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An Index for Measuring Community Resilience to Flooding in Baton Rouge, Louisiana

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AN INDEX FOR MEASURING COMMUNITY RESILIENCE TO FLOODING IN BATON ROUGE, LOUISIANA

A Thesis
Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Sciences in The Department of Geography and Anthropology

by
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ABSTRACT

The greater Baton Rouge area in Louisiana has been impacted by repeated floods throughout its history. The most recent flood in August 2016 resulted in damages to over 80,000 homes and businesses and upwards of $430 million in public assistance granted by the Federal Emergency Management Agency. East Baton Rouge Parish and neighboring Livingston and Ascension parishes are expected to face compounded pressures and risks with the threat of increasing frequency of flood events coupled with expanding populations due to continuing suburbanization and inland migration from those living on Louisiana's coast. The purpose of this research is to create and validate an index to measure community resilience to flooding across Ascension, East Baton Rouge, and Livingston parishes from 1983-2016. Using a combination of environmental and socioeconomic variables, the index is applied to three different years where historic and devastating flooding has occurred in the region: 1983, 1993, and 2016. A brief history of suburban sprawl, flood mitigation strategies, and land use changes provides a framework to measure the efficacy of the index. This historic perspective allows for a better understanding of how capacity for building resilience has evolved, and how we might expect it to progress in the future. This research helps understand how community resilience has changed over time after repeated flood events. Furthermore, this will help quantify the components that lend themselves to community resilience, so that future natural hazards may be recognized and their harmful effects may be mitigated.
CHAPTER 1. INTRODUCTION

Flooding is one of the most common natural hazards that impact communities in the United States (National Flood Insurance Program, 2016a). While flooding is due to climactic and meteorological events, there are many other factors that influence flooding such as policies, structures, community resources, and social inequalities. The state of Louisiana, in particular, is very prone to flooding events. Recently, a low pressure tropical weather system moved slowly across southeastern Louisiana, dropping 20 to 30 inches of rainfall in August 2016 (National Weather Service, 2017). During the period from August 12 to 14, 2016, this event caused major damage to the area surrounding the capital city of Baton Rouge, Louisiana, including the parishes of East Baton Rouge, Ascension, and Livingston (National Oceanic Atmospheric Administration, 2016). This flood broke river crest and height records on both the Amite and Comite rivers by several feet. The Amite River at Denham Springs reached 46.2 feet during the 2016 flood, while the previous record stood at 41.5 feet 1983 (National Oceanic Atmospheric Administration, 2018). The high water killed 13 people, prompted over 83,000 Federal Emergency Management Agency (FEMA) approved individual assistance applications, and led to more than $430 million in public assistance grants (FEMA, 2016).

With its proximity to large water bodies, relatively low elevation and its many wetlands, this region is no stranger to water and flood events. Since the early 1900s, decision makers have recognized that flooding is a problem best solved through engineering adequate structures or flood resistance measures. With the right set of angles and equations, man-made levees confine water, allowing it to rush quickly through cities (Wright, 2000). However, flood structures can only do so much to protect a community against flooding. More recently, organizations such as the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Global Change
Research Program recognize floods as extreme national events that are going to continue to impact communities, especially due to climate change (NOAA, 2014; Georgakakos et al., 2014; Intergovernmental Panel on Climate Change, 2015). As opposed to resistance, communities and planning agencies are focusing on mitigation and resilience (Viglione et al., 2014). Built structures have design limits for the amount of impact they can withstand until their compromise is inevitable. Resilience approaches seek to minimize the consequences that come after a flood hazard occurs (Restmeyer et al., 2015). Resilient cities may be hit by extreme natural events, but will quickly rebound and reorganize, returning to a stable state much quicker than those that are not resilient.

 Throughout the past century, the capital-city region of Louisiana has often been considered one of the fastest growing cities in the state (Harland Bartholomew & Associates, 1946; City-Parish Planning Commission, 1988). Since its inception in 1949, the City-Parish Planning Commission (CPPR), has called for better zoning and city organization (Harland Bartholomew & Associates, 1946, CPPR, 1980; CPPR, 1988). However, pressures for developers have driven expansion of businesses and structures further into the floodplain (Emmer, 1986; Davison, 1986). In addition to commercial pressures for expansion, pressures of suburban sprawl and calls for better school systems have led to the creation of new communities across the natural floodplains. The cities and communities where sprawl is most evident include Central, Denham Springs, Prairieville, and Gonzales. They are situated within the parishes of East Baton Rouge, Ascension, and Livingston and were among the hardest hit by the August 2016 flood (FEMA, 2017a). Given their flood-prone situation and their recent experiences, these parishes will constitute the study area for this thesis.
Flood events are affecting communities within the study area with increasing frequency (FEMA, 2016). With the impending effects of global climate change, including sea level rise and increased extreme weather events, coastal areas are also facing magnified threats. East Baton Rouge, Ascension, and Livingston parishes are not considered coastal regions, however, water movement in the lower reaches of the Amite River can be influenced by temporary or long-term sea and lake-level rises in lakes Pontchartrain and Maurepas. These parishes are also expected to receive increases in populations as migrants move away inland from the coast (Intergovernmental Panel on Climate Change, 2014; Coastal Protection and Restoration Authority, 2017). However, if weather events such as those that caused the August 2016 floods continue to occur with higher frequency, coastal and inland residents will still be at risk. Furthermore, without careful planning and development processes, inland communities are likely to continue to extend further into the floodplain as their populations grow due to an influx of coastal residents, making the area even more vulnerable to floods and other natural hazards. The multiple, dynamic processes that are occurring at the same time in this region, including increasing suburban sprawl, coastal migrants, and flood events coupled together with sea-level rise, coastal land loss, and increasing frequency of natural hazards make this region an important area of study.

The concept of resilience, situated within the natural hazards discipline, refers to the ability to anticipate, respond, recover, and reduce vulnerabilities to a disturbance in a way that minimizes the damage to individuals and communities (Colten, Kates, and Laksa, 2008; Colten, 2012). Individuals with greater capacity for resilience are able to return to a “normal,” or even an improved way of life quickly after a natural hazard event occurs (McEwen et al., 2017). Since resilience is practiced before, during and after an event, it is an adaptive, historical process
that is constantly changing (Hemmerling, 2017; McEwen et al., 2017). Policymakers, developers, and community members need to be familiar with the local historical responses to past natural hazards to better understand and predict how communities will behave in the future (Hemmerling, 2017). Better comprehension of resilience specific to these communities can mitigate the effects of future natural hazards, allowing individuals to rebound better.

In an effort to better gauge historic capacity for resilience, this research will create and validate a flood resilience index to measure community resilience to flooding across Ascension, East Baton Rouge, and Livingston parishes from 1983-2016. The goal of this research is to answer the following questions: 1) What are the key variables that can be used to measure community resilience to flooding? This will be accomplished through the creation of a flood resilience index that will increase understanding of how resilience changes over time and after repeated flood events. 2) How has resilience changed, spatially, across the parishes of East Baton Rouge, Livingston, and Ascension, and temporally, since the Amite River flood of 1983?

This research is in response to existing studies of resilience within geographic and natural hazards literature. While many studies have attempted to theoretically understand human resilience and/or vulnerability in the face of natural hazards, few have used indexes to quantify resilience, and fewer still have concentrated specifically on flooding (Cho and Chang, 2017). Furthermore, most resilience studies tend to focus on social aspects. However, there are many ecological factors that contribute to community resilience, as well. A small number of studies have focused on both social/demographic factors and biophysical factors of resilience (Cutter, 2016a; Kotzee and Reyers, 2016). This research responds to and refines natural hazards research and resilience indexes in several ways. The flood resilience index will refine previous studies by emphasizing both social and environmental variables that contribute to local capacity for
resilience to flooding. Furthermore, as a means to understand resilience as a continuous process and to examine responses to past flood events, this study will be one of the first to analyze a resilience index at multiple points in time. This research will ultimately help to understand how community resilience has changed over time after repeated flood events. Furthermore, this will help quantify the components that lend themselves to community resilience, so that future natural hazards may be recognized and their harmful effects may be mitigated. Finally, this study adds to the new and growing set of literature about resilience to natural hazards, specifically resilience to flood events.
CHAPTER 2. LITERATURE REVIEW

This chapter discusses prominent research on resilience to natural hazards since it was first introduced within the concept of ecological systems in the 1970s. As resilience scholarship has evolved, so too have the ideas of how to gauge and measure resilience. Some scholars rely on history, social analysis, and community memories to understand the unique and nuanced resilient practices within communities (Colten and Giancarlo, 2012; Leong et al., 2007; McEwan et al., 2017). However, others stress the importance of quantitative measures to provide baseline and comparative scores of resilience as these methods can be easily replicated and applied to almost any region (Cutter et al., 2010; Cutter, 2016a; Biggs et al., 2012). This chapter will discuss prominent literature and the gaps within the disciplines of natural hazards, social ecological resilience, and urban planning.

