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A PLACE VULNERABILITY ANALYSIS OF CHANGING FLOOD RISK IN GRAND FORKS, NORTH DAKOTA: 1990-2010

by

Melissa Marianne Wygant
Bachelor of Arts, Gustavus Adolphus College, 2012

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota
August
2014

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This thesis, submitted by Melissa M. Wygant in partial fulfillment of the requirements of the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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PERMISSION

Title: A Place Vulnerability Analysis of Changing Flood Risk in Grand Forks, North Dakota: 1990-2010

Department: Geography

Degree: Master of Science

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Melissa Marianne Wygant

July 9, 2014

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LIST OF ACRONYMS

Acronym	Definition
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Maps
GIS	Geographic Information System
NFIP	National Flood Insurance Program
SoVI	Social Vulnerability Index
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

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“Strength: A river cuts through a rock not because of its power but because of its persistence”.

To all those who have lost their life or home to flooding.

ABSTRACT

Floods are the most common natural hazard in the U.S.; each year they leave communities in destruction and despair. Despite the efforts of emergency managers, local government officials, and scientists, flood damages in the U.S. have increased significantly over the past 100 years. It is increasingly important to evaluate a community's risk and vulnerability to flooding in order to develop efficient emergency operation plans, and to improve upon flood management practices.

Communities in the Red River Valley of North Dakota have dealt with flood hazards for a very long time. In particular, Grand Forks, North Dakota, Fargo, North Dakota, Moorhead, Minnesota, and East Grand Forks, Minnesota have experienced extensive flooding for more than 100 years. The Grand Forks community experienced one of the worst floods in the Red River Valley in the spring of 1997. The purpose of this study is to evaluate flood risk and vulnerability at Grand Forks from 1990-2010 prior to and following completion of the $420 million levee system constructed by the U.S. Army Corps of Engineers. This study identifies the extent to which flood risk has actually been reduced over time. A place vulnerability approach is used as the organizing framework to provide a quantitative spatial assessment of flood risk. To date, few research studies have examined place vulnerability for non-coastal communities and for flood hazard applications. Existing place vulnerability studies have also been static and not considered changes in vulnerability over time. This study aims to fill multiple gaps in the literature by providing a quantitative and dynamic analysis of flood hazard risk and vulnerability over time in a community that has experienced catastrophic loss to flooding in the past.

Results show that there has been an increase in place vulnerability of flood risk from 1990-2000 but a slight decrease from 2000-2010. This suggests that various structural and non-structural strategies have been helpful in reducing flood hazards. However, there continues to be residual risk, and areas throughout Grand Forks are still at risk from flooding. As Grand Forks increases in population in the coming years, various social factors could increase social vulnerability and place vulnerability.

CHAPTER I

INTRODUCTION

1.1 Problem Statement

Flooding is the most common and pervasive natural hazard in the U.S., causing extensive damage and economic loss annually. In particular, flood damages in the U.S. have increased significantly over the years placing millions of individuals and billions of dollars in capital investment at risk from flood waters (Burby 2001; James and Korom 2001; Larson and Plasencia 2001; Galloway 2005; Brody et al. 2011; Kousky 2011; Highfield et al. 2013). Economic losses related to flooding continue to rise in the U.S. (Figure 1). There appears to be no end to the trend of rising economic loss even though there has been extensive national efforts towards flood mitigation, structural advancement, as well as continual improvement in floodplain management (James and Korom 2001; Fraser et al. 2006; Brody et al. 2011; Kousky 2011).

In classical natural hazard research there is a twofold juxtaposition of nature and society. On one side natural events such as river discharge provide crucial resources for human use. On the other hand, natural events create hazards that can lead to property damage and loss of life. As seen in Figure 2, the classic theory begins with an initial natural hazard which triggers response. The response then triggers both human use systems as well as natural event systems. Examples of human use systems include: allocation of resources, improving well-being, as well as social organization. In contrast, natural event systems are modified after a hazardous event, often through anthropogenic means, including manipulating various meteorological and

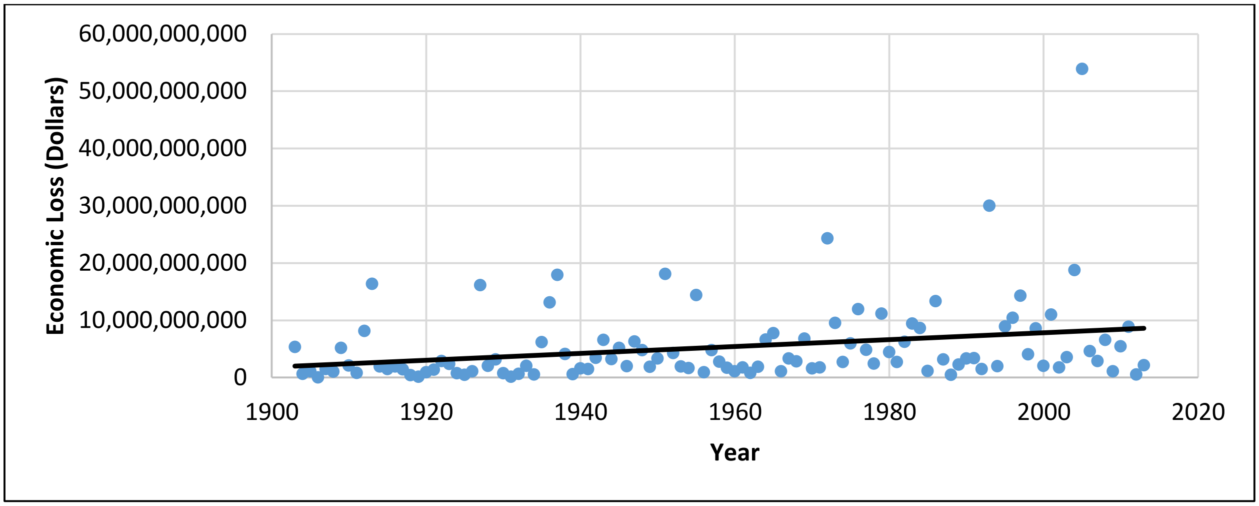

Figure 1: Flood Losses in the U.S. (1903-2013), courtesy of the National Oceanic and Atmospheric Administration's National Weather Service. Values adjusted to 2013 inflation.

geomorphic processes. The final step in the classic theory is resources, which is quite a natural progression. There is always more research and resources allocated to communities once it has been impacted by a catastrophe (Burton et al. 1978). It is evident that the process is iterative and continues to perpetuate on-going loss of life and property as a result of hazardous events.

The classical natural hazard theory is easily applicable to flood hazards and explains one of the reasons why communities throughout the U.S. cannot seem to get out of the continuous cycle of flood damages and economic losses. It is clearly evident that once a flood hazard occurs several federal agencies come to the aid of disaster victims. In some instances aid is provided for temporary measures whereas other forms of aid help disaster victims in the long-term. In addition, various mitigation measures are implemented and can perpetuate this iterative cycle. For example, when the U.S. Army Corps of Engineers (USACE) manipulates a river channel it drastically changes the flow and in some instances creates negative consequences such as increases in flooding and flood loss. It is a never ending battle from which the American population and policy-makers never seem to be able to get out of. It is clearly evident that

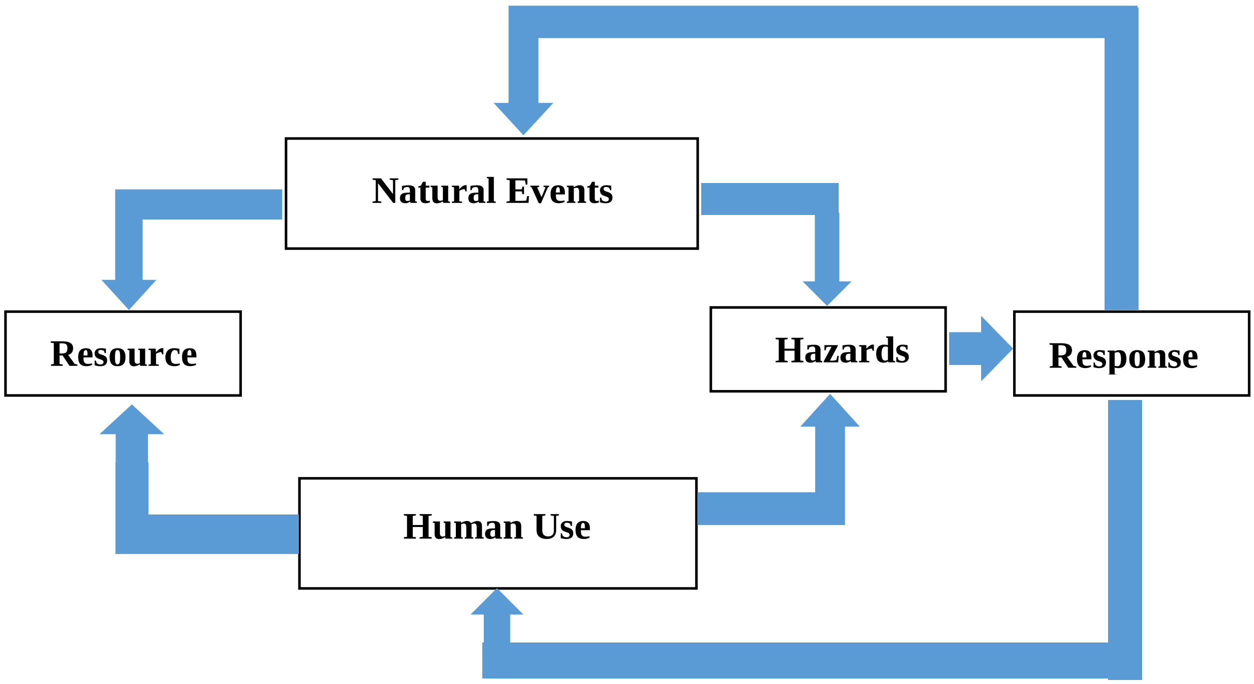

Figure 2: Resources and hazards from nature and man (Burton et al. 1978).

flood loss will continue to rise in the coming years if drastic changes do not occur and this cyclical pattern is not changed. Often the cycle cannot be broken because of political affairs, monetary issues, and local failures such as failures in structural solutions (Pinter 2005). Also, while there is extensive effort and strict guidelines for development within the 100-year floodplain, there continues to be less regulation of development in the rest of the floodplain (Pinter 2005). Thus, any significant progress through mitigation strategies is obsolete or insufficient.

Communities along the Red River Valley of North Dakota and Minnesota have an extensive history of flooding and flood losses. In particular, the Grand Forks and Fargo, North

Dakota, and East Grand Forks and Moorhead, Minnesota metropolitan areas have experienced severe flooding over the past 100 years (Todhunter 1998; LeFever et al. 1999). The Grand Forks Flood of 1997 was one of the single most devastating flood disasters in U.S. history (Todhunter 1998, 2001; James and Korom 2001). The Fargo-Moorhead metropolitan area narrowly escaped similar catastrophic flood damages on multiple occasions during the 2000s. Reducing the probability of a recurrence of a flood disaster similar to the 1997 flood in Grand Forks is crucial to maintaining the sustainability of a major metropolitan area.

This study focuses on flood hazard risk and vulnerability in Grand Forks from 1990-2010, and evaluates if flood risk has decreased over time. Specifically, this study provides a dynamic interpretation of flood risk and vulnerability rather than a static depiction, by evaluating flood risk and vulnerability over a 20-year period. A place vulnerability conceptual model is used as the organizing framework to provide a quantitative spatial assessment of flood risk. Aerial interpolation is applied to produce quantitative estimates of how many individuals have been and continue to be at risk to flooding in Grand Forks. The study provides a quantitative and spatially explicit assessment of flood risk in the Grand Forks area during three critical time periods: (1) floodplain development prior to the 1997 flood; (2) floodplain settlement after the 1997 flood but before USACE certification of the levee system in 2010; and (3) floodplain encroachment following USACE certification of the levee system in 2010. These critical time periods provide an overview of how flood mitigation has changed throughout the years for the City of Grand Forks and the implications it has had for the population and economic development.

There are relatively few studies that assess place vulnerability in a non-coastal community, and very few studies that evaluate flood risk over time for a city that is under

100,000 in population. Thus, this study is timely and provides a template for future place vulnerability studies in smaller urban settings. This study also provides critical information for local emergency managers, government officials, and citizens within the Grand Forks community. More specifically, this study provides critical flood risk and vulnerability information that the City of Grand Forks is lacking. In addition, this analyzes place vulnerability over an extended period of time, providing a dynamic interpretation. This is a unique contribution in place vulnerability studies, and is crucial since risk and vulnerability studies can prove to be a resourceful and interactive tool for emergency responders.

The objectives for this study are the following: (1) Develop geo-referenced maps of floodplain settlement in Grand Forks at the time of the 1997 flood, focusing on the 100-year and 500-year floodplains based on the 1990 Decennial Census; (2) Develop geo-referenced maps of floodplain settlement in Grand Forks after the 1997 flood, buyouts by FEMA, and prior to the certification of the levee system, focusing on the 100-year and 500-year floodplains based on the 2000 Decennial Census; (3) Develop geo-referenced maps of floodplain settlement in Grand Forks following the USACE certification of the levee system based on the 2010 Decennial Census; (4) Quantify and map social vulnerability at the Census block group level for three U.S. Census periods:1990, 2000, and 2010; (5) Use a geographic information system (GIS) to quantify and map place vulnerability in Grand Forks for three distinct years: 1990, 2000, and 2010; (6) Use areal interpolation to determine the number of individuals residing within the 100-year and 500-year floodplains in 1990, 2000, and 2010; (7) Identify the extent to which biophysical vulnerability, social vulnerability, and place vulnerability have changed in Grand Forks over the 20-year study period; and (8) Provide an objective and spatially-based evaluation of how flood risk changed following the 1997 flood disaster.

CHAPTER II

STUDY AREA

The study area is the City of Grand Forks, North Dakota, situated in the northern portion of the Red River Basin (Figure 3). Grand Forks is a thriving community and an integral part of the economic livelihood of North Dakota. The city is located in northeastern North Dakota, within the Red River Basin (Coulter 1910). This basin covers over 45,000 square miles (Rogers et al. 2013). The Red River of the North flows north from headwaters located near Wahpeton, North Dakota. Here, the confluence of the Bois de Sioux and the Ottertail River form one of the longest rivers in North America (Stoner et al. 1993; Rogers et al. 2013). From Wahpeton, the Red River of the North flows northward along the borders of Minnesota and North Dakota, and enters Manitoba, Canada (Stoner et al. 1993; James and Korom 2001; Todhunter 2001; Simonovic and Carson 2003; Rogers et al. 2013). The mouth of the river is situated north of Winnipeg, Manitoba. In Winnipeg it is joined by the Assiniboine River and continues to flow into Lake Winnipeg. From Lake Winnipeg, it flows to the Nelson River and eventually into Hudson Bay (Coulter 1910). The path of the Red River of the North impacts several rural farming communities, as well as several metropolitan areas such as: Fargo, Grand Forks, East Grand Forks, and Moorhead.

The Red River of the North is a shallow, meandering river, with a narrow channel (Stoner et al. 1993; Simonovic and Carson 2003; Todhunter 2011; Rogers et al. 2013). The topography in the Red River Valley has a very low channel gradient and there is very little topographic relief (Coulter 1910; Todhunter 2011). This is a result of past glacial and fluvial processes. Specifically, Grand Forks is located within the Red River Valley that used to be part of Glacial Lake Agassiz (Coulter 1910; Stoner et al. 1993; Todhunter 2001; Schwert 2011; Todhunter 2011; Rogers et al. 2013). Given its geomorphic, hydrologic, and hydroclimatic characteristics, the Red River of the North experiences annual flood risk resulting from spring snowmelt or summer heavy precipitation events (Stoner et al. 1993; Todhunter 2011).

The climate of Grand Forks is continental, with cold winters and warm summers. The city is classified within the subhumid climate scheme and experiences a variety of air masses, causing drastic changes in the weather (Stoner et al. 1993). During the spring and summer months warm, moist air progresses from the Gulf of Mexico, bringing instability, opportunity for severe weather and humid conditions. Also, the “climate of [Grand Forks] is a primary factor causing a diverse hydrologic regime for streams and surficial aquifers” (Stoner et al. 1993). Precipitation varies within the region, thus, Grand Forks experiences wet cycles and dry cycles. During a wet cycle, flooding is especially problematic for the area and can result in extensive drainage issues within farm fields in the basin (Stoner et al. 1993).

Historically, the Red River has been an avenue for fur trade and recreation (Todhunter 2001). From the mid-1800s through the early 1990s, the river was used for barge traffic as well as steamboat travel. The river allowed for easy access to other waterways and a majority of Grand Forks’s factories were built near the river for easy transportation access. During the 19th Century, the Red River Valley was a prime destination for farm settlement by immigrants. The region is known for its nutrient-rich soils, which provide exceptional conditions for crop growth (Stoner et al. 1993; James and Korom 2001). In previous years, the primary crops grown were wheat, barley, oats, sugar beets, and potatoes (Stoner et al. 1993). Today, the area continues to be a leader in crop production and with intensive sugar beet cultivation, while soybeans and corn have also gained popularity. The growth of Grand Forks can be attributed to its strategic proximity to the Red River, industrial business, and agricultural benefits. Grand Forks was chosen for this study because of its historical occurrence of catastrophic flooding, continued urban development, and increase in population over the past 20 years.

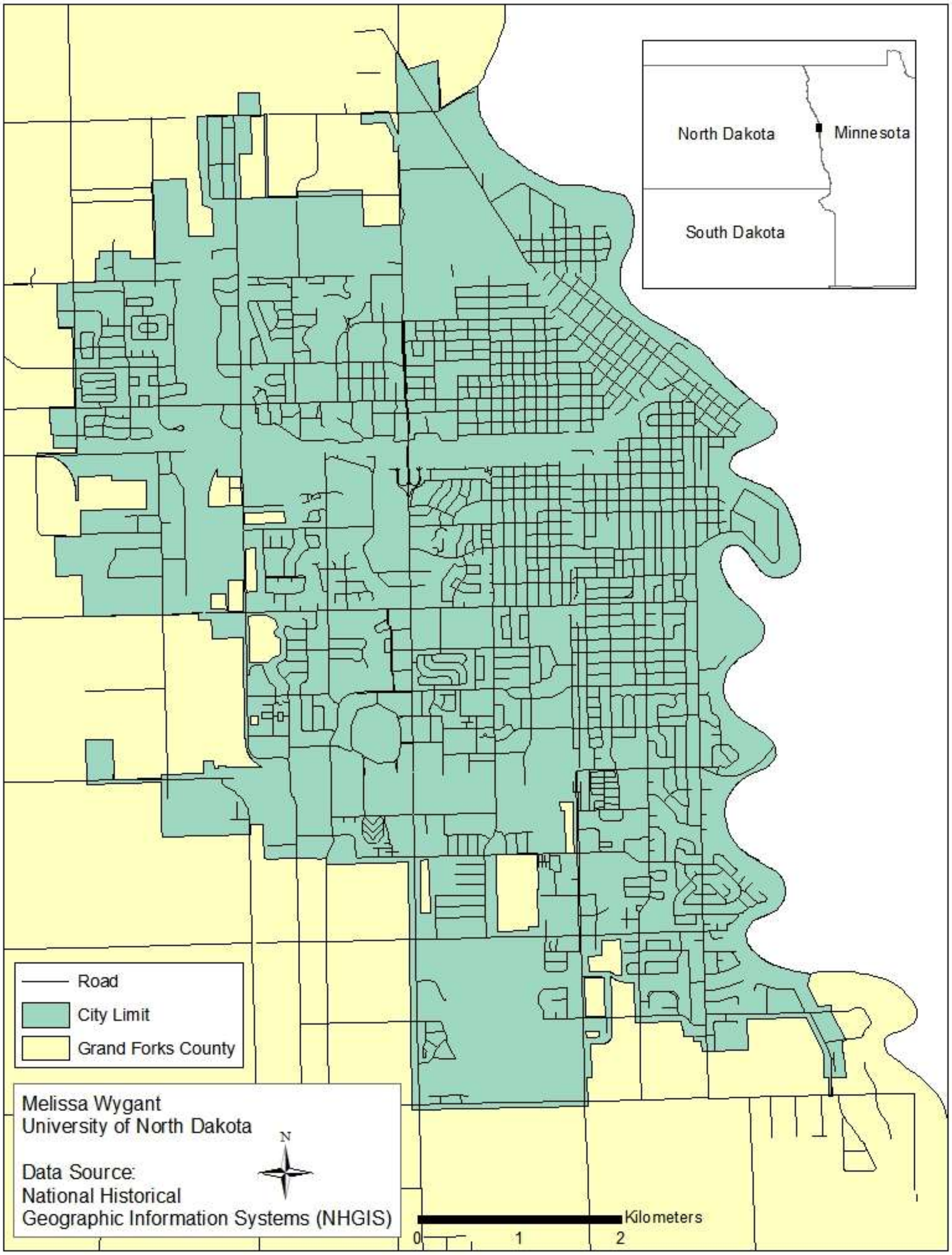

Figure 3: Base map of Grand Forks, North Dakota.

CHAPTER III

LITERATURE REVIEW

3.1 Flood Hazards

Flooding throughout the U.S. can be attributed to a variety of types of weather, failure mechanisms, and anthropogenic factors. Each factor can drastically increase the risk of flooding and alter land-use hydrology (Ntelekos et al. 2010; Brody et al. 2011). In some instances, flooding is an annual occurrence for communities as a result of snowmelt or excessive amounts of rainfall that allows adequate time for preparedness and mitigation (James and Korom 2001). In other communities, flash flooding occurs with little advanced warning as a result of convective thunderstorms. In some instances, dam failure can occur with little advance warning and produce extraordinary flooding depending on the type and duration of failure mechanisms. Various environmental characteristics can also influence flooding. The first factor is the actual basin area, which impacts the discharge. Discharge is the rate of water flow at a given location along a river. If a drainage basin has a large area, there is an increase in discharge and a higher likelihood for flooding. The second factor influencing flooding is the basin shape, which influences peak flow rates. The third factor is topography, mainly concentrating on slope and the amount of water that is stored within the given body of water. Slopes that have a steep gradient often experience an increase in rainfall and peak discharge, as well as increased annual volume flow (Brody et al. 2011). Also, there are four distinct precipitation characteristics that impact flood potential: intensity, depth, duration, as well as spatial distribution (Brody et al. 2011).

Changes in flood risk and vulnerability can also be attributed to climate change, which directly impacts the severity of flood frequency and magnitude (Larson and Plasencia 2001; Olsen 2006; Ntelekos et al. 2010). Over time, there is the likelihood that flood frequency and magnitude will continue to increase in some locations (Pielke and Downton 2000; Burby 2001). Thus placing more individuals at risk for flood hazards. Increases in rainfall intensity and the probability of flooding are also possible and problematic (Galloway 2005; Olsen 2006). In contrast, as climate change progresses, some locations may experience less frequent rainfall events but during those instances when it rains, the magnitude will be of greater intensity (Olsen 2006; Ntelekos et al. 2010).

In addition to environmental implications, flood hazards can also be attributed to continued human encroachment on floodplains and coastal environments (Todhunter 1998; Burby 2001; Larson and Plasencia 2001; Galloway 2005). Urban environments contribute to this factor due to extensive alterations of the landscape; this includes increases in impervious landscapes and a reduction in vegetation (Black 2012). There are several downfalls to increased impervious surfaces, for instance it can increase flood intensity, decrease infiltration rates, and increase runoff (Brody et al. 2011). Land-use development drastically changes the characteristics of a given floodplain, including alterations to runoff, magnitude of flooding, as well as flood damages (Black 2012; Brody et al. 2011). Whether due to anthropogenic effects or natural processes, it appears as though flood hazards will continue to occur and affect the U.S. population in the future.

3.2 Flood Mitigation in the United States

Historically, natural hazard research has been addressed through a variety of paradigms and disciplines, both in professional and academic settings. It is an emerging field of research since natural hazards continue to occur throughout the world, placing more individuals in vulnerable environments, and limiting economic development. Natural hazard research has become a dynamic discipline that is relevant to numerous fields.

Flood hazards in the U.S. have been addressed through three different paradigms: the engineering, behavioral (non-structural), and the no adverse impact paradigms (Pielke 1999; Brody et al. 2011; Smith and Petley 2009). Each paradigm has changed floodplain management and aims to improve upon preparedness, mitigation, response, as well as recovery strategies. More specifically, each paradigm has continued to improve upon research and to determine effective and efficient ways to reduce the loss of life and property, whether from a hydrological, geographic, or a meteorological standpoint.

The first paradigm, the engineering paradigm, emphasizes human control over natural processes through the development of flow control structures that attempt to control the flow of flood waters. This paradigm focuses on viewing flood hazards as a result of geophysical events rather than as a result of anthropogenic contributions to altered landscapes or meteorological changes (Smith and Petley 2009). Examples of engineered solutions include: levees, channels, dikes, and flood control dams. Structural mitigation has been preferred by residents and government officials throughout the U.S. over the years, and continues to be a predominant solution in water resource management (Brody et al. 2011).

Engineered methods have been extensively applied throughout the U.S. and were especially prominent during the early 20th Century (Tobin 1995; Smith and Petley 2009). In fact, the roots of the engineering paradigm can be traced back to 1927 when the banks of the Mississippi River were engulfed, and communities throughout the Great Plains and Southern U.S. were flooded (Brody et al. 2011). During this time citizens and government officials pushed for structural solutions to combat current and future catastrophic flooding. At this time, engineering solutions provided a sense of security and reduction in the frequency of catastrophic events. Even to this day, structural solutions are the backbone of national flood mitigation efforts.

In addition, the foundation of floodplain management and water resource public policy was introduced during the late 1930s. During this time period that political figures pushed for federal regulations and construction of structural solutions. Specifically, the initial creation of flood policy was established during this time period, which was a result of catastrophic flooding along the Ohio River (Ntelekos et al. 2010; Black 2012). In 1936, the Flood Control Act was passed by the U.S. Congress, addressing the need for structural solutions to flooding and policy change related to water resource management (Galloway 2005; Ntelekos et al. 2010; Brody et al. 2011; Black 2012). During this time period, the USACE organized an elaborate program to create dams, dikes, and manipulate flood channels throughout the U.S. (Ntelekos et al. 2010). Since engineered solutions were first introduced, there has always been a strong preference towards using only structural engineered solutions to reduce flood risk and vulnerability (Tobin 1995). The major explanation for this non-intuitive finding involves the “levee effect” or rather the “levee love affair”, as it is often referred to by researchers (Tobin 1995; Brody et al. 2011). This term implies that individuals often have a strong preference for structural control approaches and become comfortable with the protection that they provide or the perception that an engineered structure could provide a sense of safety.

There are over 25,000 miles of engineered structures throughout the U.S., which offer protection for urban developments and industrial areas. The construction industry, land developers, the USACE, FEMA, as well as Congress, have pushed for continued structural flood management approaches in order to increase revenue (Dr. Robert Jarrett, U.S. Geological Survey 2013, personal communication). Americans have been over-reliant on the use of levees and dams, resulting in an under-appreciation of the consequences of their use (Tobin 1995; Pinter 2005; Dr. Robert Jarrett, U.S. Geological Survey 2013, personal communication). As a result, individuals residing near a levee or dam structure often have the perception that they are completely safe from floods (Tobin 1995; Pinter 2005). In some instances, rainfall and streamflow data also provides a false sense of safety (Jarrett, U.S. Geological Survey 2013, personal communication). Tobin and other researchers have noted that in reality, engineered structures provide a false sense of protection and have the potential to fail or simply not provide enough protection when a flood occurs that exceeds the design capacity. It is essential to further improve upon flood mitigation strategies, preparedness plans, as well as forecast and warning systems. However, even though this paradigm has been extensively applied, it has not reduced the flood hazard problem faced by residents in the U.S (Tobin 1995; Larson and Plasencia 2001; Galloway 2005; Pinter 2005).

Ludy and Kondolf (2012) arrived at similar conclusions to Tobin (2005) and Brody et al. (2011). They emphasize that individuals residing within floodplains may know very little about the risk of flooding, simply because local decision makers no longer consider the area a threat to flooding. Both stress that just because a community is not at risk for a 100-year flood that does not mean they are completely safe from other floods. This idea is known as residual risk, and it is important to evaluate. Individuals who reside close to a body of water could be at risk for a 101-year flood, 250-year flood or even a 500-year flood (Burby 2001; Ludy and Kondolf 2012). Often individuals believe that a majority of flood losses stem from the 100-year flood. When in reality, “most flood losses in the U.S. stem from less frequent flood events” (Burby 2001). This should concern those who reside in and manage flood-prone areas.

There continues to be a significant amount of flood damage despite extensive efforts to combat this natural hazard (Pinter 2005; Larson 2009). Human development significantly contributes to increases in flood hazards and the 100-year floodplain zones have become a safety net and crutch in the U.S. flood-management strategies. This emphasizes the need for improving methods to reduce flooding hazards through a variety of mitigation strategies. The problem is once there is extensive development encroaching into a floodplain, engineered methods in some instances end up being the only cost-effective and reliable solution (Dr. Robert Jarrett, U.S. Geological Survey 2013, personal communication). It is clearly evident that it is important to have other methods of flood protection that go beyond the standard engineered methods.

Unfortunately, communities have been reluctant to adopt other flood mitigation methods beyond structural approaches. There continues to be a preference for structural flood mitigation approaches (Brody et al. 2011). Use of structural measures allow floodplain development to continue, resulted in increased land values in the floodplain. They are also largely paid for by non-local taxpayers, and foster a perception that the flood risk has been eliminated. As a result, floodplain development has often intensified following construction of structural measures (Pinter 2005). In addition, capital investment and human occupancy in the floodplain have increased such that when a subsequent flood occurs that exceeds the design-level of the flood-control structure even greater damages result. North Dakotans have followed this approach as witnessed by the $420 million flood control project recently completed in Grand Forks, and the forthcoming $1+ billion diversion project planned for Fargo.

The second paradigm is known as the behavioral paradigm (Pielke 1999; Smith and Petley 2009). This paradigm has played an integral part in understanding complex and dynamic relationships between people and the hazardous landscape in which they reside. The grassroots of the behavioral paradigm occurred in the 1950s in the U.S. (Brody et al. 2011; Smith and Petley 2009). During this time, there was drastic shift in flood hazard research. The emphasis was focused less on developing structural solutions, but rather gravitating towards management of riverine flooding, by improving upon flood forecast and warning information, as well as mitigation strategies. One of the prominent researchers leading this new approach was Dr. Gilbert White, the renowned geographer. Rather than solely focus on scientific methods and engineering analysis, White encouraged others to focus on human and environmental interactions, often referred as human ecology (Smith and Petley 2009). This field of thought focuses on a holistic approach centered on the interaction between nature and society. White pointed out that in spite of the investment of billions of dollars in structural control works, flood damages continued to rise (Smith and Petley 2009; Brody et al. 2011). Thus, he advocated the use of non-structural approaches, such as floodplain management, flood insurance, flood forecasting, warning and response systems, as well as flood-proofing of individual structures in order to reduce flood damages.

