FACTORS INFLUENCING RESILIENCE IN FLOOD RESPONSE, RECOVERY, AND PREVENTION CASE STUDY OF THE SOURIS RIVER VALLEY, MINOT, NORTH DAKOTA

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ABSTRACT

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MARK S. BRODIE

Adequate future flood prevention along the Souris River is a necessity for the residents in the city of Minot, North Dakota. While roughly a quarter of the city's residents and homes were directly affected by a catastrophic June, 2011 flood, the rest of the city's residents, as well as North Dakota state and federal tax payers were indirectly affected. First, this thesis project uses ArcGIS software to map the areas of Minot, North Dakota affected by the June, 2011 flood. Second, this project tracks the progress of clean-up, the construction of new, permanent flood protection structures such as dams and levees, and the deployment and implementation of new and additional sensors, such as stream gauges, to give the city of Minot and its residents earlier warning when the next flood comes. Third, this thesis models the effectiveness of newly proposed flood control measures, to be put in place in the city of Minot and Ward County using ArcGIS modeling, to see how well the city could be protected should the 100-year flood conditions that occurred in June 2011 occur again.

Keywords: flooding, flood recovery, flood prevention, emergency preparedness, disaster response, emergency management, adaptive capacity, resilience, crisis planning

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Chapter 1: Introduction

Background:

On June 22, 2011, the waters of the Souris River, also known as the Mouse River, in Minot, North Dakota reached a record high of 1,561 feet above sea level, 12 feet above the river's flood stage of 1,549 feet, and four feet higher than the previous record flood which occurred in 1881 (National Weather Service 2012). Due to a lack of stream gauges upriver in rural parts of Canada, the town received only three days warning to prepare for the catastrophic flood that was to come (Wirtz 2011: 8). Although the city had permanent levees designed to withstand a 100-year flood in which the Souris was expected to reach 5,000 cubic feet per second (cfs) and had twice hired contractors to bolster the existing levees by building temporary dikes rated to withstand 11,000 cfs, the city's preventative efforts were ultimately in vain. The Souris River, which during a normal summer run-off season typically flows at a rate of a couple hundred cfs, roared to 29,000 cfs, rendering the dikes inadequate to protect the town. The river remained above the flood stage for weeks, ultimately causing 4,100 homes, businesses, and public buildings to be inundated. Of these 4,100 structures, over eighty percent took at least six feet of water on the ground floor (Wirtz 2011: 3). Over 11,000 people, roughly a quarter of the city's population, were evacuated (New York Times 2011). Some were fortunate enough to find shelter with family and friends on higher ground; others had to take shelter in FEMA trailers or at the municipal auditorium, which had been set up as a disaster relief center. With the limited amount of prior notice, some Minotians were lucky to move their belongings into storage on higher ground ahead of the flood; however, many lost everything. Of the thousands of people affected by the flood, over ninety percent did not have flood insurance (CBS News 2011). After the waters receded, and the full scope of the flood's effects could be seen, estimates as high as $1 billion were assessed to the damage (Minot Daily News 2011).

> While Minot will receive significant reimbursement for the money spent preparing for and cleaning up after the flood, fiscal realities at the federal level mean the city and its residents will bear more of the costs of flooding—including improvements to existing flood protections (Wirtz 2011: 10).

Over four years have passed since the flood waters receded; some areas affected by the flood are still waiting to be cleaned up or rebuilt.

Purpose:

This research investigates the cleanup and prevention processes in Emergency Management related to flood occurrence and floodplain management. Specifically, this research uses a case study approach to investigate what measures have been and are still being taken to recover from this historic flood, and more importantly, what measures are being taken to prevent a catastrophe of this magnitude from affecting the citizens of Minot again in the future. Furthermore, this research evaluates whether the proposed new measures to be taken are going to be adequate when the next 100-year flood occurs and will answer the question of how well the city of Minot and its citizens are protected. Finally, this research compares the policies used in the Minot flood to current emergency management flood policy models in order to denote changes, similarities, and differences.

Research Questions:

1. What are the federal and state regulations governing emergency management of floods and how do they impact the Souris flood cleanup and future flood prevention?

2. What specifically is being done by the city and state to prevent another flood (dams, levees, more early warning equipment such as stream gauges upriver, future agreements with Canada,

and actions by the U.S. Army Corps of Engineers) and will the measures or proposals the city and state are taking to prevent another flood be effective enough to mitigate a flood of similar scope and magnitude as that of June 2011? What impediments have been found in the cleanup and prevention processes?

3. How do the policies and processes in the current Souris River flood prevention policy compare to the ideal as available in emergency flood management literature?

Research Objectives:

To answer the research questions posed, several research objectives must be met. First, a review of emergency management literature and policies related to flood clean up and mitigation is necessary in order to understand the parameters and ideal processes.

Second, in order to understand the catastrophic flood prevention strategy, the policies used by the local and state entities will be identified and discussed. This includes ascertaining rezoned and flood abatement areas, where new dams and levees will be built, and how existing dams and levees will be improved. It must also be determined whether the new dams and levees will be built in areas destroyed by the flood, i.e. whether the city is buying destroyed properties. This also includes understanding what additional early warning systems will be put in place and exactly how much additional warning the citizens of Minot will receive in comparison to the three days' notice they received for the June, 2011 flood.

Third, in order to test whether the new flood prevention policies and mitigation measures will be effective, an ArcGIS model will be constructed to determine the extent flood waters might penetrate new defenses if the same sequence of events occurred again in the future, resulting once again in unusually high volumetric flow rates of water through the river basin (i.e.

timing and amounts of water released from the Alameda and Rafferty Dams in Canada and the Lake Darling Dam in North Dakota).

Finally, the policies used in the Minot case will be compared to current literature on emergency management and flood prevention policies and their efficacy in this situation will be discussed.

Flooding in the Souris River Valley:

Evidence of major flooding in the Minot area dates as far back in recorded history as 1881, when pioneers and the first settlers witnessed the rising waters of the Souris River from snowmelt and heavy rainfall (Mighty Mouse River). In 1904, another flood inundated the area, and several hundred of the population of 1,200 people at the time had to leave their homes. Engineers today estimate the peak flow of the 1904 flood to have been 12,000 cfs. After a series of minor floods in the 1920s in Minot, Congress authorized an initial study of flood control possibilities, but due to prohibitively high costs, no flood control measures were implemented until 1935 when the Lake Darling Dam, 52 river miles upstream from Minot, was built. However, it should be noted that the primary purpose behind the construction of Lake Darling Dam was to provide water from its reservoir during times of extreme drought. More minor flooding occurred in Minot during the late 1940s and early to mid-1950s, but no additional flood protection measures were put in place. Most people in Minot believed, perhaps overconfidently or complacently, that the Lake Darling Dam would be sufficient to protect the town from major flooding. The worst damage from flooding in the late 1940s and early to mid-1950s was realized more by farmers and ranchers downstream than by residents of the town itself. However, Congress once again asked for a review of Souris River flood control in 1955. Results of the study led the Minot Chamber of Commerce to press for additional flood control measures as early as 1960, but multiple reviews, proposals, and recommendations regarding the flood control plan effectively delayed anything concrete actually being done before the next major flood came in 1969. That year's flood, with a peak flow of 6,300 cfs, caused $15 to $20 million in damage to the city and forced 12,000 residents to leave their homes for a period of six weeks until the flood waters receded (Mouse River Facts 2011). Following the 1969 flood, the U.S. Army Corps of Engineers embarked on an eight-year project between 1971 and 1978 to improve flood control measures for the protection of the city. The project involved nearly 16 miles of clearing and snag removal from the Souris River, as well as 11 miles of improvements to the river's channel and 15 channel cutouts. Additionally, the project included 12 new channel structures and six pumping stations. All these improvements were supposed to give Minot adequate protection from Souris River flow rates up to 5,000 cfs.