Resilience Theory

Resilience was first introduced as a term describing ecological systems by C.S. Holling in 1973. Holling defined ecosystems as having the properties of both resilience and stability. Under this definition, resilience referred to the ability for relationships within systems to persist and for the systems to absorb many changes and perturbations (Holling, 1973). The process of ecological resilience is described through the four stages of the adaptive cycle: growth/exploitation, conservation, release, and reorganization/renewal (Holling, 1973). When ecological systems are in the growth phase populations are thriving and rapidly expanding. Eventually population growth slows and reaches the conservation stage as ecosystems reach ideal living conditions. Disturbances trigger a transition into the release phase, which may diminish either populations or resources available to the population. After the release will come reorganization. The reorganization allows ecosystems to recuperate from the disturbance,
resulting in more growth, and thus a repetition of the cycle. The adaptive cycle is an iterative process that will continue as long as a population of species exists. By Holling’s definition of resilience, a population’s capacity for resilience lies within the ability to persist, even in the face of many changes (Folke, 2006).

It was not until years after Holling’s pioneering work that resilience was transferred into the discipline of natural hazards and geographic scholarship. Timmerman was the first person to apply the term of resilience within natural hazards research, where he referred to resilience as the capacity of a system to recover or absorb from a damaging event (Timmerman, 1981; Burton, 2015). Before resilience was introduced, researchers were more focused on the role of individuals, rather than analyzing entire human systems. Gilbert F. White and Eugene Haas blamed a lack of individual responsibility in choosing safe locations to live and an ignorance of local hazards for the rise in numbers of people affected by natural hazards (White and Haas, 1975; Community and Regional Resilience Institute, 2015).

As the concept of resilience became a popular ecological theory, other disciplines have adopted it, including geography and natural hazards (Adger, 2000). The second assessment of hazards research introduced a paradigm shift which placed importance on creating disaster resistant communities through preparedness, response, recovery, and mitigation (Mileti, 1999; Cutter et al., 2008). Instead of avoiding dangerous environments, this shift in literature encourages individuals to interact with and understand their environment. As hazards study has evolved, concepts of sustainability, reduced vulnerability, risk reduction, and resilience have been introduced as measures to protect individuals and communities from natural hazards.

Resilience has re-emerged and evolved conceptually as a way to understand more than just ecology, and so have components of the adaptive cycle. The main differences between the
resilience of ecological systems and social systems are social memory, capacity for adaptation, and the ability to apply critical thinking to decision making. Changes in the way ecological systems respond to disturbances rely on aspects out of their control, such as gene mutations or changes in the environment. Humans and social systems, on the other hand, have the ability of decision making and can learn from past events. An analogue to Holling’s adaptive cycle can be used to describe resilience in disaster management: anticipation, response, recovery, and reduced vulnerability (Colten et al., 2008). An individual or community’s ability to accomplish each of these four processes, while minimizing harms to health, safety, and environmental systems is resilience (Willbanks, 2007; Colten et al., 2008; Hemmerling, 2017). This occurs before, during, and after a natural hazard, and resilience is therefore a process that is constantly developing.

While the way resilience of ecological systems operates is different from the way social systems do, resilience scholarship has also linked social and ecological systems together (Adger, 2000). Social resilience relies on the ways humans anticipate, respond, recover and reduce vulnerability to natural hazards, which are inherently linked to ecological systems. Each of these human processes are reliant on the way ecological systems operate, and vice versa. Thus, social-ecological resilience thinking relies on the adaptive cycle of ecosystems and humans to continue to function in the face of changes while simultaneously providing humans with important ecosystem services (Adger et al., 2005). In urban ecosystems there are especially complex linkages between the way humans and ecosystems function (Alberti and Marzluff, 2004). Patterns of human development, and urban sprawl in particular, are directly related to environmental systems of air, energy, land, and water (Wilson and Chakraborty, 2013). One way communities can build social and ecological resilience to flooding is through responsible land use and development patterns. Flood hazard mitigation techniques include many techniques,
such as runoff reduction, flood-proofing houses, land acquisition, relocation, and the limitation of hazardous building patterns (Burby, 1998; Dawson et al., 2011). Each of these approaches rely on limiting human interference and allowing ecological systems to function as they should naturally.

If a community is not resilient, after a flood it will rebuild without any changes to existing construction standards and policies, which will cause the cycle to continue in an unstable manner, as extreme natural events will continue to negatively affect the community. At the local level, there are not many entities that intentionally integrate land management tools for hazard mitigation (Burby, 1998). Instead, remiss land use plans and regulations lead to sprawling development, characterized by low-density, discontinuous, and uncontrolled land use (Wilson and Chakraborty, 2013). To create sprawling development, developers convert land that was previously farmland, open space, wetlands, forest, and habitat into subdivisions. Specifically, in the Baton Rouge region, sprawl extends into the Amite River floodplain, in areas where development was once avoided. This process results in the loss of ecological services and simultaneous increases in impervious surfaces, which reduce groundwater discharge, and increase the runoff, exacerbating flood risks.

Instead of relying on engineers and other professionals to design hard structures, some flood risk management paradigms recognize the importance of collective, local memory practices to build flood resilience (McEwen et al., 2016). Social memory plays an important role in a community’s capacity for resilience to floods. An effort to record flood memories, “flood materialization” is the use of items such as graphics, plaques, and photographs to capture experiences and actively remember a flood event (McEwen et al., 2017). Understanding the ways in which communities build social memory after flood events can allow for enhancement of the
process of recovery and anticipation in regions that are lacking. As time passes after catastrophic events, the social memory of the harm inflicted slowly wears off (Colten and Giancarlo, 2011). People eventually are less likely to integrate the social memories of these events into their daily decision making. Thus, the aftermath of major flood events presents cities with an opportunity to re-evaluate and improve upon flood protections while the memory is fresh and individuals are more inspired to take action.

**Resilience Indexes**

Much of resilience literature focuses on the conceptual components of resilience and the historic processes a community goes through, which can only be examined under a social sciences lens (Lam et al., 2017). However, the fields of geography and spatial sciences have the most advanced means for integrating the understanding of resilience across different disciplines due to analytical tools and the focus on spatial interactions and space, which allows for robust quantitative measures of social processes (Cutter, 2016b). Research groups recognize that being able to numerically measure capacity for resilience will allow communities and their policymakers to identify areas of improvement, track changes in resilient practices, and conduct cost-benefit analysis on the benefits of increasing resilience (National Research Council, 2012; Burton, 2015). This section discusses efforts to quantify and measure the process of resilience as a means to better understand how communities can be more resilient, and to identify areas that are lacking resilient practices.

The most notable index related to resilience is the Social Vulnerability Index (SoVI) (Cutter, Boruff, and Shirley, 2003). While vulnerability and resilience are opposite ends of the same continuum, reducing vulnerability is a key element in the cycle of building resilience (Blaikie et al., 1994; Colten et al., 2008). Therefore, some of the variables in the SoVI are
pertinent to measuring community resilience in regards to flooding. This index found eleven key
dimensions of social vulnerability: personal wealth, age, density of built environment, single-sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, and infrastructure dependence which explained 76 percent of the variance.

More recently, Cutter et al. have conceptualized the Disaster Resilience of Place (DROP) model, which aims to present the concepts of vulnerability and resilience together, using easily quantifiable variables (Cutter et al., 2008). The DROP model contains fifty variables narrowed down to thirty-six, which fit under the subcategories of: social resilience, economic resilience, institutional resilience, infrastructure resilience, and community capital. The authors selected variables that were robust and could capture important nuances of the various kinds of resilience within counties. The authors standardized the data and performed transformations so that each variable could be represented numerically from 0 to 1, with higher values indicating more resilience. Finally, adding variables together created the disaster resilience score. This model is important as it provides a baseline to compare resilience scores across the country both at the local level, aggregated up through various other levels. However, the authors do not provide any means for validating the model, they instead rely on the assumption that their choice in variables is well supported through resilience literature.

The DROP model and many other resilience indexes provide frameworks for measurements at a single, national level (Cutter et al., 2008; Burton, 2015; Lam et al., 2015). PEOPLES, however, is a framework that attempts to measure community resilience across different spatial and temporal scales (Cimellaro et al., 2016). This framework relies on seven dimensions to measure community resilience: population and demographics, environmental and ecosystem, organized and governmental services, physical infrastructures, lifestyle and
community competence, economic development, and social-cultural capital. Each of these dimensions represents resilience across different scales. The authors argue that the multilayered aspect of this framework provides for a holistic measure of community resilience. Lifestyle and community competence is the only dimension that does not rely on quantitative measures, and instead suggests that quality of life surveys can be used as indicators making the PEOPLES framework more of a quantitative approach than one of mixed methods.

There are few attempts to measure resilient processes that operate at the local level. The Community and Regional Resilience Institute (CARRI) with support from FEMA, created a Community Resilience System for communities to use (2015). This system serves more as a tool for guidance and self-evaluation than a comparative index, with six dynamic stages: engagement, assessment, visioning, planning, implementing, monitoring, and maintaining (CARRI, 2015). The Community Resilience System is comprehensive, however, it is primarily geared towards community leaders to complete the assessment, as they can serve as subject matter experts on detailed facets of the community resilience. It acts as an educational tool rather than an assessment that produces values for comparison across communities.