In addition, public policy related to floodplain management improved drastically during the behavioral paradigm with political attention focused on mitigation measures. In 1968, the National Flood Insurance Act was passed and the National Flood Insurance Program (NFIP) was established to improve upon flood loss related to homes and business (Burby 2001; Pinter 2005; Bell and Tobin 2007; Tate et al. 2010; Brody et al. 2011; Highfield et al. 2013). The main objectives of the NFIP are to gravitate land-use planning and development projects toward more sustainable practices and to reduce development within a given floodplain through risk assessment, floodplain management, and flood insurance (Burby 2001; Brody et al. 2011; Highfield et al. 2013). Both residential and non-residential buildings can be covered under NFIP and the premiums are based on national flood loss and categorized accordingly. For example, riverine floods are classified as A and coastal flooding is categorized as V, for properties within the 100-year floodplain (Burby 2001). The NFIP also focuses on integrating uniform floodplain management strategies from the federal government level down to a local community (Burby 2001; Kousky 2011). Specifically, the roles and responsibilities of the federal government include: determining premium rates, identifying flood hazard zones and risk, as well as establishing specific guidelines for floodplain development. In comparison, the state government regulates floodplain development and supports local government regulations. The roles and responsibilities of the local government are to regulate land-use within floodplains and apply NFIP processes. Private insurance companies are in charge of distributing and marketing flood insurance policies to homeowners and businesses (Burby 2001). Ideally, given the costly premiums and strict land-use planning, the NFIP should aim to deter individuals from developing and residing within floodplains across the U.S. (Burby 2001). However, in many instances this is not true as, individuals often choose to ignore the consequences.

In spite of extensive efforts towards the NFIP, it has not been as fruitful as individuals had anticipated. In fact, researchers have emphasized that even though more than 22 ,000 communities participate in the NFIP and implement its requisite floodplain management based upon the delineation of the 100-year and 500-year floodplains, that flood damages continues to increase (Burby 2001; Larson and Plasencia 2001; Kousky 2011; Highfield et al. 2013). Also, it is evident that the NFIP encourages new development in floodplains, which creates an increase in flood risk and vulnerability, but very little is done to acknowledge new flood levels and new land-use planning (Larson and Plasencia 2001; Pinter 2005). Burby (2001) has found that the NFIP has created more problems that contribute to flood hazard loss. While it is commendable that the federal government is trying to maintain low-cost premiums for residential and non-residential insurance policy holders, there are consequences that negatively impact individuals across the U.S. Since there is less monetary collection for the NFIP, there is often little funding available to revise Flood Insurance Rate Maps (FIRMS) and update the maps to current conditions. In several instances, the maps are outdated and do not represent accurate flood risk (Highfield et al. 2013). Also, the low premiums rates encourage floodplain encroachment (Burby 2001). Government officials have decided to forego mapping regions that experience flooding as a result of storm water damage, locations susceptible to dam failures, and other flood works. It is also important to note that these factors are not factored into the insurance premiums. In addition, there is no action required for local governments to map and regulate land-use planning, to ensure future hazardous events are accounted for and prevented as best as possible. Finally, Burby (2001) points out that even though there are FIRMS for communities across the U.S., the level of detail and integration of flood-hazards is considerably lacking. Again, it is evident that a single based solution to flood hazards has simply not been enough. Clearly the NFIP has not significantly reduced floss loss, but rather perpetuated the issue. Additional measures are required in order to reduce future flood hazards across the U.S.

Over the past 100 years, structural solutions and floodplain management techniques have not proved adequate to reduce flood losses in the U.S. It is essential for policy makers and grass root organizations to emphasis the benefits of combining structural solutions (engineering paradigm) and non-structural solutions (behavioral paradigm) for floodplain management in the

U.S. (Galloway 2005). Together, this two-pronged approach to flood damage mitigation will ensure thousands of Americans will not continue to see increases in loss of life and property in our nation's floodplains.

Natural hazard researchers and water management professionals are now advocating a third approach, sometimes called a no-adverse impact or living with water approach (Larson and Plasencia 2001; Galloway 2005; Pinter 2005; Black 2012). This paradigm seeks to return waterways back to a more natural state and to provide greater room for flood waters to naturally flood (Pinter 2005; Smith and Petley 2009; Black 2012). The no-adverse impact paradigm first became popular in the 1990s and continues to be at the forefront of natural hazard research and floodplain management. The emphasis for the no-adverse impact paradigm is less upon short-term preparedness and responses, and more on long-time mitigation (Smith and Petley 2009). More specifically, one of the main objectives of no-adverse impact is to ensure that:

> "the action of one property owner or community does not adversely affect the flood risks for other properties or communities as measured by increased flood stages, increased flood velocity, increased flows, or the increased potential for erosion and sedimentation, unless the impact is mitigated as provided for in a community of watershed based plan" (Larson and Plasencia 2001).

The hope is to apply these concepts to floodplain management and natural hazard research across the U.S., and essentially to force policy makers to transition to combined solutions and improve upon flood mitigation (Larson and Plasencia 2001). This paradigm has prompted sustainable and strategic floodplain planning. The no-adverse impact paradigm warrants that development within and outside a given floodplain will be determined and enforced at the local level, rather than the national level; this ensures that local decision makers are held liable (Larson and Plasencia 2001).

One of the greatest challenges with the no-adverse impact approach is getting the general public and policy makers to accept the ideas and apply the various techniques. This paradigm seeks to drastically change floodplain management and mitigation. Individuals are often set in their ways and there is very little room for improvement and new concepts. However, while it may be challenging, it is essential to incorporate new strategies to floodplain management since previous paradigms and the various strategies have not produced the desired effects. Fortunately, individuals are now becoming more aware of the livelihood and importance of river ecosystems and accepting of the natural processes related to flooding (Pielke 1999).

3.3 Floodplain Management in Grand Forks

Grand Forks experiences a chronic and severe snowmelt flood hazard that is engrained in the history of the city (Todhunter 2001). Annually the community experiences snowmelt which poses a flood threat. In some instances, convective summertime storms also contribute to flood hazards within the region. Historically, flooding within the community has been cyclical, increasing and then decreasing in magnitude and frequency as time has progressed. Figure 4 illustrates the annual peak streamflow (cubic feet per second) of the Red River in Grand Forks from 1892-2012. The graph shows the annual cyclic pattern, and shows that there has been an increase in flood magnitude and frequency over time. Over the past few decades the Red River Valley, and more specifically Grand Forks has experienced a wet pattern. Prior to the 1997 flood, Grand Forks participated in the National Flood Insurance Program. This program established actuarial flood insurance rates demarcated in FIRMS that were based upon detailed

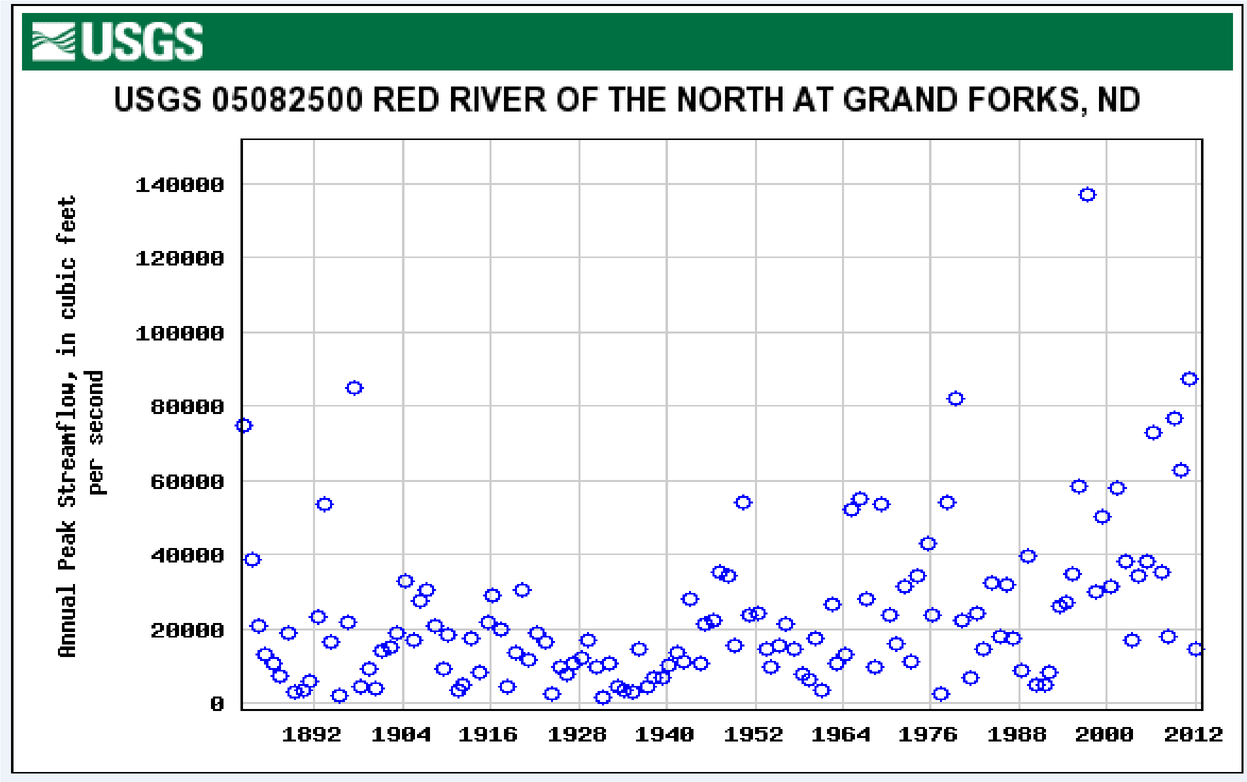

Figure 4: Annual peak streamflow (cfs) for Grand Forks, North Dakota, 1892-2012 (USGS).

hydrologic and hydraulic engineering studies. Participation in the program required the city to adopt floodplain management that placed restrictions on development within the 100-year floodplain (Burby 2001). As a result, neighborhoods like the Lincoln Park area filled with residents, and land-use planning was not monitored. Thus, there was a lot of development next to the Red River of the North. Following the 1997 flood, nearly 800 homes within the Grand Forks metropolitan area were bought out by the Federal Emergency Management Agency (FEMA) (Todhunter 1998), the land reverted to city ownership, and development on the former home lots was prohibited. Over 300 families were relocated as a result (Galloway 2005). When the USACE levee project was officially certified in 2010, the old 100-year floodplain lines were rendered obsolete, because the design of the levee system exceeded the 100-year flood level and new flood frequency estimates were created. These lots have since been offered for sale, and are rapidly being built upon. In most instances, these lots are occupied by upper class residents and more expensive homes than what were there prior to the 1997 flood. There are also a few lots that have yet to be developed. It appears as though areas like the former Lincoln Park neighborhood, which housed lower-middle class residents no longer appear in the newer 100-year floodplain boundaries. There has been extensive residential development in the southern portions of Grand Forks, and slowed development towards the western part of the city. Overall, since the 2010 certification of the levee, there continues to be growth in the community.

Many residents, city officials, and home buyers alike perceive that the flood threat has been eliminated in Grand Forks since the levee system is in place. However, there continues to be a significant residual flood risk. Grand Forks offers a living laboratory where the "levee effect" can be evaluated. Floodplain development is accelerating and capital investment is increasing in floodplain land that is still exposed to substantial residual risk. By encouraging such development, city officials are increasing the likelihood of catastrophic flood losses when low frequency-high magnitude floods exceed the design level of the existing structural flood-control works. It is imperative that sustainable land-use practices are implemented for Grand Forks, as it continues to prosper and grow in the years to come. There also needs to be discussion on residual flood risk, and more educational outreach regarding flood hazards.

3.4 Place Vulnerability Conceptual Model

Hazard researchers have devoted considerable time to better understand natural hazard risk and vulnerability through both qualitative and quantitative research (Azar and Rain 2007). In some instances, natural hazards are assessed using risk management, insurance rates, and statistical significance, whereas in other instances interviews, surveys, and geospatial techniques are vital.

Some hazard researchers focus solely on the biophysical factors of a given hazard, whereas other researchers focus only on the societal impacts (social vulnerability). Yet, there is a great need to blend both nature and society perspectives in examining the impacts of natural hazards (Montz and Tobin 2003; Chakraborty et al. 2005; Schmidtlein et al. 2008). Biophysical vulnerability refers to the "distribution of hazardous conditions arising from a variety of initiating events such as natural hazards (hurricanes, tornadoes)…" (Cutter 2001). Biophysical vulnerability is often based upon the magnitude, duration, frequency and spatial distribution of extreme natural events (Smith and Petley 2009). There are limitations to evaluating biophysical risk; it is often problematic to extract complete and accurate data, which can hinder the analysis or produce skewed results. Chakraborty et al. (2005) state that it is difficult to obtain such data for growing populations and regions where the topography and hazardscape is constantly changing.

A majority of natural hazard research has focused on biophysical vulnerability, and until recently, less on the social characteristics of risk (Chakraborty et al. 2005). As a result, social vulnerability research became a primary focus in natural hazard research and has gained popularity since the early 2000s (Cutter 2001). Social vulnerability is defined as "demographic characteristics of social groups that make them more or less susceptible to the adverse impacts of hazards" (Cutter 2001). In addition, social vulnerability quantifies spatial and temporal changes related to demographic characteristics (Schmidtlein et al. 2008). Populations that are known to have a high level of vulnerability include those who are of minority ethnicity or race, elderly, females, and children under the age of five (Burton and Cutter 2008; Chakraborty et al. 2005). Other demographic characteristics may also increase an individual's vulnerability include: median household income, renter occupied housing, educational attainment, etc. (Burton and Cutter 2008; Chakraborty et al. 2005).

Cutter (2001) is acknowledged as the original creator of a hazard vulnerability index called the Social Vulnerability Index (SoVI); this index quantifies demographic characteristics and determines a population's social vulnerability to natural hazard. (Chakraborty et al. 2005). This index estimates social vulnerability based on demographic data obtainable from the Decennial Census and can be extracted at the tract, block group, or block level (Cutter and Finch 2008). The SoVI index has been applied extensively to specific locations across the U.S. that experience severe coastal or continental natural hazards (Montz and Tobin 2003; Chakraborty et al. 2005; Burton and Cutter 2008; Schmidtlein et al. 2008; Tate 2012).

Studies analyzing relationships between specific demographics and hazards have also been researched. Specifically, Morrow (1999) found that the elderly, children, and women are often most at risk during a hazardous event. This is important to take into consideration when determining which specific characteristics to evaluate in this study. GIS can be very useful in mapping disaster risk and vulnerability at local scales. Morrow (1999) suggests an increase in community planning for disaster preparedness and response, and recommends that more women become involved in the policy and decision making process related to natural hazards. Other methods used for social vulnerability have been attempted by other hazard researchers (Montz and Tobin 2003; Chakraborty et al. 2005), but none have gained as much popularity as the methods developed by Cutter (2001). Chakraborty et al. (2005) created the index for social vulnerability for evacuation (SVEI). However, this method was not applicable to this study and is not as widely adopted as the methods of Cutter (2001).

While most hazard researchers find the SoVI index to be quite helpful for their research, there are limitations with its application to the analysis of social vulnerability. It is evident that "although there is a broad interest in the need to quantitatively model social vulnerability, there is far less consensus regarding the ideal set of methods used for the production of indexes" (Tate 2012). As a result, there is the possibility for uncertainty and error when determining various social vulnerability attributes. These factors could lead to an overestimation of vulnerability in some instances, whereas in other cases they might lead to underestimation in vulnerability. In addition, it is difficult to determine which socio-demographic characteristics are more important than others when evaluating hazard vulnerability. For example, who is to say that a woman with four young children, all under the age of five, is more vulnerable to a natural hazard than an elderly woman? It is simply something to take into consideration when evaluating the social vulnerability using SoVI (Graham Tobin, Professor, University of South Florida, 2013, personal communication). Despite limitations to the SoVI index, it has been used by numerous researchers, and has been shown to be beneficial to use in examining hazard risk and vulnerability.

A place vulnerability conceptual model takes both biophysical vulnerability and social vulnerability into consideration when assessing the overall risk and vulnerability of a natural hazard. Together, these two factors provide a thorough examination of a given hazard and allow researchers to determine areas that may be vulnerable and require extensive efforts in hazard preparedness, response, mitigation, and recovery (Cutter 2001; Montz and Tobin 2003; Chakraborty et al. 2005; Burton and Cutter 2008).

A place vulnerability conceptual model was first introduced in hazard research by Cutter et al. (2000), and has been adopted and modified by other researchers (Cutter et al. 1997; Montz and Tobin 2003; Cutter et al. 2003; Chakraborty et al. 2005; Azar and Rain 2007; Burton and Cutter 2008). It is a valuable resource for geographers and other hazard researchers because it creates the opportunity to transform demographic characteristics and biophysical hazardous events (Chakraborty et al. 2005; Azar and Rain 2007). Also, a place vulnerability conceptual model usually requires the use of geographic information systems (GIS) to create maps (Morrow 1999; Cutter 2001). Place vulnerability maps provide a spatial interpolation of various risks and vulnerabilities.

One of the benefits of using a place vulnerability conceptual model is that it provides a concise and simplified format that allows decision makers to use it in their Emergency Operation Plans (EOP), mitigation strategies, and land-use planning. Place vulnerability conceptual models also help prevent future disasters (Azar and Rain 2007).

For the purpose of this study, a place vulnerability analysis is used as the conceptual framework for the geographical determination of flood risk. Biophysical vulnerability related to flooding is the traditional quantification of flood risk based on hydrologic and hydraulic considerations and frequency-magnitude concepts. It is based on the concept that certain places face greater flood risk due to their proximity with respect to flood-causing processes. For the purpose of this study, flood risk is assigned the basic 100-year and 500-year floodplain probabilities of 0.01 and 0.002 (Chakraborty et al. 2005).

CHAPTER IV

DATA AND METHODS

4.1 Data Sources

Data for this study were collected from four different sources and inputted into ArcGIS 10.1, to determine SoVI, biophysical flood risk, place vulnerability, within the Grand Forks city limits over the time periods of the study period. As seen in Table 1, the datasets include: Decennial Census Block Group data for 1990, 2000, and 2010, block group shapefiles, a road shapefile, and Flood Insurance Rate Map (FIRMS) data. The social vulnerability, composite social vulnerability, place vulnerability, total housing units, and total population data were classified in ArcGIS using manual classification. This type of classification allows the user to set class breaks that fit the range of the data, allowing comparison between the years studied.

Table 1: Sources and datasets included in the study.

Data Source	**Type of Data**	**Years Included in Analysis**
National Historical Geographic Information Systems	Census Block Group Data, block group shapefiles	1990, 2000, and 2010
City of Grand Forks GIS Department	Flood Insurance Rate Maps	1990 and 2000
Houston Engineering Incorporated	Flood Insurance Rate Maps	2010
North Dakota Department of Transportation	Road shapefiles	2010

Specifically, data from the City of Grand Forks GIS Department and Houston Engineering Incorporated was used to create biophysical risk maps, as well as place vulnerability maps. Shapefiles of the 100-year floodplain from 1990 and 2000 came from the City of Grand Forks GIS Department and the 100-year floodplain shapefile for 2010 came from Houston Engineering Incorporated. The 500-year floodplain data was also obtained from Houston Engineering Incorporated and used for biophysical risk, aerial interpolation, and place vulnerability maps for 1990, 2000, and 2010. Decennial Census Block Group for 1990, 2000, and 2010 was extracted from the National Historic Geographic Information Systems and used to determine SoVI and aerial interpolation.

This study involves three major steps to determine changes in flood risk and vulnerability; an additional fourth step is used to estimate how many individuals reside within the 100-year and 500-year floodplain during 1990, 2000, and 2010. Specifically, biophysical and social vulnerability were initially calculated individually and then combined to calculate place vulnerability. Together, these methods provide critical historical and present day information for the City of Grand Forks. This analysis also helps determine how flood risk and vulnerability have changed during floodplain encroachment prior to the 1997 flood, floodplain settlement after the 1997 flood but before the 2010 certification of the levee system, and during floodplain development following the USACE certification of the levee system.

4.2 Biophysical Vulnerability Analysis

The biophysical vulnerability for 1990, 2000, and 2010 was determined using flood probabilities obtained from FIRMS. The biophysical vulnerability dataset came from the City of Grand Forks GIS Department and Houston Engineering Incorporated. The 100-year floodplain prior to the 1997 flood was utilized for biophysical vulnerability analysis for both 1990 and 2000. This dataset displayed a wider 100-year floodplain than what currently exists. A separate dataset for the 100-year floodplain was utilized for 2010. The 100-year floodplain for 1990 and 2000 came from the City of Grand Forks GIS Services and was the only digital copy available. The data was of poor quality when it was initially extracted; thus, several important geospatial techniques were applied to the original data. In addition, there was no digital record of the 500-year floodplain for Grand Forks for 1990 and 2000. As a result, the 500-year floodplain boundaries from 2010 were applied to the 1990 and 2000 shapefiles. This method was applicable since areas that were not in the 100-year floodplain were designated as the 500-year floodplain. The 100-year floodplain for 1990 was also used for 2000, since the floodplain boundaries did not officially change until 2010, when the USACE approved the levee system.

Initially the 2010 floodplain data, including both the 100-year and 500-year floodplain, were combined with the 1990 100-year floodplain data using the Identity geoprocessing tool. This allowed all of the datasets to be displayed on the dataframe. The projection of the block groups for 1990 had to be changed to match the biophysical map projections. This was done in the Arc GIS toolbox, and the feature was projected from USA Contiguous Albers Equal Area Conic to UTM 1983 Zone 14 North. Then, the combined biophysical map was blended with the block group shapefile by applying the Identity tool once again. Specifically, 140 polygons were examined and edited to ensure that the data was clean and ready to use for biophysical risk and analysis. The amount of block groups changed slightly from 1990-2010. 49 block groups came from the 1990 dataset, 47 block groups from the 2000 dataset, and 44 block groups from the 2010 dataset.

Since the data was poor quality to begin with, each block group had to be analyzed to eliminate any gaps or inconsistencies. The process began with selecting a block group individually and using the Dissolve tool under Data Management properties and Generalization. This helped clean up some of the unnecessary polylines. However, in this process not all of the glitches were fixed. It often revealed that polygons consisted of major gaps and thus, in order to resolve the issue, a new shapefile polygon was created. This new polygon was then unionized with the dissolved block group. This process was necessary to fill in the gaps and ensure a smooth, finished product. Once the block group was unionized, the Multi-Part to Single-Part tool was applied. A new shapefile was then created once the tool ran in ArcGIS. The attribute table in the newly constructed polygon was then edited to ensure that any missing floodplain data was appropriately assigned a value. Once the table was edited, all of the attribute characteristics within the block group were selected. The final process for the edited block group required using the Dissolve tool once again. This allowed the original polygon outline to disappear and to reveal a clean and accurate block group. These steps were applied to any block group that required additional detail and cleaning. Once the block groups were all edited, the geoprocessing tool Merge was used to combine all of the block groups to produce the final biophysical risk maps for 1990, 2000, 2010.

4.3 Social Vulnerability and Composite Social Vulnerability Analysis

Several different indices for measuring social vulnerability have been developed; however, for the purpose of this study the methods developed by Cutter et al. (2001) and Montz and Tobin (2003) were applied. Research on social vulnerability indicates there are several demographic characteristics that determine if an individual is vulnerable to natural hazards. Common relevant demographic characteristics include: gender, age, income, and race (Cutter

1996; Cutter 2001; Chakraborty et al. 2005; Cutter et al. 2008). In this study, fourteen demographic characteristics were derived from Decennial Census data to determine specific SoVI characteristics, as seen in Table 2. A majority of these characteristics follow similar suit to other social vulnerability studies (Cutter et al. 2001; Montz and Tobin 2003; Chakraborty et al. 2005; Azar and Rain 2007). SoVI analyses can often encompass up to 40 demographic characteristics. However, given the time scale of this study and lack of similar data across all three Decennial Census periods, only fourteen variables were found and included in this study.

Table 2: Demographic characteristics used to determine social vulnerability indices.

Demographic Characteristics Included in the SoVI Analysis
Individuals under the age of 25 without a high school diploma
Median household value
Household incomes $75,000 and greater
Renter occupied housing
Total population
Total housing units
Children under the age of five
Elderly 65 years and older
Females
African American descent
American Indian descent
Asian descent
Caucasian descent
Other races

One additional SoVI characteristic was included in this dataset that is normally not used in SoVI analysis; namely Caucasian race. Normally the race demographic inputted into SoVI calculations focus only on minority races, such as African Americans, Asians, and American Indians etc. However, it was appropriate to include the Caucasian demographics, given that the majority of Grand Forks's population is of Caucasian or European descent. In addition to Grand Forks's minority population, the Caucasian population was also severely impacted by the 1997 flood. Thus, it was best to encompass all races in this study to see how flood risk and vulnerability changed over time.

There are a number of steps required to calculate SoVI for a given demographic characteristic. The first step requires organizing all of the specific demographic characteristics for each time period in a Microsoft Excel dataset. The data was initially extracted for the entire state of North Dakota and then the Excel table was edited to only encompass Grand Forks County data (Table 3).

Table 3: A sample of the social vulnerability index dataset.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	GISJOIN	YEAR	BLCKGRPA	TRACTA	COUNTY	COUNTYA	DIVISIONA	REGIONA	STATE	ANPSADP	WHITE	XWHITE	LARWHITEX	WHITESOVI
2	G380035001011	1990	1	101	Grand Forks	35	4	2	North Dak	BG 1	1023	0.015322	0.118803	0.128971

Once the demographic data was organized in Excel, the individual SoVI score was calculated for each demographic variable for 1990, 2000, and 2010. As seen in equation (1), the SoVI scores were calculated using similar methods to Cutter (1996) and Cutter et al. (2008). The equation is as follows:

$$X = \frac{\#\ in\ the\ Census\ Block\ Group}{\#\ \text{in the County}} \tag{1}$$

The purpose of using equation (1) is to calculate the value of each variable in each block group. For example, the number of children under the age of five in block group 1 is divided by the number of children under the age of five within Grand Forks County. This value, indicated as ‘X’, is then used in a second calculation. The second calculation determines the SoVI value and allows all demographic characteristics to be measured on the same scale. Equation (2) calculates the SoVI score and is as follows:

$$SoVI\ of\ a\ given\ demographic\ characteristic = \frac{X}{Maximum\ X\ Value} \qquad (2)$$

The Maximum X Value is the largest X value found for a given demographic characteristic out of all of the block groups. The X value is from the previous equation and together they determine a SoVI score. Overall, the SoVI can range from 0.00-1.00. A block group with a value of zero indicates that individuals within the block group are not vulnerable based on the demographic characteristics and calculations. Block groups with SoVI scores that are higher than zero but lower than 0.40 represent a very low amount of vulnerability; again this is based on the demographic characteristics and calculations. In contrast, SoVI scores around 0.50 indicate a moderate level of vulnerability. Lastly, SoVI scores in a given block group that are between 0.5-1.00 are considered to have a high vulnerability. In this study, each algebraic equation mentioned above was applied to the Decennial Census Block Group data for 1990, 2000, and 2010.

After determining the individual SoVI scores, the composite SoVI score was calculated for all of Grand Forks. Composite social vulnerability is important since it provides an overview of the demographic characteristics and determines the vulnerability of a given block group, combining all of the Decennial Census datasets. This value is calculated by using the following equation:

$$\sum_{i=1}^{14} SoVI_i \qquad (3)$$

As seen in equation (3), the composite social vulnerability score is the summation of the SoVI scores for each demographic characteristic. The composite social vulnerability scores are then used in the assessment of place vulnerability.

4.4 Place Vulnerability Analysis

Place vulnerability analysis combines the biophysical vulnerability dataset and the composite social vulnerability dataset for each time period: 1990, 2000, and 2010. Specifically, the composite social vulnerability score was multiplied by the biophysical risk value, as seen in equation (4).

$$Place\ Vulnerability = Composite\ SoVI\ score \times Biophysical\ Risk\ Value \tag{4}$$

In the case of flooding, a value of 0.01 was assigned to areas within the 100-year flood plain and a value of 0.002 was designated for regions within the community that are in the 500-year flood plain. The multiplication of biophysical risk and composite social vulnerability provides a quantitative assessment of overall risk. In this study, place vulnerability was crucial to evaluate changes in flood risk of the study period. Place vulnerability analysis is a simple geospatial technique that provides critical spatial and temporal data.

4.5 Aerial Interpolation

A simple method of aerial interpolation was applied to this study to determine how many individuals reside within the 100-year and 500-year floodplain for 1990, 2000, and 2010. This geospatial technique requires using the biophysical risk data and the individual block group data for 1990, 2000, and 2010. Before intersecting the two, the area was calculated for the block group shapefiles, as seen in equation (5). Once the biophysical risk and block group data were combined, the area was again calculated for each block group. The two area values were then divided, with the original area in the denominator and the second area calculation in the numerator. The divided area value was then multiplied by the given population and summary statistics were run to provide a linear spatial estimate of people living within the 100-year floodplain and the 500-year floodplain.

$$Aerial\ Interpolation = \left(\frac{Area_{\ 1}}{Area_{\ 2}}\right) \times population \qquad (5)$$

CHAPTER V

RESULTS AND DISCUSSION

5.1 Social Vulnerability Analysis

Each demographic characteristic analyzed provides a unique perspective of the City of Grand Forks and provides a quantitative and visual representation of vulnerability. Certain demographic characteristics contribute to an increase in vulnerability, whereas other demographic characteristics decrease the potential for vulnerability. As seen in Table 4, the minimum, maximum, and mean value of the SoVI were collected for 1990, 2000, and 2010. This data provides critical information for local decision makers, and helps them better understand the resident population residing in Grand Forks, and the range of specific needs they may have in the event of a hazardous event.

Female demographic information was important to include in this study because this demographic characteristic is known to contribute to increased vulnerability. Specifically, research indicates that this demographic is associated with a lack of resources (Cutter et al. 1997). The female SoVI data indicates that there has been an increase in vulnerability from 1990-2010. Initially, the minimum SoVI score was almost zero, with a value of 0.04 in 1990 and 0.09 in 2000. In 2010 the minimum value increased to 0.17. Overall, the maximum female SoVI score increased significantly over the twenty year period. Initially, the highest SoVI for females was 0.41, which is considered to be a level of moderate vulnerability. In 2000, the SoVI score increased to 0.80 indicating a dramatic shift and increase in vulnerability for females. The

SoVI for females increased yet again in 2010, from 0.80 to 1.00. Even though there was widespread variability between the minimum and maximum female SoVI scores, the average SoVI scores were 0.13 for 1990, 0.25 in 2000, and 0.42 in 2010. As seen in Appendix A, the SoVI map of females for 1990 displays the highest concentrations of vulnerability in the central portions of the city limits.