The last large flood in Minot, prior to the flood of June, 2011 was the 1976 flood. On April 18, 1976, the Souris River crested in Minot at 1,556 feet and reached a flow rate of 14,800 cfs, forcing 12,000 people to evacuate their homes (Time 1976: 45; Mouse River Facts 2011). A lack of adequate flood control in the Minot area had been identified prior to the flood, but the Army Corps of Engineers project had yet to be finished. The Army Corps of Engineers had deepened the Souris River's channel and built approximately 50 miles of dikes as preventative measures, but ultimately, these measures were not enough. There were discussions in the 1970s of building another dam on the Souris to help control future flooding, but farmers and environmentalists in the area were opposed to the idea. Currently, the only dam upriver of Minot in the United States is the Lake Darling Dam. Two additional dams, the Alameda Dam and

Reservoir and the Rafferty Dam and Reservoir, are located upriver in the Canadian province of Saskatchewan.

In October, 2007, the United States Geological Survey (USGS), in partnership with Canada, started pooling stream gauge and reservoir data on the Souris River at various locations (USGS 2012). This interactive website is a great resource for quantitative data on the water level of the Souris River, both historically and presently. Additionally, it shows the locations of all existing stream gauges and reservoirs. Based on the date ranges of the data available for each stream gauge, one can discover how long a stream gauge has been in service at a particular location. One of the locations at which there is a stream gauge is the Broadway Bridge in Minot, North Dakota. The data provided by this stream gauge during the June 2011 flood was vital for creating ArcGIS models for analysis in this thesis.

Water flows on the Souris River are largely decided by the Saskatchewan Watershed Authority, the Canadian authority responsible for managing the Rafferty and Alameda reservoirs, which both feed water into the Souris River prior to the river flowing into the United States (Wetzel 2011). In the U.S., the Army Corps of Engineers controls the Lake Darling Dam and its associated reservoir, just 52 river miles upstream from the city of Minot. On June 19 and 20, 2011,

> 4 to 7 inches of rain deluged parts of the southern province [Saskatchewan], falling on ground already waterlogged from earlier rains and melting snow. […] Authority officials decided to gradually increase water releases from the dams to levels certain to cause major flooding downstream. […] Both Rafferty and Alameda could not store any more water and another large storm could have pushed water on the tops of the dams, risking a catastrophic failure (Wetzel 2011).

Under normal, non-flooding conditions, the flow rate on the Souris River through Saskatchewan is only 70 cfs; due to the Rafferty and Alameda Dams having to release water to prevent failure, flow rates ranged from 15,900 to 18,000 cfs in June, 2011.

As the waters of the Souris River continued to rise in June, 2011, approximately 11,000 Minotians were ordered by the city to leave their homes (New York Times 2011: 13). City officials realized that the water would top the city's levees and moved to build dikes in an effort to protect their citizens and infrastructure.

The June 2011 Flood

The largest flood on record in Minot, North Dakota took place in June, 2011, with waters of the Souris River reaching an unprecedented crest of 1,561 feet above sea level (National Weather Service 2012). This surpassed the January 1, 1881 record of 1,558 feet. According to the USGS, the city, and the county, the river is considered to be in flood stage once the waters reach 1,549 feet above sea level. Above this water level, it is assessed that a hazard to lives, property, or commerce might exist. Typically, the city and home owners will start to sandbag, reinforce levees, and move belongings to higher ground once the water level reaches 1,548 feet above sea level, which is referred to as the action stage. At 1,551 feet above sea level, which is considered to be moderate flood stage, water will begin to approach homes nearest to the river's banks, and at 1,555 feet, which is considered to be a major flood stage, the city's permanent flood protection will be surpassed, resulting in widespread flooding, no longer contained to just the areas nearest the river.

Three schools, including Ramstad Middle School, which was flooded to the roof, had to be closed for the 2011-2012 school year as a result of the June, 2011 flood (Education Week

2011). Also as a result, over 1,000 students had to be absorbed into other schools in the Minot School District. The damage to Ramstad Middle School eventually proved so severe that the school district declared it a total loss and built an entirely new Ramstad Middle School on a different site, this time located on the higher elevation of Minot's north hill.

Approximately 4,100 buildings were inundated as a result of the June, 2011 flood in Minot, North Dakota (Wirtz 2011: 1-10). Of these 4,100 buildings, approximately 80% had water rise to at least six feet above the level of their main floors. The flow of the waters of the Mouse River increased to a rate of 29,000 cfs, roughly double the previous high water discharge rate set during the April, 1976 flood. The high rate was initiated by heavy rains in remote parts of Canada, where the government does not maintain stream gauges. Minotians only received three days' warning of the level at which the waters of the Mouse would eventually crest. Ninety percent of Minotians in the flood zone did not have flood insurance (CBS News 2011).

A few weeks after the waters of the flood reached their peak, the U.S. Homeland Security Secretary at the time, Janet Napolitano, who oversaw the Federal Emergency Management Agency, or FEMA, surveyed the damage done to Minot by the flood (Bacon 2011). She told the city government and Minot's residents that while FEMA would make aid available, they "should not expect the federal government to make them whole because assistance is capped under federal law" and "residents should prepare for future flooding" (Bacon 2011). The responsibility for that preparation largely falls on the city government as "the responsibility of levee maintenance falls to the city" and

> Minot's levees have been found deficient because standards have changed or circumstances have occurred over the years that place the levees in need of fixes. For instance, erosion around storm sewer outfalls or inside of river banks, growth of trees on or near the dikes and encroachment by residents through fences or buildings can result in deficiencies (Schramm 2015: 8).

The estimate for damages to public infrastructure statewide in North Dakota as a result of the June, 2011 floods of the Souris and Missouri Rivers was $450 to $500 million according to the North Dakota state director of the Department of Emergency Services (Minot Daily News 2011). Once the estimate for damages to private infrastructure, i.e. homes and businesses, is added to this tally, the overall cost could be over $1 billion.

<u>The Aftermath of the June 2011 Flood</u>

On July 12, 2012, roughly a year after the flood, the Mayor of the City of Minot, Curt Zimbelman, released the city government's action plan for flood recovery, including the figure below showing the current stages of the flood repair.