Many efforts to measure resilience have focused on social aspects of resilience, without tying in ecological resilience. Biggs et al. (2012) outlined several general criteria for enhancing ecosystem services resilience. The seven generic principles for enhancing the resilience of ecosystem services, according to Biggs et al. are: maintain diversity and redundancy, manage connectivity, manage slow variables and feedbacks, foster an understanding of social-ecological systems as complex adaptive systems, encourage learning and experimentation, broaden participation, and promote polycentric governance systems.
Many resilience indexes focus on natural hazards as a whole. However, there have been few studies that have looked exclusively at resilience to flooding. Kotzee and Reyers (2016) created an index for measuring flood resilience. Using the principles of resilience defined by Biggs et al. (2012) and other dominant literature, the authors compiled variables that were thought to be related to flood resilience. Using Principle Component Analysis, the authors determined that their variables fit into these main components: social resilience, economic resilience, ecological resilience, and recovery, with wetland diversity and access/evacuation potential standing out in their own category. Of the twenty-four variables, the ones that explained the most variance were: education, communication capacity, place attachment, water infrastructure, income disparity, employment equity, ecological buffers, employment sector diversity, soil retention, and wetland diversity. However, while Kotzee and Reyers (2016) have already created a flood-specific resilience index, many of the components focus specifically on social attributes, and are missing some key biophysical attributes.

**Common Measures of Resilience**

Building off previously discussed resilience indexes, this section covers specific variables that are considered in the study and how they contribute to an individual’s resilience. Social and demographic attributes of a community enable comprehension of what resources and/or opportunities individuals have, which allow a person to be more or less resilient. After a flood event, an important step within the recovery phase is to re-accumulate capital and physical infrastructure (Peacock and Ragsdale, 1997; Tobin and Whiteford, 2001). However, disadvantaged residents - those with higher percentages of minority populations, low incomes, both young and old ages, and women- are likely to experience slower recovery rates (Bolin and Bolton, 1986; Peacock and Ragsdale, 1997; Tobin and Whiteford, 2001).
Lower income residents are disproportionately affected by disasters (Flanagan et al., 2011). With fewer financial resources a person may be unable to evacuate during the flood event and recover well afterwards. Household expenses often represent a larger portion of a low-income individual’s total assets and for this reason, it is proportionately more expensive to replace or repair after a flood (Flanagan et al., 2011; Tierney, 2006). Families with a higher income level have greater safety nets and are able to withstand losses that may occur due to a flood. Even if a flood impacts a family with higher income levels, their financial resources enable them to “bounce back” and recover more efficiently than someone who cannot afford to fix their home, get a hotel room, or buy new clothes after a flood (Cutter et al., 2003).

In general, minorities are very vulnerable during natural hazards. However, there are plenty of instances where minorities have shown extreme resilience after a natural hazard events. The Vietnamese population in New Orleans was particularly vulnerable to the effects of Hurricane Katrina: many in this population were low-income, had little English speaking abilities, and were immigrants (Cutter, 2016a). However, this population had substantial social capital through self-reliance, place attachments, and religious networks that allowed the Vietnamese community to demonstrate effective resilience and recover very quickly after Hurricane Katrina with rapid rebuilding, strong mobilization, and empowerment (Leong et al., 2007; Cutter, 2016a). Furthermore, there is evidence that racial minorities may be more resilient in the face of natural hazards due to enhanced preparedness before an event. It was found that black and Hispanic families had greater chances of receiving help from family members than Anglo families before Hurricane Andrew (Morrow, 1998). However, studies have found that in general, racial and ethnic minorities experience more social and economic marginalization than
non-minorities (Cutter et al., 2003). This study area has very concentrated racial populations, so it is especially important to include measures of race.

There are many recognized differences in the response and recovery between genders during and after natural hazards (Enarson et al., 2006; Enarson and Morrow, 1998; Morrow, 2008). These differences are due to cultural and social organizations, rather than physical differences. Women are often affected more negatively by disasters than men because they usually receive lower wages than men, even for the same job (Morrow and Enarson, 1998). Furthermore, women hold lower social status, usually perform caregiver roles, and have lower levels of power than men, which decrease their resources and responses during and after disasters (Fothergill, 1998).

Those on both ends of the age spectrum may also be less resilient in the face of floods. Both those that are very young and elderly require more care and attention than those that are not. Parents of young children may not be as resilient after a flood event, as resources such as daycare and school may be affected after a flood. This occurred after the flood in August 2016 in Baton Rouge, where $50 million in flood damages caused the entire parish’s public school system to close for about two weeks (The Advocate, 2016a). Some schools suffered such severe damage that they had to be merged with other schools. This put parents at a disadvantage when they had to sort out childcare after the flood to try to return to work, in many cases while living in temporary shelters. In addition to the extra care that some elderly people may require, they also may have mobility constraints. During a flood, this can make it more difficult for an elderly person to evacuate. If an elderly person’s home is damaged, their sometimes limited mobility and extra care required may make it harder to find a new place to live and return to normal life.
Education plays a large role in how people understand their risk to natural hazards and how they respond after one hits. Most emergency entities write educational materials for a reading level well above the sixth grade level, even though it is recommended that they be at the sixth grade level or lower (Morrow, 2008). This gap can make it more difficult for those lacking proper education to make proper decisions both before, during, and after a flood event.

In addition to social attributes, there are also many environmental factors that influence resilience. Sprawl is used in this study as a proxy for planning efforts and of spatial distribution. Suburban sprawl has been considered a wasteful form of urbanization and land use both because it takes up land that could be used for other purposes such as agriculture, conservation, or as a flood buffer, it requires more resources and energy to provide services such as sewer lines and power, and it often forms fragmented and uneven development, with surrounding areas of land having few uses and functionality (Torrens and Alberti, 2000; Ewing, 1997). Typically, sprawl occurs as metropolitan areas expand due to unplanned growth (Ewing, 1997; Peiser, 1989). Baton Rouge, Louisiana is one of the most sprawling medium metro areas in the nation (Smart Growth America, 2014). Because of the fragmented nature of land ownership and uses resulting from sprawl, often these areas have inefficient road networks and consequently, poor accessibility due to the transport system serving dispersed development. Separation from the city core increases the cost for a city to provide services such as water, gas, and electricity, thereby straining city budgets and service providers, while also increasing residents’ vulnerabilities. During a flood, it may be harder to provide services for and rescue those living in areas of sprawl.

Sprawling and urbanized areas cause increases in impervious surfaces, which exacerbate the effect of flooding. Impervious surfaces increase the amount of surface runoff and peak
discharge time in rivers. When rain falls, impervious surfaces such as roads and roofs allow water to glide across the surface, moving quickly and directly to their final routed destination, which is usually a storm catchment basin or a body of water. Identifying impervious surfaces is an important tool in aiding planning measures, such as understanding run-off control and water quality (Arnold and Gibbons, 1998). Impervious surfaces, therefore, increase the intensity of a flood, and lessen resilience in an area as the flood is more likely to happen quickly and more intensely.

Waters in rivers and streams initially comes from precipitation. However, there are many different processes and factors that can alter and affect stream flow. The volume and direction of flow are determined by environmental factors such as climate, geology, topography, soils and vegetation (Poff et al., 1997). Land-use changes across the watershed can have dramatic impacts on river hydrology. Logging, livestock grazing, agriculture, and intensive urban land uses can restrict the soil infiltration of water and instead increase run-off, causing heightened size and frequency of floods (Poff et al., 1997).

Vegetation works in the exact opposite way of impervious surfaces, allowing water to be absorbed, lessening the effect of flooding. Dense, tall vegetation can lessen the impact of rainfall on the ground and decreases the velocity of surface runoff. Furthermore, vegetation allows water to be recharged through the ground, rather than flowing off the surface and straight into a river, or body of water. Therefore, taller, denser vegetation decreases the peak discharge time of a river, and lessens the effects of flood.

Regardless of the type and amount of vegetation, most of Louisiana’s soil has high clay content and organic matter, which impedes percolation and accelerates runoff (FEMA, 2017b). When soils are permeable, they have small holes in them that allow water to seep through the
soil, making its way into the water table. Soil with high clay content is thick and impermeable meaning water will cannot seep into it, affecting how quickly an area will flood, as well as the recovery time after a flood event (Archer et al., 2013).

However, elevation can also increase the surface runoff, affecting the severity of flooding during a heavy rain event. Beginning roughly south of I-12, the topography of the study area flattens considerably, which influences the effects of backwater flooding (Jacobsen, 2017). Furthermore, coastal flooding can occur in the region due to wind-driven water inundating nearby low-lying land (Jacobsen, 2017). The proximity of the study area to Lake Maurepas and Lake Pontchartrain puts much of the low-lying land at risk for flooding.
CHAPTER 3. BACKGROUND

Study Area

The study area (Figure 1) encompasses the Louisiana parishes of Ascension, East Baton Rouge, and Livingston. The areas of Ascension, East Baton Rouge, and Livingston parishes are 302 mi², 472 mi², and 653 mi², respectively. While each of the parishes shares borders with each other, they are comprised of very different kinds of both natural and developed environments, with dynamic city structures and demographics. East Baton Rouge Parish was the largest parish in the state during the 2010 census, with a population of 440,171 (U.S. Census Bureau 2010). East Baton Rouge Parish is home to the capital city of Baton Rouge, has the densest population of the three parishes, and is also the most urbanized. However, both Ascension and Livingston Parishes have been growing rapidly in recent decades as communities have begun to sprawl out of East Baton Rouge Parish into less densely populated areas. In the 2010 census, Ascension and Livingston parishes had populations of 107,215 and 128,026, up 33 and 46 percent since 1980, respectively. Ascension contains the cities of Donaldsonville and Gonzales, while Livingston contains the towns of Denham Springs and Walker. Including the three parishes allows for a dynamic study of many different communities and areas.