In contrast, the 2000 SoVI map highlights an increase in vulnerability with at-least six block groups with a deep purple color gradient, indicating a moderate-high vulnerability. These block groups have a SoVI ranging from 0.38- 0.80. It appears as though a majority of the block groups near downtown Grand Forks are categorized as a low-moderate SoVI score. In 2010, there are distinct patterns showing an increase and redistribution of vulnerability. There are more block groups near downtown Grand Forks with a moderate-high vulnerability, highlighting increases in vulnerability of females. A majority of block groups with a high SoVI score are located in the interior portion of the Grand Forks city limits.

Table 4: Summary statistics of social vulnerability indices, 1990, 2000, and 2010.

Year	Demographic Characteristic	Minimum	Maximum	Mean
1990	Female	0.04	0.41	0.13
2000	Female	0.09	0.80	0.25
2010	Female	0.17	1.00	0.42
1990	Elderly	0.00	0.92	0.27
2000	Elderly	0.00	1.00	0.23
2010	Elderly	0.00	1.00	0.27
1990	Children Under the Age of 5	0.007	0.156	0.05
2000	Children Under the Age of 5	0.027	0.443	0.09
2010	Children Under the Age of 5	0.070	0.958	0.26
1990	25 Years and Older Without a High School Diploma	0.00	1.00	0.31
2000	25 Years and Older Without a High School Diploma	0.03	1.00	0.31
2010	25 Years and Older Without a High School Diploma	0.00	0.83	0.27
1990	African American Race	0.000	0.047	0.009
2000	African American Race	0.000	0.093	0.02
2010	African American Race	0.000	1.000	0.14
1990	Caucasian Race	0.05	0.46	0.13
2000	Caucasian Race	0.10	0.85	0.26
2010	Caucasian Race	0.17	1.00	0.43
1990	American Indian Race	0.00	1.00	0.25
2000	American Indian Race	0.00	1.00	0.19
2010	American Indian Race	0.00	1.00	0.14
1990	Asian Race	0.00	0.45	0.04
2000	Asian Race	0.00	0.48	0.09
2010	Asian Race	0.00	1.00	0.06
1990	Other Races	0.00	0.22	0.04
2000	Other Races	0.01	0.30	0.07
2010	Other Races	0.00	1.00	0.14
1990	Renter Occupied Housing	0.00	0.25	0.08
2000	Renter Occupied Housing	0.00	0.90	0.17
2010	Renter Occupied Housing	0.00	1.00	0.28
1990	Household Incomes $75,000 and Greater	0.00	1.00	0.09
2000	Household Incomes $75,000 and Greater	0.00	1.00	0.22
2010	Household Incomes $75,000 and Greater	0.00	1.00	0.26
1990	Median Household Value	0.00	1.00	0.46
2000	Median Household Value	0.00	1.00	0.49
2010	Median Household Value	0.00	1.00	0.27
1990	Population	0.05	0.41	0.11
2000	Population	0.09	0.73	0.23
2010	Population	0.20	0.72	0.43
1990	Housing Units	0.08	0.37	0.16
2000	Housing Units	0.08	1.00	0.26
2010	Housing Units	0.16	1.00	0.36

SoVI data for the elderly from 1990-2010 did not change significantly in comparison to other demographic characteristics in this study. Overall, the minimum value of SoVI was 0.00 for all three time periods. The average elderly SoVI initially was 0.27 in 1990, decreased to 0.23 in 2000, and returned to 0.27 in 2010. Thus, it appears as though there are quite a few areas in Grand Forks that have a low SoVI score for elderly. However, it should be noted that even though the average SoVI was low, for each year analyzed there were four block groups that had a SoVI score that was classified as moderate-high. As seen in Appendix A, the 1990 SoVI elderly map displays several block groups in the central and southern portions of Grand Forks with a high level of vulnerability. In addition, there is also a higher concentration found throughout portions of downtown Grand Forks and a distinct block group near the Red River of the North. In comparison, the 2000 SoVI elderly map has a higher vulnerability range than the 1990 data. In addition, it is evident that the elderly residents appear more concentrated further away from downtown and the portions of the city near the river. Rather, the higher concentrations of vulnerability are found in the central portion of the city. The 2010 data again indicates a shift in vulnerability away from portions of downtown Grand Forks, and an even higher concentration of elderly in the southern and central portions of the city. This demographic characteristic contributes to an overall increase in vulnerability because elderly often need extra assistance during a disastrous event and do not recover as quickly as others after a disaster (Cutter et al. 1997). The maps show a migration of elderly who once lived closer to the Red River of the North and have a transitioned towards elderly care in the southern and central portions of the city.

Children under the age of five were included in this study because this demographic is often known to be highly vulnerable during a natural hazard. Specifically, children at this age are not able to make decisions for themselves and rely heavily on their parents or guardians. Also, children under the age of five often require additional resources than perhaps their older counterparts (Cutter et al. 2003). The children under the age of five years old data present an overall increase in vulnerability from 1990-2010. The 1990 SoVI map appears to show dark gradients of vulnerability; however, when examining the data the overall vulnerability of children under the age of five during this time period was very low. The minimum value was small with a value of 0.007. In addition, the maximum SoVI score found for this demographic characteristic in 1990 was 0.156, indicating very low vulnerability. The average SoVI for this time period was 0.050. Thus, the data indicates that prior to the 1997 flood there were very few children who were vulnerable to such a catastrophe. Perhaps most children accounted for were older than the age of five. The 2000 SoVI data and map showed a slight increase in vulnerability than the 1990 data. The minimum SoVI score was 0.027 and the maximum value was 0.443, with an average SoVI score of 0.260. Again there is very little vulnerability; however, there are a few areas of moderate vulnerability for children under the age of five. As seen in Appendix A, these areas are located mostly in the central and southern portions of Grand Forks. The 2010 SoVI data shows the greatest contrast between low-high vulnerability of children under the age of five. The 2010 minimum SoVI was 0.070, a very low value. However, the maximum SoVI was 0.958, indicating pockets of high vulnerability within Grand Forks. It is evident that areas with a higher vulnerability score are in the southern and central portions of the city. However, since the data is classified to compare between all three time periods, the 2010 map consists mostly of dark green values. It is important to note that the darkest color gradient includes values of low-high vulnerability, ranging from 0.140-0.958.

Educational attainment is also an important demographic characteristic to analyze. Individuals who have a lower education level tend to have lower abilities to understand warning information and obtain essential natural hazard recovery information (Cutter et al. 2003). This is especially prominent in individuals who have not obtained a high school diploma and are older than 25 years of age. In this study, the SoVI data for individuals 25 years and older without a high school diploma indicted levels of high vulnerability for all three time periods. This demographic characteristic was surprisingly high, and varied quite a bit by block group throughout the City of Grand Forks. In 1990, the minimum SoVI was 0.00 and the maximum SoVI score was 1.00, with an average score of 0.31. Concentrations of high vulnerability were found sprinkled throughout downtown, in the northern portions of the city, as well as portions of central Grand Forks. The 2000 SoVI data showed a minimum value of 0.03, a maximum SoVI value of 1.00 and an average value of 0.31. There was an increase in vulnerability in 2000 in block groups located in the western side of Grand Forks. Also, concentrations of high vulnerability were found in the northern portions of the city and some in the central portions. The 2000 map (Appendix A), indicates a few block groups in downtown Grand Forks with a high vulnerability, but less than found in 1990. The 2010 SoVI data shows a small decrease in vulnerability of individuals 25 years and older without a high school diploma. The minimum SoVI was again 0.00, however the maximum SoVI decreased to 0.83. While it decreased by 0.17, the highest value is still considered to represent high vulnerability. The average SoVI score also decreased to a value of 0.27. Again, small decreases in vulnerability generally occurred but it is important to stress that there were concentrations of high vulnerability throughout the city. Specifically, individuals 25 years and older without a high school diploma were found in the western portions of the city and pockets near downtown Grand Forks. The 2010 data, as seen in Appendix A, displays lower vulnerability near the eastern portion of Grand Forks.

Renter occupied housing SoVI data from 1990-2010 showed an increase in vulnerability. In 1990, the highest concentrations of renters were located near downtown and portions of central and southern Grand Forks. No concentrations of moderate-high vulnerability were indicated in 1990. The minimum SoVI score was 0.00, the maximum was 0.25, and the average SoVI was 0.08. Clearly, this demographic characteristic did not contribute too significantly to place vulnerability in comparison to other demographic characteristics in 1990. An increase in rental properties and vulnerability spiked from 1990 to 2000 and 2010. In 2000, the minimum SoVI was 0.00, the maximum value was 0.90, and the average SoVI was 0.17. Areas with a high vulnerability for renters, indicated in Appendix A, are found in portions of downtown Grand Forks along the river, in the central portions of the city, as well as a few block groups in the southern portions. In comparison, renter occupied housing vulnerability increased slightly from 2000 to 2010. In 2010, the SoVI minimum value was 0.00 and the maximum value was 1.00. The average SoVI value was 0.28. So while the average of each time period was low, there were block groups that indicated a high vulnerability. As the Grand Forks community continues to grow, there will continue to be an increase in rental properties, and its associated increase in vulnerability. This demographic characteristic is important to include in this study since these individuals often lack financial resources and could hinder opportunities for successful recovery and finding financial aid (Cutter et al. 2003). It is a demographic characteristic that should continue to be monitored and will be important for local decision makers to keep in mind when updating emergency operation plans, mitigation strategies, as well as land-use planning.

Household incomes $75,000 and greater was an important demographic characteristic to include in the SoVI analysis because households with occupants that generate a higher income often suffer greater economic loss from a natural hazard such as flooding. In this study, there were definitely distinct spatial and temporal patterns from 1990-2010 for this demographic characteristic. In 1990, there was only a few block groups in the Grand Forks city limits that indicated a high vulnerability of household incomes $75,000 and greater. These block group were situated in the southern portion of the city, right next to the Red River of the North. The rest of the city had a low vulnerability and very few occupants generated more than $75,000 a year. During this time period the minimum SoVI score was 0.00 and the maximum value was 1.00. While this demographic characteristic displayed the full spectrum of SoVI scores, the average was 0.09, indicating very little to no vulnerability. Similarly, the 2000 SoVI scores were 0.00 for the minimum and 1.00 for the maximum. The average SoVI score did increase to 0.22, yet remained quite low. The 2000 SoVI map (Appendix A), shows the highest concentrations of vulnerable populations in the southern portion near the river and also a concentration in the central to western portion of the Grand Forks city limits. The higher concentrations to the south correlates with newer development and occupants with the highest income in the city. This area of Grand Forks has often been known as the most affluent area of the community. In 2010, the minimum SoVI value was again 0.00 and the maximum was 1.00. The average SoVI value did increase, but the increase was very minimal, to 0.26. The highest concentrations of household incomes $75,000 and greater were found in the southern and central portions of Grand Forks, with a few concentrations in the central corridor. The low-moderate vulnerability block groups were found near downtown and to the north of the city. It is evident that there has been a gradual increase in higher income vulnerabilities with several of the locations located near the Red River of the North.

Median household value was also included in this study, providing one of several indicators of vulnerability. A lower median household value often translates to a population that is more vulnerable. Partially this is because these individuals may not have enough resources and lower median household values indicate that the building structure may not be of as high quality and able to withstand certain hazardous events. Whereas, higher median household values indicate that a given population is less vulnerable and the buildings are made out of premium materials (Cutter et al. 2003). The average SoVI values for median household value were the highest of all the demographic characteristics. The SoVI values presented the full spectrum of values that are possible for a demographic characteristics. All three years evaluated had a minimum SoVI value of 0.00 and a maximum SoVI value of 1.00. The average SoVI for 1990 was 0.46, indicating an overall moderate level of vulnerability based on median household value. In 2000, the average increased slightly to 0.49, but 2010 the average SoVI value had decreased to 0.27. Perhaps this fluctuation could be a result of a shift in land-use planning from mostly single-family homes to mixed-housing and more rental properties constructed throughout Grand Forks over the past twenty-years. The 1990 map (Appendix A), displays the low-moderate vulnerability near downtown Grand Forks and two block groups towards the central portion of the city limits. Concentrations of moderate-high vulnerability are located in the southern, central, and western portions of Grand Forks. The 2000 map does not show much difference in the spatial patterns of vulnerability. There appears to be fewer than five block groups that distinctly show an increase in vulnerability, and in those instances the new additions are next to the block groups that showed higher vulnerabilities in 1990. The 2010 map shows more of a contrast in vulnerability of median household values. Specifically, the highest concentrations are found in the northern portion of the city limits. There are a few distinct block groups near downtown Grand Forks that had a high vulnerability. The low-moderate vulnerability scores are found in the southern portion of the city, as well as scattered throughout downtown Grand Forks. Overall, the median household value characteristic did not show much contrast between each of the years studied. However, this demographic characteristic did contribute disproportionately to total social vulnerability over the years in comparison to the other demographic characteristics.

Total population was included in the SoVI analysis for this study and can be used to determine population density. Greater density of population results in a greater vulnerability because resources must be split between more individuals (Cutter et al. 1997). Similar to other demographic characteristics, there was an overall increase in vulnerability from 1990-2010. In this instance, the population demographic characteristic increased almost twofold. In 1990, the minimum SoVI was 0.05 and the maximum SoVI value was 0.41. The average SoVI value was 0.11. The 1990 map (Appendix A) shows that overall, there was no account for high vulnerability of the total population. The largest SoVI values for this time period were measured as moderate vulnerability, with concentrations in central Grand Forks. By 2000 the minimum value did not change much, however the maximum SoVI value did significantly increase in value. In 2000, the minimum SoVI value was 0.09 and the maximum SoVI value was 0.73. The average SoVI value for 2000 was reported as 0.23. While the average remained low, the overall range between the minimum and maximum SoVI values was larger in 2000 than in 1990. The highest concentrations of vulnerability based on total population remained in the central and southern portions of Grand Forks. Low-moderate vulnerability encompassed the majority of downtown, southern portions of the city, and northern Grand Forks. The 2010 data showed very little change in the minimum SoVI value, with a value of 0.20. The maximum SoVI value increased from 0.72 in 2000 to 1.00 in 2010, which is the highest value a block group can be assigned. The average SoVI value also increased from 2000 to 2010. In 2010, the average SoVI value was 0.43. This indicated that for the total population, there was overall moderate vulnerability. As seen in the 2010 map (Appendix A), the highest concentrations of total population vulnerability are distinctly in the southern, central, and northern portions of the city and scattered throughout downtown Grand Forks. Some portions of downtown Grand Forks are considered to be low-moderate vulnerability. As the City of Grand Forks increases in total population it is evident that there is a gradual increase in vulnerability. While currently it is at only moderate levels of vulnerability, if trends continue it could become problematic.

Evaluation of housing units was also included in this study, and was analyzed to determine SoVI values and contribute to composite social vulnerability and place vulnerability analysis. Specifically, this characteristic was important to include because, like total population, the number of housing units is a good indicator of population density and a better understanding of the amount of resources needed for hazardous event (Cutter et al. 1997; Cutter et al. 2003). The minimum SoVI value was 0.08 in 1990 and in 2000. The 1990 data did not account for any SoVI values that ranged from moderate-high vulnerability. Rather, the maximum value for SoVI was 0.37 and the average was 0.16 in 1990. The low-moderate vulnerability is displayed in Appendix A and it is evident that in 1990 there was very little variation in housing units and the vulnerability it presented. In 2000 though, there was a drastic change in the range between low-high vulnerability. Specifically, the maximum SoVI value was 1.00 and the mean was 0.26. This indicated an increase in vulnerability overall. The 2000 map displays areas of housing units with a high vulnerability near the southern portion of the city, as well as the central corridor.

Overall, portions of downtown Grand Forks remained low-moderate in vulnerability. In 2010, the minimum SoVI value of housing units rose from 0.08 to 0.16 and the maximum SoVI value remained at 1.00. The mean SoVI value increased, however, from 0.26 in 2000 to 0.36 in 2010. The 2010 map is similar to the 2000 map, as seen in Appendix A. The highest concentrations of vulnerability are located in the southern and central portions of the city. An increase in vulnerability occurred from 1990-2010, but the increase in vulnerability was minimal. It is important to note that SoVI values of housing units are critical to record and take note of for decision makers. Over time, drastic changes in housing can significantly contribute to increases or decreases in vulnerability.

Five races were also included in this study and SoVI values were calculated for four minority races—African American, American Indian, Asian, and other races, as well as one majority race—Caucasian. Each race was analyzed for 1990-2010. Minority races were included in this study because this demographic characteristic is often known as a vulnerable population. Minorities often do not recover as quickly from a natural hazard and often do not have the resources needed to successfully recover from a hazardous event (Cutter et al. 1997). Over the study period there has been a small but steady increase in minorities residing in Grand Forks. The community has seen an influx of immigrants within the past few decades, as a result of social service support and religious organizations. Also, there has been great economic opportunity for individuals in North Dakota and more specifically Grand Forks due to increases in oil drilling, thus transforming the ethnic and racial composition. However, even though there has been a gradual influx of minorities, the majority of Grand Forks's population has remained of Caucasian descent and it was important to evaluate these individuals as well in this study.

In 1990 there were very few African Americans residing in Grand Forks, thus the calculated SoVI values were relatively low compared to other demographic characteristics. There were not enough individuals to consider moderate-high SoVI pockets in the community in 1990. The minimum SoVI value of African Americans in 1990 was 0.000, the maximum value was 0.047, with an average value of 0.009. At this time period the contribution of African American ethnicity to social vulnerability was virtually zero. The 2000 data did not present much of a change to the SoVI scores. During this time period the minimum SoVI value remained the same as 1990, at 0.000. The maximum SoVI value was 0.093 and the average SoVI was 0.020. It was not until 2010 that this factor made a significant contribution to SoVI. In 2010, the minimum value was once again 0.000. The maximum value jumped to 1.000, however, and displayed distinct pockets of high vulnerabilities for African Americans. The mean also increased, from 0.020 in 2000 to 0.140 in 2010. While the average remained unchanged, there appears to be in the concentration of African Americans residing within Grand Forks. In the 2010 map (Appendix A), it is evident that the highest concentrations of vulnerability are in the western portion of the city with a few distinct blocks in the central corridor. Moderate-high vulnerability is present near downtown Grand Forks, with mixed values in the central corridor. However, even though there are obvious areas of moderate vulnerability for African Americans, there still appears to be an overall presence of low vulnerability within the city. This can again be attributed to the small population of African Americans residing in Grand Forks.

In contrast to the African American demographic data and SoVI values, the American Indian data consistently provided a range of low-high vulnerabilities over the study period. For all three time periods, the minimum SoVI value was 0.00 and the maximum SoVI value was 1.00. There was a small decrease in the average SoVI values from 1990-2010. Specifically, the average SoVI for 1990 was 0.25, in 2000 it was 0.19, and in 2010 it was 0.14. As seen in the 1990 SoVI map of American Indians, areas with a low vulnerability were in the south-eastern portion of the city, as well as portions of western Grand Forks. Concentrations of moderate vulnerability were found in the central portions of the city and high concentrations were found in portion near downtown and in the northern corridor of the city. In comparison, in 2000, the highest concentrations of vulnerability remained near the northern portion of the city. There were additional concentrations of moderate vulnerability for 2000, located in the western portion of Grand Forks and in the central corridor. Again in 2010, distinct pockets of high vulnerability for American Indians were located near the northern portion and downtown Grand Forks. It appears as though there has remained an overall moderate-high SoVI for American Indians; however, the areas with these SoVI values has shifted over the years.

Individuals of Asian descent were included in this study, and in 1990 the minimum SoVI value was 0.00, the maximum SoVI value was 0.45, and the mean was 0.04. Overall, there was no indication of high vulnerability for this time period. There were distinct areas with a moderate level of vulnerability (Appendix A), including a few block groups in the north-central portions of the city. In 2000 there was no account of high SoVI values for Asians. The minimum SoVI was 0.00 and the maximum SoVI value increased to 0.48, while the mean SoVI was 0.09. The concentrations of moderate vulnerability were concentrated in the central to north-central areas of Grand Forks. The lowest SoVI values were found near downtown Grand Forks. The 2010 SoVI data showed the greatest variation between low-high vulnerability of Asians. Specifically, the minimum SoVI value remained 0.00, however, the maximum SoVI value increased to 1.00 for 2010, with mean value remaining low at 0.06. The 2010 map (Appendix A) shows a distinct cluster of high vulnerability in the central and north-central portions of the city, with very little to none in the rest of the city limits.

The demographic characteristic of other races was analyzed to determine SoVI values and find concentrations of high vulnerability within Grand Forks. This demographic attribute, similar to other minority races, did not provide significant results, nor display much of a concentration of vulnerability within the city. This is simply because there is not a large minority population. Thus, in 1990 the minimum SoVI value was 0.00 and the maximum was 0.22, with a mean SoVI value of 0.04. Clearly, there was no areas of moderate-high vulnerability for 1990, as seen in Appendix A. The 2000 data was similar, with a minimum SoVI value 0.01 and a maximum SoVI value of 0.30. The mean SoVI was 0.07 for 2000. Again, no evidence was found of moderate-high vulnerability (Appendix A). All of the block groups display an extremely low vulnerability value. The 2010 SoVI map and data provides the greatest variation from low-high vulnerability. The minimum SoVI was 0.00 and the maximum value was 1.00. It is evident that there are distinct portions of Grand Forks where other races are classified as being highly vulnerable. These areas include portions of northern Grand Forks, the central corridor, as well as a few block groups in the southern portion of the city. The concentrations of low vulnerability are found in the southern portion of downtown Grand Forks and on the eastern edge of the city.

The Caucasian race was also included in this study since the majority of Grand Forks's population is of Caucasian descent. In 1990, the minimum SoVI value was 0.05, which increased slightly in 2000 to 0.10, and to 0.17 in 2010. The maximum SoVI value for 1990 was 0.46, indicating a moderate vulnerability on the high end of the spectrum and an average SoVI of 0.13. Areas with a moderate vulnerability were found near the central Grand Forks.

Concentrations of low vulnerability were found near, the northern and southern corridors, as well as eastern Grand Forks. In comparison, in 2000 the SoVI maximum value increased to 0.85 and the mean SoVI value increased two-fold to 0.26. By 2000 there was an overall increase in vulnerability of Caucasians. As indicated in the SoVI map of Caucasians (Appendix A), areas of high vulnerability are found near the central portion of Grand Forks and pockets of low-moderate vulnerability near downtown and the areas near the Red River of the North. Similarly, vulnerability of Caucasians in 2010 increased again to a maximum SoVI value of 1.00 and a mean SoVI value of 0.43. Concentrations of high vulnerability in 2010 were found in the southern portion of Grand Forks, along the eastern corridor, near the Red River of the North, as well as central portions of the city (Appendix A). Low-moderate vulnerability was found near downtown and in the northern portions of Grand Forks. Overall, vulnerability of Caucasians has increased over the years. Surprisingly, there were no areas prior to the 1997 flood that were considered to have a high vulnerability due to concentrations of Caucasians. However, this trend has changed and over the years the spatial distribution, as well as concentration of Caucasians has slowly contributed.

A majority of the demographic characteristics analyzed in this study has contributed to a continual increased in residual risk, and a consistent increase in vulnerability. While not every demographic characteristic contributes significantly to increasing social vulnerability, a few are especially prominent: Caucasian descent, females, total population, as well as housing units. Even though this study only evaluated SoVI values for three different time periods, this analysis provides a solid foundation for the City of Grand Forks to continue to assess and monitor demographic changes. It is also a valuable resource for local decision makers to use in assessing vulnerability within the city based on specific demographic data. Analyzing SoVI values over the course of twenty years provides unique insight to the social and demographic changes occurring over time in Grand Forks.

5.2 Composite Social Vulnerability Analysis

The composite social vulnerability map of 1990 (Figure 5) displays more than five census block groups with a high vulnerability. In this case, five characteristics contribute to the high vulnerability results: individuals 25 years and older without a high school diploma, elderly, individuals of American Indian race, median household value, and household incomes $75,000 and greater. Each of these demographic characteristics had at least one block group for 1990 that had a composite social vulnerability score of 0.5-1. There are three distinct clusters where individuals are classified as moderate-high vulnerability, as seen by the 1990 composite social vulnerability map. The block groups with the highest vulnerability are situated along the southeastern portion of the Grand Forks city limit, central Grand Forks (near the University of North Dakota and main clusters of residential housing), as well as portions of downtown. The vulnerability throughout downtown Grand Forks varies from block group to block group, with an area closer to the historic district displaying a higher vulnerability. The composite social vulnerability data for 1990 has a minimum value of 1.09, a maximum value of 3.41, with a mean value of 2.15.

The composite social vulnerability map of 2000 (Figure 6) displays a significant change in the number of block groups with high vulnerability. Specifically, there are over 10 block groups with moderate-high vulnerability. Several characteristics contribute to the moderate-high vulnerability; the most influential being median household value, followed by individuals 25 years and older without a high school diploma, household incomes $75,000 and greater, females, individuals of Caucasian race, population, individuals of American Indian race, housing units, and renter occupied housing. Portions of southeastern Grand Forks have high levels of vulnerability, as well as central Grand Forks, and portions of downtown. There are three distinct block groups in downtown Grand Forks near the river that display a high vulnerability in 2000. There also appears to be a moderate-high vulnerability for portions of western, northern, and southern block groups of the city. In comparison to 1990, the 2000 composite social vulnerability map has a wider range of vulnerabilities, with a minimum value of 1.32, and the maximum composite social vulnerability score of 8.47, and a mean value of 2.90. Overall, it appears as though the composite social vulnerability of Grand Forks increased from 1990-2000.

The composite social vulnerability map for 2010 (Figure 7), shows a significant variation in high vulnerability for a majority of the block groups situated along the Red River of the North. It appears as the majority of block groups with a high vulnerability are located either in central and southern Grand Forks. There are a few distinct pockets near downtown Grand Forks that indicate a moderate-high vulnerability. The low vulnerability block groups are mainly near downtown Grand Forks or along the eastern portion of the city. Every demographic characteristic analyzed in this study displayed at least one time with a high vulnerability value. However, the characteristics that contribute the most in 2010 include: individuals of Caucasian race, females, renter occupied housing, housing units, as well as the total population. Similar to 2000, there is a wide span of composite social vulnerability scores for 2010. The minimum value is 1.63 and the maximum value is 8.20, with a mean value of 3.68.

The spatial distribution within each of the composite social vulnerability maps and a comparison of all three maps over time reveals that social vulnerability shows complex and variable patterns over time. It is evident that there are a variety of demographic characteristics that explain the social and composite social vulnerability of Grand Forks from 1990-2010.

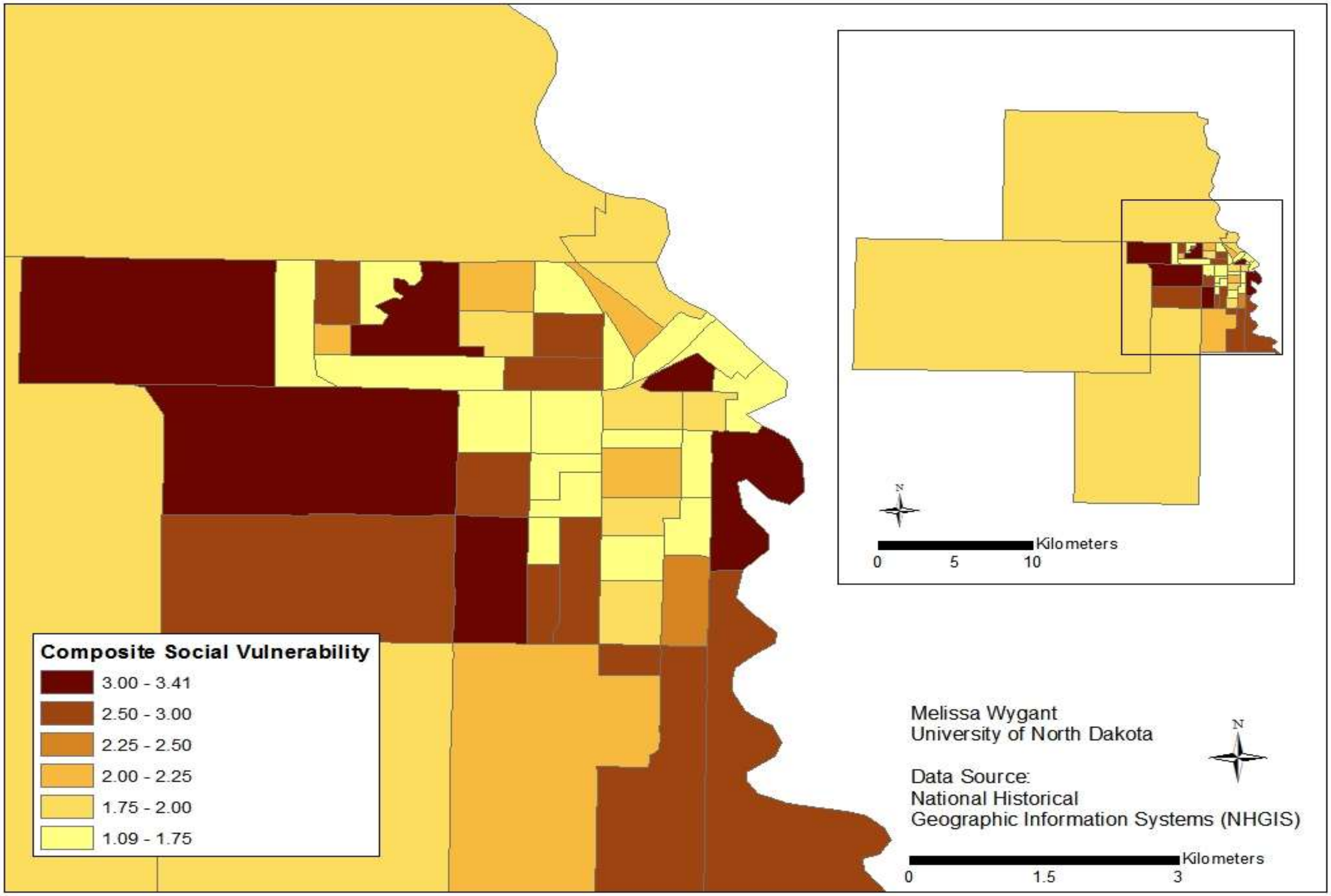

Figure 5: Composite social vulnerability of Grand Forks, North Dakota, 1990.