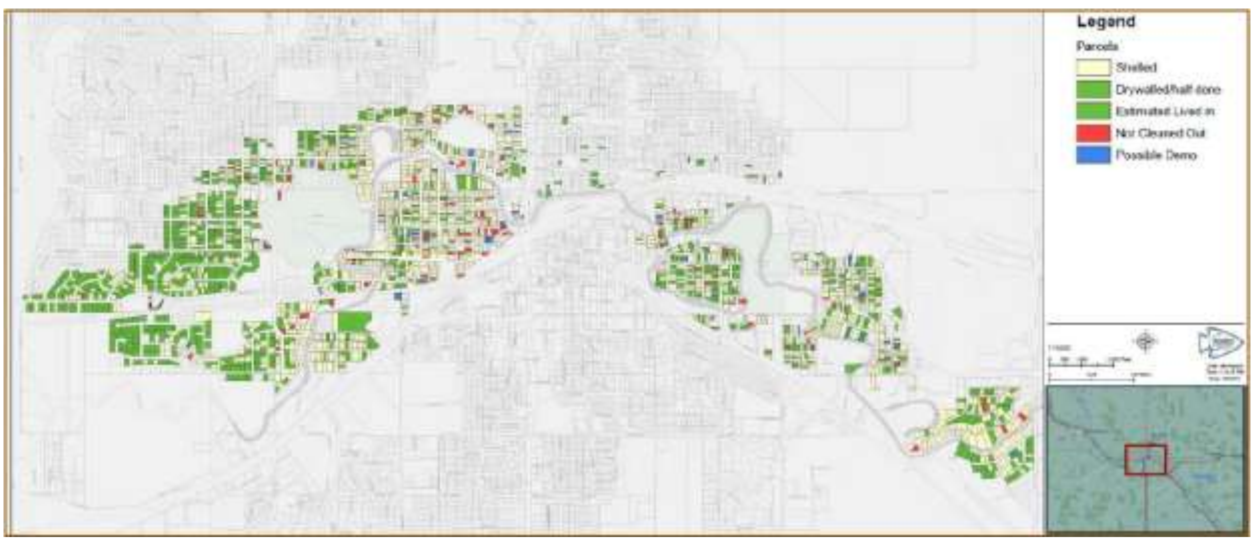

Figure 1: State of Flood Repair in Minot as of July 12, 2012 (Zimbelman 2012: 14).

In the final week of September, 2012, the City of Minot and Ward County closed on the first two of approximately 130 home buyouts needed in order to make way for future flood protection (City Closes 2012). Once buyouts are finalized, the flood-damaged homes will be demolished. The Finance Director for the City of Minot, Cindy Hemphill, said "There is a possibility of completing demolitions before the end of the year" (City Closes 2012).

The City of Minot released to the public on November 28, 2012 a map of the newly proposed flood control and abatement properties (see Figure 2 on page 9 of this document). This map shows the proposed locations of new flood control levees and floodwalls and outlines new zoning for areas of the city that would be considered to lie in the new flood plain. The placement and height of the new flood control structures, as well as the locations of the abatement properties, are crucial pieces of information for the accuracy of the ArcGIS modeling for this project as these features will be overlaid on a contour or topographic map of the city.

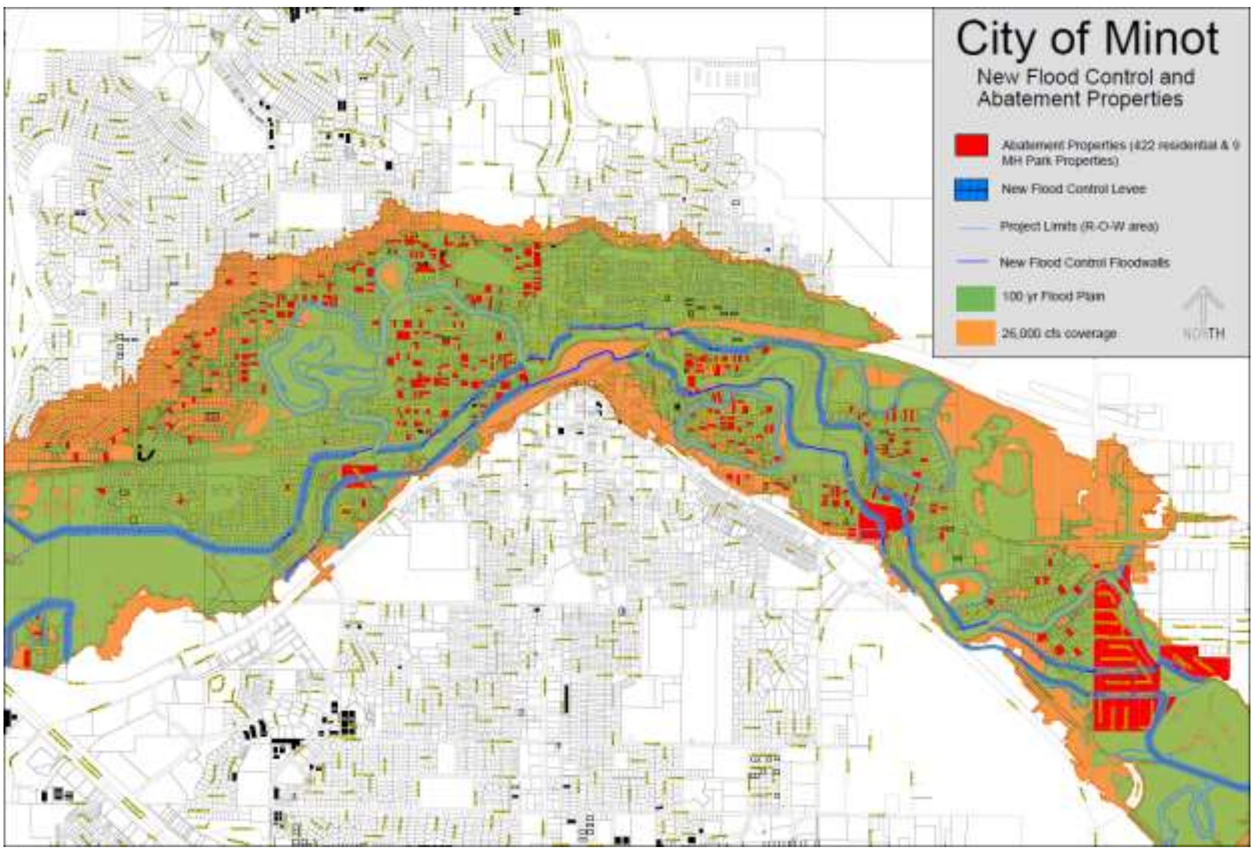

Figure 2: Proposed New Flood Control and Abatement Properties in Minot, ND (Flood Abatement Map 2012).

On December 3, 2012, at a Minot city council meeting, the council members discussed whether or not to have FEMA adopt a new advisory base flood elevation for a flow rate of 9,600 cfs in order for Minot's proposed flood mitigation projects to qualify for FEMA federal hazard mitigation grant money under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (Flood Plain Options 2012).

> The state of North Dakota is eligible for $100 million to $150 million in grant money from the Federal Government to help mitigate future flooding — money that could be used in Minot to buy heavily damaged homes, relocate other homes, along with protecting public infrastructure. The catch is the city must act within weeks to change the shape and size of the flood plain (Sipma 2012).