Important comparisons can also be made among the other cities within East Baton Rouge Parish, such as Baker, which has a predominately African American population. Central, however, which became a city in 2005, has a very strong school system, higher median income, and is predominately white relative to the region. Since there is a lot of new development on the fringe of the city of Baton Rouge, communities and political entities face the critical challenge of proper planning. Many of the houses impacted by the most recent flood in August 2016 were in
the new and growing communities in the region. Development traditionally avoided these areas due to their location in the natural floodplain, but newer communities now occupy these areas (Harland Bartholomew and Associates, 1946).

Figure 1. Study Area with major watersheds and water bodies.

In addition to the many different types of communities represented in the study area, the parishes are also exposed to different types of flood events. The study area’s close proximity to many water bodies, coupled with low elevation and slope makes it susceptible to frequent flooding (Jacobsen, 2017). In fact, water bodies define several of the parishes’ boundaries within the study area. The Mississippi River bounds East Baton Rouge and Ascension parishes on the
The Amite River bounds these parishes on the east and Livingston Parish on the west. Lake Maurepas and Lake Pontchartrain are south of the study area. The largest tributary of the Amite River is the Comite River. The Comite River flows for 64 miles through East Baton Rouge Parish, and enters the Amite River on the parish boundary at Denham Springs (Gulf Engineers and Consultants, 2015). Ultimately, the Amite River drains into Lake Maurepas, south of Livingston. Some of the flooding in this region has been due to development in risky areas that have a tendency for flooding (Coxe, 1992).

Figure 2. Minority populations.
Most of Baton Rouge, Ascension and Livingston parishes fall within the Amite River basin. Within this region, there are three main types of flooding that affect people: flash flooding, headwater river flooding, and backwater river flooding (Jacobsen, 2017). As its name suggests, flash flooding occurs locally at the neighborhood level in small pockets of land that prevent rainfall from draining out of the area quickly. This type of flooding can occur from any rain event, such as an isolated thunderstorm or longer, steadier rains. Headwater river flooding occurs from increasing amounts of water from a point upstream. This mainly occurs when there is a lot of rainfall at an upstream location. Furthermore, steep topography upstream can exacerbate the flooding downstream.
Finally, there is backwater flooding, which is a much more complex type of flooding that commonly occurs in the study area (Jacobsen, 2017). This type of flooding occurs when the downstream portion of a waterbody has already received much water, and the stream becomes,
literally, “backed up.” There are several reasons that the Amite River watershed, in particular, is susceptible to backwater flooding. First, the lower portion of the Amite River, roughly around the three-parish area, has a topography that is much flatter than it is upstream. This low relief allows more water to back up. Second, the Amite River flows upstream into several tributary streams, which cause backwater flooding. Lake Maurepas’s water level also affects backwater flooding in the study area. Finally, there are several built and natural structures that cause both constriction and obstructions to the river. This includes highway crossings, bridges, control gates, and lakes.

**Summary of Recent Flood Disaster Declarations**

The August 2016 flood broke records dating back to the Amite River flood in 1983. In between these dates, there have been several other flood events that have impacted the three parishes. They occurred in the years 1983, 1989, 1993, 2011, and twice in 2016. The 1983 Amite River flood broke record flood stages for the Amite and Comite rivers (United States Army Corps of Engineers, 1983). This flood resulted in the inundation of over 5,000 residences and cost $172 million ($249 million adjusting for inflation) across the Amite River Basin (Davison, 1986; United States Army Corps of Engineers, 1983). The Amite River basin had received some heavy raining that resulted in flooding in December of 1982. This caused ground water levels to be higher than normal, which exacerbated flooding when rainfall fell from April 5 to April 8, 1983 with rainfall ranging from 7 to 14 inches across the region (United States Army Corps of Engineers, 1983). In addition to the rainfall, the Comite River crested at 29.7 feet, which at the time was four feet higher than ever recorded, while the Amite River crested at 41.45 feet. The governor of Louisiana declared disasters in eleven parishes, however, the federal
government ultimately only determined Ascension, East Baton Rouge, and Livingston parishes were eligible for federal disaster aid (United States Army Corps of Engineers, 1983).

The next major flood event occurred when Tropical Storm Allison dropped rainfall from June 24 through the 27th, 1989 and impacted Texas and parts of Louisiana. Of the three-parish study area, only East Baton Rouge parish was eligible for federal aid (NOAA, 1990). Baton Rouge received 9.7 inches of rainfall within a 24-hour time period (United States Army Corps of Engineers, 1995). This flood caused about $7.4 million in damages in Louisiana (The Advocate, 1989).

The next major flood event in the region occurred four years later in 1993. A stationary front over the Mississippi River Valley caused damages to all three parishes. Maximum rainfall of 11.23 inches occurred over Baton Rouge. More than $1 million in damages were reported in the parishes of Ascension, East Baton Rouge, East Feliciana, and Livingston (United States Geological Survey, 1994).

The next emergency disaster declaration occurred in 2011. This situation was different than previous ones, due to high statistics predicting flooding in the Mississippi River. The U.S. Army Corps of Engineers opened the Morganza spillway, for only the second time in its history since being constructed in 1954, due to the threat of heavy flooding (United States Army Corps of Engineers, 2017). The opening allowed water to be diverted from the river at a location upstream from the study area. While this event caused major disturbances to transportation on the river and to industrial sites located on the river it did not cause any damages to homes or lives in the Amite River region.

Finally, in 2016 there were two disaster declarations in the region. The first one occurred in March 2016 and affected both Ascension and Livingston parishes, but not East Baton Rouge
During this event, rain fell from March 8 through the 11th, causing flooding near the lower part of the Amite River, as well as in much of north Louisiana. Five months later, historic backwater flooding occurred in the Amite River. The August rainfall exceeded the historic 1983 Amite River flood event. Flooding caused destruction and damages to around 80,000 structures, and more than 100,000 vehicles. Between 75 to 80 percent of damaged homes were uninsured (FEMA, 2017b). Of the cities in the study area, Central, Denham Springs, and Walker were the hardest hit, with 50, 32, and 31 percent of all households in each city, respectively, receiving temporary housing and/or funds through FEMA individual assistance grants (FEMA 2017b). In comparison, only 14 percent of households in the city of Baton Rouge received assistance (FEMA 2017b).

**Flood Management in the United States and Unsafe Development in the Amite Basin**

A person’s capability for resilient practices is dependent on individual attributes such as level of education, personal income, and community connections. However, resilience can also be influenced by things that occur at the regional and national scale due to culture, laws, and regulations. Regional land-use changes and the resilience of development in regard to flooding in the Baton Rouge area was largely influenced by several factors including: the introduction of the National Flood Insurance Program (NFIP), the post-World War II economic and housing boom, the national standardization and popularity of both building codes and concrete slab, suburban ranch houses, and the introduction of bussing in the 1980s and subsequent white flight. The following sections will examine the progression of these trends and how each of these elements has led to a common pattern of unsafe development in floodplains and lessened capacity for resilience in the region.
The Mississippi River basin is the largest in the United States and fourth largest in the world. Since this basin drains into Louisiana, living with water and flooding has always been a facet of life in this region. In the 1540s, Native Americans built their houses on high land and retreated to hand built earthen mounds during high water events (Clarke, 1982). Even when the first levees were built in New Orleans in the early 1700s, water still frequently inundated the city (URS Group, 2012). Since the 1927 Mississippi River flood, flood mitigation policies have relied on hard structures such as dams, levees and floodwalls to protect people (Birkland et al., 2003).

For decades humans treated rivers and other environmental hazards as entities that could be managed through engineering. Levees and other flood mitigation structures enable people to live near bodies of water. However, these same structures meant to protect humans ultimately exacerbate the strength and effects of flood events when they occur, placing humans in greater risk and causing increasingly greater damages and costs. Furthermore, levee systems narrow, straighten, and restrict the natural courses of rivers which separate rivers from their natural floodplains (Poff et al., 1997; Burton and Cutter, 2008). Levees and cement culverts serve to restrict bodies of water and to rush the water out as quickly as possible (Tobin, 1995). Floodplain ecosystems serve as buffers for mitigation during floods (Gunderson, 2010). Now planners and scientists realize that allowing rivers to flow naturally, and slowing things down through green infrastructure, bioswales, retention/detention ponds, allow for ecological resilience, which in turn affects community and social resilience to flooding (Gill et al., 2007).