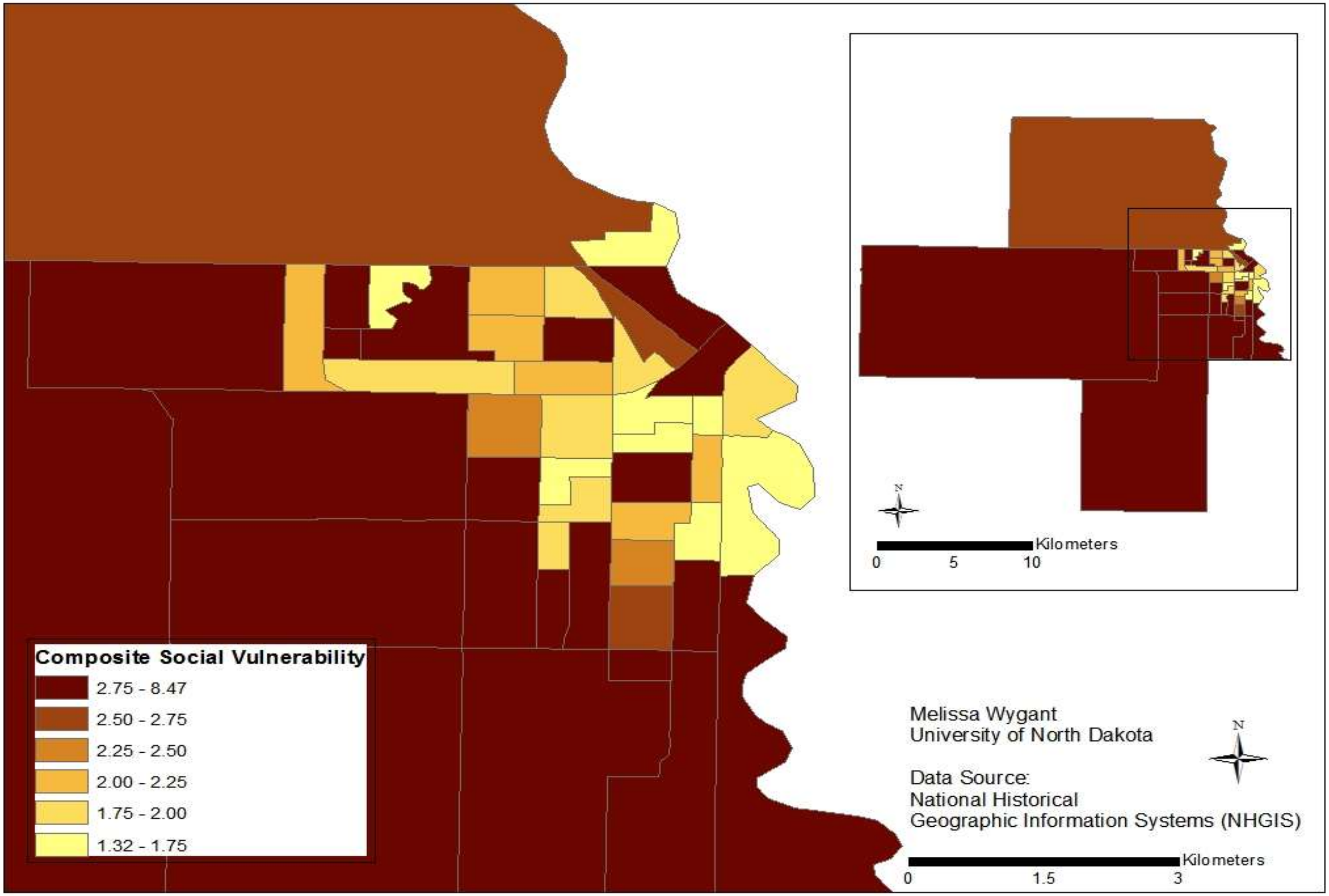

Figure 6: Composite social vulnerability of Grand Forks, North Dakota, 2000.

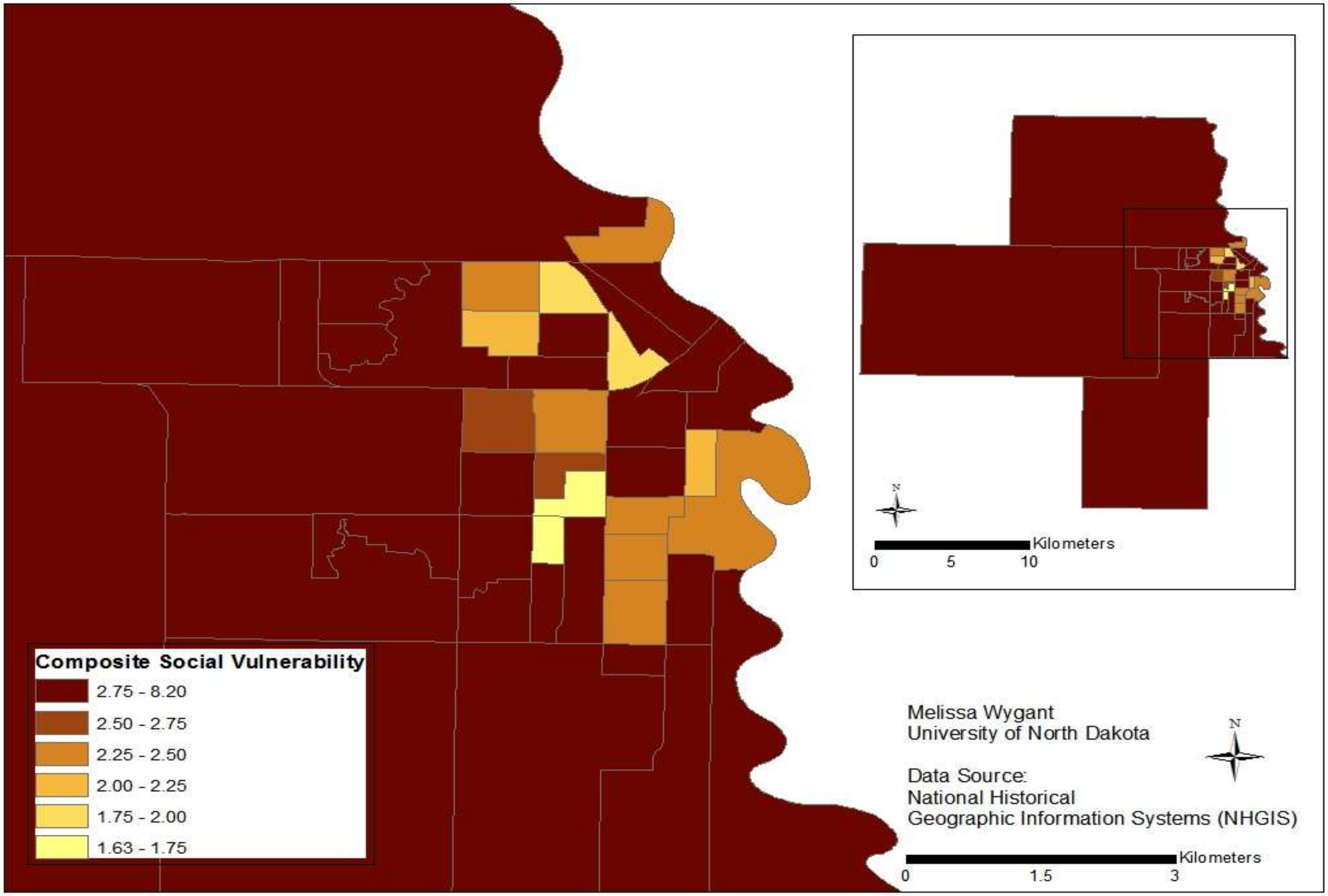

Figure 7: Composite social vulnerability of Grand Forks, 2010.

5.3 *Biophysical Vulnerability Analysis*

The biophysical risk maps (Figure 8 and Figure 9) display the flood risk probabilities and risk for Grand Forks during from 1990-2009 and 2010-present. The first map, in effect prior to the 1997 flood, displays the 1989 FIRM. The second displays the 100-and 500-year floodplain as of the latest approved FIRM for Grand Forks in 2010. The sources for the biophysical risk data are the 1989 and the 2010 FIRMS. The areas with the highest probability of flood risk for 1990-2009 were near downtown Grand Forks and residential communities closest to the Red River of the North. It is also evident that the 100-year floodplain for 1990-2009 was much wider than the 2010-present floodplain. The 1990-2009 floodplain incorporated areas within the historic district, the Lincoln Park neighborhood and other neighborhoods closer to the central portion of Grand Forks. The 100-year floodplain for 1990-2009 also included residential communities in the southeastern portion of the city. The second map in Figure 9, displays the current flood risk for the City of Grand Forks, as officially established in 2010. Again, neighborhoods near the Red River of the North are considered part of the 100-year floodplain; with the exception of the former Lincoln Park neighborhood, which is now classified as open green space. Also, the 100-year floodplain extends into portions of downtown and central Grand Forks. While the majority of Grand Forks's city limits may never have been within the 100-year floodplain and continue to not be within this zone, the majority of the city is located within the 500-year floodplain. It is critical that individuals who decide to reside within these specific flood zones understand the consequences of flooding regardless of the levee system that is in place and other structural solutions the city has developed over the years.

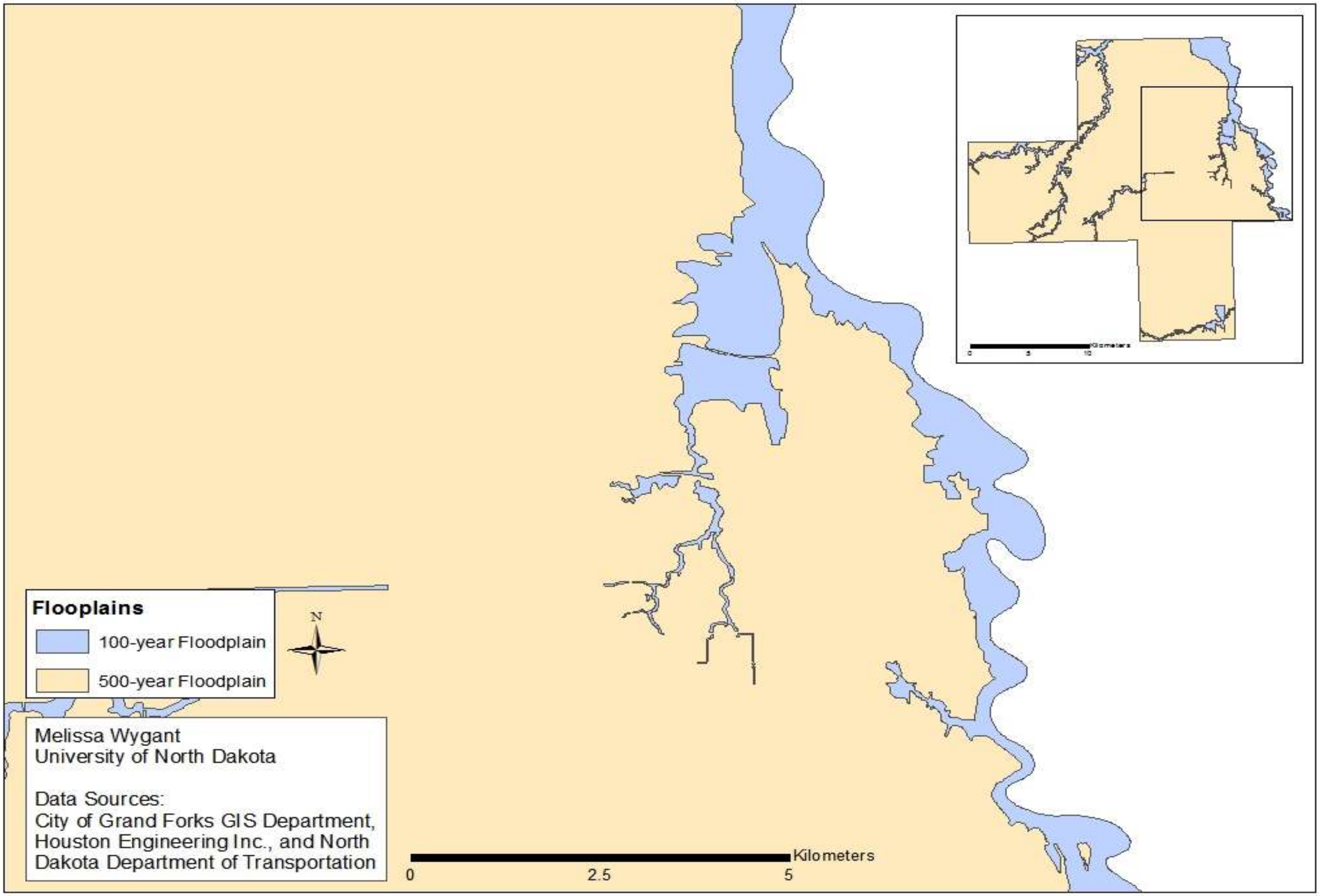

Figure 8: Biophysical vulnerability in Grand Forks, North Dakota, 1990-2009.

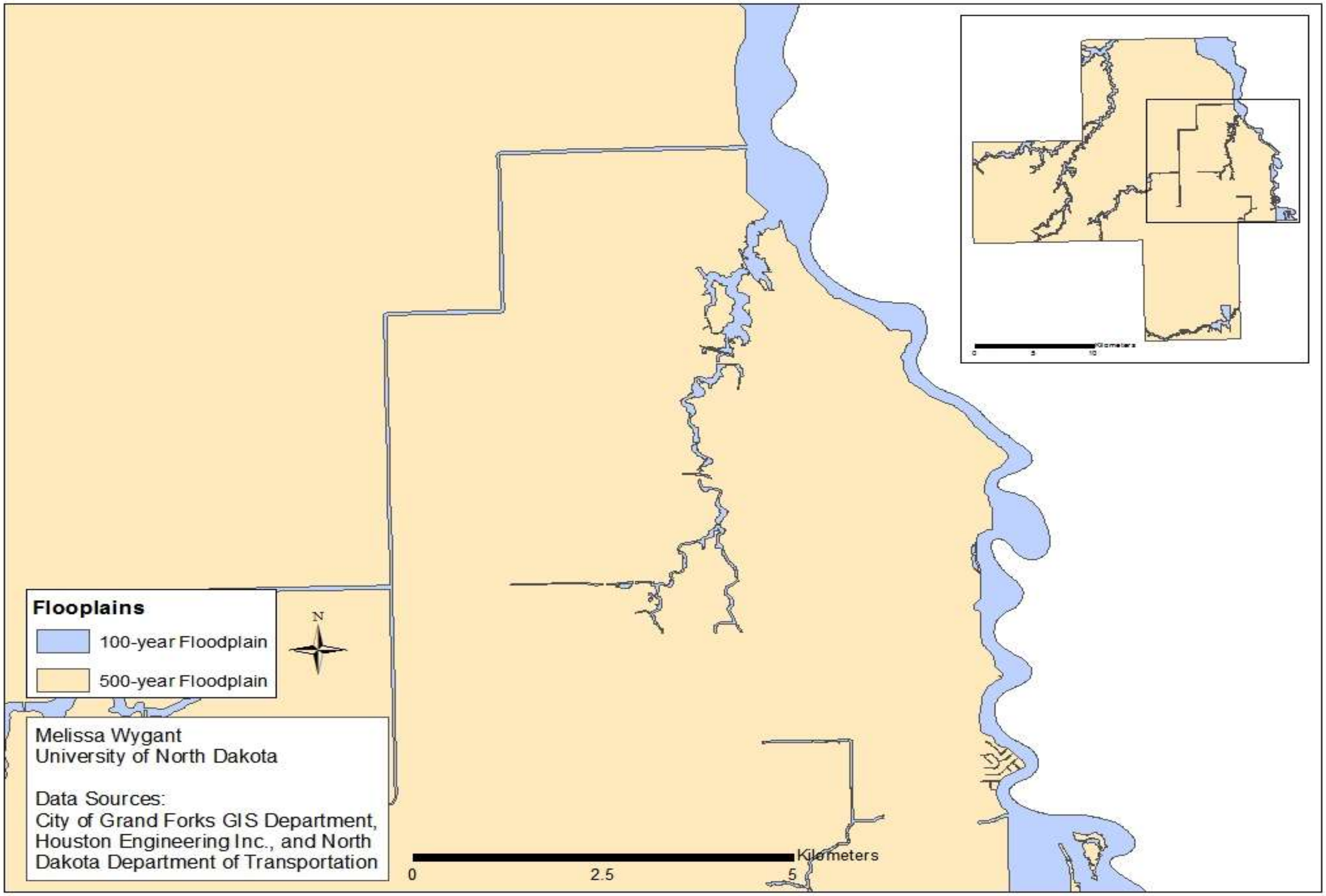

Figure 9: Biophysical vulnerability in Grand Forks, North Dakota, 2010-present.

5.4 Place Vulnerability Analysis

The place vulnerability map of flood risk for 1990 indicates a moderate value of place vulnerability for all of Grand Forks (Figure 9). The majority of the block groups in the moderate range were found in the eastern, western, as well as central portions of the city. Block groups near the river had the highest value of place vulnerability. However, even though these portions had higher values, the amount of vulnerability measured was nowhere as high as the other years analyzed. Low values of place vulnerability were found throughout portions of downtown Grand Forks, especially in areas where there were more businesses than residential neighborhoods. The place vulnerability scores for 1990 ranged from a minimum score of 0.002 to a maximum score of 0.034. The average place vulnerability score was 0.012.

The place vulnerability results for 2000 indicate an increase in place vulnerability in comparison to 1990 (Figure 10). Specifically, portions of the old floodplain consistently had higher place vulnerabilities values. Central Grand Forks had a mix of moderate-high place vulnerability scores in 2000. The range between low-high place vulnerability nearly tripled from 1990 to 2000. The minimum place vulnerability value was 0.003 and the maximum value was 0.085. The average place vulnerability value was 0.022 during this time period. It appears that, while the majority of the city appeared to continue to have moderate levels of place vulnerability in 2000, there still were distinct areas within the city that had a high place vulnerability, much higher than in previous years. The 2010 place vulnerability map of flood risk shows the changes in risk and vulnerability following the certification of the levee system (Figure 11). As a result, areas closest to the river saw an increase in place vulnerability. While portions of downtown Grand Forks either remained unchanged in place vulnerability or slightly increased. Portions of central and southern Grand Forks had a moderate place vulnerability value for 2010. Areas of moderate-high place vulnerability are found near the streams in the western portions of the Grand Forks city limits. Also, the entire newly updated floodplain is still classified as having a high place vulnerability value; however, the aerial extent is much smaller. The minimum value of place vulnerability was 0.003, the maximum was 0.081, and the average place vulnerability value was 0.03 in 2010. Thus, this analysis indicates that as of 2010, the maximum value for place vulnerability of flood risk in Grand Forks reduced slightly since 2000.

It is evident that the overall place vulnerability increased from 1990-2000 and then decreased slightly from 2000-2010. Portions of Grand Forks especially those near the river have experienced the greatest shift in flood risk and vulnerability. This could be a result of the various structural solutions, mitigation strategies, and strategic land-use planning that has occurred since the 1997 flood and certification of the levee system. However, even though the level of risk and vulnerability has been slightly reduced from 2000-2010, it is still important to assess changes in place vulnerability, and to pay attention to any significant shifts in demographic characteristics and development within the City of Grand Forks.

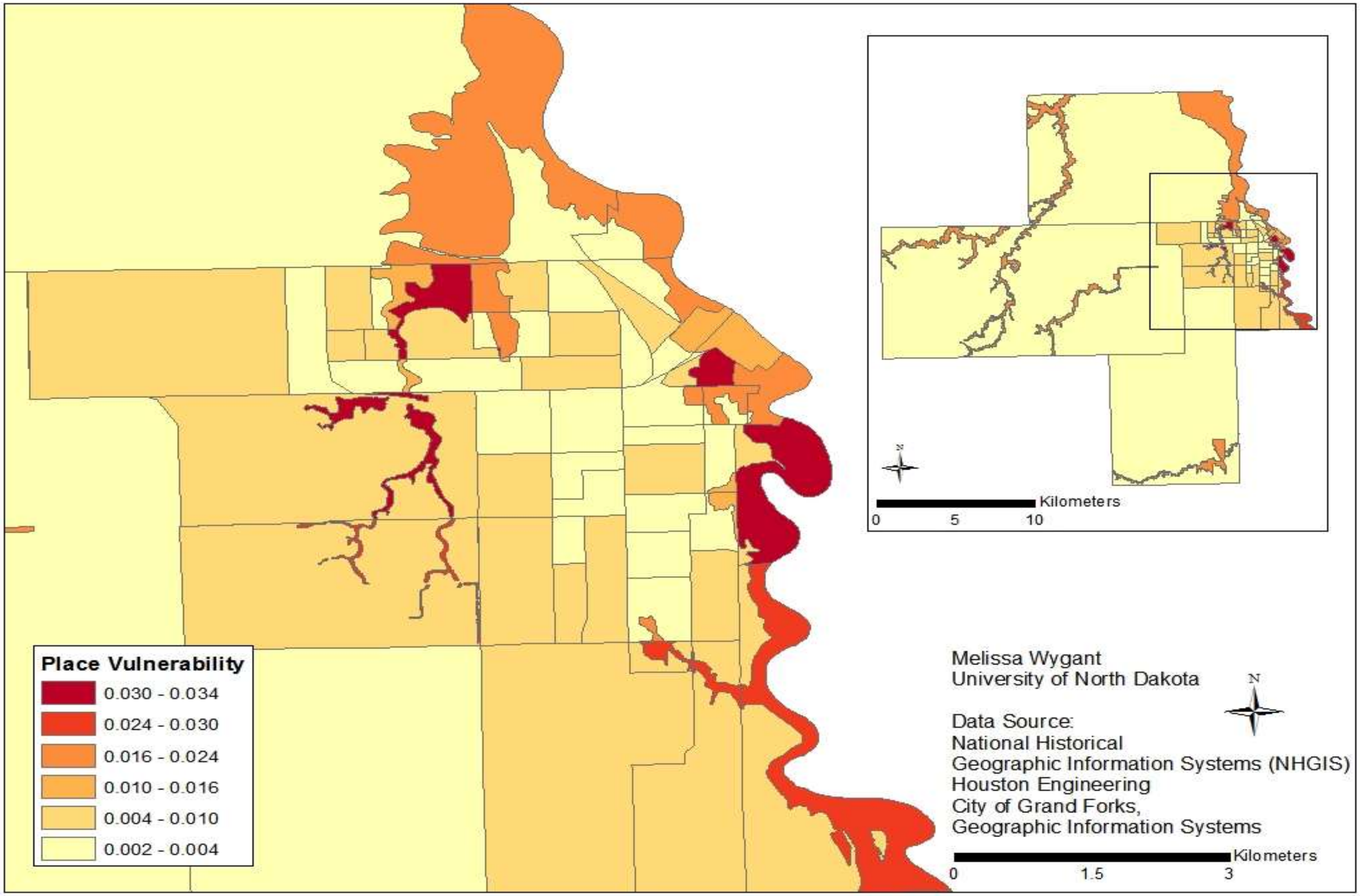

Figure 10: Place vulnerability analysis of Grand Forks, North Dakota for 1990.

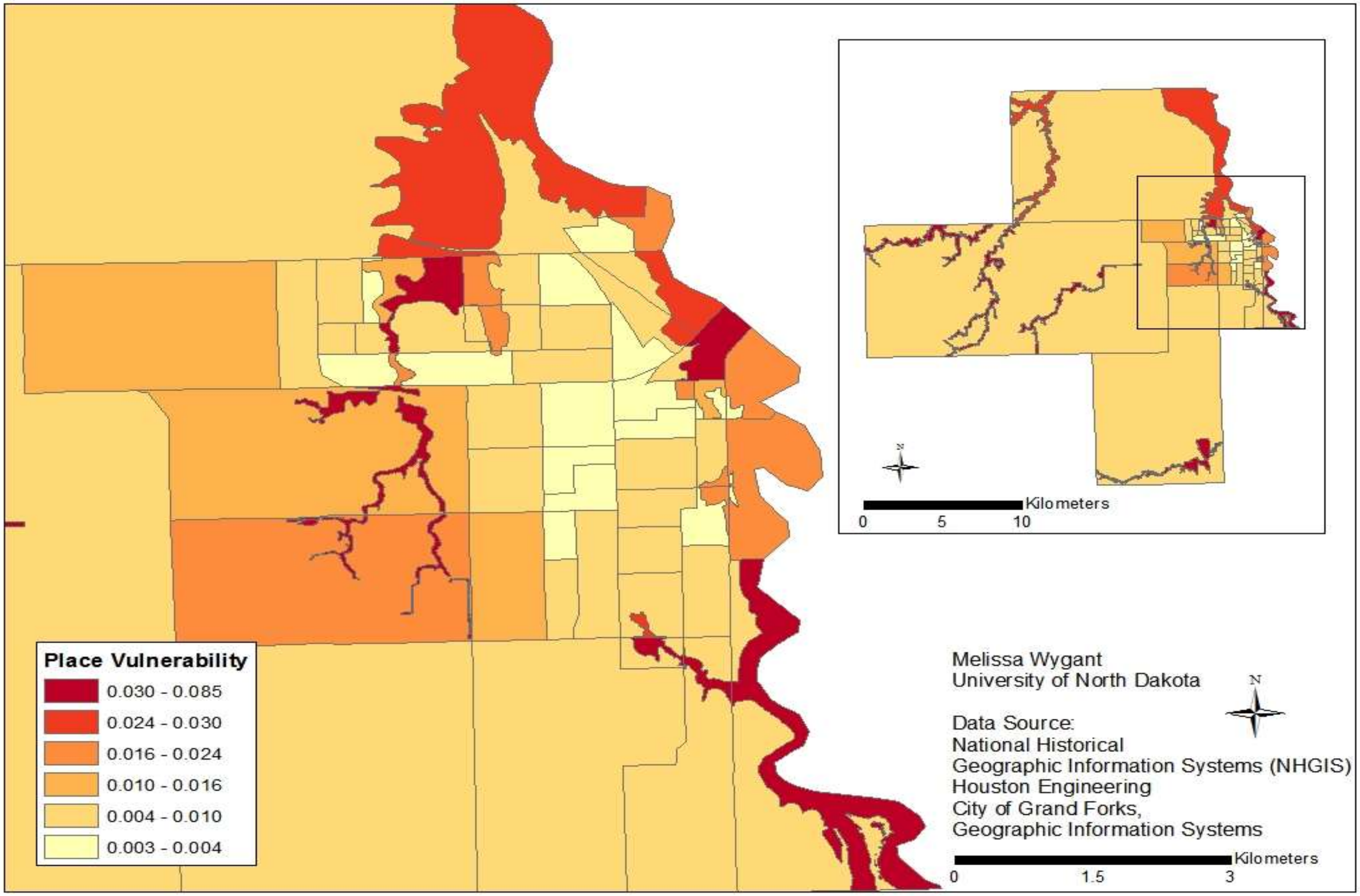

Figure 11: Place vulnerability analysis of Grand Forks, North Dakota for 2000.

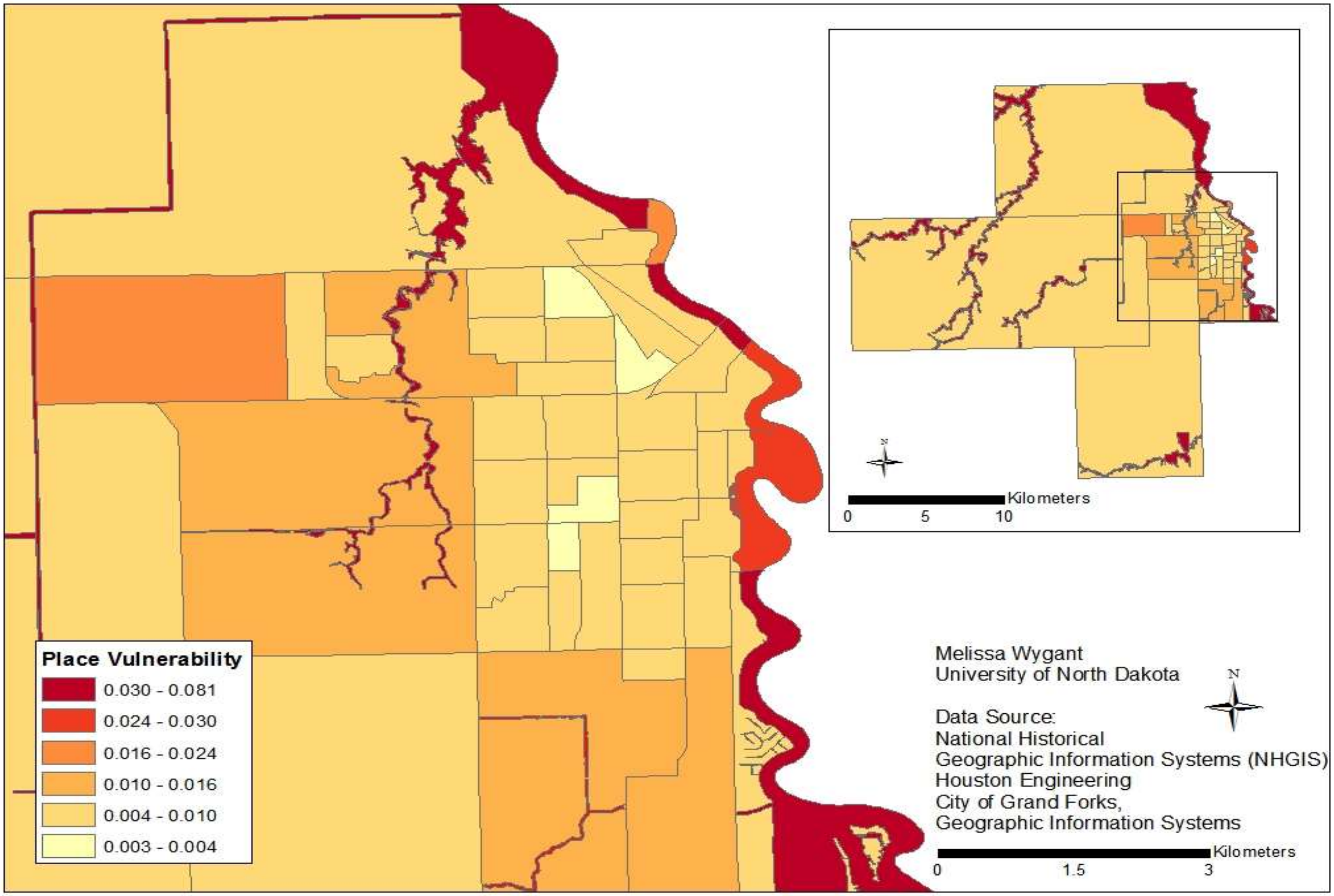

Figure 11: Place vulnerability analysis of Grand Forks, North Dakota for 2010.