Currently, the city does not have the funds to perform all the home buyouts and cover all the construction costs of building additional flood protection. However, asking FEMA to adopt a new advisory base flood elevation, or ABFE, in order to qualify for funding, does have its drawbacks. First, "the process of creating new maps and a new flood plain could take three years or more" (Flood Plain Options 2012). Second, the city would have to put in place new codes or construction standards that would require a house's main floor to be raised as much as seven to eight feet. This could put current construction on hold for a while as well as make for odd-looking neighborhoods in the valley as some homeowners have already completed flood repairs and would not be required to go back and comply with the new standards. Finally, it "would make flood insurance required for more homeowners" in the valley, and already, flood insurance "premiums are expected to increase once FEMA completes final flood maps" (Flood Plain Options 2012). On December 18, 2012, the Minot City Council voted to “deny adoption of the (new) advisory base flood elevation (ABFE), in order to allow the normal progression of the creation of the flood insurance rate map (FIRM) process (Jundt 2012).

As of fall 2015, not much physical evidence of additional flood protection has been witnessed, save for the clearing of some trees near the water treatment plant. One Minot resident, Randy Pogorelski, was quoted in a newspaper article as saying "All I've seen is a lot of money being spent for studies and things like that. There are no dikes being built." (Fundingsland 2015: 3). Following a major flood of the Red River of the North in 2009, "Fargo went from needing nine million sandbags to […] one million for the same flood. That's a lot of progress in six years. I hope Minot can say the same thing in two years but I don't think it'll even be close" (Fundingsland 2015: 3). Mr. Pogorelski's observations are on point as "Construction on the initial phases of the proposed" flood control "project are not scheduled to begin until 2017 at the earliest. The remainder of this year [2015] and all of 2016 is devoted to environmental review, design, and further public comment" (Fundingsland 2015: 9). The city is currently working on the creation of a new emergency action plan, which it "hopes to complete within a year" in order to comply "with the U.S. Army Corps of Engineers' Systemwide Improvement Framework process" and "address how to bring" the city's "flood protection up to current Corps guidelines;" however, completion of the emergency action plan is just the first of a number of hurdles to clear before comprehensive flood protection for the city is made a reality (Schramm 2015: 8). The next major hurdle includes "two major permit processes" which "must be completed prior to the start of any flood control constructions," specifically Section 408, which "involves any project that could affect existing U.S. Army Corps of Engineers projects, and Section 404, which "includes approval for only the least environmentally damaging practicable alternative" (Fundingsland 2015: 9). This permitting process alone could take years, especially with regard to Section 404, as "the flood control project will have significant adverse impacts on the environment" (Fundingsland 2015: 9). Once permitting has been approved and funding has been found to cover the costs, the issue still remains of where to start. The general consensus is "to protect the water treatment plant first" using a "combination of levees and flood walls […] including portable walls that would cross 16th Street in two locations in the event of high water" (Fundingsland 2015: 3). Following flood mitigation measures around the water treatment facility, the project proposes to start work on additionally flood protection in the vicinity of "Fourth Avenue Northeast, Napa Valley, and Forest Road" (Fundingsland 2015: 9).

In September, 2015, the city took two important steps forward for flood recovery and prevention. First, the city broke ground on "the first construction associated with bringing permanent flood protection to Minot, [… a] project to protect the Minot Water Treatment Plant from future floods" (Schramm 2015: 1). While the ground-breaking might only have been symbolic, and work on the project for the remainder of 2015 will most likely be limited with the snow and ice of another North Dakota winter on its way, it is still a step in the right direction, and the first real tangible sign of progress on the part of government for permanent flood protection becoming a reality. Meanwhile, "design work is ongoing on additional flood control phases that could start next year to begin the process of protecting homes and businesses" (Schramm 2015: 1). The project to protect the water treatment plant involves "building 1,720 feet of concrete floodwalls on the south side of the Souris River, near the plant. These floodwalls will tie into two, new, temporary roadway closure structures at 16th Street Southwest and 12th Street Southwest. Earthen levees and the adjustment of intake structures at the treatment plant also are part of the project" (Schramm 2015: 1). The project "is costing more than $24.7 million just for the construction" of which the "state of North Dakota is providing about $3 million" and the "largest share of the funding is coming from $22 million in federal Hazard Mitigation Grant Program dollars, which had been a sizeable sum not easy to get from the Federal Emergency Management Agency" (Schramm 2015: 1). The water treatment facility protection project is "the largest structural mitigation project ever funded in (FEMA's) Region VIII" to date, and "construction is expected to finish in mid-2017" (Schramm 2015: 1). The second step the city took involves being able to assess blighted houses, many of which were damaged in the flood and left abandoned by their owners. "The Minot City Council's Public Works and Safety Committee […] voted to recommend the council amend city ordinance to allow the building official to enter a property with a search warrant, even if that warrant hasn't been personally served on the owner, as long as an attempt is made to locate the owner" (Schramm 2015: 9). This amendment to the ordinance will allow the inspector to enter homes in which "the city has been unable to locate the owners" so that the homes can "be internally inspected for possible condemnation of the property" (Schramm 2015: 9). Not only will this clean up the look of the town and increase the curb appeal in neighborhoods, but it will also allow for lands near the Souris River, in addition to areas where the city is or has conducted home buyouts, to be cleared for flood mitigation projects.

Chapter 2: Literature Review

This literature review provides a broad background of research and case studies dealing with flooding, emergency management policy evolution, resiliency, and efforts across all levels of government to prepare for, counter, and recover from major disasters, particularly flooding.

Evolution of Emergency Management with Regard to Flooding in the U.S.:

Flood prevention in the United States has been an ongoing effort since even before colonial times. “In 1543 the Spanish explorer, Hernando de Soto noted how the Native Americans raised mounds by hand and built them high where they could” (Priscoli & Stakhiv 2015: 62). As colonial expansion spread west, so too did flood mitigation efforts—“By 1727, Nouvelle Orleans was protected by a 4 foot embankment” (Priscoli & Stakhiv 2015: 62). After the colonies won their independence from the English crown, the newly formed federal government continued to play an active “role in water resources […] consisting mostly of clearing navigation hazards, such as sandbars and debris, with continual Congressional debate about flood control roles by the federal government in response to a series of severe floods in the mid-1800s – 1917” (Priscoli & Stakhiv 2015: 62). “From the 18th to early 20th century, flood management […] was primarily dealt with as a local problem;” however, the federal government began to take action in response to some flooding disasters over that time: the founding of the Mississippi River Commission in 1879, the Flood Control Acts of 1917, 1928, and 1936, in response to flooding on the Mississippi River, the Sacramento River, and the Ohio River Valley (Priscoli & Stakhiv 2015: 60-62). Over this period of time, the federal government’s role in flood prevention evolved from “planning and financing flood control measures” to “cost-sharing between the federal government and local governments, where the federal government would pay two-thirds of the costs, and the local share would consist mostly of lands, easements, and rights of way" to Army Corps of Engineers being charged with creating "flood control reservoirs" with federal investment "to be based on a benefit-cost analysis" (Priscoli & Stakhiv 2015: 62). It is worth noting though that the Flood Control Act of 1928, while charging the Army Corps of Engineers with building flood control structures, also granted it "legal immunity" from "lawsuits in the event of […] failures" (Adelmann 2015: 38).