Congress created the National Flood Insurance Program in 1968 in order to make flood insurance more accessible to homeowners, as private flood insurance options at the time were limited and expensive (Gerdes, 1963; Anderson, 1974). This program encouraged communities to adopt flood mitigation techniques and responsible land use practices. The NFIP creates flood
maps and helps assess flood preparedness for communities. Communities that accept the flood maps and enact zoning regulations created by FEMA are eligible for federally guaranteed flood insurance. The NFIP has provided subsidized flood insurance to many households, placing financial burden on the program, which in 2012 had roughly 20 percent of its policies located in high risk areas (United States Government Accountability Office, 2013). While FEMA advises that the best way to reduce the chance of incurring losses from floods is to leave floodplains clear of development, they still provide households with information on how to live with this risk on floodplains (FEMA, 1986).

The NFIP guides land use through building elevation requirements and the Community Rating System, which is a voluntary program that incentivizes communities to adopt measures such as open space zoning, removal of high-risk buildings from flood plains, and enhanced flood mitigation education, in exchange for insurance rate reductions. However, the NFIP does not require homes outside of FEMA defined floodplains to be insured (NFIP, 2016b). It also does not require homes damaged by floods to rebuild with more flood protection unless the damage is over 50 percent (FEMA, 2013). Flood Insurance Rate Maps (FIRMs) are meant to support flood insurance rates, and are not meant as guides for when, where, and how much damage will occur from floods. Communities work with FEMA to determine what their FIRMs will look like. While FEMA is required to assess floodplain areas every five years, they are not required to update FIRMs with any sort of regularity, except when communities have significant new building developments or changes in their flood protection systems (Horn and Brown, 2017).

While the intent of this program is to provide individuals with affordable access to flood insurance and an enhanced understanding of flood preparation, it has instead created misleading flood terminology and incentivized risky development. Instead of relying on the entire natural
floodplain, where many people would have to apply for flood insurance, but would be relatively low risk, Congress decided to require flood insurance only for those who had at least a one percent chance of getting flooded in a given year, otherwise known as the 100-year floodplain.

While the NFIP is an insurance measure, it has indirectly influenced development and planning efforts, along with individual perception and understanding of flood risk. It is possible those living in areas prone to flooding do not completely understand how differing magnitudes of floods potentially damage homes, likely because outreach and communication efforts focus on flood probability as opposed to potential damage (Petrolia et al., 2013; Kousky and Michel-Kerjan, 2015). It has also been suggested that many interpret living in the 100-year floodplain to mean that they will be safe from such an event for 99 years after a 100-year flood (Mount, 1995). In fact, over the lifetime of a 30-year mortgage, risk from floods larger than 100-year floods is 26 percent (Bell and Tobin, 2007).

Current flood management and insurance efforts such as those used by the NFIP do not mitigate risk to floods, but instead exacerbate them through subsidizing risky behavior (Birkland et al., 2003). The “safe development paradox” has been attributed as a social process that intensifies the effects of floods and other natural hazards (Burby, 2006). Most flood protection development was aimed to protect new potential development in the city (Burby, 2006).

However, before the U. S. Army Corps built the levees, people were less likely to live so close to flood prone areas (Stevens et al., 2010). Now that the NFIP subsidizes flood insurance people are willing to endure flood damages, since someone else ultimately ends up paying to fix and rebuild.

This concept says the policies put in place to make communities safer provide a false sense of security (Stevens et. al., 2010). With an increased perceived sense of security, people
then build and live closer into the floodplain, thus actually exposing themselves to greater risk from more extreme events. There are two ways that NFIP plays a role in the safe development paradox. First, by providing insurance assistance across the United States, individuals are under the false assumption that they are covered entirely in the event of a damaging flood. Secondly, by setting standards, which have an intent to reduce the risk of being damaged during a flood, homeowners may assume that they do not need to exceed these standards in protecting their homes.

Levees also contribute to the safe development paradox. Originally built to protect people, communities have instead transformed large swaths of land from wetland into more “productive” areas of land that humans can inhabit. Specifically in New Orleans, following the legislation and subsequent construction of these levees, the numbers of people living in the area increased dramatically. The levees were built to reduce the impact of relatively high impact, lower frequency natural hazards facing the city of New Orleans. However, their construction has provided citizens with a false sense of security, which has caused more development in flood prone locations. The NFIP has also enhanced the effect of the safe development paradox with respect to levees. Land that is within the natural floodplain, but adjacent to and protected by certified levees is not considered to be within the floodplain (Ludy and Kondolf, 2011). However, if the levee is only designed and built to withstand a 100-year event, those living nearby are still at risk of being affected by floods larger, even a 101-year flood.

Since the 1927 Mississippi River flood, flood mitigation policies have relied on hard structures such as dams, levees, floodways, and floodwalls to safeguard people (Birkland et al., 2003). These built structures have design limitations and can only protect against flooding up to a certain height. Flood structures can oftentimes cause significant degradation to the
environment through the alteration of the natural flow of the river (Birkland et al., 2003). In addition, flood structures may encourage more development, which cause greater environmental impact and increases in runoff. This decreases the ability for natural recharge and containment of rainwater, causing a cycle of need for increased flood protection with subsequent increased development in the absence of good planning measures and resilient practices.

**Housing and Land Use**

Better land use policy is a form of flood mitigation that is superior to engineered hard structures or government subsidization of risky development (Berke and French, 1994; Dalton and Burby, 1994; Berk, et al. 1996; Burby, 1990; Burby et al., 1999). Suggested land-use improvements can include preserving wetlands, creating wildlife habitat, open space acquisition, and low intensity land uses. The best way to gain ecological benefits and mitigate flood impacts is through discouraging intensive land development on natural floodplains altogether (Birkland et al., 2003). There have been proposals to incorporate flood mitigation land uses within the Baton Rouge area, however most ideas have not made it beyond city plan suggestions.

While there have been several flood events since the late 1980s, flooding has always been a factor of life in the region. The city of Baton Rouge was first incorporated in 1817. During the city’s first 100 years, the urban core of the city was situated on the banks of the Mississippi River, which provided means for transportation and commerce. The state capitol, also located in the city center, attracted other state offices and retail business into the area (City-Parish Planning Commission, 2016). As businesses expanded and developers built skyscrapers, residents used automobiles to commute longer distances from suburbs beyond the urban core (City-Parish Planning Commission, 2016).
Since the inception of a planning commission in 1946, there has been an acknowledgement that developers should take special care and avoid building in the floodplain (Harland, Bartholomew, and Associates, 1946; City-Parish Planning Commission, 1962). However, since recommendations from the planning commission began, decision makers have typically ignored proposed enhancements to drainage plans and green infrastructure in favor of spending money on public services such as schools, parks, and streets (City-Parish Planning Commission, 1962). In 1946, an entire greenbelt around the city of Baton Rouge was proposed (Figure 5). While the goal of this project was to make use of land that otherwise could not be developed since it was in the floodplain, the greenbelt alternatively would have provided a connected park system with many schools, as well as protecting land in the floodplain with the important ecological function of absorbing excess water. The City-Parish Planning Commission has proposed similar ideas throughout their history, however, this greenway has never actually been built.
Regardless of specific architectural styles, residents in Louisiana along the Mississippi River traditionally elevated their homes several feet above the ground in response to environmental conditions, particularly floods (URS Group, 2012). Elevated homes continued to be the standard until post-World War II, when regionally, and nationally, building codes and construction techniques swelled the number of concrete slab homes (URS Group, 2012). The economic and housing boom that came after World War II urged planners to implement guidelines, which were quickly standardized for fast, inexpensive cookie-cutter cities (Aoki, 1993). Subdivisions first began in the Baton Rouge area during the 1950s, most of which were still relatively close to the urban core of the city (City-Parish Planning Commission, 2016). As houses in the region have been destroyed due to past floods and other events, their owners and
developers have chosen housing styles popular at the national level, rather than those most beneficial for the regional environment (Kniffen and Wright, 1963). Slab concrete housing grew in popularity as it was a cheap and quick way to build homes. Developers built subdivisions across the nation along highways in any flat patch of land regardless of location, so long as the commute into the city was not too long (Aoki, 1993).

Figure 6. Historic subdivision map (Livingston Parish data were not available).

The Baton Rouge area was no exception to this pattern, even though it is full of flood-prone land (Figures 7 and 8). From the 1950s to 1970s, development in flood-prone areas rapidly increased as the petrochemical industry was thriving and local governments did not put many restrictions on housing development growth (Davison, 1986; Emmer, 1986). With the
prominence of floodplains throughout the region, the 1971 Capital Region Planning Commission Land Use Plans called for keeping most of the land east of the Comite River in East Baton Rouge Parish and Livingston Parish agricultural (Figure 7). However, into the 1970s, developers built subdivisions further from the city center, beyond Airline Highway (City-Parish Planning Commission, 2016). By 1975, most of the population of Baton Rouge was suburban, and local businesses and community services, such as parks, grew beyond the urban core to meet the demands (City-Parish Planning Commission, 2016).

Figure 7. 1971 Proposed land use map (image adapted from Capital Region Planning Commission 1971).
Figure 8. FEMA designated 100-year floodplains (A FIRM Zones).