5.5 Aerial Interpolation and Demographic Assessment

The City of Grand Forks has seen an increase in population from 1990-2010. As indicated by Figure 13, in 1990 there were 52,245 persons, in 2000 there were 52,610 persons, and in 2010 there were 56,209 persons. This increase can be linked to increases in economic opportunity, recruitment by the local community college and university, as well as increases in the minority population due to refugee settlement.

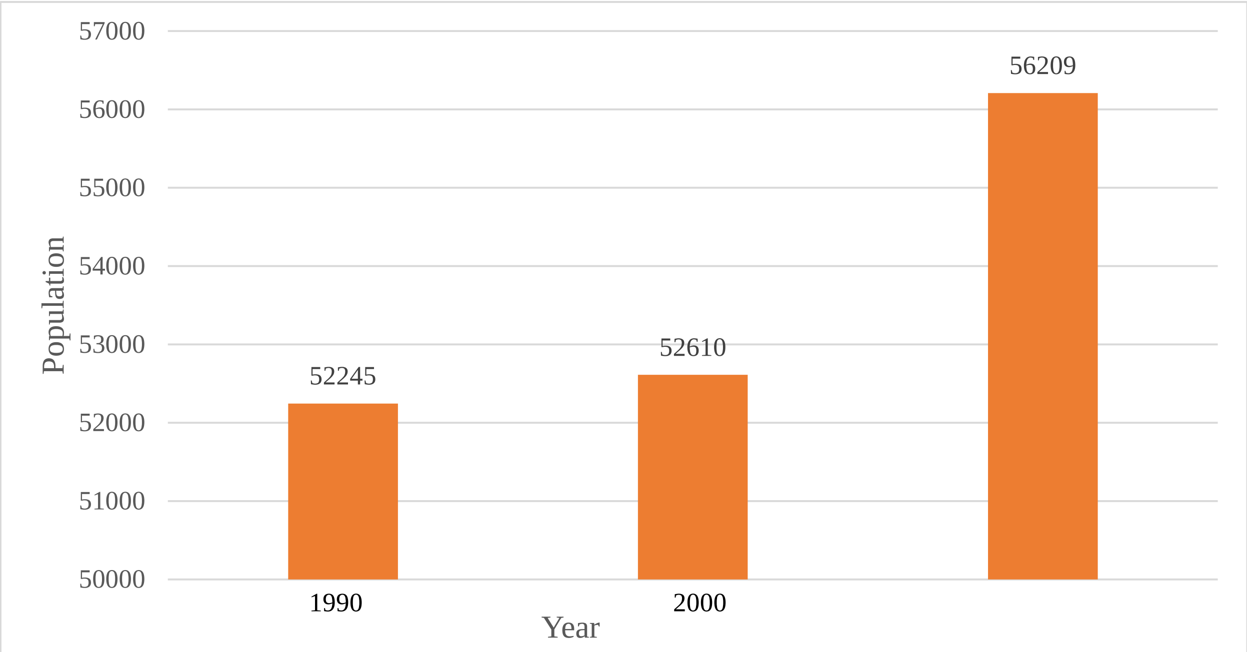

Figure 13: Population change in Grand Forks, North Dakota, 1990-2010.

The aerial interpolation indicated that there has been a decrease in the number of individuals residing within the 100-year floodplain over the 20-year period. As shown in Figure 14, 8,978 persons resided within the floodplain in 1990, 7,171 persons in 2000, and 3,474 persons in 2010. The Lincoln Park and Central Park communities, and much of the Riverside Park community were destroyed in the 1997 flood, and those individuals were bought out by FEMA and removed from the floodplain. In contrast, there has been an increase in the number of individuals residing within the 500-year floodplain (Figure 15). In 1990, 43,194 persons resided in the 500-year floodplain. This increased to 45,393 persons by 2000, and by 2010 there was an increase in the number of individuals residing in the 500-year floodplain to 52,735 individuals. A majority of Grand Forks's development since the 1997 flood has occurred in the southern portion of the city. However, there are pockets near the certified levee that have been filled in since the 1997 flood. These residential areas consist of relatively affluent residents and expensive housing. Even though there has been a distinct decline in the number of individuals residing within the 100-year floodplain, there continues to be substantial residual risk. Thus, even though risk has been reduced, if there were to be a catastrophic flood, the economic losses would be immense.

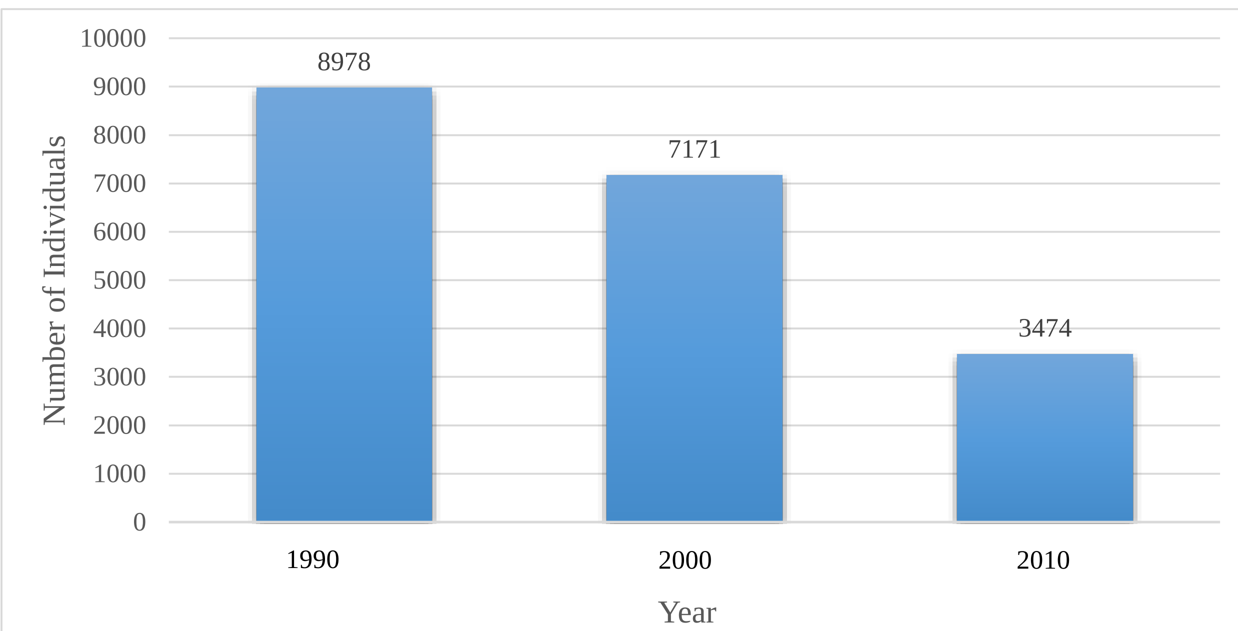

Figure 14: Individuals residing within the 100-year floodplain, 1990-2010.

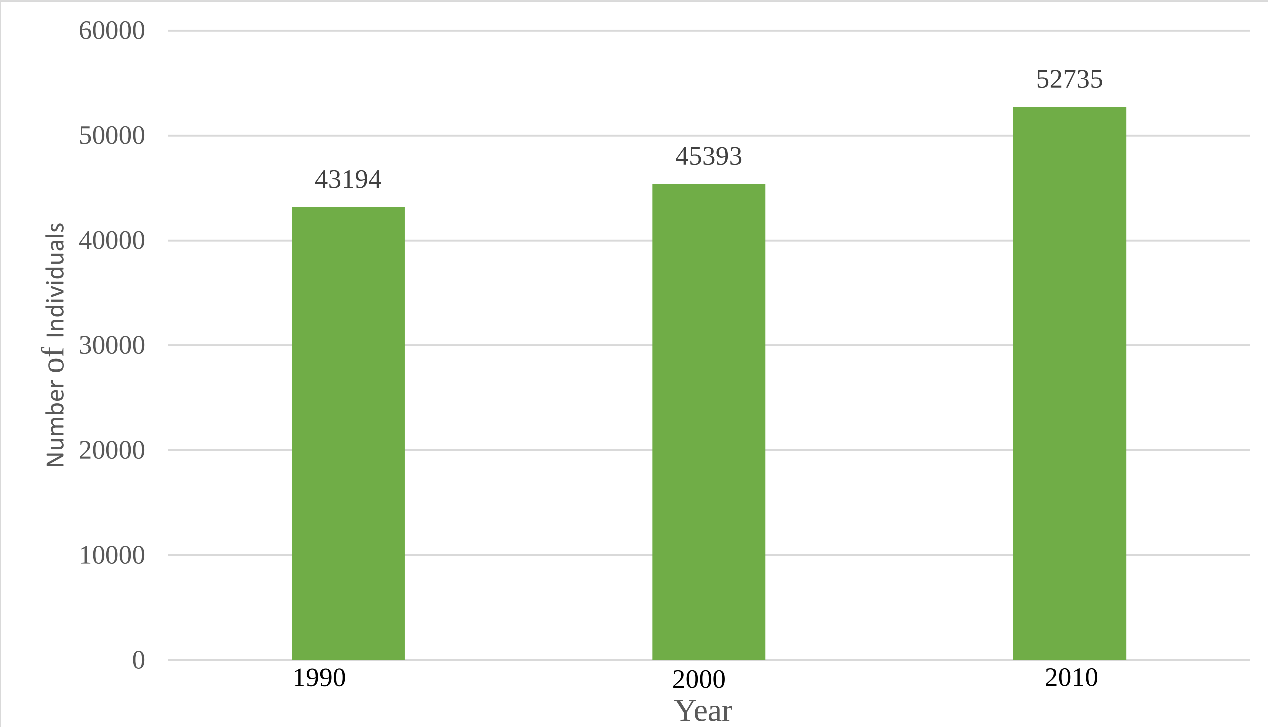

Figure 15: Individuals residing within the 500-year floodplain, 1990-2010.

The total number of housing units by block group and the total population by block group were also analyzed for this study. A housing unit is defined as "a house, an apartment, a mobile home, a group of rooms, or a single room that is occupied (or if vacant, is intended for occupancy) as separate living quarters" (U.S. Census Bureau). In 1990, the number of housing units ranged from 212-963 units per block group. Areas within the city that had the most housing units in 1990 included portions of central and southern Grand Forks. Portions of downtown Grand Forks had a medium-high account of housing units, as seen in Figure 16. In 2000, as seen in Figure 17, the greatest number of housing units remained in the central portion of the city, and there was an increase in the number of housing units in the western and southern portions of Grand Forks. The range of housing units in 2000 was 148-1810. One block group on the eastern portion of Grand Forks, near the Red River of the North is drastically fewer in housing units in

2000 than in 1990. This is the area where the former Lincoln Park neighborhood used to be, and which were bought out by FEMA and designated as uninhabitable. The downtown housing unit density for 2000 was comparable to 1990, with pockets of low-high housing units. Figure 18 shows a large increase in the number of housing units for the southern and central portions of Grand Forks in 2010. Also, areas near eastern Grand Forks have a higher number of housing units in 2010 than in 2000. This map reflects a gradual infilling of development as individual homeowners migrate back to the old floodplain. The overall range of housing units for 2010 is higher than the other two years analyzed. The number of housing units ranges from 258-1545.

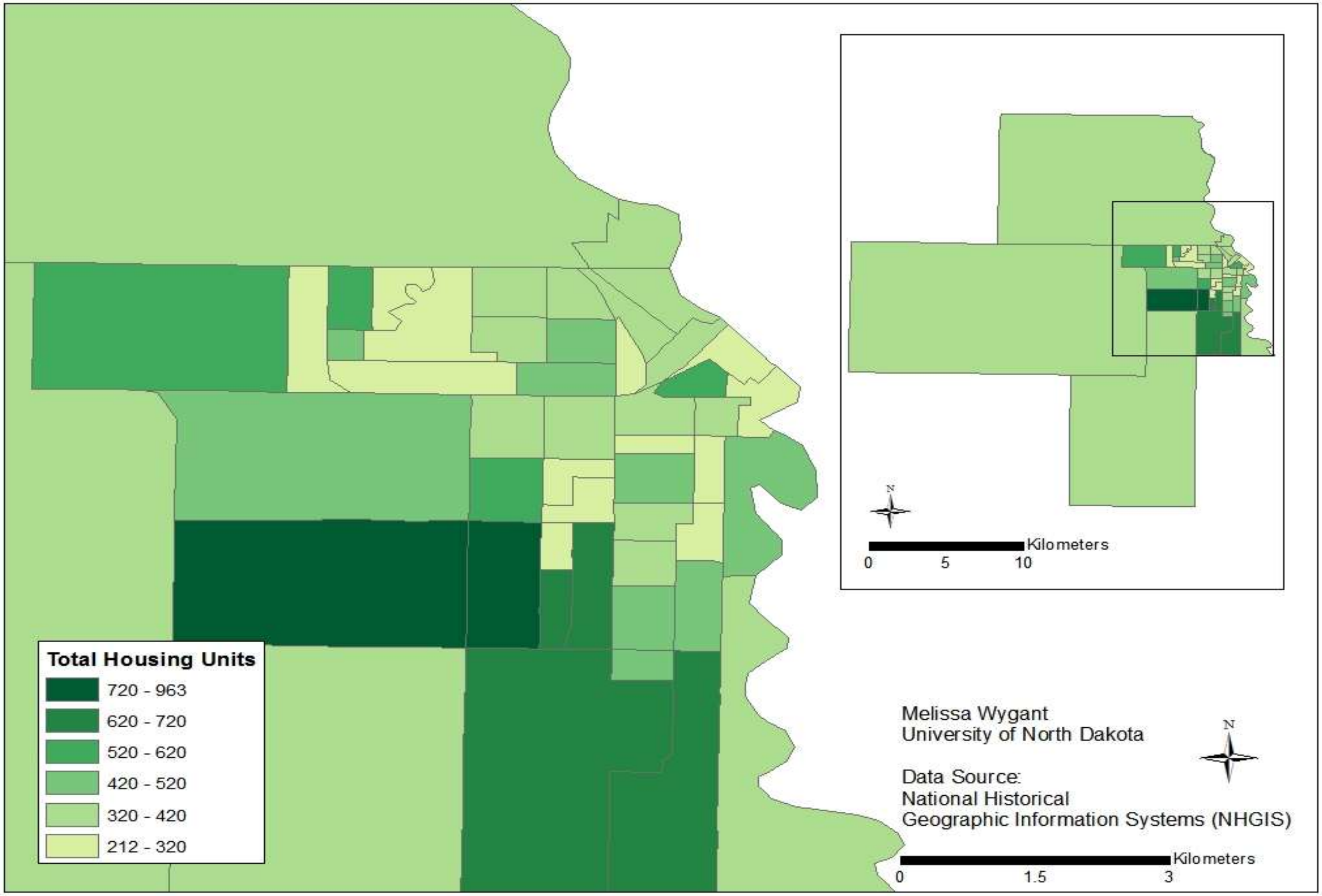

Figure 16: Total housing units for Grand Forks, North Dakota, 1990.

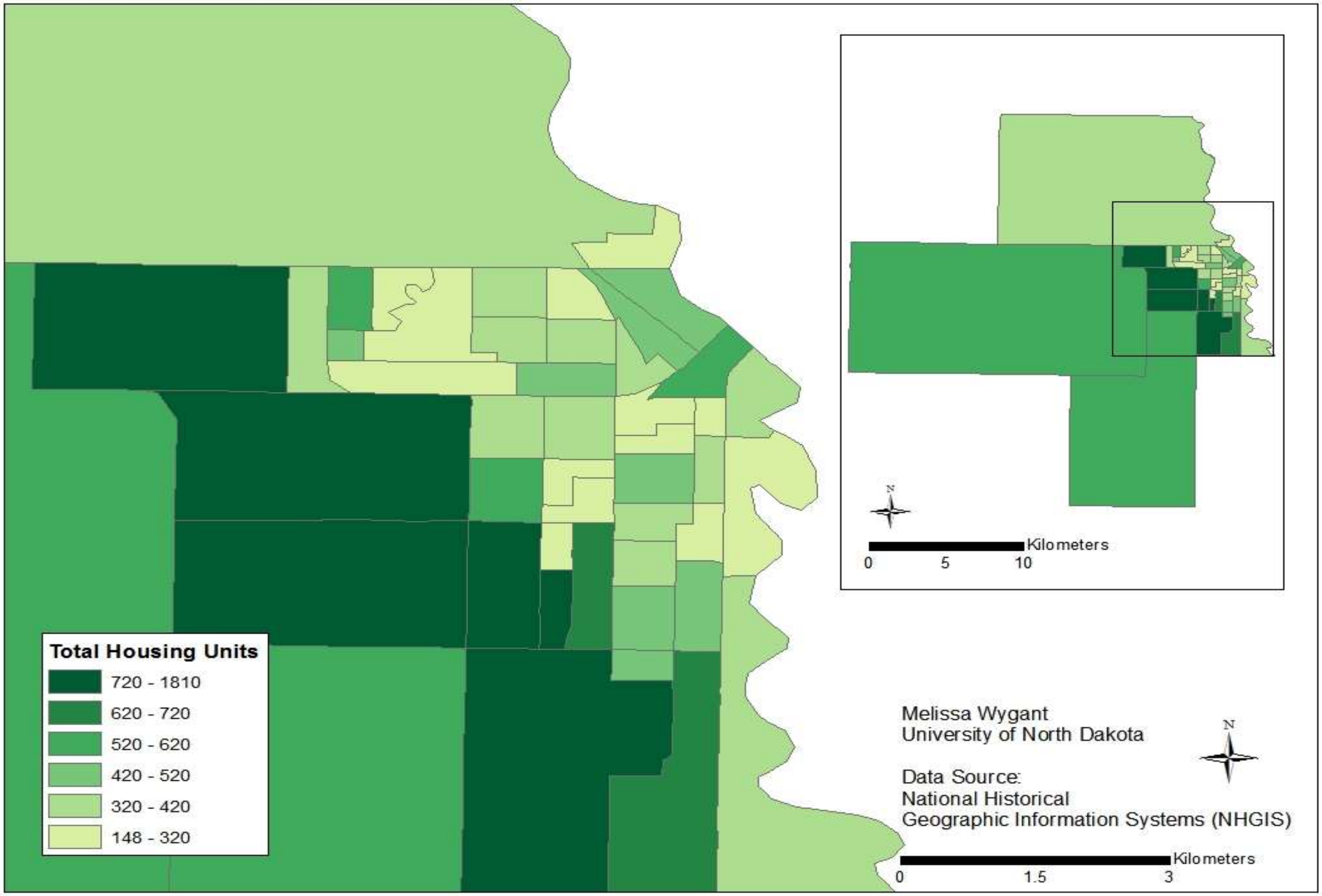

Figure 17: Total housing units for Grand Forks, North Dakota, 2000.

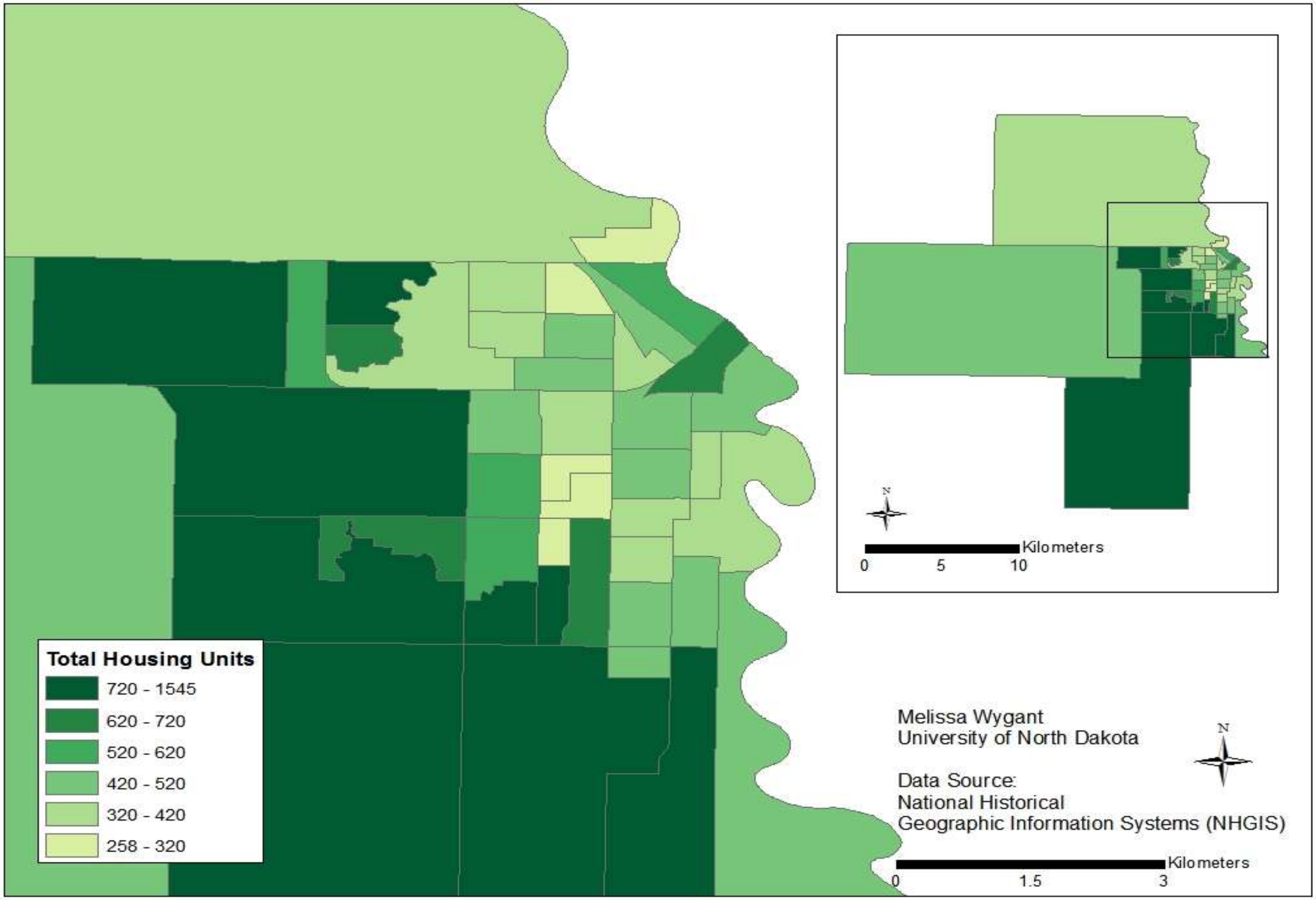

Figure 18: Total housing units for Grand Forks, North Dakota, 2010.

In addition to the number of housing units, the total population provides a dynamic interpretation of population density, and the spatial and temporal changes occurring over the study period. In 1990 (figure 19), the majority of individuals were located in the western, central, and southern portions of Grand Forks. Pockets of eastern Grand Forks also have moderate levels of population density. In 2000, there is an increase in population per block group. Specifically, highest concentrations of population are found in central Grand Forks. There is also an increase in population for parts of southern Grand Forks, as seen in Figure 20. By 2010, a majority of the total population of Grand Forks reside in the southern portion of the city and in central Grand Forks. In 2010, a few areas of downtown Grand Forks continue to exhibit population growth (Figure 20).

Overall, the total population and total housing unit analysis reaffirm the growth that has been occurring throughout Grand Forks over the past 20 years. The majority of housing has mostly been occurring in the southern and central portions of the city. However, there are subtle indications that individuals are once again moving back to areas in the old floodplain that are close to the river

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Figure 19: Total population for Grand Forks, North Dakota, 1990.

Figure 20: Total population for Grand Forks, North Dakota, 2000.

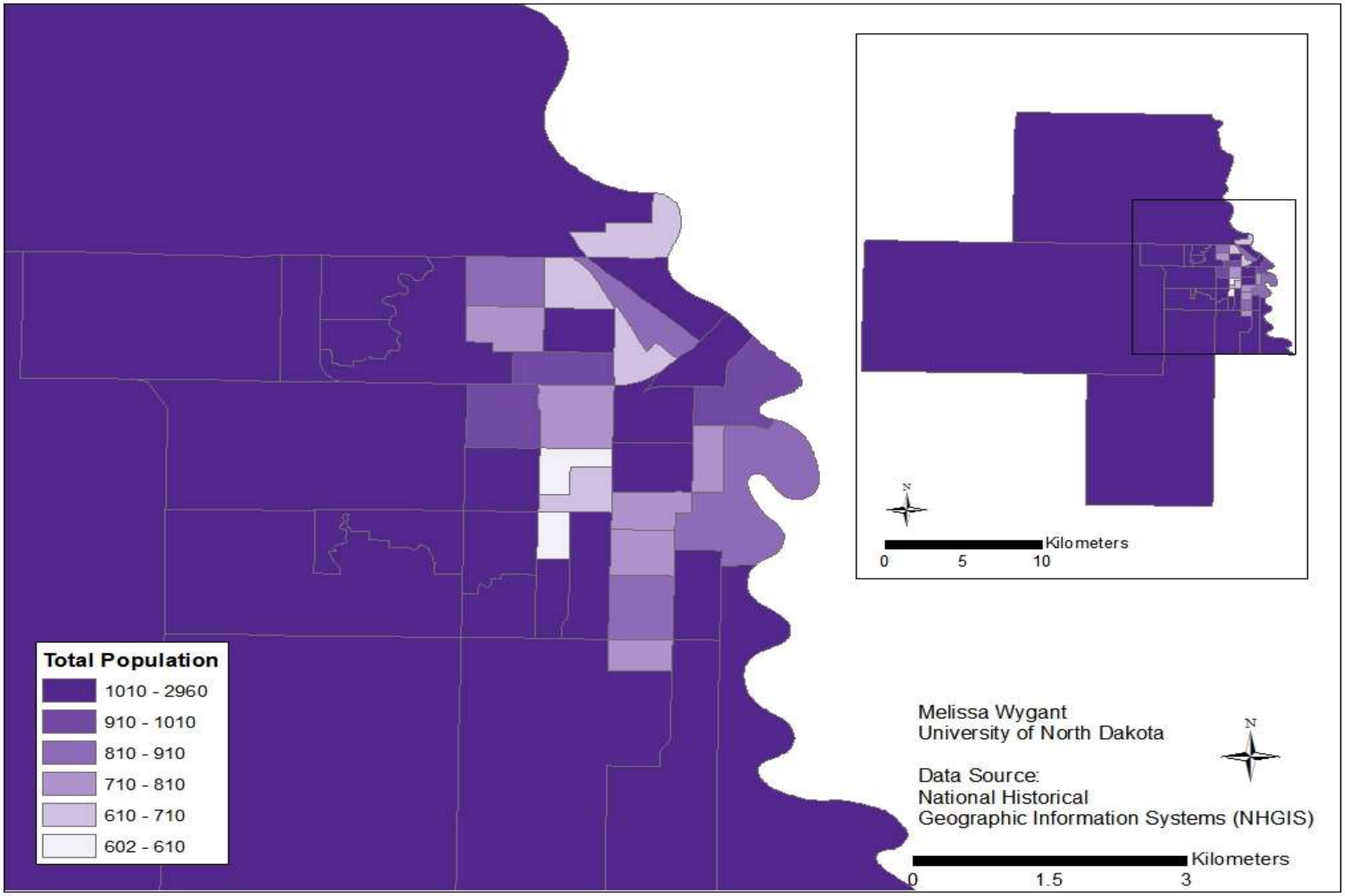


Figure 21: Total population for Grand Forks, North Dakota, 2010.

5.6 Critical Limitations of Methods

It is important to mention the limitations of the methods used for this study and how it impacted the results. Specifically, it is essential to note that the social and composite social vulnerability analysis did not account for all vulnerable populations. The analysis only included fourteen demographic characteristics, in comparison to other place vulnerability studies which have used over twenty different demographic characteristics. Also, an additional demographic characteristic was added to the SoVI scores that has not been included in other place vulnerability studies— Caucasian race. Some hazard researchers could argue that this demographic characteristic was not appropriate to add simply because it is not considered to be an indicator of vulnerable populations. However, who is to say that one population is more vulnerable than another population? During a catastrophic hazard such as flooding, any individual could be at risk for loosing property or their life if precautions are not taken. However, a place vulnerability analysis is one of the preferred methods of analyzing risk and vulnerability within the natural hazards research community. This methodology does provide a baseline for emergency responders and local decision makers to use to determine preparedness and mitigation strategies.

Also, while the manual classification scheme applied to social vulnerability, composite social vulnerability, place vulnerability, total housing units, as well as total population maps allowed variables to be compared with each other between the years, it did not provide the best visual representation of low-high vulnerability. In some instances, the darkest color gradient represented a range of values that were not classified as high vulnerability, but rather low-high vulnerability. As a result, some of the social vulnerability maps visually misrepresented the data and appeared to show the entire city as vulnerable for that given characteristic when it was clear that the entire city was not vulnerable. This issue was a result of a wide range of values between each time period. More specifically, often variables analyzed for 1990 had significantly lower values then in 2000, and 2010. Various weighting techniques could improve upon this issue if further analysis was done.

It is evident that there are some limitations to applying a place vulnerability analysis to a given city in order to determine areas most vulnerable. However, the limitations are outweighed by the positive contributions this analysis does, specifically aiding local decision makers with critical information to improve their best management practices. This study also provides timely and essential geospatial data for the City of Grand Forks to use in future floodplain mitigation and management.

CHAPTER VI

CONCLUSION

This study provides a dynamic spatial and temporal analysis of flood risk for Grand Forks, North Dakota. It demonstrates that a place vulnerability framework can be used to examine flood risk and vulnerability for a non-coastal community with a smaller population. GIS can be used successfully to determine natural hazard risk and vulnerability.

The place vulnerability analysis produced the anticipated results. There has been a gradual increase in place vulnerability of flood risk from 1990-2000 and a slight decrease from 2000-2010; this suggests that various structural and non-structural strategies have been helpful in reducing flood risk. However even though flood risk and vulnerability have been addressed through these solutions, specific areas of Grand Forks are still susceptible to flooding in spite of extensive floodplain management. It is evident that there will continue to be residual risk as long as residents of Grand Forks live within the 100-year floodplain and 500-year floodplain. Also, as more individuals migrate to Grand Forks for economic opportunities or educational purposes, social factors could increase social vulnerability and place vulnerability. This study meets all of the research objectives, indicating that GIS can be used for natural hazard analysis. The results of this study will be helpful for local decision makers who deal with flood hazards on an annual basis.