"During the mid-20th century the national federal role grew and so did the use of large structures" (Priscoli & Stakhiv 2015: 60). "The Corps of Engineers and the United States Geological Survey (USGS)" began and "continued to set up stream gauge networks during this period. The U.S. Forest Service studied the relationship between timber harvest and runoff. Additionally, a national program for the study and management of upstream watersheds was authorized" (Priscoli & Stakhiv 2015: 63). In time, the "National Oceanic and Atmospheric Association (NOAA)" would come to monitor "conditions that could lead to floods 24 hours a day, 7 days a week" (Meintel 2015: 28).

"Later on in the 20th century" once large scale dam and levee projects such as the Grand Coulee Dam, Hoover Dam, and the Lake Pontchartrain and Vicinity Hurricane Protection Project were completed, "the United States moved back to a more local focus" in regard to flood prevention and mitigation (Priscoli & Stakhiv 2015: 60). Starting with the passing of the Environmental Protection Act of 1970 and continuing with similar and more expanded environmental legislation as time went on,

> A variety of prescriptive environmental criteria and standards, not always consistent among the federal agencies, indirectly served as constraints on water resources management plans by substantially reducing the range of economically feasible options. These environmental criteria superseded the traditional purposes and procedures

> associated with water resources development solutions. As the number of planning constraints grew, so did the costs of solutions, making them less affordable for communities (Priscoli & Stakhiv 2015: 59-60).

Over this same time period, the federal government also took an active role not only in the prevention of floods using dams, reservoirs, and levees created by the Corps of Engineers, but also in disaster response. Eight years after the founding of the American Red Cross in 1889, the organization faced its first real disaster response effort to a major flood after a dam in Johnstown, Pennsylvania failed (Wharton-Michael 2012: 24). As time progressed and major flooding, especially along the Missouri and Mississippi Rivers occurred, the government acted to expand its ability to respond to natural disasters, creating the Federal Emergency Management Agency (FEMA) in 1979. FEMA, the American Red Cross, local police, fire, medial, search and rescue units, utility company workers, and the U.S. military, primarily the National Guard units contained within each state, have formed the backbone of U.S. disaster response for the past thirty-six years and remain so to this day.

> As early as the mid-1800s some realized the problem [or root cause of major flooding disasters] was settlement and cultivation in the floodplain. […] In the late 1960s and early 1970s, floodplain management began to take root as a complementary approach to structures as a way to manage the nation's flood problems. In 1968, Congress enacted the National Flood Insurance Act which established the National Flood Insurance Program (NFIP). The NFIP encouraged the widespread adoption of floodplain regulatory controls to discourage further development of damageable improvements in the nation's floodplains, and established a threshold of a 100-year flood zone (Priscoli & Stakhiv 2015: 63).

"Federal water resources planners were instructed to devise non-structural flood protection plans as viable alternatives to structural measures" (Priscoli & Stakhiv 2015: 64). That being said,

> Congress did not follow up with meaningful comprehensive legislation to transform these conceptual ideas into a permanent footing, and local communities continued to favor structural solutions, which were seen to be more reliable and permanent. This created an uncomfortable dichotomy for the federal water management agencies—the local sponsors generally preferred structural solutions, while the federal entities promoted non-structural

approaches. Meanwhile, Congress, which represented their constituents, kept funding studies and structural solutions (Priscoli & Stakhiv 2015: 64).

However, finding funding for flood prevention and studies, given the current state of the country's economy and recent sequestration, is no small hurdle to clear. "Gerald Galloway, a University of Maryland professor and leader in national flood-control analysis" notes that "the latest round of flooding underscores the tough choices faced by local officials in known flood zones in the U.S. With federal funding scarce, local funds even scarcer, and local opposition to flood-control measures a barrier to action, it typically takes a devastating event to create consensus and sources of funding" (Setzer 2009: 15).

Floodplain management has always "inherently relied on the land use regulatory powers of the state and local entities—not federal agencies," (Priscoli & Stakhiv 2015: 61). This is predominately due to the Tenth Amendment to the U.S. Constitution—"the powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people" (Bill of Rights 1791). In many cases, "states and local entities" have not been "successful in controlling floodplain encroachments by the agricultural sector or municipalities" (Priscoli & Stakhiv 2015: 63). Such is the case in Minot, North Dakota where "levees have been found deficient because standards have changed or circumstances have occurred over the years that place the levees in need of fixes. For instance, erosion around storm sewer outfalls or inside the river banks, growth of trees on or near the dikes, and encroachment by residents through fences or buildings" (Schramm 2015: 8). In contrast to the position many American local and state governments have taken for decades in relation to flood prevention and mitigation, "Europeans have been far more aggressive about keeping development out of their floodplains and giving their rivers room to spread out" (Grunwald 2011: 27). This approach is something from which U.S. local and state governments have only recently learned and benefitted. "After decades of monomaniacally moving dirt and pouring concrete, the corps has gone along with nonstructural efforts to reduce flood damage by restoring wetlands, buying out vulnerable properties, and retreating from rivers" (Grunwald 2011: 27). This new position, or more accurately, a balancing of this new position with the older solely structural flood prevention and mitigation methods of dams and levees, can be evidenced as experience with flooding in the United States has progressed over time. The following case studies, presented chronologically, will cover major flooding events in the U.S. and Canada over the past 126 years, will discuss the prevention methods used and why they either failed or succeeded, and will explain the lessons learned and best practices adopted by government at the local, state, and federal levels to prevent future disasters.

Case Studies:

<u>1889 Johnstown, PA Flood Case Study</u>

The set up for this catastrophic flood actually began decades before in the 1840s when a dam was constructed at the confluence of South Fork Creek and the Little Conemaugh River to "provide a feeder reservoir," known as the South Fork Reservoir, "for the Pennsylvania Mainline Canal" (Ludlum 1989: 89; Kreiser 2015: 40). The "dam had proved troublesome from the beginning," having "failed in 1847 and again in 1862," but fortunately, damage from these failures 14 miles downstream in Johnstown, "a manufacturing city of some 30,000 souls," was minimal (Kreiser 2015: 40; Wharton-Michael 2012: 24; Lundlum 1989: 89). The dam itself "stood 72 feet high and more than 900 feet across" and the reservoir it created formed a "body of water over two miles long and a little less than one mile across at its widest point" covering an area of "about 450 acres" and holding "3.6 billion gallons of water" (Kreiser 2015: 40; Lundlum

1989: 90). The “canal project was” eventually “abandoned in favor of the railroad” and “remained unused and neglected until 1879, when” a group of wealthy sportsmen,” known as the South Fork Fishing and Hunting Club, purchased “the property to create a fishing camp” (Ludlum 1989: 89-90; Wharton-Michael 2012: 24). Even before the sportsmen purchased the property, the structural integrity of the dam had been compromised; “in 1875 the cast-iron sluice pipes at its base were removed and sold for scrap. With no way to drain the reservoir for much-needed repairs, a few make-do patches were made,” but these were the extent of any preventative maintenance (Kreiser 2015: 40). Shortly after having made their purchase, the members of the South Fork Fishing and Hunting Club “discovered the dam was leaking and the sluiceways were too narrow,” however, “they refused to acknowledge the structure’s damage” and failed to “invest money into repairing the reservoir, which might have prevented the great flood” (Wharton-Michael 2012: 24).