In addition to the growing boundaries of where people lived, average house sizes grew tremendously as well. With an elevated house, flood waters will flow below the house, so long as the flood levels do not reach the height of the house. However, concrete slab housing, with structures flush to the ground level, does not protect its owners during a flood event. By the 1980s, major stores and retail complexes moved out of the city center toward the increasingly suburban population. In addition to the fact that this new type of home was not flood-proof, the increasing development during this period expanded urban and built-up lands further into flood-prone areas (Emmer, 1986).

The governor appointed the Amite Basin Drainage and Water Conservation District in 1981 to provide flood-reduction proposals to the government, however, many complained that the state was not providing the board with enough funding and support, and members of the board rarely actually spoke about reducing flood damages (Morning Advocate, 1982; Emmer,
Much like the City-Parish Planning Commission’s greenway park proposals, not many large-scale drainage projects in the parish have been fulfilled. The Office of Public Works and Louisiana Department of Transportation and Development has studied the Comite River Diversion since 1983, however, while the government has slowly funded the project since 2001, the Army Corps of Engineers still expects that it will be several more years until the project can be completed (Emmer, 1986; The Advocate, 2017; Louisiana Legislative Auditor, 2017).

Many significant changes, related to sprawl, education, and white flight have occurred in the study area since the 1980s. In a desegregation lawsuit in 1981, East Baton Rouge Parish School Board closed schools and bussed students in an effort to achieve less racial disparity in the area (Bankston III and Caldas, 2002). This resulted in a large increase of white students enrolling in private schools in East Baton Rouge, with significant population increases in the neighboring Livingston and Ascension parishes as well. In the year after the court-ordered bussing, East Baton Rouge Parish Schools lost 7,000 white students, with a resulting increase in the proportion of African American students in the student body (Bankston III and Caldas, 2002). Through the 1990s, African American representation in schools increased at a rate three times larger than the overall African American population in the parish (Bankston III and Caldas, 2002). At the same time that East Baton Rouge Parish schools were losing students, the neighboring Ascension and Livingston parishes were gaining students. Denham Springs Junior High Principal commented that the large growth in the parishes ‘is almost exclusively driven by white flight and the initial location of new hires [workers] for industry in EBR who will not live where they work’ (Bankston III and Caldas, 2002).

Eventually, in the 1990s, sprawl began to grow into the parishes of Ascension and Livingston (City-Parish Planning Commission, 2016). As sprawl has continued throughout the
region there have been many major land-use changes. From 2001 to 2011, the land cover within the Amite Watershed has had a 50 percent increase in high intensity developed land, 33 percent increase in medium intensity developed land, 14 percent reduction in deciduous forest, and 11 percent reduction in evergreen forest (FEMA, 2017b). An example of the suburban growth in the floodplain is in the Greenwell Springs area in the city of Baton Rouge, just near the boundary of Central. This completely residential suburban neighborhood has more Severe Repetitive Losses than other areas in the region. In 2009, 71 percent of the homes were built on concrete slab, 95 percent of homes were single story homes, and 52 percent of the homes were on FEMA’s Repetitive Loss list (University of New Orleans, 2009).

Most of the land within Ascension Parish that is not within the FEMA 100-year floodplain contains subdivisions and citizens have increasing worries that the rural character of the area is dwindling. The increase in populations to the area has caused mounting pressure on residential development, which is being pushed further into the floodplain (Ascension Parish, 2009). While there are some ordinances that limit development in floodplains, developers often find loopholes in these rules. The Baton Rouge Horizon Plan allowed for development even in hazardous areas such as backswamps, as long as retention ponds and mitigation areas are filled in on the floodplain (Coxe, 1992).

Parents with adequate resources may often overlook environmental and financial factors in order to ensure their children go to the best schools. A homeowner in a flood-prone Baton Rouge subdivision chose his house because it was the only one they could afford within the school district they wanted to be a part of (Coxe, 1992). However, this sort of sacrifice is not economically advantageous, nor is it a resilient practice. Housing developments in flood-prone areas may seem affordable on the outset, however the market value of residential property can
decline significantly after a flood event (Tobin and Montz, 1988). Furthermore, the resulting demand for structural programs from a flood event transfer financial costs to the general public, all due to human occupation of flood-prone, hazardous land (Coxe, 1992).

Consideration of the history of land use, development and flood mitigation policies under the four stages of the adaptive cycle indicate a general lessening in the capacity for resilience in relation to floods in the region from the 1980s to present, especially in the newer subdivisions located closest to the floodplain. This history of housing regulations, local development patterns, and sprawl in the region indicate that generally: 1) new developments are not flood-proof, indicating a lack of anticipation to future flood events and likely increased recovery times after the next flood occurs; 2) home loans and the NFIP have allowed for complacency and the feeling that someone else will take care of the cost of a home in the event of a flood or natural hazard. This may increase the recovery time after a flood event, since oftentimes federal grants may cover damages. However, this leads to development further into the floodplain, which increases vulnerability and shows a lessened capacity for anticipation of the next flood event; and 3) Suburban sprawl, partly triggered by white flight and bussing in the 1980s has increased considerably. This results in greater racial and financial disparities in the region, which increases the vulnerability for minorities and low-income individuals. While the high concentration of white, wealthier individuals are less vulnerable and have greater capacities for responding to disasters, their sprawl places them in more hazardous, flood-prone areas.

A brief history of the region can provide a general understanding of resilience in the Baton Rouge area. However, resilience indexes have become an effective way for understanding and comparing resilience. Quantitative indexes are applicable at many different geographical scales. However, researchers do not all agree on the variables and methods that should be used.
Indexes are so attractive because they can be used and calculated for almost any time, geographic scale, and place. Furthermore, this could allow stakeholders and decision makers with even the most limited resources to be able to understand resilience in one’s own community, regardless of how small or large. Most resilience indexes have been intended for use at the national level and hence have used the county or parish scale for analysis. Furthermore, many resilience studies lack a strong environmental component and instead rely on mostly social-economic factors. This study, however, will explore a resilience index for a more localized level, incorporating environmental flood related factors.
CHAPTER 4. DATA AND METHODS

This chapter covers the data and methods involved in creating the resilience index. Unlike other indexes, the same metrics span the years 1983, 1993, and 2016 at the census-tract and block group level. First, this section will discuss the variables that were ultimately included in the index calculation. Next, it will discuss data aggregation and the index calculation.

An extensive review of existing natural hazards resilience literature provided the basis for the assembly of a set of over forty variables, which served as the basis for a “wish list.” Finding consistent data from the 1980s across each of the three parishes that was also analogous with present-day datasets was the biggest obstacle to gathering consistent data. While there were originally more attributes considered in this study, both temporal and geo-political restrictions limited what was available. Most attempts at resilience indexes occur at one time period, across a large geographical extent so that comparisons can be made across multiple localities. This study differs by focusing on a localized region, but at several points in time as a way of considering resilience as an ongoing process that occurs before, during, and after an extreme natural hazard occurs.

Since 1983, there have been five events that triggered emergency disaster declarations: 1983, 1989, 1993, 2011, and 2016. The floods in 1989 and 2011 are not included because they impacted a limited geographic extent. The 1989 flood, likewise impacted only a limited area in East Baton Rouge. Although it could have altered many of the parish demographics, its limited geographic impact prompted its exclusion. This study excluded the 2011 flooding because it occurred in the Mississippi River, where the opening of the Morganza Spillway threatened residents west of the river and not in the Amite River Watershed. Furthermore, this flood only
affected East Baton Rouge Parish. Therefore, the index will be applied to events in 1983, 1993, and 2016.

Table 1. Variables used in study.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>per capita income</td>
<td>U.S. Census</td>
</tr>
<tr>
<td>percentage of minorities</td>
<td>U.S. Census</td>
</tr>
<tr>
<td>percentage over age 18 and under 65</td>
<td>U.S. Census</td>
</tr>
<tr>
<td>percent educational attainment</td>
<td>U.S. Census</td>
</tr>
<tr>
<td>housing density</td>
<td>U.S. Census</td>
</tr>
<tr>
<td>percentage of women</td>
<td>U.S. Census</td>
</tr>
<tr>
<td>average Normalized Difference Vegetation Index</td>
<td>Landsat</td>
</tr>
<tr>
<td>length of principal and secondary roads</td>
<td>U.S. Census</td>
</tr>
<tr>
<td>average elevation</td>
<td>USGS NED DEM</td>
</tr>
<tr>
<td>average monthly precipitation</td>
<td>USGS</td>
</tr>
<tr>
<td>% well drained soils</td>
<td>USDA SSURGO</td>
</tr>
<tr>
<td>average distance from Amite River</td>
<td>USGS</td>
</tr>
</tbody>
</table>

The analysis considers census-block group levels, except for 1983, when the tract level was the highest resolution census level available. Each block group is intended to be a homogenous geographical unit sharing similar population characteristics, economic status and living condition, which is why this level was chosen for analysis (Sampson et al., 2002; Burton, 2015). The census block group is also small enough that it is similar to a neighborhood within urban areas (Burton, 2015). For the data representing 1983 conditions, data are not available at the block group level. While the census tract comprises a much larger area than the block group, it will still allow for baseline comparisons across the three-parish region.

