	1
WI	Montello	1,397	6/23/2004	2	0	$1,000,000	$1,130,000	26	809	146	1

State	Community	Population	Date	EFS	Deaths	Damage	Damage Component	Vulnerability Score	Damage Score	TICV	TC
WI	Muscoda	1,453	8/18/2005	1	0	$100,000	$109,000	28	75	46	1
WI	Siren	988	6/18/2001	3	2	$10,000,000	$26,200,000	30	26518	887	4
WI	Spring Green	1,444	8/18/2005	1	0	$7,000	$7,630	19	5	10	1
WI	Stoughton	12,354	8/18/2005	1	1	$409,000	$7,409,000	20	600	110	1
WI	Stoughton	12,354	6/7/2008	3	0	$7,700,000	$8,393,000	20	679	117	1
WI	Verona	7,052	5/30/2003	0	0	$0	$0	15	0	0	0
WI	Viola	667	8/18/2005	2	0	$1,600,000	$1,744,000	29	2615	275	2
WI	Waupun	10,718	6/23/2004	3	0	$3,000,000	$3,390,000	19	316	77	1
WI	Zoar	124	6/7/2007	3	0	$2,700,000	$2,808,000	27	22645	776	4
WY	Antelope Valley-Crestview	1,642	6/12/2001	0	0	$0	$0	14	0	0	0
WY	Laramie	27,204	5/22/2008	2	0	$300,000	$300,000	23	11	16	1
WY	Newcastle	3,065	6/9/2001	0	0	$0	$0	28	0	0	0
WY	Slater	82	5/23/2008	0	0	$0	$0	12	0	0	0
WY	Sleepy Hollow	1,177	6/12/2001	0	0	$0	$0	16	0	0	0

Appendix C - List of Acronyms Used

Table C.1: Acronyms used within this research.

AHP	Analytical Hierarchy Process
AIS	Abbreviated Injury Scale
AQI	Air Quality Index
BMI	Body Mass Index
BTI	Baron Tornado Index
CST	Central Standard Time
CVI	Coastal Vulnerability Index
DI[19]	Damage Indicator
	Damage Index
DII	Disaster Impact Index
DOD	Degrees of Damage
DPI	Damage Potential Index
DRI	Disaster Risk Index
EFS	Enhanced Fujita scale
EM-DAT	Emergency Events Database
ESI	Environmental Sustainability Index
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GIS	Geographic Information System
HAZUS-MH	Hazards United States-Multi-Hazard

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[19] The acronym DI is used to refer to “Damage Indicators” in reference to the Enhanced Fujita Scale (e.g., Wind 2004; Potter 2007, Table 2.1) as well as the “Disaster Index” of Gardoni and Murphy (2010) (Equation 2.3). Usage and reference is obvious within the text.

HP	Hazards-of-Place Model
HVI	Hurricane Vulnerability Index
IESI	Influenza Epidemic Severity Index
II	Indicator Index
LEED	Leadership in Energy and Environmental Design
M_L	Richter Scale
MMS or M_W	Moment Magnitude scale
NCDC	National Climatic Data Center
NESIS	Northeast Snowfall Impact Scale
NEXRAD	Next Generation Radar
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
O Scale	Outbreak Scale
OIS	Organ Injury Scale
OSVI	Oil Spill Vulnerability Index
PAR	Pressure and Release Model
PCA	Principal Components Analysis
PSI	Pollution Standards Index
ReSIS	Regional Snowfall Impact Scale
RH	Risk-Hazard Model
SEIM	Soil Erosion Index Model
SOFA	Statistics Open for All
SoVI	Social Vulnerability Index
SPC	Storm Prediction Center
SPSS	Statistical Program for the Social Sciences
TC	Tornado Impact-Community Vulnerability Index Categories

TICV	Tornado Impact-Community Vulnerability Index
UN/ISDR	United Nations International Strategy for Disaster Reduction
UNDP	United Nations Development Programme
USD	United States Dollars
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USTOR2000	United States Tornadoes, 2000-2009
UTM	Universal Transverse Mercator
VOL	Value of Life
VSL	Value per Statistical Life
WPI	Water Poverty Index