Prior to this study, there was very little data on flood risk and vulnerability within the Grand Forks community; especially using georeferenced spatial data. Flood risk information was initially difficult to obtain, which was quite surprising considering the history of flooding in

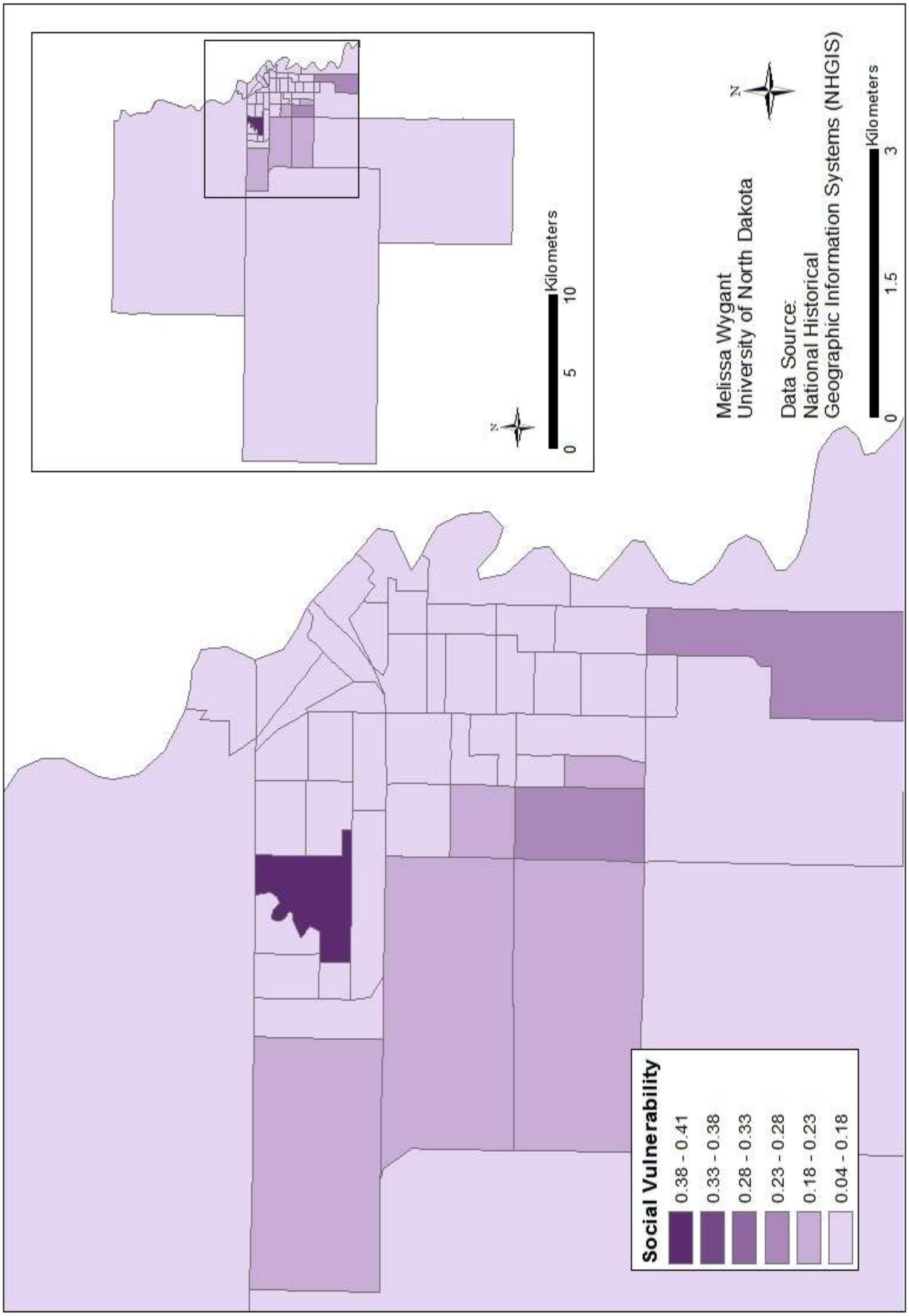
Grand Forks. There were no digital copies available of historic FIRMS from FEMA, and it was extremely difficult to obtain a paper copy of the original FIRMS prior to the 1997 flood. In addition, the GIS Department in Grand Forks lacks useful historic and current floodplain data. The files that were available from the GIS Department in Grand Forks were of poor quality. Most of the data included missing data points, gaps, and poor construction of polylines. The poor quality of the geospatial data made it extremely difficult to finish the place vulnerability analysis. Several geospatial techniques were required to clean up the floodplain data.

GIS can be incorporated into natural hazard analysis and provides helpful preparedness, mitigation, response, and recovery information for local decision makers. It is extremely helpful to update floodplain boundaries and to better understand distribution of various socioeconomic populations. As flood hazards continue to occur within the Grand Forks community over the years, local decision makers will be even more prepared to address the needs of vulnerable populations and control land-use planning. It is essential that local decision makers express the continued residual flood risk that is prevalent in Grand Forks. If not, individuals in the community will continue to become quite comfortable with current mitigation strategies and no longer believe that there is still the possibility for future flooding and catastrophic flood loss. Educational outreach will be a key to spreading the word about flood hazards.

For future studies, it is important to continue to maintain and update the current place vulnerability maps. As Grand Forks continues to expand, it will be interesting to see the various changes in demographics and land-use in the coming 10-20 years. Also, it would be important to extend this study through qualitative methods, analyzing perceptions of the flood risk from the past and present through interviews and surveys. Further analysis of social vulnerability would be beneficial, specifically examining changes in race, age, and gender. Regardless of the methods, there needs to be continued monitoring of flood risk and vulnerability in Grand Forks.

APPENDIX

Appendix A-Social Vulnerability Maps



Appendix A1: Social vulnerability of females in Grand Forks, North Dakota, 1990.

Appendix A2: Social vulnerability of females in Grand Forks, North Dakota, 2000.

Appendix A3: Social vulnerability of females in Grand Forks, North Dakota, 2010.

Appendix A4: Social vulnerability of elderly in Grand Forks, North Dakota, 1990.

Appendix A5: Social vulnerability of elderly in Grand Forks, North Dakota, 2000.

Appendix A6: Social vulnerability of elderly in Grand Forks, North Dakota, 2010.

Appendix A7: Social vulnerability of children under five years of age in Grand Forks, North Dakota, 1990.

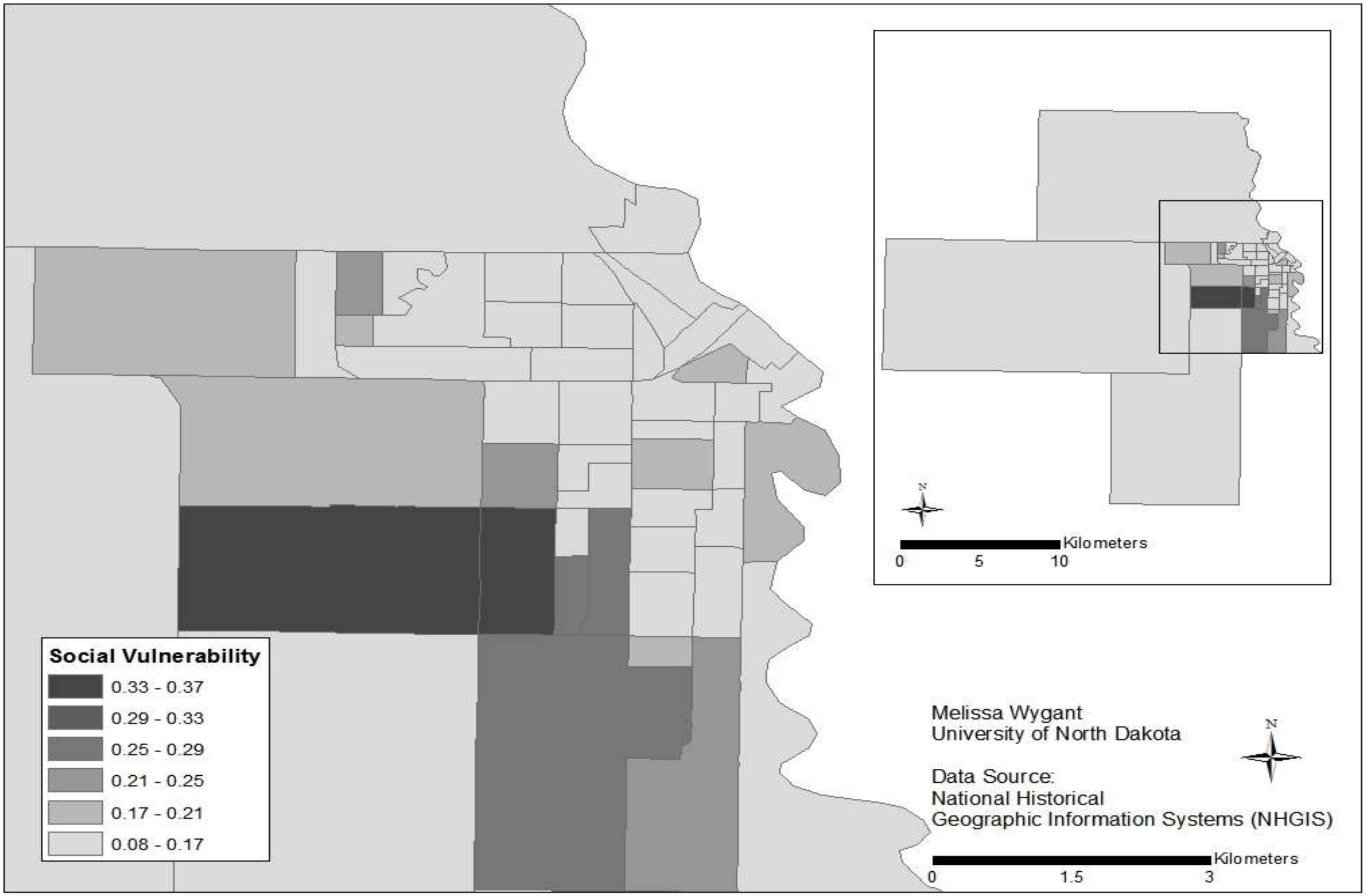
Appendix A8: Social vulnerability of children under five years of age in Grand Forks, North Dakota, 2000.

Appendix A9: Social vulnerability of children under five years of age in Grand Forks, North Dakota, 2010.

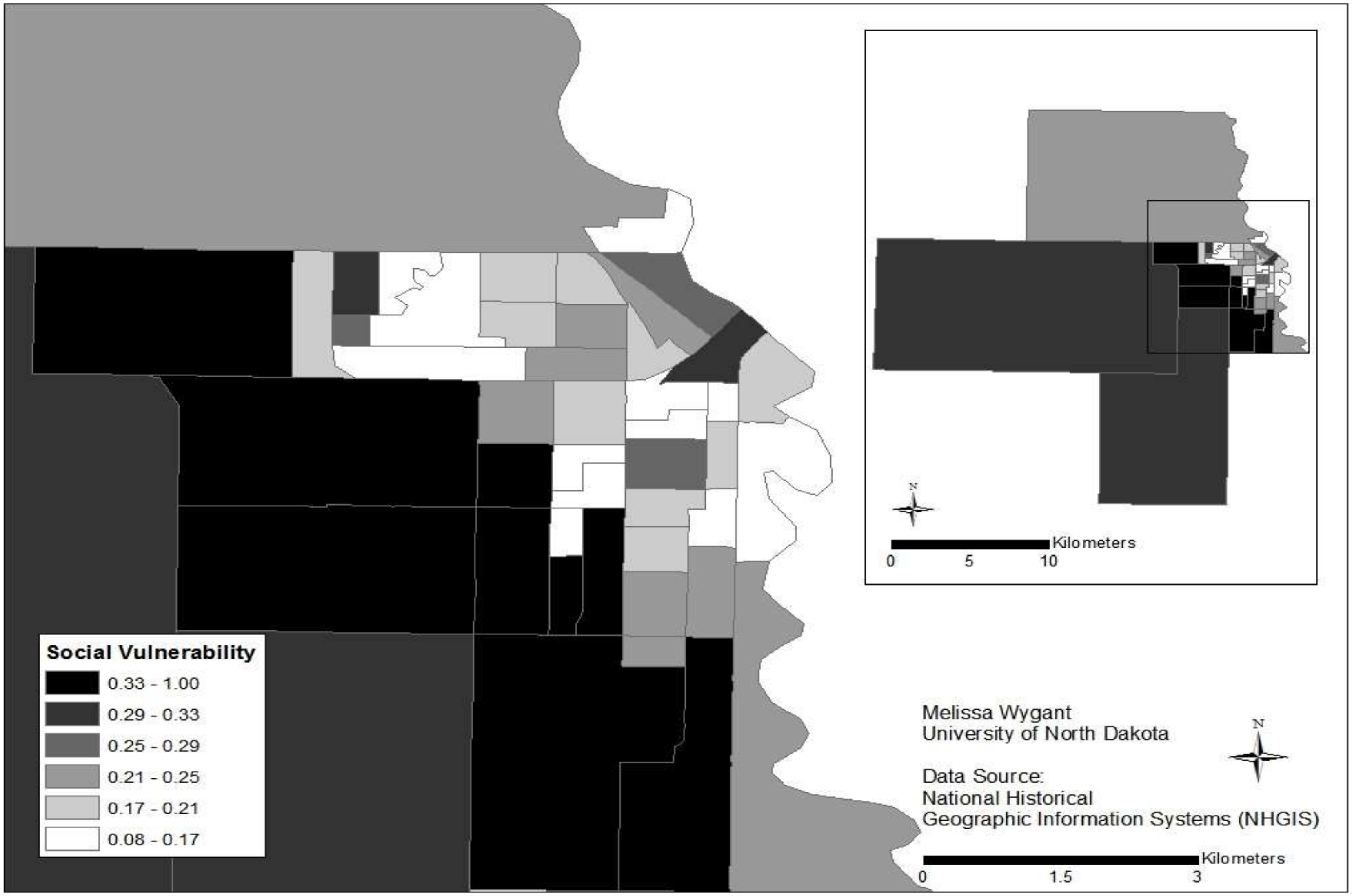
Appendix A10: Social vulnerability of household incomes $75,000 and greater in Grand Forks, North Dakota, 1990.

Appendix A11: Social vulnerability of household incomes $75,000 and greater in Grand Forks, North Dakota, 2000.

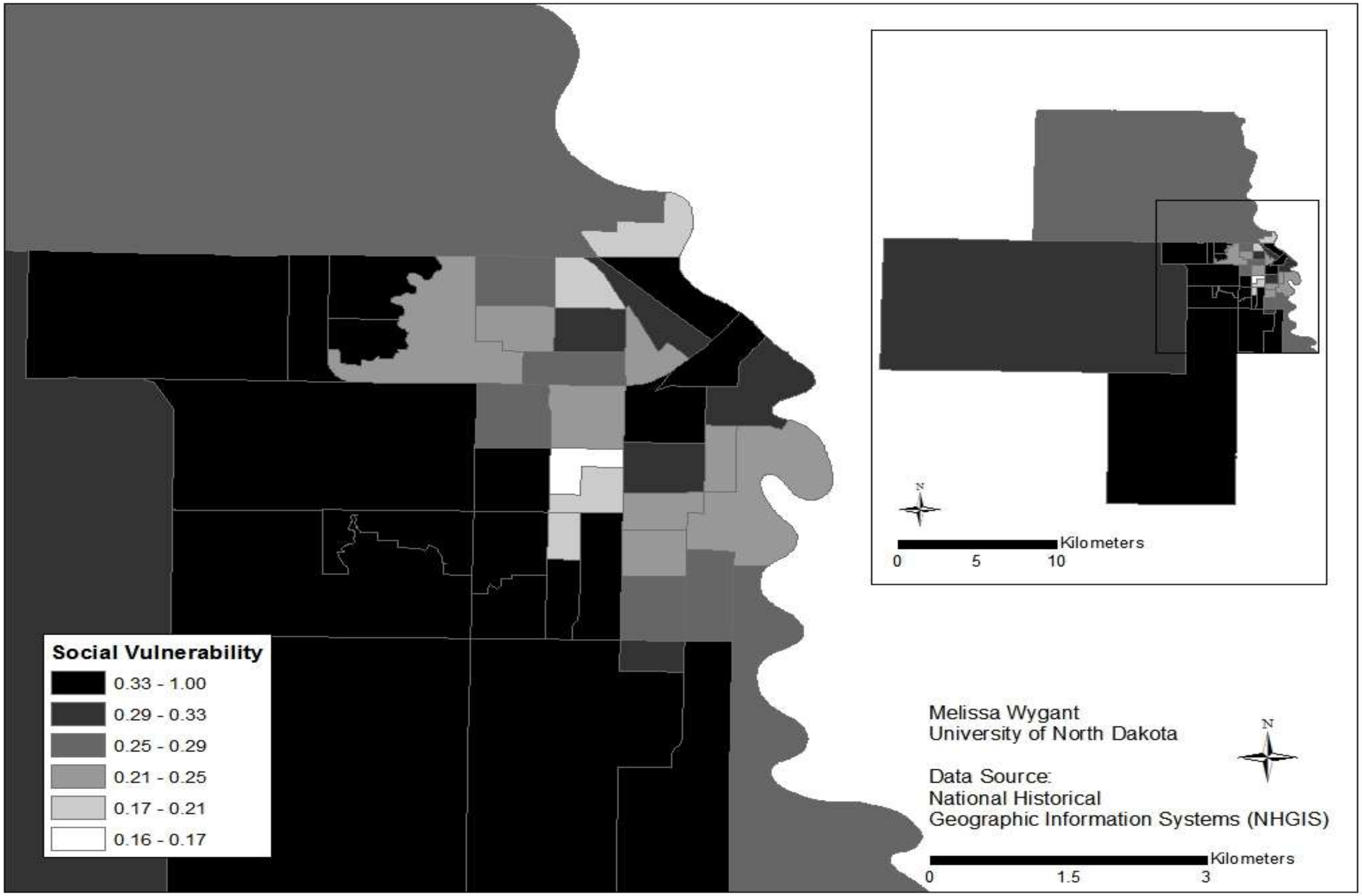
Appendix A12: Social vulnerability of household incomes $75,000 and greater in Grand Forks, North Dakota, 2010.



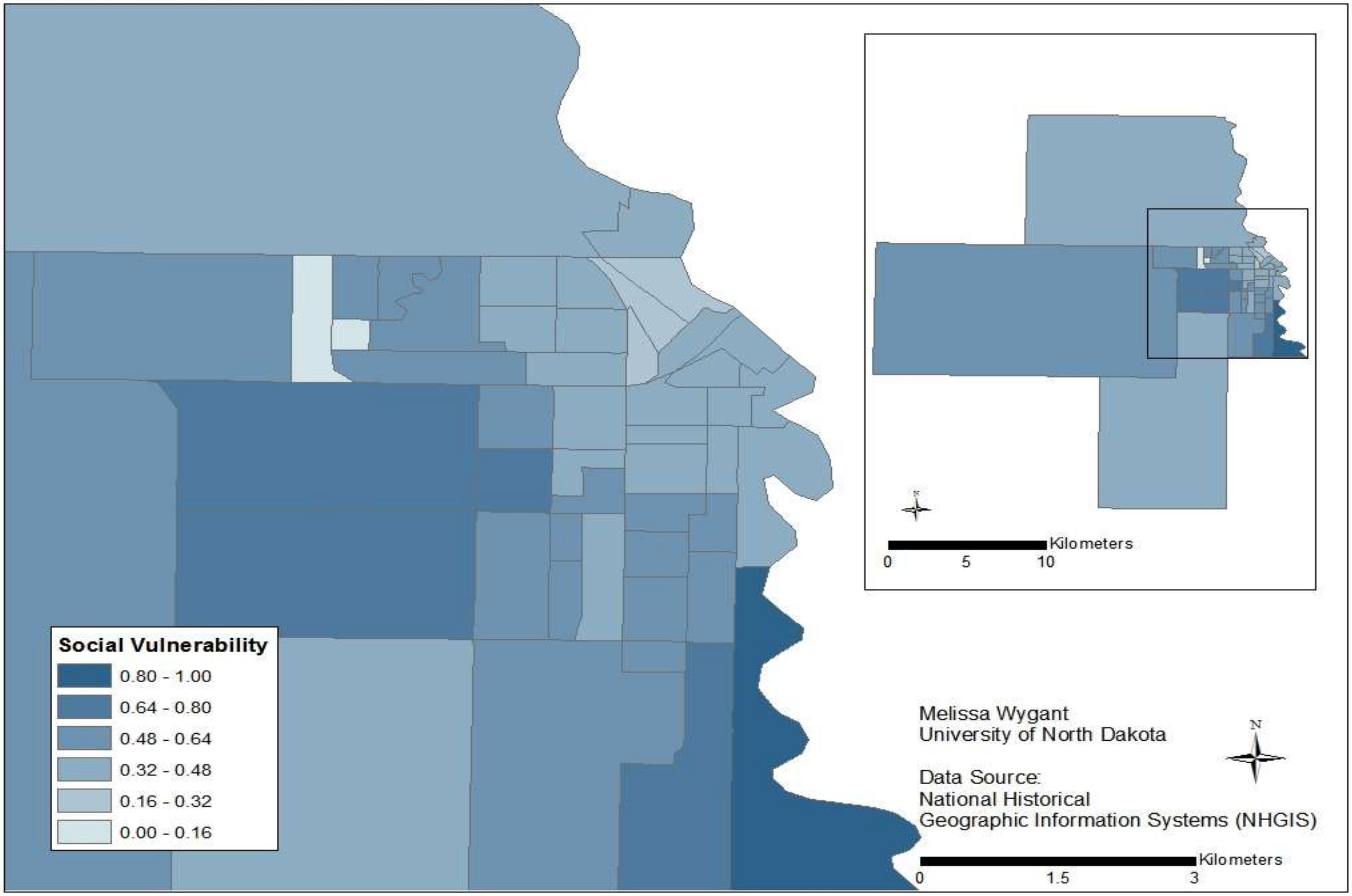
Appendix A13: Social vulnerability of housing units in Grand Forks, North Dakota, 1990.



Appendix A14: Social vulnerability of housing units in Grand Forks, North Dakota, 2000.



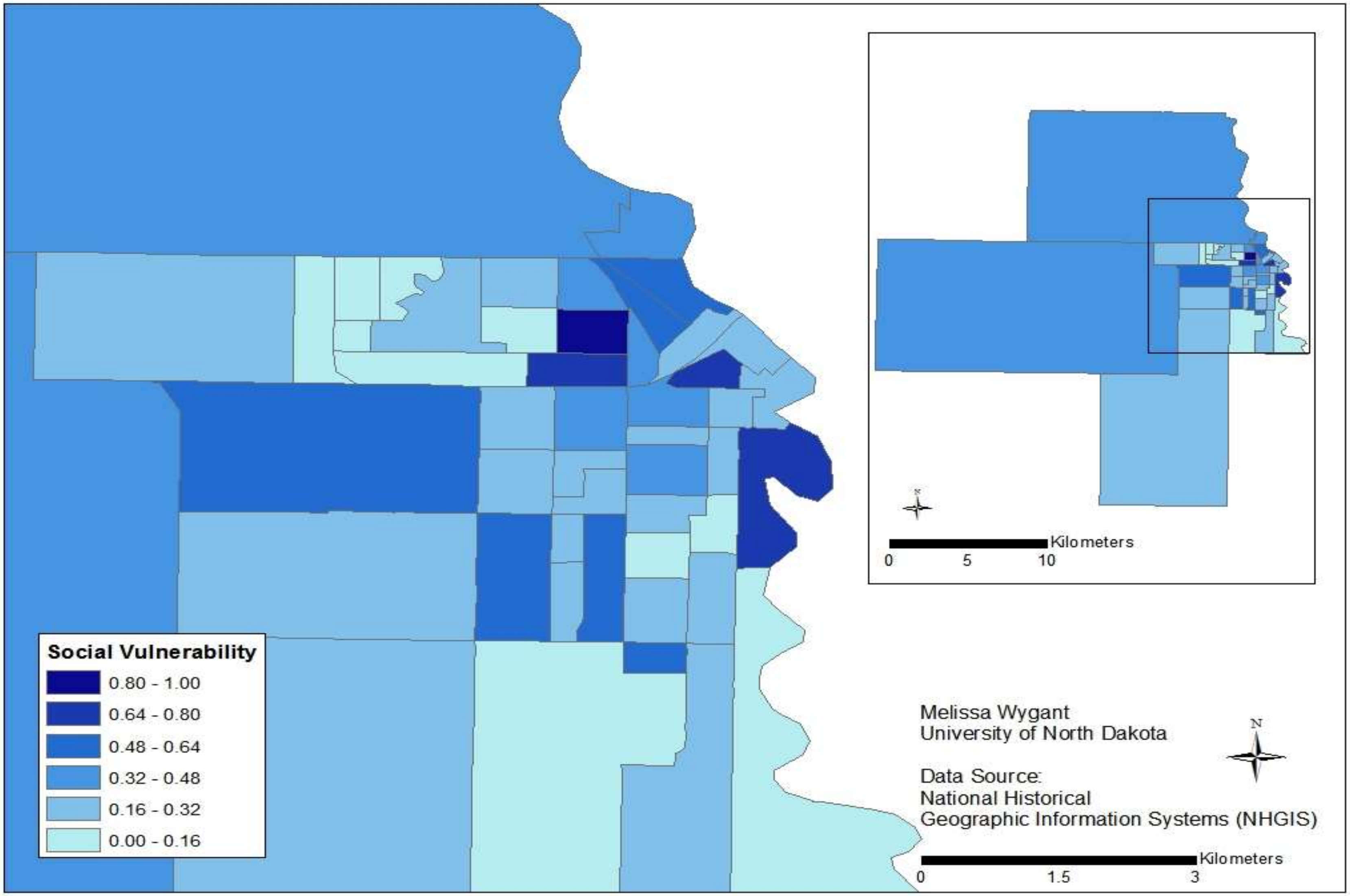
Appendix A15: Social vulnerability of housing units in Grand Forks, North Dakota, 2010.



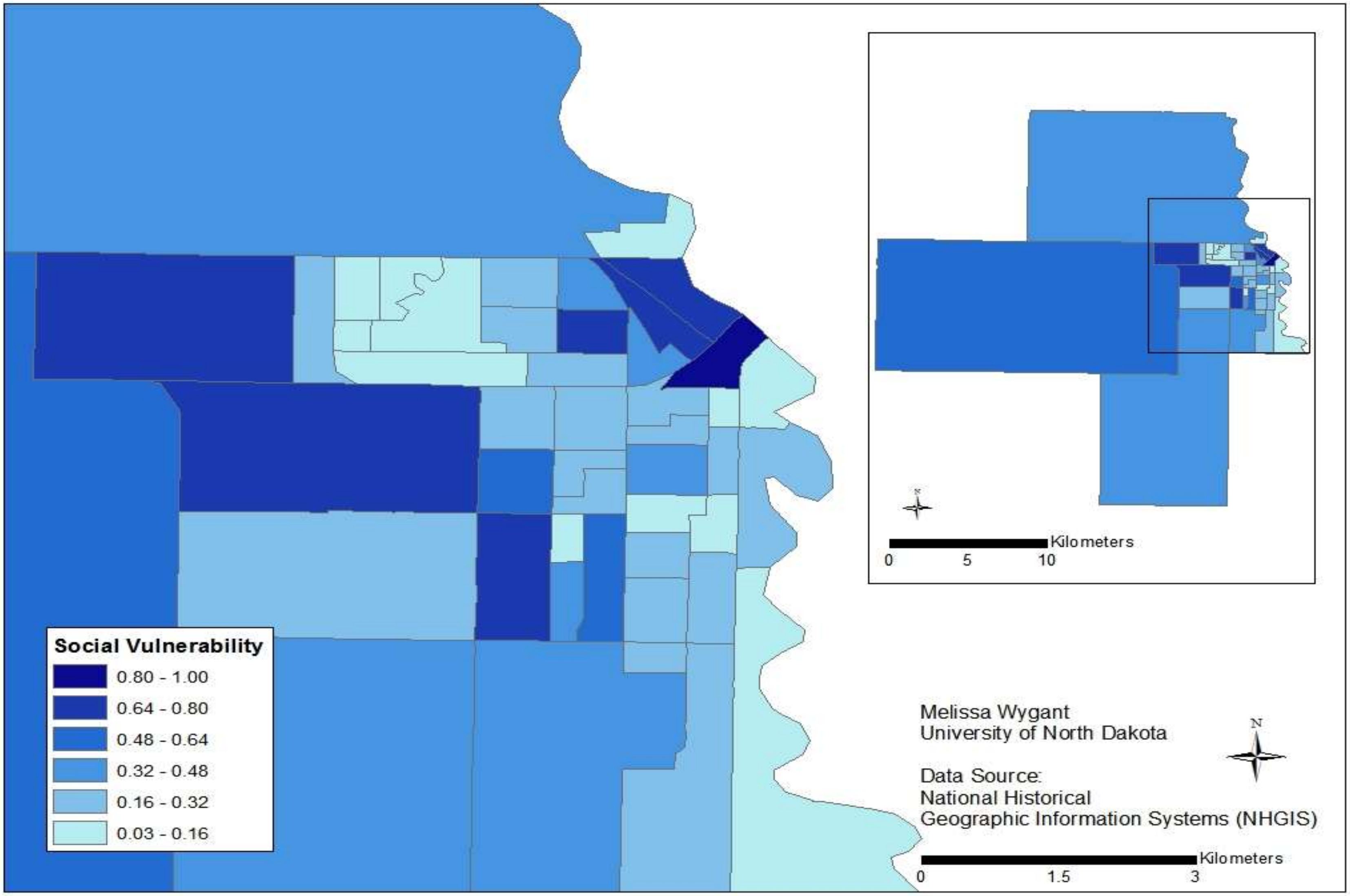
Appendix A16: Social vulnerability of median household value in Grand Forks, North Dakota, 1990.

Appendix A17: Social vulnerability of median household value in Grand Forks, North Dakota, 2000.