All of the social and demographic data are derived from the United States Census Bureau. These data were based on the decennial census for 1980 and 1990, while the data for 2015 came from the American Community Survey (ACS) five-year estimates. The ACS estimates are not as precise as census data; however, they are the primary source of geographic
information about the U.S. population and are widely used in research (Spielman et al., 2015). The Integrated Public Use Microdata Series National Historical Geographic Information System (IPUMS NHGIS) provided the census data and GIS shapefiles (Manson et al., 2017). This organization, housed at the University of Minnesota, provides data from the U.S. Census Bureau. IPUMS NHGIS also provides historic census shapefiles that are not available from the U.S. Census Bureau directly.

Normalized Difference of Vegetation Index (NDVI) serves as a measure of greenness. NDVI is a measure of actively photosynthesizing vegetation and correlates directly with vegetation productivity (Pettersson et al., 2005). NDVI is one of the few tools that can extract climate and vegetation data at both large spatial and temporal scales (Pettersson et al., 2005). Furthermore, NDVI provides a numerical measure of vegetation, which can be input into the final resilience index. Landsat imagery provided the basis for NDVI values. Landsat images are the only satellite imagery data set that has consistency throughout the entire period of study. Landsat Level 1 images were from both row 39 and paths 22 and 23. Each of the Landsat images had 0.2 percent or less of cloud cover. NDVI was calculated, all water bodies were masked out of the raster, and then the mean NDVI was aggregated to the block group level. This study used two Landsat 4 Thematic Mapper images, collected on March 8 and 12, 1983 from with 30 m resolution. One of the scenes had 2 percent cloud cover, however, the majority of this coverage was outside of the study area limits. Landsat 5 Thematic Mapper provided images for the 1993 analysis, taken on October 5, 1992 and November 29, 1992. Finally, this study uses images from Landsat 8 Combined Operational Land Imager and Thermal Infrared Sensor, taken on February 10 and 17, 2016. Each of the scenes from 2016 had 0.01 percent cloud cover.
Mean elevation was extracted through USGS National Elevation Dataset Digital Elevation Models (DEMs). I calculated mean elevation for each block group by downloading twelve 1/9 arc-second DEM files mosaicking them together. The same elevation data enable comparable calculations for each period of the study.

NOAA National Centers for Environmental Information provided the monthly average precipitation data. While there are many precipitation stations throughout the study area, only fifteen stations have continuous records spanning of the three study years. I mapped data points for each of these stations and determined the nearest station to each census-tract/polygon were. Then, I assigned each polygon with the corresponding station’s monthly average precipitation for the year.

United States Department of Agriculture’s (USDA) National Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database provided soil data. This database assembles the records of soil surveys across the entire nation. Furthermore, this dataset includes the hydrologic soil group (HSG) classifications, which expresses the runoff potential. There are four HSG classifications based on the ability for soil infiltration when the soils are bare and unprotected from vegetation, wet, and are receiving precipitation from long-duration storms (USDA NRCS, 2007). The four soil groups are: Group A (high infiltration rate): well drained soils that have a high rate of water transmission, usually sand or gravelly soils; Group B (moderate infiltration rate): fine to coarse textured soils; Group C (slow infiltration rate): soils that hinder downward movement of water; and Group D (slow infiltration rate/high runoff potential): soils that are mostly clays which have a very slow rate of transmission. Some of the soils have a dual classification because the soil itself may drain well, but the water table is within 24 inches of the surface. The USDA NRCS Web Soil Survey Interface provided HSG shapefiles.
I calculated the proxy for surface runoff through the percentage of soils in each block group that are in either Group A or Group B. This data represents the soils that have good drainage and therefore provide benefits during heavy rainfall and flood events.

I used length of main roads per capita as a proxy for evacuation potential and network connectivity. Road line data were collected from the US Census Bureau TIGER/Line Shapefile Collection. The U.S. Census Bureau has several road classifications, called Census Feature Class Codes (CFCCs). There are seven main CFCC categories: Primary Highway with Limited Access (A1), Primary Road Without Limited Access (A2), Secondary and Connecting Road (A3), Local, Neighborhood, and Rural Road (A4), Vehicular Trail (A5), Road with Special Characteristics (A6), and Road as Other Thoroughfare (A7). This study adopts the CFCC designations of A1, A2, and A3 as main arterial roads. Using government records, the completion date for each of these roads was added to the dataset, so that just the roads that had been built prior to the each of the study years could be reconstructed. Then, the length of roads within each block group for each time period were calculated.

After I obtained all the data and aggregated it to corresponding census tract/block group polygons, I standardized it through calculation of percent, density, and per capita functions. Finally, I analyzed the variables for significantly high correlations between each other, eliminating those having a Pearson’s R >0.70. This resulted in twelve final variables that I split between two sub-indexes. The environmental category is made up of percentage of primary and secondary roads, average monthly precipitation, average NDVI values, percent of high runoff soils, distance from the Amite River, and average elevation. The socioeconomic category includes: density of households, per capita income, percent of population between the ages of nineteen and sixty-four, percentage of the population that is female, percent of the population
that has at least a high school diploma or equivalent, and percent of the population that are minorities.

After I gathered and standardized the final set of variables, I completed Min-Max rescaling. This process uses the following formula:

$$z_i = \frac{x_i - \min(X)}{\min(X) - \max(X)}$$  \hspace{1cm} (1)

where $X = \{x_1, \ldots, x_n\}$ is the original set of variables, and $z_i$ is the new rescaled variable. This procedure rescales all variables so that the maximum value is one and the minimum value is zero. After rescaling, I inverted the necessary datasets so that a score of 0 indicates low capacity for resilience, while a score of 1 indicates relatively high capacity for resilience. While already standardized, this method also makes the variables equally weighted. Following this step, the variables were divided between the environmental and socioeconomic categories. Within each category the variables were added together and averaged, producing an environmental sub-index and a socio-economic sub-index. Averaging the variables together within each sub-index gives each of the sub-indexes equal weight when calculated into the final score (Cutter et al., 2010). Finally, I added each of the sub-indexes together, resulting in the final resilience index score.
CHAPTER 5. RESULTS

This chapter includes the results of the resilience index for each year of analysis (Figures 9-11). Each of the maps displays the standard deviation from the mean of the resilience scores for each year. Since higher resilience scores indicate higher capacity for resilience, the scores that have positive standard deviations indicate more resilience, and are in blue-green colors. The values that are relatively close to the mean and indicate average relative resilience for each particular year appear in yellow. The values that are lowest and furthest from the mean, indicating low capacity for resilience are in brown and dark brown.

Figure 9. 1983 resilience index results.
Figure 10. 1993 resilience index results.

Figure 11. 2016 Resilience index results.
Resilience Scores

In 1983, the lowest resilience scores are in the suburbs of Central, Prairieville, and Gonzales, with almost the entirety of Ascension Parish having low to medium scores. The center urban core of the City of Baton Rouge, extending north and into the City of Baker has low resilience scores. The highest scores are in the City of Zachary, the southern and eastern portion of Baton Rouge, and in northern Livingston Parish.

In 1993, there are more scattered pockets with relatively high resilience scores in Ascension and Livingston parishes. While there are still similar patterns of high and low resilience between 1983 and 1993, there are changes. There are also less homogeneous collections of high and low resilience. The southern portion of Livingston Parish has lower resilience values, while the southern portion of the city of Central has some higher values of resilience. Within the urban core of the city of Baton Rouge, there are more areas with low levels of resilience. However, the areas on the eastern edge of “Mid-City” Baton Rouge, known as the Broadmoor-Sherwood Forest area have an increase in resilience. Generally, it appears that low levels of resilience are increasing out north and east from the urban core of Baton Rouge.

In the 2016 resilience index, values increase, most notably in Ascension and Livingston parishes. There is a new band of high resilience scores surrounding the western edge of Livingston Parish and eastern East Baton Rouge Parish. The levels of resilience in the southern portion of Central, where the majority of the population resides, have declined. Within the urban core and Mid-City Baton Rouge, some areas that previously had high resilience levels in 1983 and 1993 have average to low scores in 2016. The northern-most portion of East Baton Rouge Parish has a large concentration of high resilience scores across the entire study area.
Environmental Sub-indexes

The environmental sub-indexes comprised one out of two sub-indexes that ultimately make up the resilience index. The variables included in the environmental sub-index are density of roads, average monthly precipitation, average NDVI values, percent of low-runoff soils, average elevation, and average distance to the Amite River.

In 1983, low resilience scores appear in southern Livingston and Ascension Parishes and in the eastern portion of East Baton Rouge Parish. Higher environmental scores are concentrated in northwestern Baton Rouge, southwestern Baton Rouge, with some high resilience in southern Ascension and northwest Livingston. While resilience scores vary a little more in 1993, due to the shift from census tracts to census block groups, there is still a similar pattern of environmental resilience scores throughout the region. However, the urban center of Baton Rouge has a scattered increase of low environmental resilience scores, while northwestern Livingston Parish has an increase in environmental resilience. In 2016, environmental resilience scores are more clustered than in the previous years. High environmental scores are located in north Baton Rouge. Low environmental scores are in western Baton Rouge, southern Livingston, and southeastern Ascension Parish.
Figure 12. 1983 environmental sub-index results.

Figure 13. 1993 environmental sub-index results.
Figure 14. 2016 environmental sub-index results.