During the late afternoon of May 30, 1889, showers began to fall in the Conemaugh Valley. “As the city slept, the showers increased to torrents, and when residents arose the next morning they found themselves already in the midst of local flooding” (Wharton-Michael 2012: 24). “The small central Pennsylvania community was accustomed to spring floods, but these waters had already risen higher than previous floods, and the pouring rain did not appear to be ending” (Wharton-Michael 2012: 23). Observers at the dam noted the rate with which the water was rising since the previous evening and rushed to “warn the people in the valley below;” however, the “forewarning was not taken seriously by a community that had heard false predictions so many times” before, and the warnings “were not passed on to others” (Wharton-Michael 2012: 24). With rain continuing to fall both in town and 450 feet above the valley floor at the dam, it was not long before the

> rising water of the heavy run-off behind South Fork Dam reached the crest. For three hours, water surged over the dam and ate away its earthen structure. Finally, about 3 p.m., the pent-up pressure became too great. The whole dam suddenly dissolved into a muddy mass that swirled down the steep incline into the valley below, while the suddenly freed waters of the fishing lake exploded downstream to gorge the already swollen Conemaugh. […] The rush of water from the South Fork joined the already flooded mainstream to form a sloping wall of water as much as 20 to 30 feet high […] traveling at the extraordinary speed [for water] of 22 feet per second (Ludlum 1989: 91-92).

"Roaring through the small towns of South Fork, Mineral Point, and Woodvale, the wall of water and debris took almost an hour to travel to Johnstown" (Wharton-Michael 2012: 25). The trees, mud, telegraph poles, automobiles, train cars, and other debris eventually came "to rest in a huge, 30-acre jumble of debris jammed against the stone arch bridge that spanned the river in downtown Johnstown" (Ludlum 1989: 92). "For a time, the bridge area was an island of safety and hope for hundreds of people and animals carried downstream on floating debris, but the jam soon caught fire and in the holocaust that followed, many who had survived the water perished in the flames, just as rescue was near" (Ludlum 1989: 92). Ultimately, the flood resulted in "2,209 confirmed dead, 1,600 homes lost, four square miles of Johnstown completely destroyed, (and) $17 million in property damage" (Kreiser 2015: 40). "Never before in this nation's history had a community been so devastated by such a calamitous disaster" (Wharton-Michael 2012: 23). The recovery effort associated with this flood was the first time the recently founded American Red Cross had been used "in times of natural disaster" and tested in a "major peacetime relief effort" (Kreiser 2015: 40).

> On the day after the flood, Clara Barton traveled with her organization, the Red Cross, to Johnstown, and immediately upon arrival, she ordered the erection of tents and the distribution of all supplies. Shortly afterward, a warehouse for materials, hotels, and even a hospital were built to serve the community and its needs. […] While the Red Cross built hotels for temporary housing, the Financial Committee decided to have 'Oklahoma' houses shipped from Chicago. These were replicas of the homes built when creating Oklahoma towns. The *Tribune* gave the Oklahomas' dimensions as twelve by twenty-six feet and described them as being furnished with a 'stove and utensils, six chairs, two beds and bed clothes, two spring mattresses, one pair of pillows, two pairs of

> sheets for each bed, woolen blankets, a bureau, a table, and tableware to set it' (Wharton-Michael 2012: 28).

Aid poured into the town from across the country and from "18 foreign countries" in the form of money, "blankets, clothing, and food" (Kreiser 2015: 40; Wharton-Michael 2012: 27). Just two months after the flood, "more than $3.3 million in contributions had been made to Johnstown and $1,088,066.96 had been sent directly to the governor's relief fund. […] Nearby New York was the top contributor donating $365,729.79" (Wharton Michael 2012: 29).

In the aftermath, the survivors of the flood and the relatives of the deceased sought to determine the cause of the dam's failure and to place blame on the owners. "The South Fork Club was found guilty of the Johnstown disaster by a coroner's jury. […] The jury found that the club had not taken the proper measures to ensure the safety of the people living in the valley below, but it was unknown what, if any, punishment might be given as a result of the verdict" (Wharton-Michael 2012: 29). Ultimately, the members of the club were never punished legally. "Despite the years of neglect and mismanagement of the dam, some of which predated the club's ownership, the courts eventually ruled that the flood was an act of God" (Kreiser 2015: 41). Finally, while "extensive flood control measures" were taken after the 1889 flood to prevent a repeat of flooding in Johnstown, the town did flood again eighty-eight years later on July 19, 1977. The flood control measures, improved engineering and building standards, and improved early warning that were developed in the span of time between the two floods did serve to save some lives and property, but ultimately at least seventy-six of the city's 42,000 residents were "drowned, and property damage exceeded $100 million" (Ludlum 1989: 92). Minot faced a similar situation to this when it flooded in 1976, just seven years after the 1969 flood. While no lives were lost, property damage was still extensive, forcing 12,000 people to evacuate, because adequate flood protection, in the form of an Army Corps of Engineers project, had yet to be completed (Time 1976: 45; Mouse River Facts 2011). Similarly, the 2011 flood in Minot and the 1889 Johnstown flood occurred in part because of a lack of responsible dam and reservoir management. In the case of Johnstown, the dam was in disrepair, and the pressure, due to the amount of water behind the dam, eventually caused a breach. In the case of the 2011 Minot flood, reservoir levels at dams in Saskatchewan and North Dakota were too high to accommodate the additional snow melt and rainfall, leading to massive releases to prevent dam failures. Had smaller releases been conducted in the months before June, 2011, perhaps the scale of the flooding or flooding in general could have been prevented. Also, just as the South Fork Fishing and Hunting Club let its dam fall into a structural state ripe for failure, so too did the City of Minot, Ward County, the State of North Dakota, and the U.S. Army Corps of Engineers let levees in and around Minot deteriorate to unacceptable and minimally acceptable conditions, not in line with inspection guidelines (AMEC 2013: 5.96-5.97). As Minot once again faces recovery and the need for more adequate flood protection measures, city, county, state, and federal agencies and leaders must work together to ensure that the measures put in place this time are capable of preventing such widespread inundation and damage. Additionally, leaders and agency workers at all levels must work to institute policy guidance and ensure communication measures are in place so that dams are managed responsibly, as the actions of a dam upstream have a direct impact on the actions of a dam downstream, especially when it comes to the release of a large volume of water over a short period of time.

1900 Galveston, TX Hurricane and Flood Case Study

Prior to September 9, 1900, the city of Galveston, with its 37,789 residents, was a thriving economic hub in Texas due to its deep port for shipping and its many resorts for tourism (Hughes 1990). All of that changed that fateful Sunday when "with no official warning, a Category 4 hurricane leveled Galveston" resulting in an "estimated 6,000 dead in the city and another 4,000 to 6,000 on Galveston Island and the adjacent mainland. Property damage at the time was estimated to be $30 million; in today's dollars, that's more than $700 million" (Roker 2015: 36). To date, this "unnamed storm" still remains the "deadliest" natural disaster "in American history" (Roker 2015: 30). The hurricane and resulting flooding from storm surge might not have been nearly as devastating in terms of lives lost and property damage had the advance warnings not been ignored, or put more accurately, prevented from being given in the first place. The set up for some of the main contributing factors to the scale and scope of this case date back to five years prior to the storm when Willis Moore became director of the U.S. Weather Bureau in Washington, D.C. "Moore made squelching Cuban forecasting one of the most important reforms he brought to the office" (Roker 2015: 31).