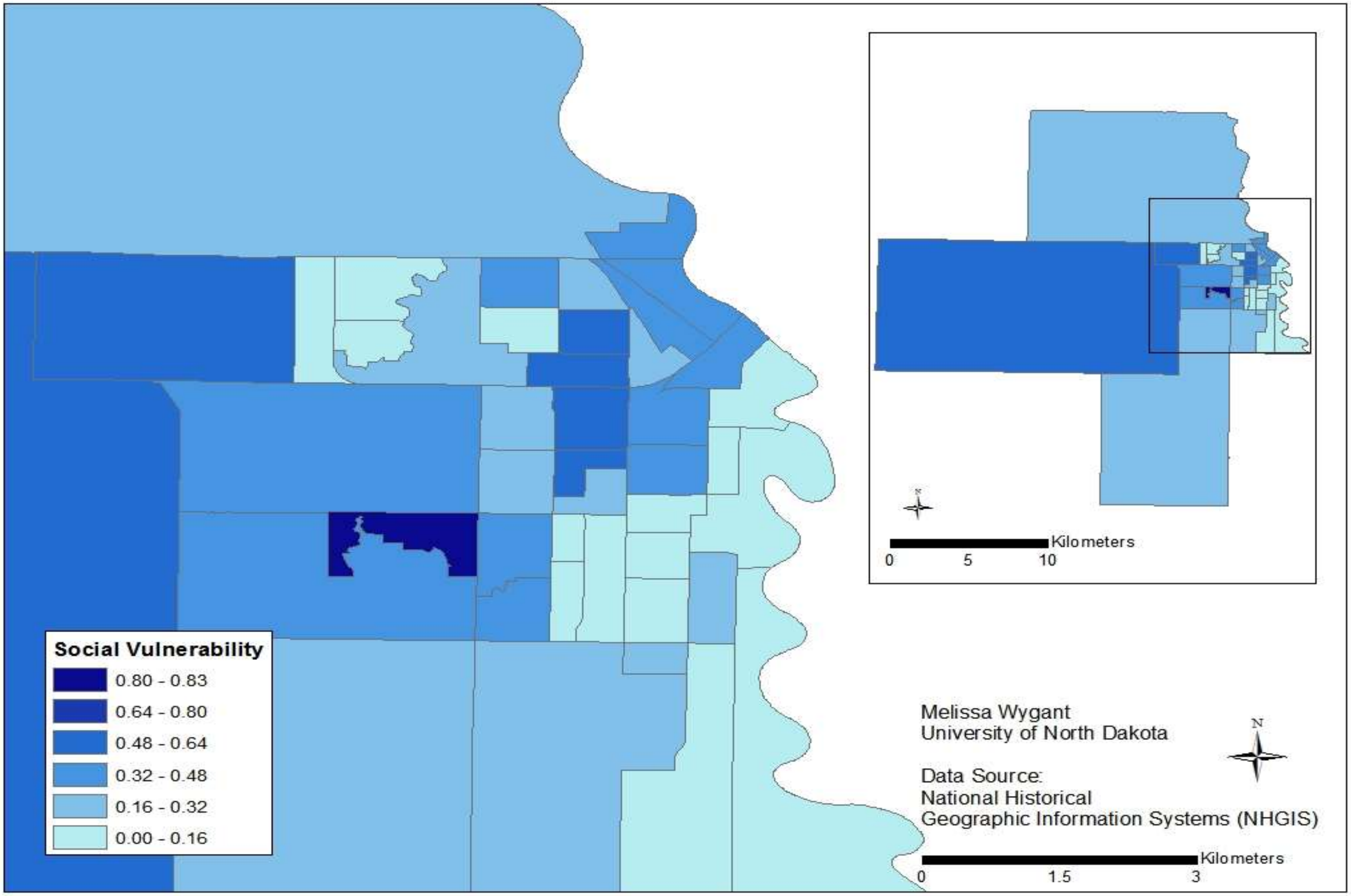
Appendix A18: Social vulnerability of median household value in Grand Forks, North Dakota, 2010.



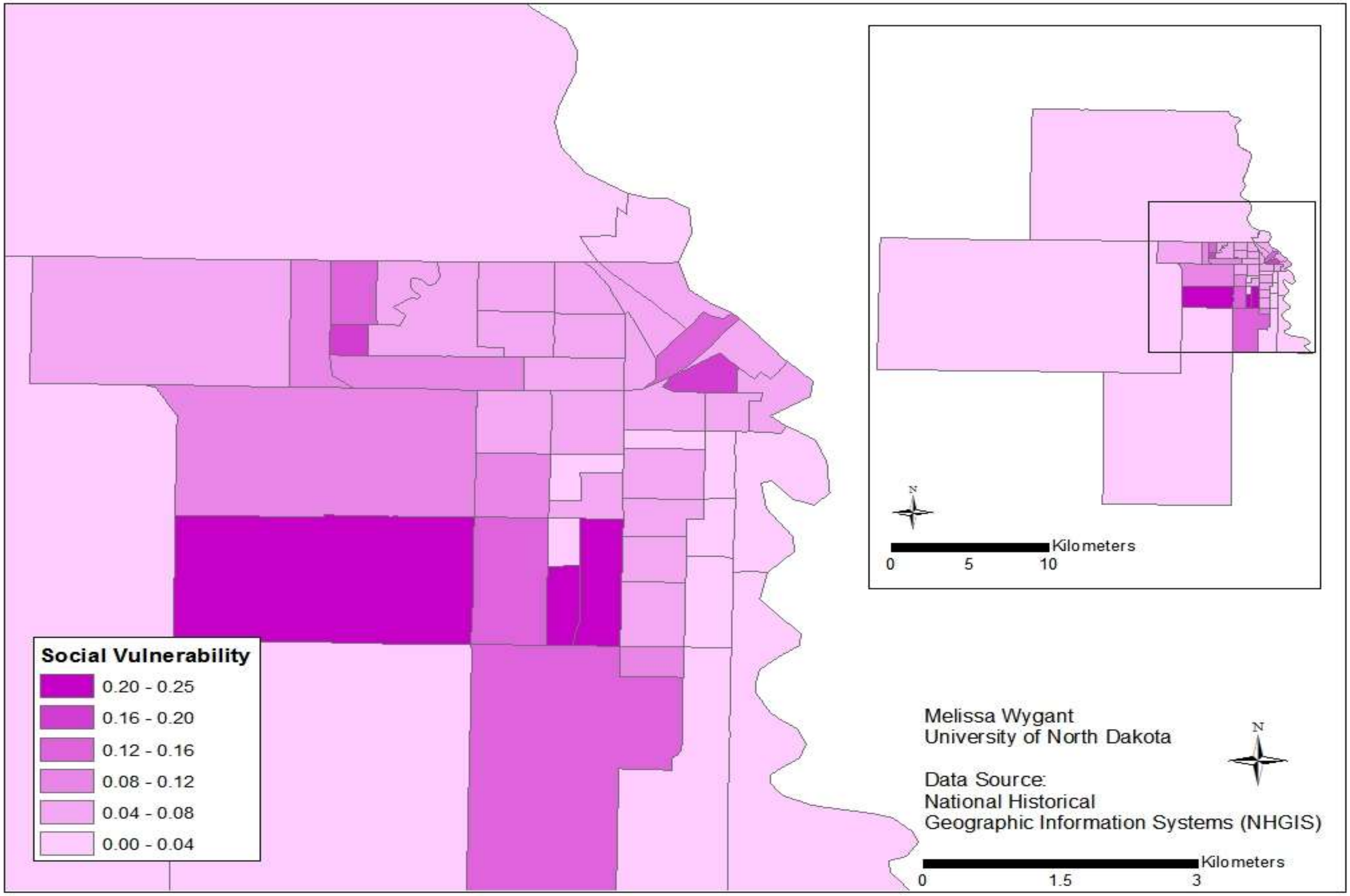
Appendix A19: Social vulnerability of individuals 25 years and older without a high school diploma in Grand Forks, North Dakota, 1990.



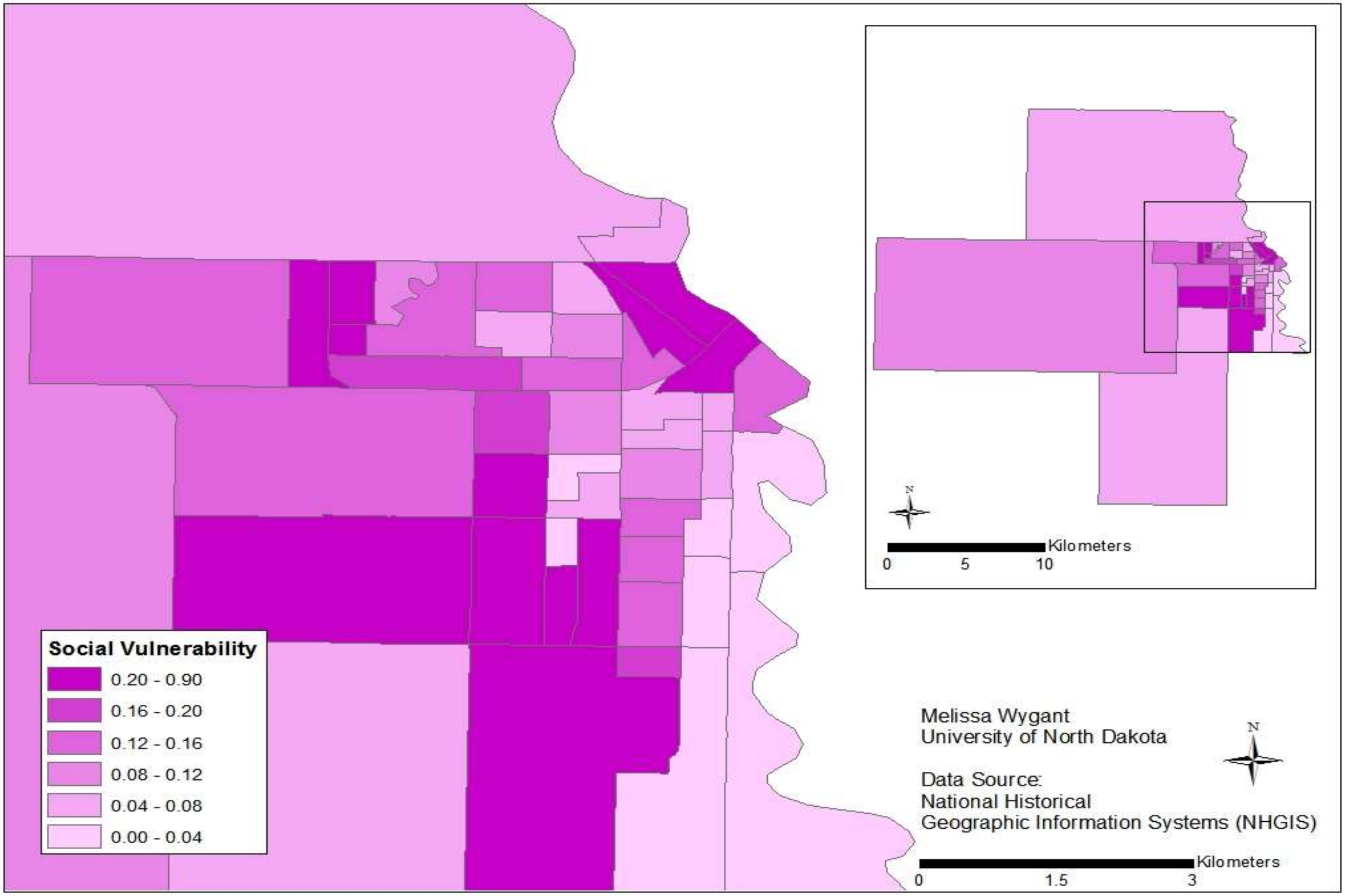
Appendix A20: Social vulnerability of individuals 25 years and older without a high school diploma in Grand Forks, North Dakota, 2000.



Appendix A21: Social vulnerability of individuals 25 years and older without a high school diploma in Grand Forks, North Dakota, 2010.

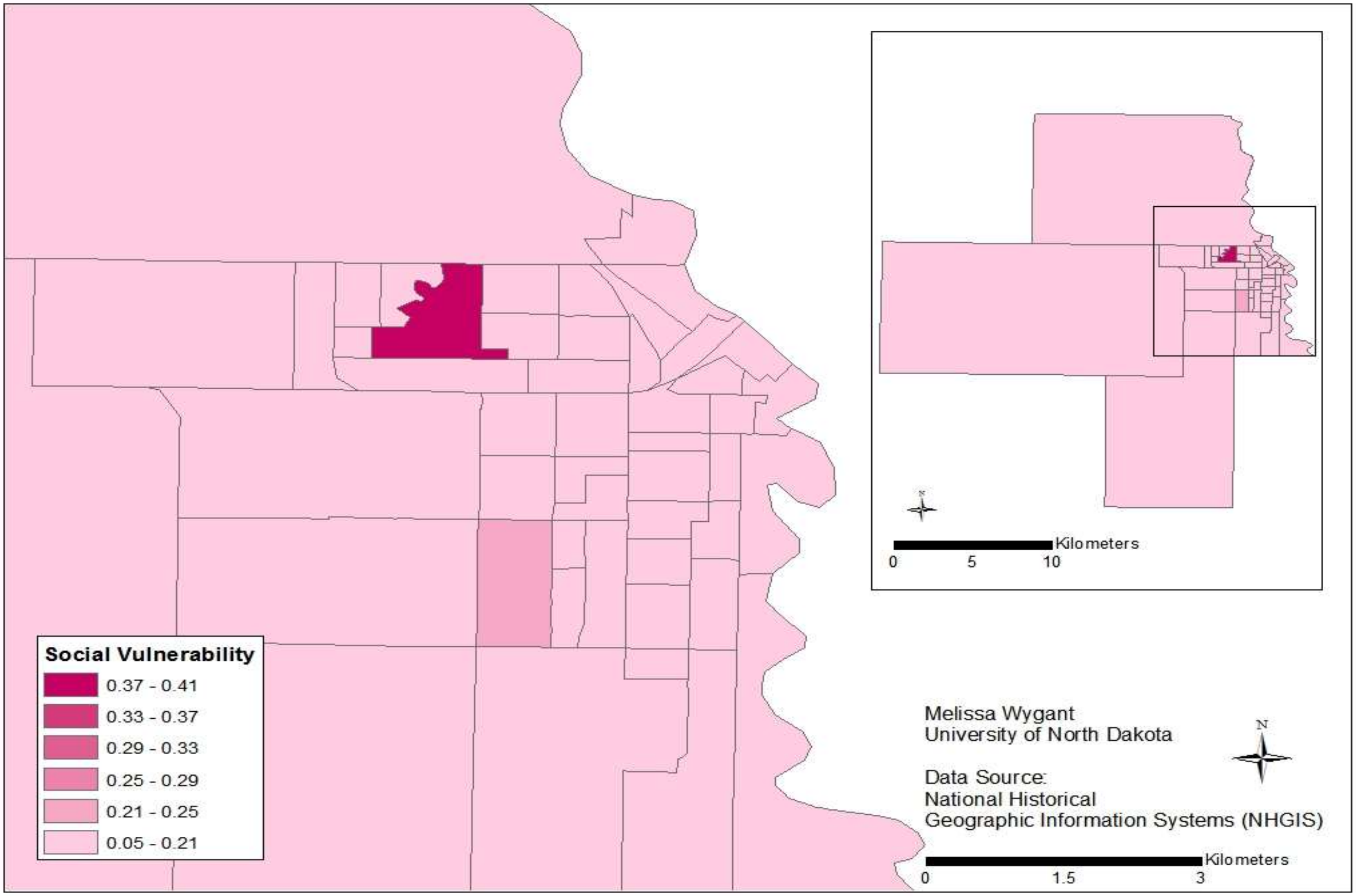


Appendix A22: Social vulnerability of renter occupied housing in Grand Forks, North Dakota, 1990.

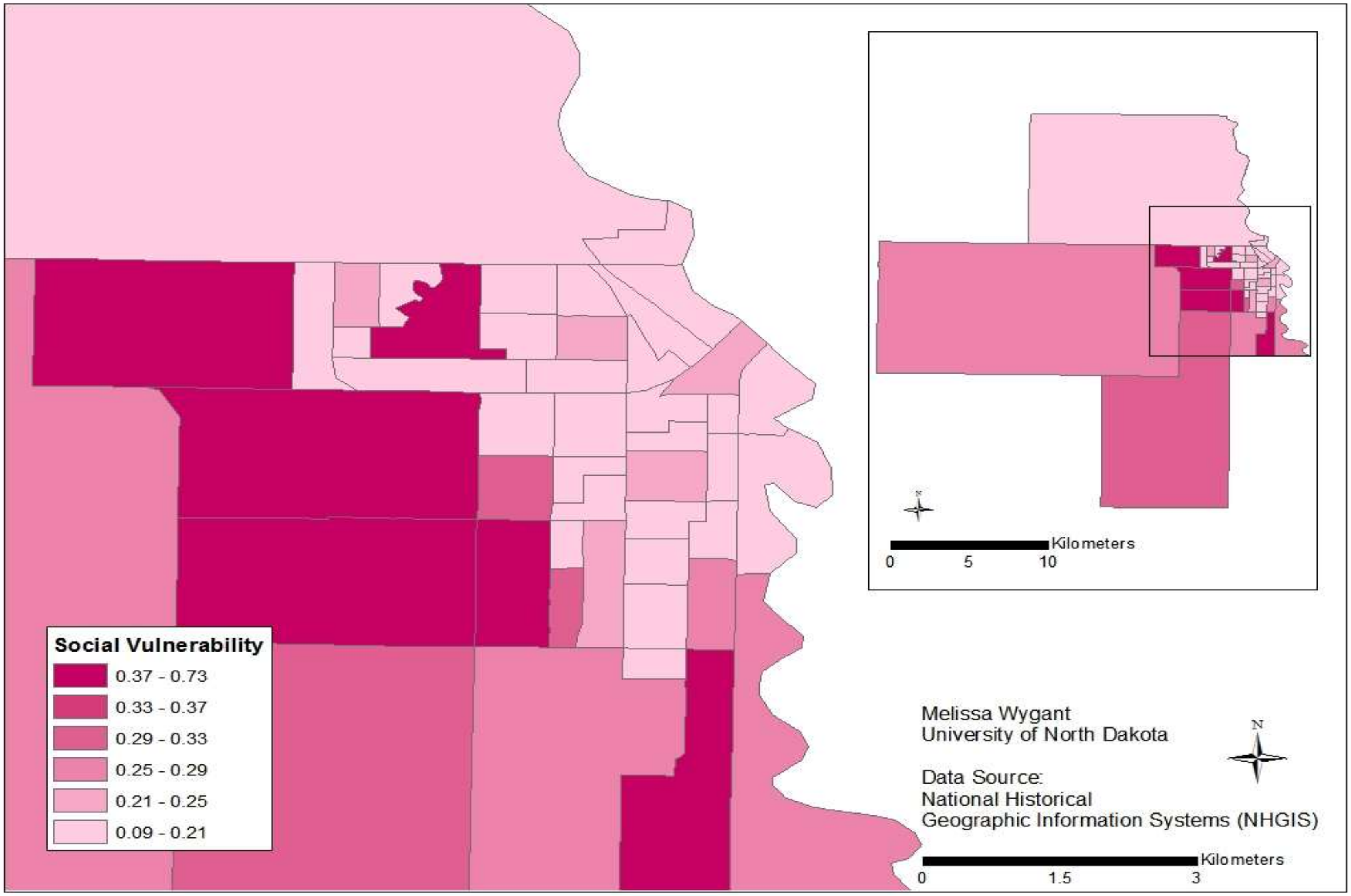


Appendix A23: Social vulnerability of renter occupied housing in Grand Forks, North Dakota, 2000.

Appendix A24: Social vulnerability of renter occupied housing in Grand Forks, North Dakota, 2010.

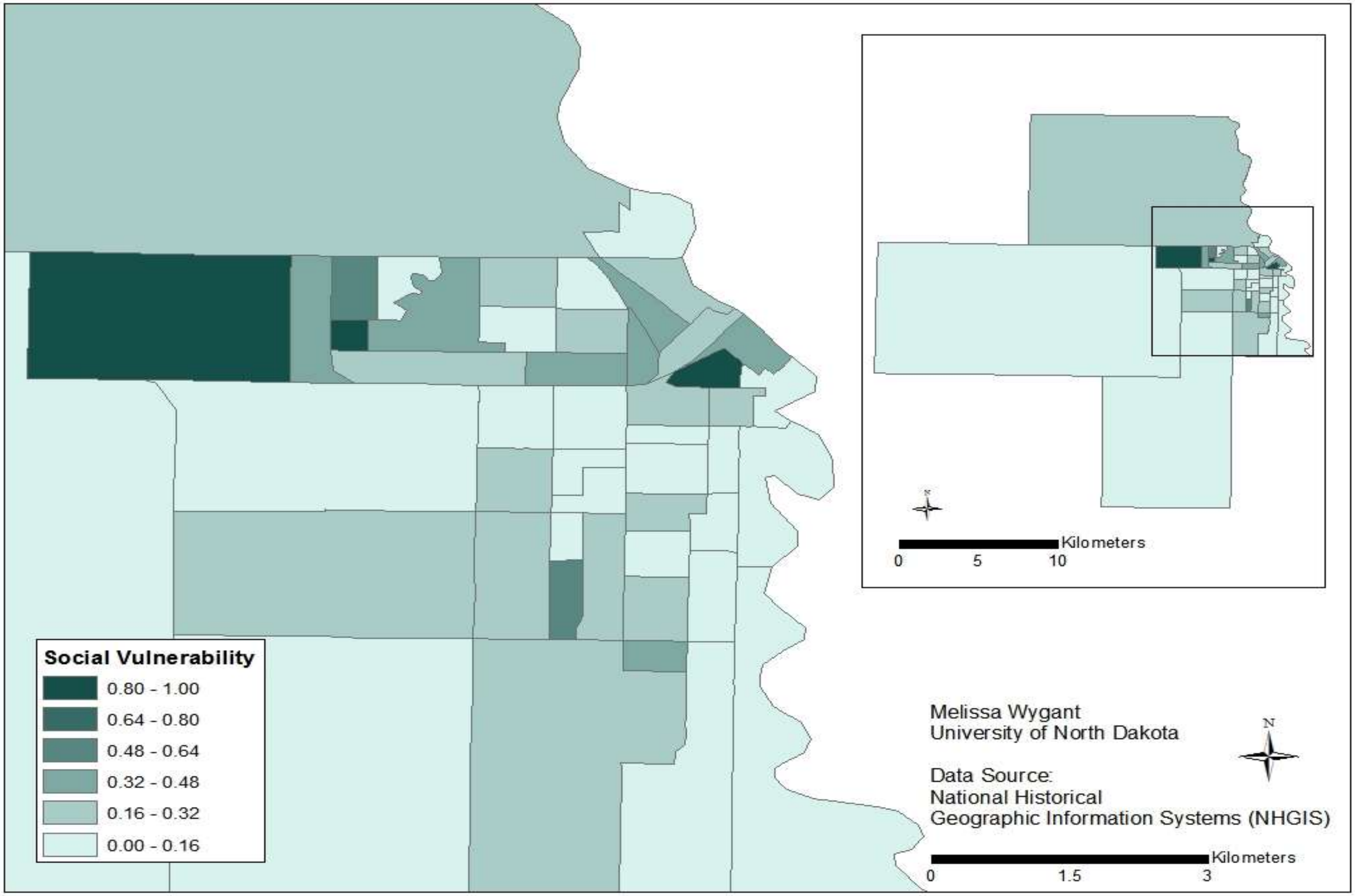


Appendix A25: Social vulnerability of total population in Grand Forks, North Dakota, 1990.



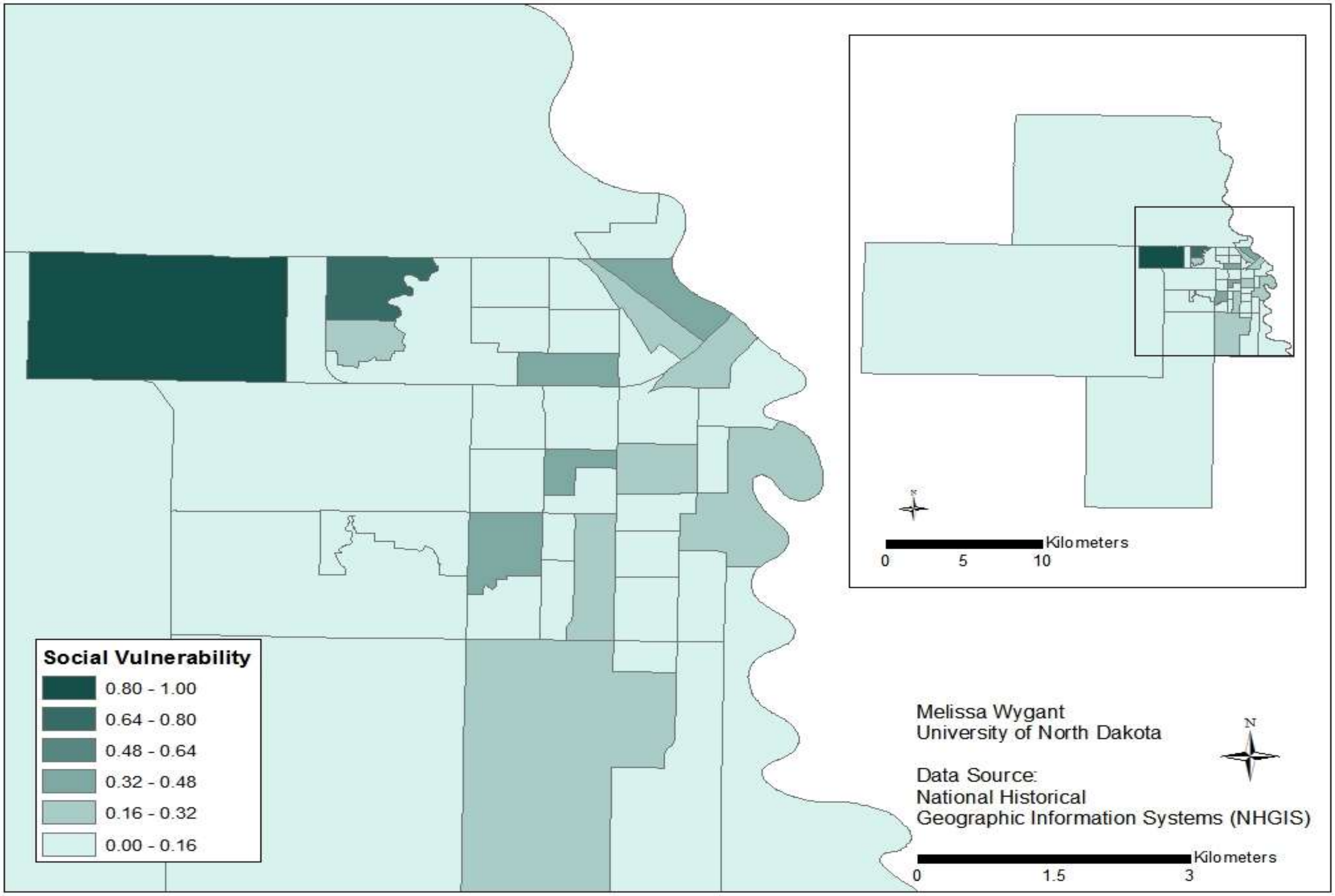
Appendix A26: Social vulnerability of total population in Grand Forks, North Dakota, 2000.

Appendix A27: Social vulnerability of total population in Grand Forks, North Dakota, 2010.

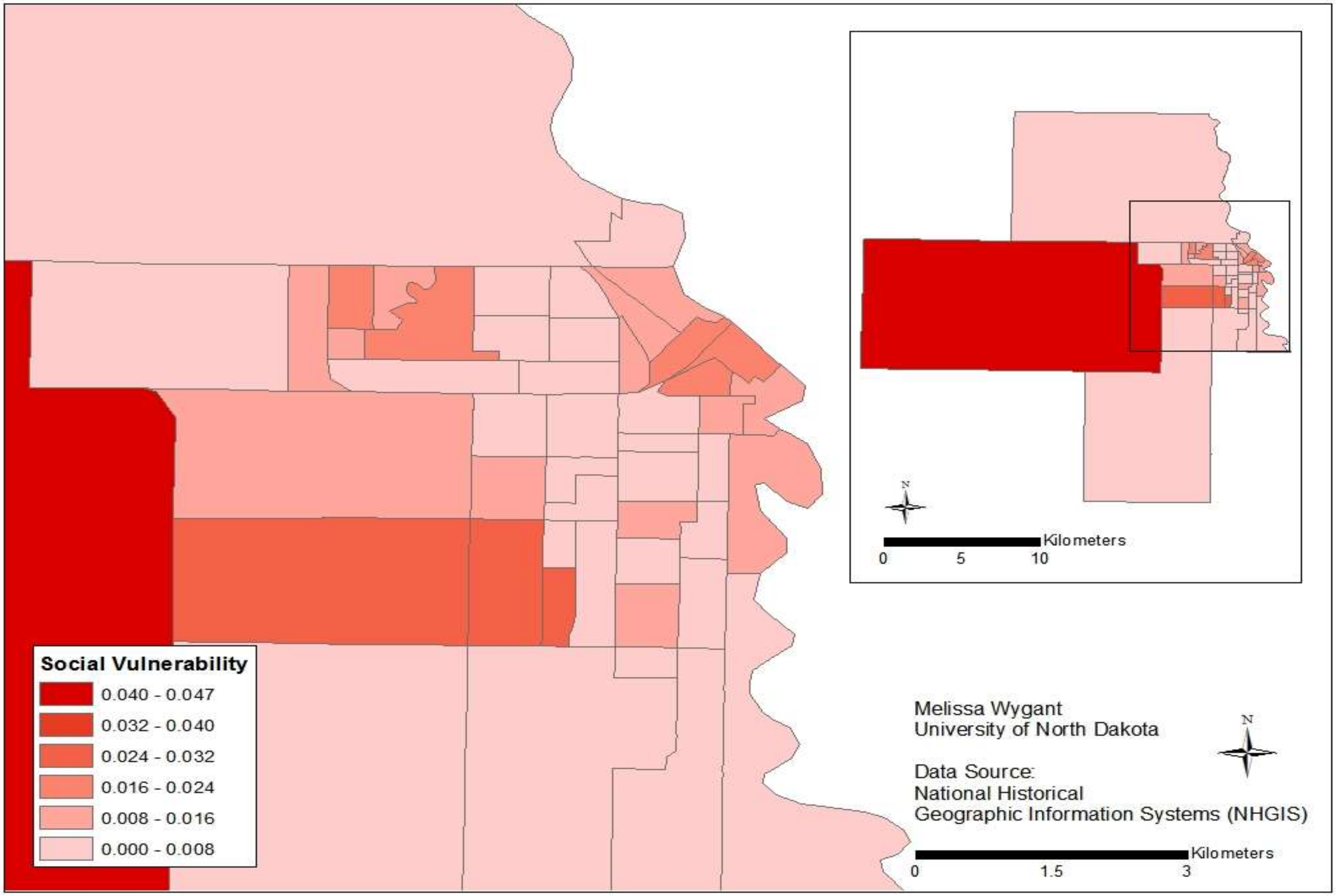


Appendix A28: Social vulnerability of American Indians in Grand Forks, North Dakota, 1990.