Social Sub-indexes

In the 1983, high social resilience scores are concentrated in the outer fringe of the city of Baton Rouge. Livingston Parish has consistently average resilience scores, while most of Ascension has average to low resilience scores. Between the years of 1983 and 1993, there is a noticeable increase in socioeconomic status, extending out of East Baton Rouge Parish and into Ascension and Livingston parishes. Most notably, northern Central shifts from very low to high social resilience scores. While Livingston and Ascension parishes have average to low social resilience scores, there are several new block groups that have a marked increase in social resilience. This shift coincides with the general trend of net migration out of East Baton Rouge and into Ascension and Livingston parishes from the 1980s to the 1990s (Winkler et al., 2013). From 1993 to 2016, this shift is even more dramatic. Much of Ascension and Livingston
parishes attain high social resilience scores. Meanwhile, the outer fringe of Baton Rouge, which use to have high social resilience scores in 1983 and 1993 declines to very low scores.

Figure 15. 1983 social sub-index results.

Figure 16. 1993 social sub-index results.
Figure 17. 2016 social sub-index results.
CHAPTER 6. DISCUSSIONS AND CONCLUSIONS

Discussion

The previous chapter provides the results of the resilience index. This chapter will include an analysis of the results. There was no way to quantitatively verify the resilience index outputs. Instead, historical analysis provides a better understanding of the overall resilience in the area and can allow for an interpretation and validation of the results. This section will include an analysis of resources that were not included in the index for a variety of reasons mostly due to the absence of equivalent resources for each of the three years.

Overall, the trends from the resilience index and sub-indexes match a pattern of population movement from the urban center of Baton Rouge and increase in sprawling development patterns that are less resilient. However, it was expected that the older core of the city would have high resilience scores for each of the three years because of its elevated topography and low risk location. As time passed, it was expected that the periphery of the Baton Rouge center would show a decrease in resilience scores, as people rapidly moved into concrete slab developments in the floodplain. While lowest resilience scores spread out from the center between each time period, most of the low scores remain within the city of Baton Rouge and the very rural areas.

While flood extents and damage information are not available for the entire study period, there is some information available for the 2016 floods. Figure 18 demonstrates the density, location, and values of FEMA Individual Assistance applications. Each purple, circled value represents 700 to 1000 applications with the value of the applications totaling between $3-5 million dollars. The areas with the highest density of individual assistance applications also correspond with areas that have medium to low resilience. This demonstrates that the resilience
index for the year 2016 was able to capture and predict where the highest density of flood damages occurred.

![Map of Resilience Index](image)

**Figure 18.** Areas with high density of FEMA individual assistance registrants (data from The Advocate, 2016b).

Across the three points in time, resilience increases in the areas surrounding the core of the city of Baton Rouge, while the low resilience areas spread out from this core. As wealthy, mostly white individuals left the city in search of schools, new subdivisions have appeared in the surrounding areas. This has lowered the resilience score within the urban core of the city.

**Limitations**

Because this study focused on data spanning back to the 1980s, there were many limitations. Consistent data such as land use, floodplains, and flood extents would enhance the study. However, due to the limited scope and time of the study, acquiring and digitizing this data
were not feasible. Furthermore, this study was conducted at a fairly localized level and was reliant on data beyond what large entities such as the U.S. Census Bureau provide. Instead, data were requested from local city and parish offices. However, finding data that was comparable across all three parishes, and across all three time periods was challenging. While each of the three parishes are within the Amite River Basin and have been subjected to many of the same floods, their governmental boundaries do not conform to the basin’s geography. There is room for more coordination among the three, especially when there are patterns of migration across these three parishes. It would be in the interest of each government entities to have more cohesive datasets, since their communities are closely connected.

There are noticeably low environmental resilience scores in southern Livingston Parish and southeastern Ascension Parish. While these areas do have components such as large areas with high-runoff soils, a small road connectivity, and low elevation, NDVI values were also low. However, this area has plentiful in wetlands and marsh habitats. While the use of NDVI is widely accepted as a simple way for quantifying vegetation, wetland values may register as low, due to their barren and low-lying nature (Barducci et al., 2009). Future studies may want to use a more advanced and comprehensive method of measuring vegetation.

Lastly, online GIS systems are relatively new, innovative systems that allow the public access to important public information. While each of the three parishes have online GIS databases with varying amounts of information, none have data that is specifically historical. Only the most current governmental data, such as zoning plans, environmental data, and parcel layers are available. Incorporating historical data into these databases requires a lot of time and effort, as they usually have to be manually digitized. However, it would benefit stakeholders and decision makers in the community, as well as the public, if this data were made available. This
would allow communities to see and understand the past, so that future changes can provide a safer, more resilient environment.

Conclusions

While researchers have created other resilience studies that are conducted across multiple scales and geographic locations, few have examined the relative change in resilience across time. Each of the three selected years of study represent major floods within the region. The first year of analysis, in 1983, was only 35 years ago, meaning a sizable portion of the region’s population has experienced at least three major floods within their lifetime. Since localized flooding occurs frequently, and major flooding occurs in the region roughly once every 20 years, it might be expected that citizens in the area build their capacity for resilience with every flood. The social memory of flood events can affect individuals long after a flood event has occurred, serving as a mechanism for enhancing the anticipation for a flood. Instead of attention to the local environment and the social memory from previous floods, history demonstrates that some community members have made housing decisions based on property value, school districts, and mainstream popular architectural styles, which have been fully backed by local planning ordinances and the NFIP.

In relation to the cycle of resilience (anticipation, response, recovery, and reduced vulnerability), housing decisions and sprawl have a direct impact on the anticipation, recovery, and reduced vulnerability of an individual. NFIP policies and the promises to build future flood diversions, such as the Comite River Diversion, encourages and incentivizes risky development in the floodplain. Deciding to build into the floodplain demonstrates a degree of lack of anticipation for flood events. The recovery from a flood event will be delayed if homes are built on concrete slabs, as the sheetrock and other inundated building materials are not flood-proof
and will have to be totally replaced, delaying property restoration and the return to a normal lifestyle. Since the 1980s, there have been several floods of which the social memory has not been retained by most individuals, as there has also been a pattern of movement further into floodplain in favor of the suburban lifestyle, increasing one’s vulnerability. This hazardous development trend has progressed since the 1950s. While local history makes it apparent that capacity for resilience is decreasing, especially in the suburban fringe outside of Baton Rouge, this study explored how a quantitative resilience index measures this change in capacity from the 1983 Amite River flood to present time.

The resilience index, based on the methodologies of Cutter, Burton, and Emrich (2010), calculated resilience scores at the tract level for the year 1983 and the block group level for the years 1993 and 2016. The final resilience scores consisted of environmental and socioeconomic sub-indexes, which were comprised of the following variables: density of road network, average precipitation, average NDVI, soil permeability, average elevation, distance to major rivers, house density, per capita income, age, percent female population, percent minority population, and educational attainment.

Overall, the index reported a reduction in resilience that shifted out of Baton Rouge’s core as time has passed. This pattern is similar to the shift in capacity for resilience that has actually occurred in the area. However, as resilience scores decreased over time in Baton Rouge’s periphery, the scores increased throughout time in many of the suburban areas, including the city of Central, Denham Springs, and Gonzales. In reality, each of these areas had a reduction in resilience capacity, particularly in the anticipation of natural hazards. Since the expansion of people moving into the region matches the profile of individuals that generally have a reduced vulnerabilities, (being wealthy, white, and educated) this led to an increased score.
This population actively contributes to the safe development paradox as they continue to move into the floodplain. Since the federal government subsidizes this risky behavior, the increasing costs of flood damages that will occur in the future will ultimately transferred from the wealthy communities situated in hazardous areas to the federal government and taxpayers. Due to data limitations, many of the variables measured vulnerability, which is just one component of resilience. Future resilience indexes should make an effort to equally incorporate all facets of the adaptive cycle and process of resilience.

This study adds to the growing body of natural hazards literature and demonstrates the importance of both quantitative and qualitative approaches to understanding resilience. It is unique in its localized and historic approach to understanding resilience. While resilience indexes cannot replace attention to history and qualitative community data, they can still provide researchers and community members important information about environmental and social patterns within the region. This index and analysis offers an important resource for the parishes of Ascension, East Baton Rouge, and Livingston to better understand importance of resilient land use planning and housing design. Furthermore, this method can be adopted by other flood-prone parishes to understand their own resilience dynamics, since the index can be replicated for almost any set of times or places. A better understanding of the collective history of land-use decisions and development patterns can help create more resilient communities so that impacts of future extreme flood events can be mitigated.
REFERENCES


VITA

Having grown up along the Ohio River in Louisville, Kentucky, Yi Ling Chan is no stranger to flooding. She has always had an interest in bridging the social sciences and natural sciences fields and learning about human impacts on the environment. After obtaining a B.S. Mathematics/B.S. Geography from the University of Louisville in 2015, Yi Ling spent a year working as a GIS intern at LSU. She expects to graduate with her M.S. in Geography from Louisiana State University in May 2018. Upon graduation, she would like to apply her strengths in GIS, environmental sciences, and statistical analysis towards research related to planning and community resilience.