> Hurricane season was well underway. This was the perfect time, Moore calculated, to shut down all communication between Cuban weathermen and the people of the United States. […] The U.S. War Department, [which] controlled all of Cuba's government-owned telegraph lines […] responded quickly to the Weather Bureau's request to formally ban from those lines all messages referring to weather. But Moore went further and banned direct communication between the U.S. Weather Bureau's office in Havana and the office in New Orleans. Havana was to report directly to Washington, and Washington would decide what information to give New Orleans and the rest of the Gulf Coast. Moore even reached out to Western Union, the commercial telegraph company, [and asked …] the company to manage what a later age would call bandwidth. He requested first priority for U.S. Weather Bureau transmission. Next would come any non-weather related messages. Cuban weather messages were to get the lowest priority. Western Union showed a patriotic willingness to cooperate. Any private telegrams from Cuba to the United States regarding weather would be slowed, bumped, or Moore hoped, discarded. His blackout of Cuba was almost total (Roker 2015: 33).

Additionally, believing that “local weathermen had been over-warning the public” and fearing that sensationalized reports might panic “local populations, Moore banned certain words from all official weather reports,” including the words “tornado, cyclone, and hurricane” (Roker 2015: 32). Finally, Moore centralized the issuing of weather reports and warnings out of the national office, taking reporting out of the hands of the local weathermen, who oftentimes and understandably so, understood what was going on locally better than someone hundreds, if not thousands, of miles away. “The local weathermen would cable regular temperature, atmosphere and wind condition reports to the central office, where clerks aggregated the morning data into a national weather map, which was then telegraphed back to each station. It was for Washington, not for local weathermen, to determine what was going on locally” (Roker 2015: 32).

The tropical storm, which was growing in intensity to hurricane force winds, was “observed by meteorologists in Cuba,” namely Jesuit Priest Father Lorenzo Gangoite, “as early as Monday, September 3rd” (Roker 2015: 33). Following a weather model pioneered by his predecessor, Father Benito Viñes, “Father Gangoite thought he could tell exactly where the storm was going: the Texas Gulf Coast,” but due to Moore’s actions regarding the telegraph system, Father Gangoite’s forecast never made it to the national office in Washington, D.C. or to the office in Galveston (Roker 2015: 33). What did make it to the residents of Galveston was the National Weather Bureau’s report that “a tropical disturbance was moving over western Cuba and heading for the south Florida coast. […] No warnings were in order west of New Orleans” (Roker 2015: 35). A local Galveston weather forecaster, Issac Cline, “defying the ban on local storm warnings” urged “beach residents and business owners to head for higher ground” and “vacationers to go home. Many visitors followed his advice, but most natives were not particularly alarmed; they had seen flooding before” (Hughes 1990; Roker 2015: 36). While this warning did save some, for many the warning came too late. “The highest point in Galveston was 8.7 feet above sea level, and the island was about to be engulfed by a 15-foot storm surge. At 3:30 Saturday afternoon, the Clines sent a cable to Moore in Washington. ‘Gulf rising rapidly,’ it read. ‘Half the city now under water’” (Roker 2015: 36).

The hurricane and storm surged wreaked utter havoc on the city. So numerous were the dead that “regular burial was impossible. A mass solution was needed, and burial at sea was suggested. […] The corpses were weighted and thrown into the Gulf. Many, however, floated back onto the beach with the incoming tide. […] On Tuesday, Galveston became a city of funeral pyres. A dark pall of smoke hung over the island for weeks as the grim work continued” (Hughes 1990).

> While the tasks of burning or burying the dead, removing debris, and disinfecting the city went on, other survivors worked to repair or restore the water supply, telegraph and telephone lines, electric lights, and railroad and streetcar service. Sympathy, supplies, and money poured in from the rest of the nation and from around the world. President McKinley made rations and tents available. William Randolph Hearst sent relief trains. Clara Barton came to Galveston to work with the relief committee. […] By Wednesday, four days after the storm, the first grocery store was open for business. The next day, telegraph service to the mainland was restored, and, for the first time, many survivors were able to send messages to frantic friends and relatives. Early Friday morning a railroad bridge to the mainland was completed; the first relief train chugged into Galveston at 6:20 a.m. By Saturday, at least one mule-drawn streetcar was operating, and electricity had been restored to a few homes and stores. Galvestonians learned from the hurricane that they needed a seawall. Flood waters of up to 20 feet, perhaps higher, had swept the eastern and southern parts of the city seaward of the barricade of wrecked homes and debris thrown up by the storm. This barrier apparently had acted as a breakwater, absorbing the terrible destructive force of the waves and catching wreckage before it could flatten buildings behind it, where most of the survivors had taken refuge. So Galveston built a seawall,” which “was completed on July 29, 1904. It was 3.3 miles long, and rose 17 feet above mean low tide. A solid 16 feet wide at the base and 5 feet across at the top, it was strengthened against undermining and erosion by a loose layer of rough granite blocks that extended 27 feet seaward (Hughes 1990).

In addition to building the seawall, Galveston “city leaders literally jacked up the entire island and its two thousand buildings, adding eleven million pounds of landfill and thereby elevating an entire metropolis" (Draper 2015: 162). "The massive undertaking was not finished until July, 1910" (Hughes 1990). Both mitigation efforts paid dividends to the city when the next major storm hit the city fifteen years later on August 16, 1915: only eight people died. "The seawall has since been extended several times and grade raising has continued as the city has grown" (Hughes 1990).

Despite all the death and damage, some of which may have been prevented had Father Gangoite's telegraph warning been able to make it through, "Willis Moore suffered no professional consequences for his decisions" (Roker 2015: 36). He was fired from his post in 1913 over a non-related incident. Despite the failings of its former director, "the Weather Bureau slowly adopted hurricane-forecasting techniques in the coming years," including the techniques which were pioneered in Cuba (Roker 2015: 36).

While this disaster was the result of a hurricane and storm surge and not a failed dam as in the Johnstown case, the two cases do have a few similarities. In both cases: 1) little or no advanced warning was given to residents/officials or else the warnings were ignored entirely/not taken seriously, 2) no one was ever legally or professionally held accountable for his or her actions or lack of actions which contributed to the scale and scope of the disaster, and 3) both cities took mitigation actions post-flood which positively impacted the cities' survivability in terms of reduced economic/property damage and fewer lives lost when the next flooding event occurred. As this literature review continues to present additional case studies, one can note that while the United States has done well over the course of the past century of natural disasters to improve mitigation efforts and advance early warning, it has done very little to improve accountability for preventing and responding to such events.