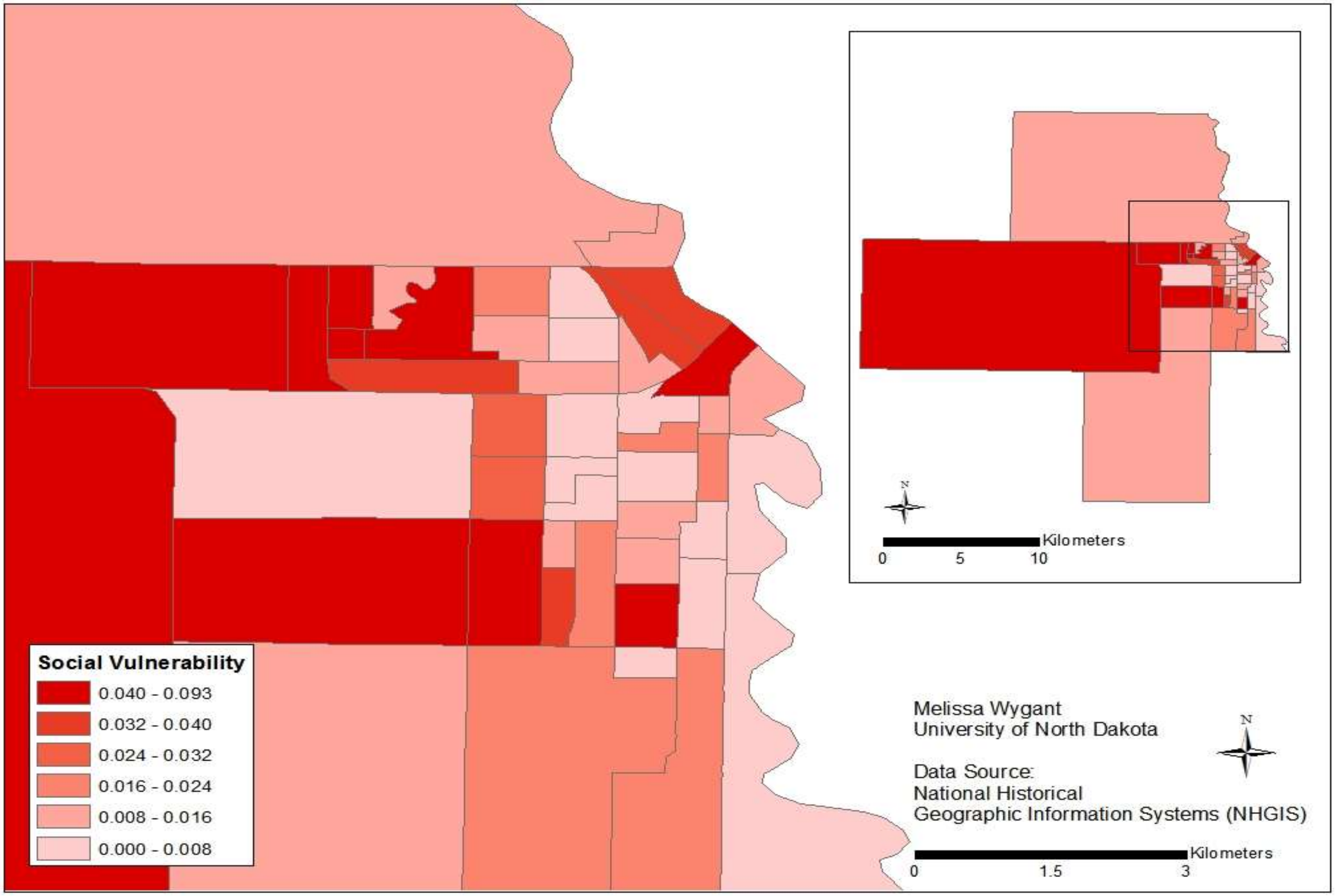
Appendix A29: Social vulnerability of American Indians in Grand Forks, North Dakota, 2000.



Appendix A30: Social vulnerability of American Indians in Grand Forks, North Dakota, 2010.

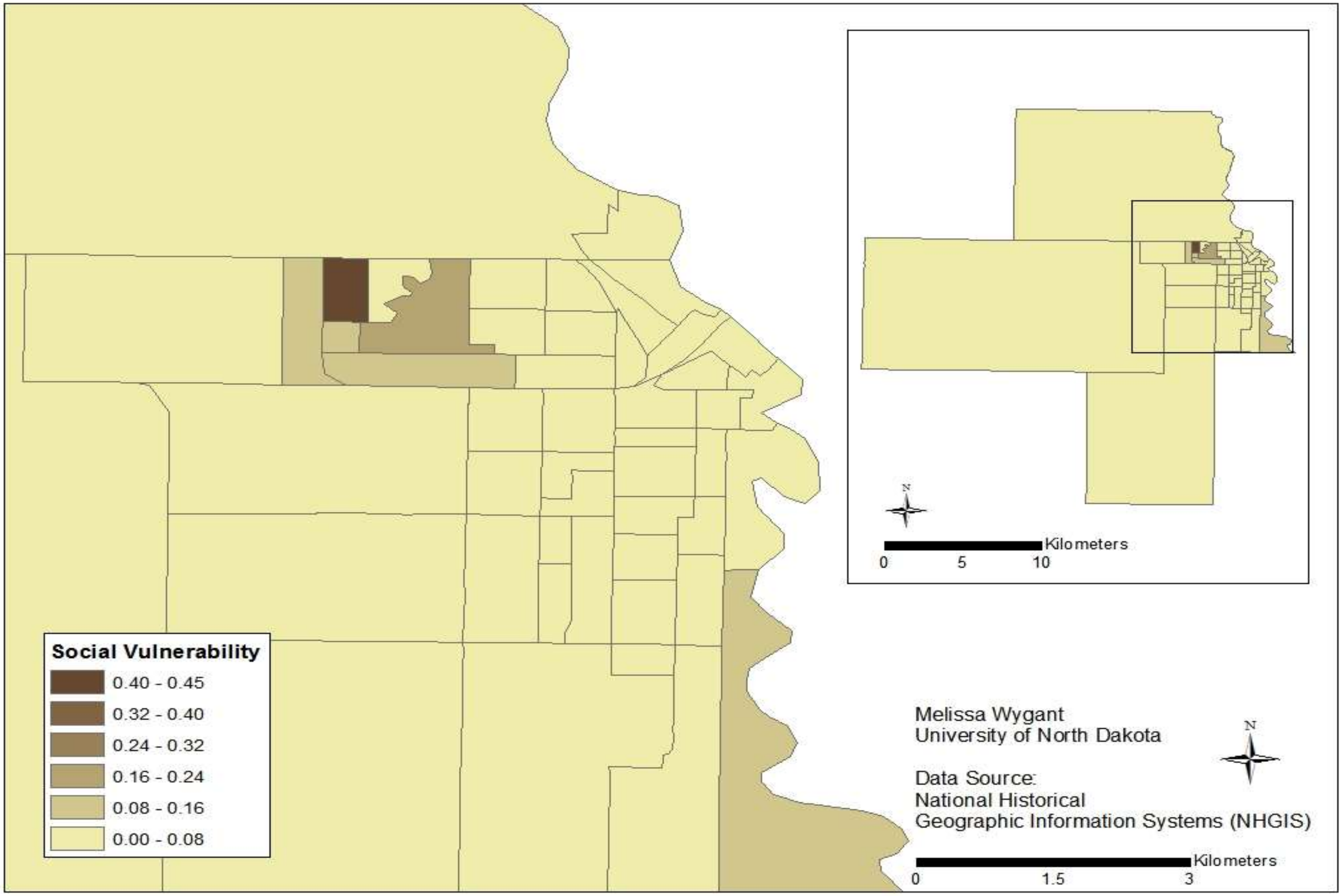


Appendix A31: Social vulnerability of African Americans in Grand Forks, North Dakota, 1990.

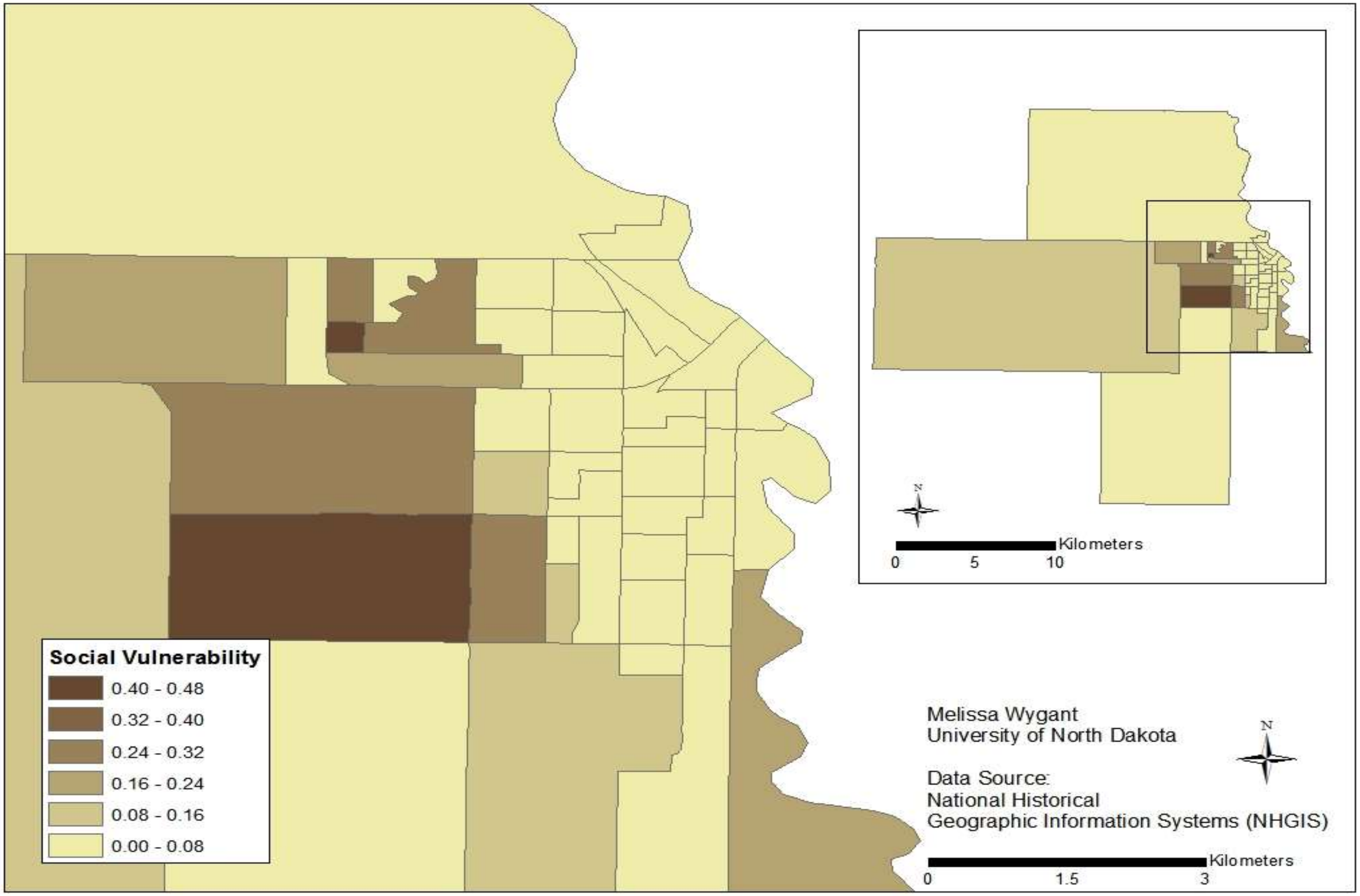


Appendix A32: Social vulnerability of African Americans in Grand Forks, North Dakota, 2000.

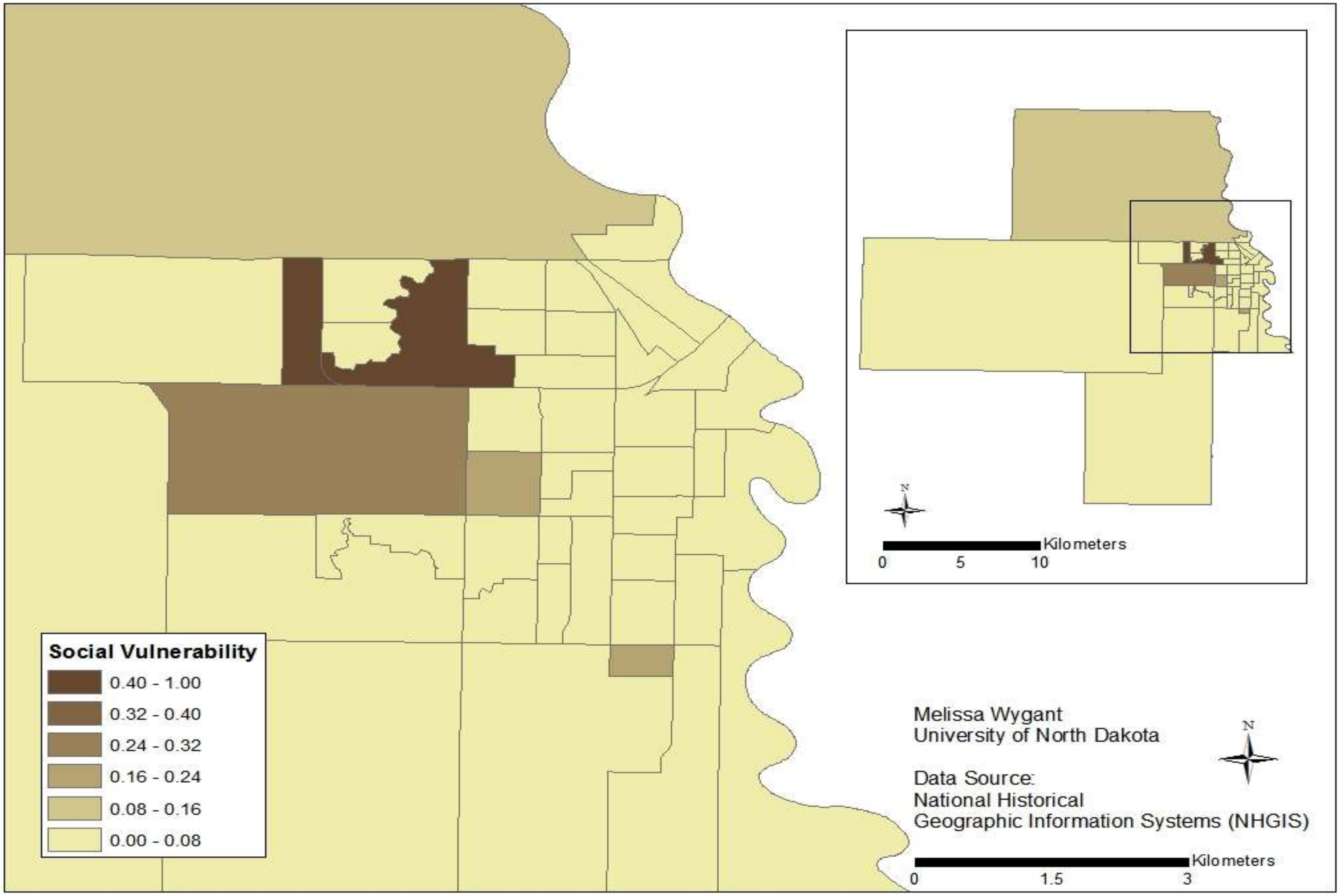
Appendix A33: Social vulnerability of African Americans in Grand Forks, North Dakota, 2010.



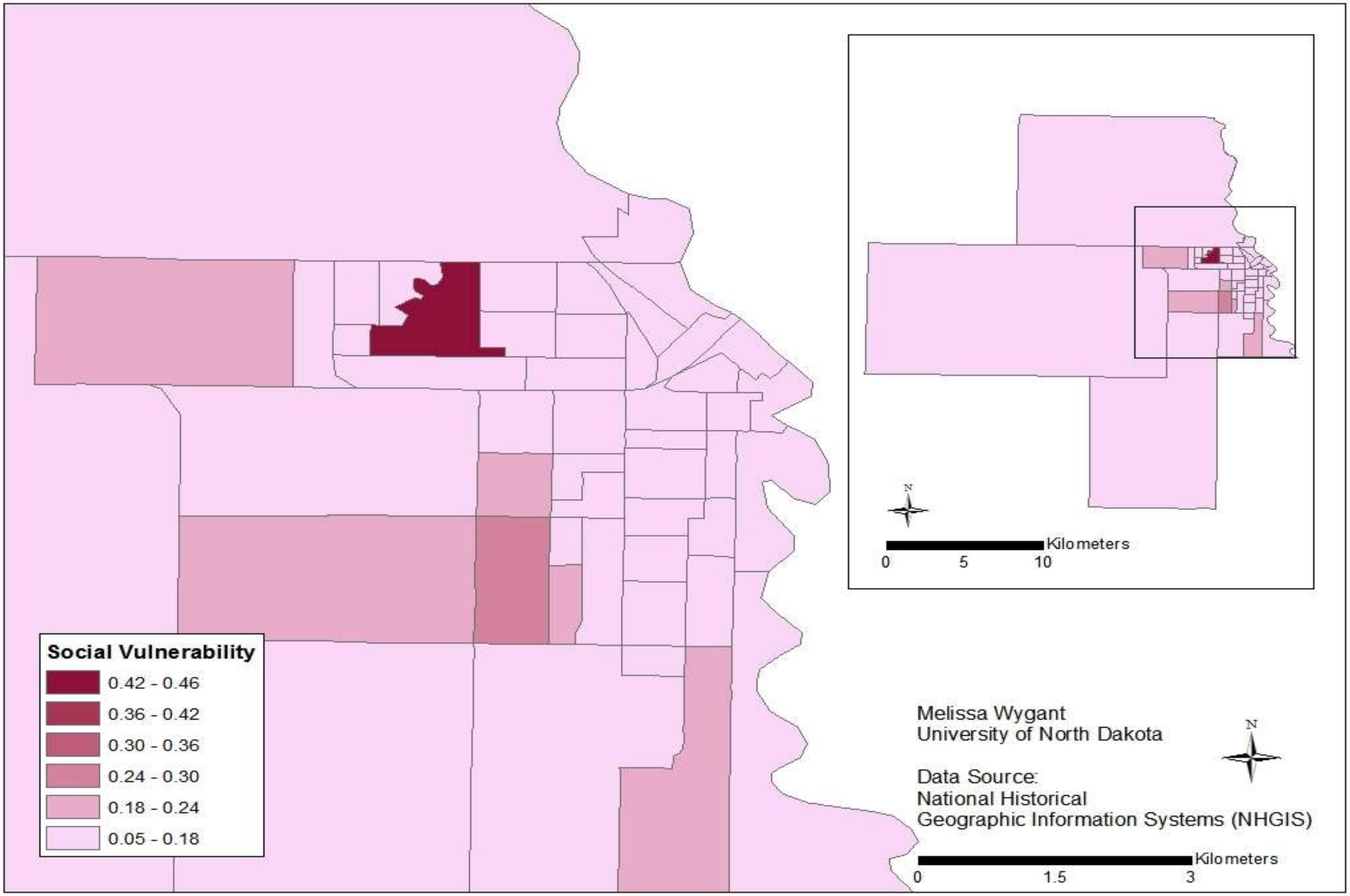
Appendix A34: Social vulnerability of Asians in Grand Forks, North Dakota, 1990.



Appendix A35: Social vulnerability of Asians in Grand Forks, North Dakota, 2000.

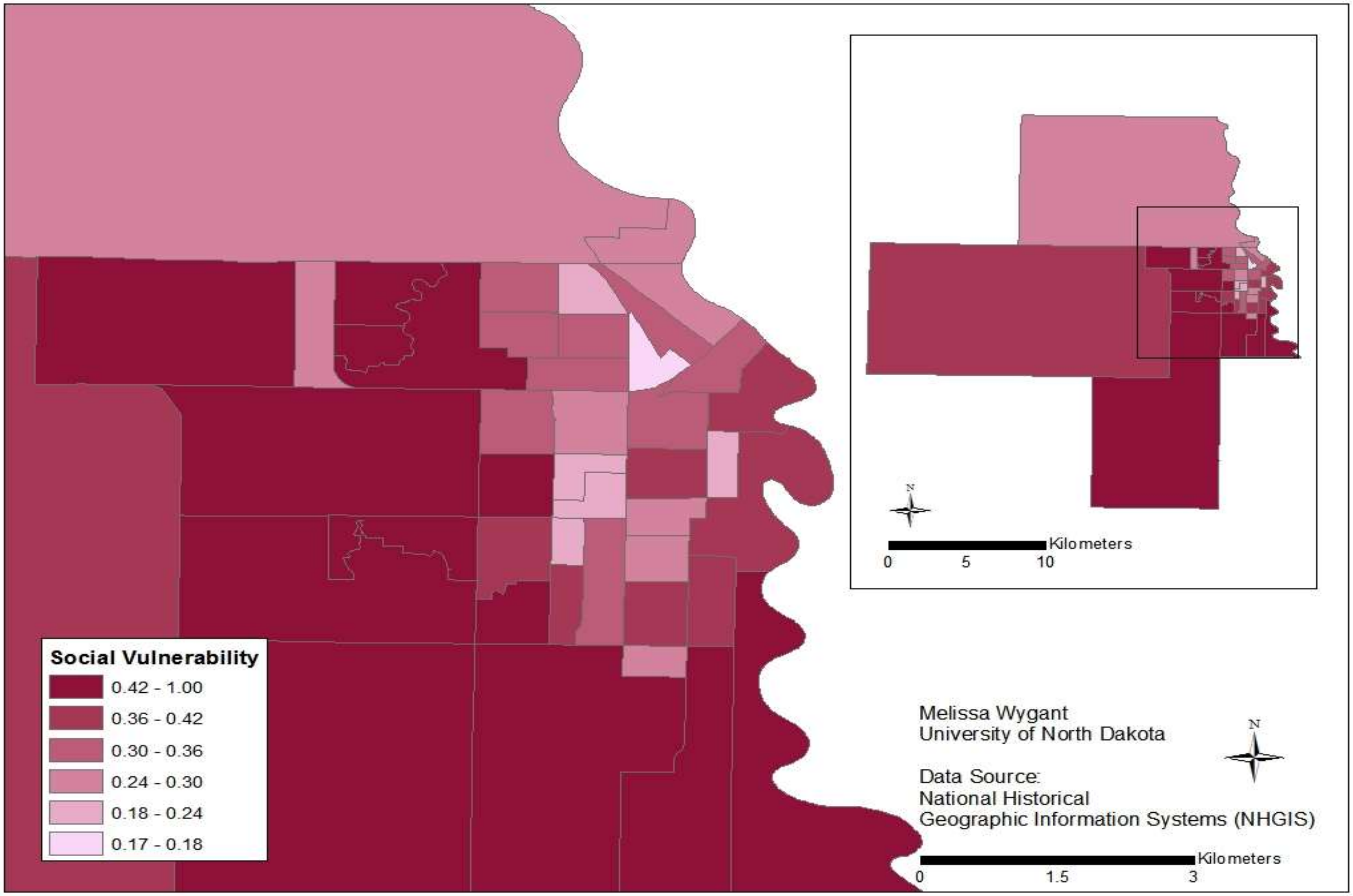


Appendix A36: Social vulnerability of Asians in Grand Forks, North Dakota, 2010.

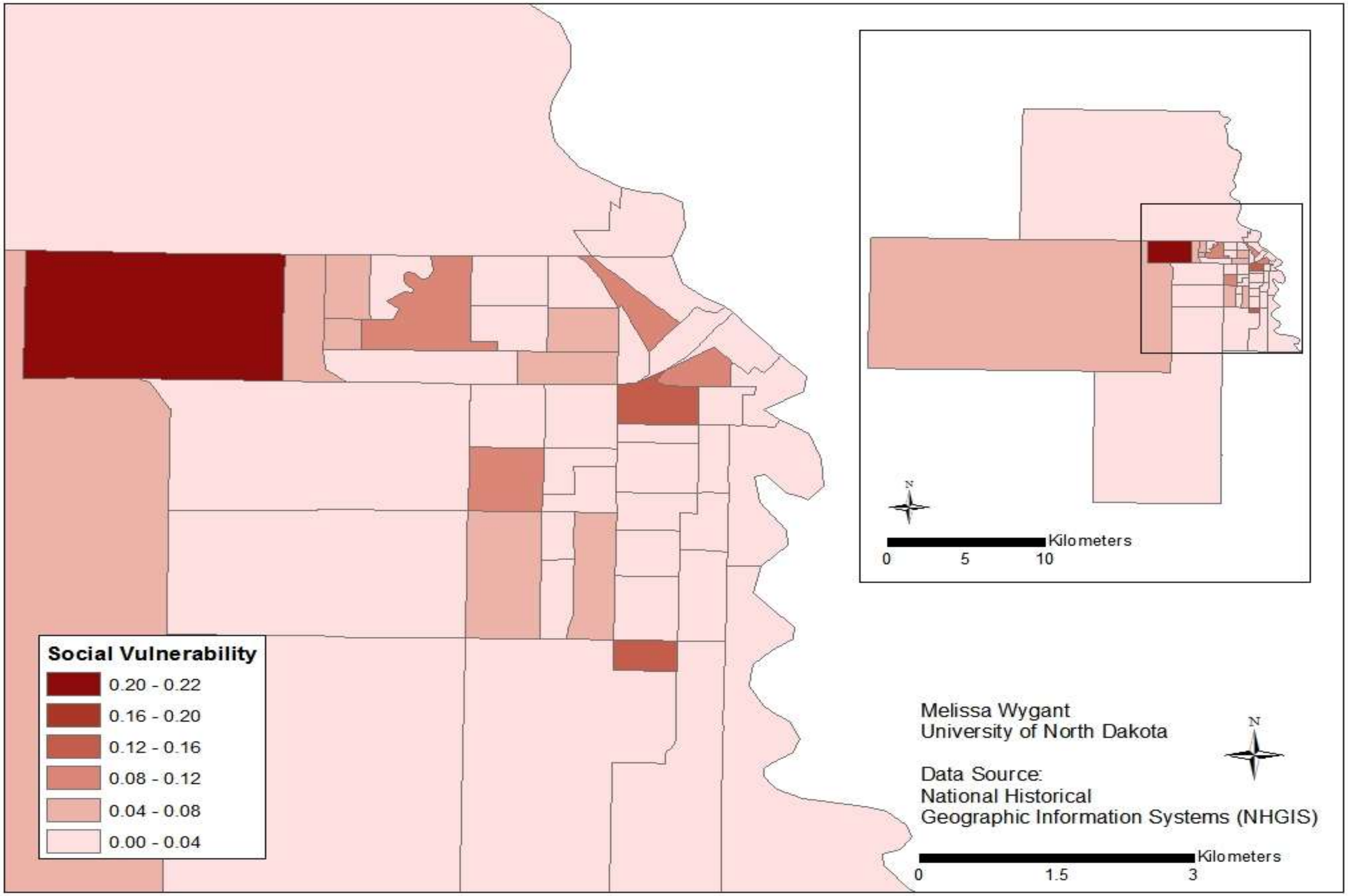


Appendix A37: Social vulnerability of Caucasians in Grand Forks, North Dakota, 1990.

Appendix A38: Social vulnerability of Caucasians in Grand Forks, North Dakota, 2000.

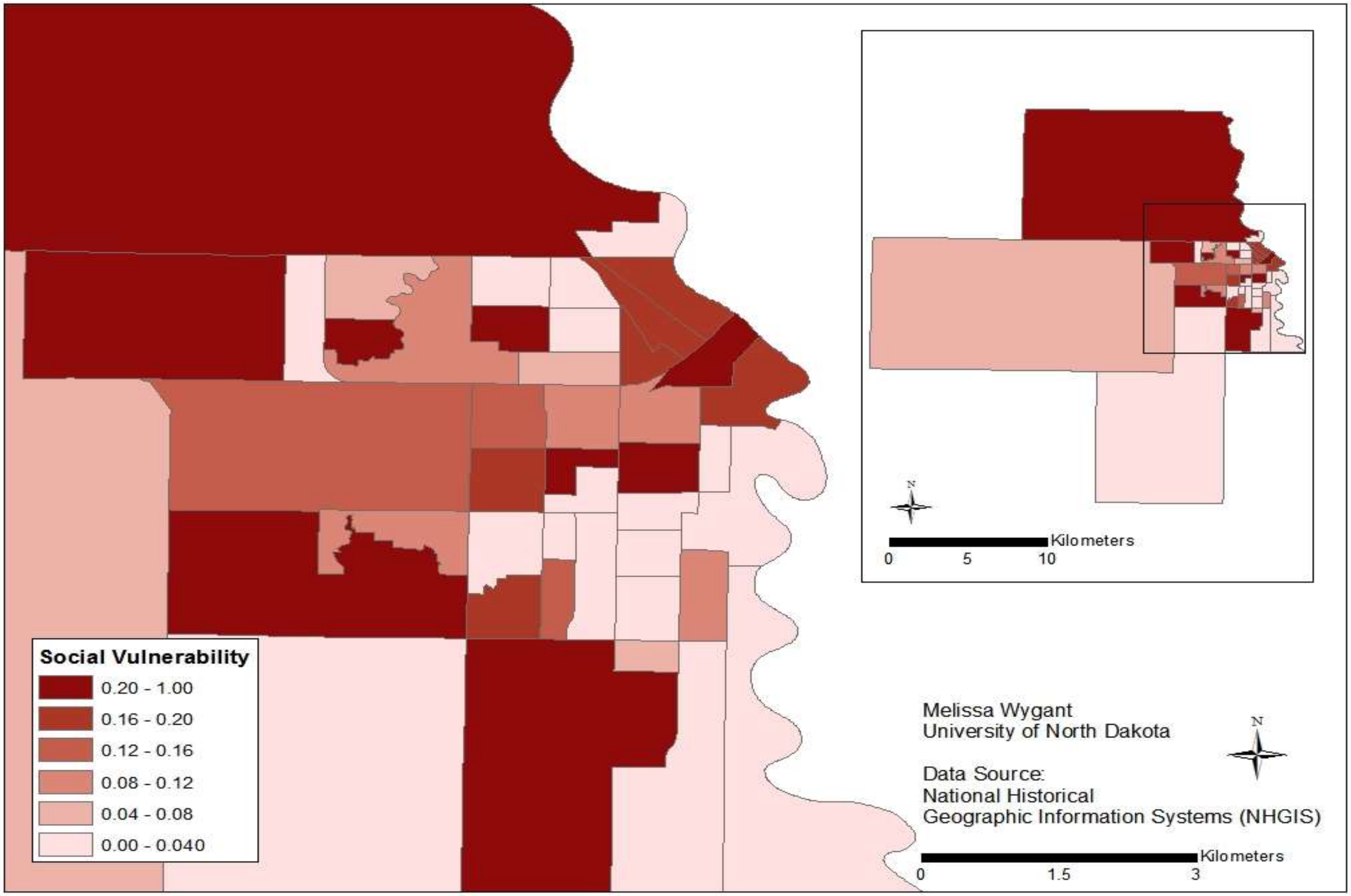


Appendix A39: Social vulnerability of Caucasians in Grand Forks, North Dakota, 2010.



Appendix A40: Social vulnerability of other races in Grand Forks, North Dakota, 1990.

Appendix A41: Social vulnerability of other races in Grand Forks, North Dakota, 2000.



Appendix A42: Social vulnerability of other races in Grand Forks, North Dakota, 2010.

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