1972 Rapid City, SD and Black Hills Flood Case Study

At 10:45 p.m. on June 10, 1972, the "Canyon Lake Dam, just southwest" of Rapid City, South Dakota failed, resulting in the flooding of "the entire downtown during the night" (Ashley 2008: 808-809; Potter 2012: 11). On its way down the canyons of the Black Hills to Rapid Creek, which flows through the center of Rapid City, the water destroyed "much of what was in its path," including "every single building in the town of Keystone, just outside of Mount Rushmore National Monument" (Potter 2012: 11). The "flood waters crested in downtown Rapid City, with an estimated flow of 50,000 cubic feet per second," 21,000 cfs greater than the June, 2011 Minot flood. Overall, the flood claimed "238 lives and injured more than 3,000 people. Total damages were estimated at the time at $160 million. The flood destroyed 1,335 homes and some 5,000 automobiles" (Potter 2012: 11).

The Canyon Lake Dam's failure was the result of "intense precipitation from the orographically forced storm system over the basins of Rapid, Boxelder, Spring, and Battle Creeks" (Nair et al 1997: 1753). Over the course of the storm, the "maximum observed point accumulation from the storm event was 380 mm" (Nair et al 1997: 1756). Similar to the events of the Galveston storm, the inability to accurately forecast weather in a timely manner played a role in the overall extent of the flooding, damage, and fatalities. "The local National Weather Service Office in Rapid City issued the following forecast for that afternoon: a few isolated thunderstorms may approach sever limits late in the afternoon and evening over Eastern Montana, Northern Wyoming, and Western South Dakota" (Potter 2012: 10). "The local NWS office issued its first flood warning—for the northern Black Hills—at 7:15 p.m. Forty-five minutes later […] the office expanded the warning to include Rapid City" (Potter 2012: 11). "By 10:15 p.m., Rapid Creek, which cuts right through the city that shares its name, began to overflow its banks. Half an hour later, Canyon Lake Dam, just southwest of the city, failed after the water level rose nearly 12 feet. For the next several hours, flood waters rushed through both canyons and populated areas" (Potter 2012: 11).

After the flood waters receded, after city officials and residents had surveyed the damage, and with help from the National Weather Service, plans were put in motion to prevent another flooding catastrophe of such magnitude from occurring in Rapid City again in the future. "A NWS survey team, which was charged with assessing the agency's performance during the event […] outlined a number of recommendations to improve the forecast and warning process, as well as to improve the availability of weather radars in the area for use by the local NWS, which at the time did not have its own radar" (Potter 2012: 11). In addition to investing in equipment and resources to improve forecasting and early warning of flash floods, Rapid City has also incorporated natural flood mitigation practices into its city planning. If one looks at a map or a satellite photo of Rapid City, one can see that while Rapid Creek does cut through the city flowing from west to east, the city has established greenways on either side of its banks including parks, sports fields, gardens, golf courses, and other amenities. These areas afford recreation and entertainment to the city's residents and the thousands of tourists the city sees each year, due to its proximity to Mount Rushmore and the Sturgis motorcycle rally, while also serving as areas where water can be diverted in times of flooding. Minot could learn much from Rapid City's example by creating additional greenways to serve as buffers between the banks of the Souris River and Minot's residential and commercial areas. Additionally, just as Rapid City's local National Weather Service office invested in weather radar to bolster future storm detection capabilities, City of Minot officials and the Army Corps of Engineers could benefit from investment in the installation of additional stream gauges up river from the Lake Darling Dam in the rural parts of northern North Dakota and southern Saskatchewan, Canada.

1993 Mississippi and Missouri River Floods (also known as The Great Flood) Case Study

"The flooding in the upper Mississippi and lower Missouri basins from mid-June through early August 1993 was caused by intense rainstorms in late June and July that came on the heels of six months of heavy and persistent rainfall. […] By late June, flood storage reservoirs were at or near capacity and soils throughout the area were saturated," a situation very similar to the reservoir and soil states along the Souris River in Saskatchewan, Canada and North Dakota in the late spring and early summer of 2011 (Myers & White 1993: 9). "Many precipitation stations in the Midwest registered the equivalent of a year's worth of rainfall in three months" (Pitlick 1997: 149). "The Great Flood of 1993 affected the lives of millions of Americans, flooding homes, farms, businesses and entire towns" (Hickcox 1993: 22). "The flooding caused significant damage in nine states: Illinois, Iowa, Kansas, Minnesota, Missouri, North and South Dakota, Nebraska, and Wisconsin. More than 1,000 levees stretching nearly 6,000 miles in length were breached or overtopped. Many others were significantly damaged" (Myers & White 1993: 25). "In the seven state flood region," involving the Mississippi but not the Missouri River, "48 people died, more than 55,000 homes were flooded, 74,000 people were evacuated and 20 million acres inundated. Damage estimates ranged from $12 to $16 billion. A year and a half later, many areas" still had "yet to recover" (Hickcox 1993: 22). "The federal government has bought out some 40,000 flood-prone properties across the country since the Mississippi flood of 1993" (Grunwald 2011: 27). Of the estimated $12 to $16 billion in damages and relief costs, the Federal Emergency Management Agency covered "about $650 million, including $250 million for individual assistance and $400 million for public assistance," which is only 4.06% to 5.4% of the overall clean up and recovery costs (Myers & White 1993: 25). Of the millions of homes and business affected by the Great Flood, the "Federal Insurance Administration estimated that there were 88,400" flood insurance "policies in force in the nine states, but it is difficult to ascertain how many of these" policies were for "structures damaged by the flood;" this is yet another commonality with Minot's 2011 flood, as over 90% of home and business owners lacked flood insurance (Myers & White 1993: 25).

As the Great Flood affected so many towns across the American Midwest, this case study also provides the opportunity to examine the effectiveness of various flood mitigation strategies. The city of Davenport, Iowa, for example, had prepared for the possibility of flooding by "adjusting its land use with a riverside park and waterfront gambling boats and had designed buildings to minimize potential flood losses. Thus, the flood's costs to the city were lower than what the city would have paid for levee construction and for restricted riverfront access" (Myers & White 1993: 27). The town across the river, Rock Island, Illinois, which employed a levee system for flood mitigation, faced significantly higher flood damage and repair costs when its levees failed or were topped. The levees in Rock Island were one of "more than 1,000 damaged levees" in the 1993 flood that "were locally owned and operated" and because of this were "not eligible for federal reconstruction assistance" (Myers & White 1993: 29). Overall, "more than 85 percent of the levees on the Mississippi and Missouri Rivers were damaged or over-topped during the 1993 flood, the vast majority" having been "built by local drainage districts to protect agricultural land" and "not designed to handle floods of this size" (Pitlick 1997: 136).

Buying out homes to create space for greenways and riverside parks that would enable natural flood mitigation can be an expensive and time consuming task, but it is not impossible.

As part of the 1993 flood cleanup, “FEMA focused the use of its Section 404 Hazard Mitigation Program grant funds—an estimated $45 million, which must be matched by the recipients on a 50/50 cost-sharing basis—on acquisition and relocation projects and also has funds available to provide technical expertise to communities wishing to undertake such projects” (Myers & White 1993: 29). The technical expertise aspect of these projects in many cases is more daunting than the cost as many cities noted that they “lacked an employee with the expertise to carry out a program to acquire and relocate flood-damaged properties” (Myers & White 1993: 26). This seems to be the current case in Minot, North Dakota, as the city has only really just begun to buy out homes—four years after the flood. It is still dealing with the Section 404 permitting process while also investing more time and money to conduct studies before breaking ground or demolishing houses for new flood protection measures, be they natural or man-made.

Something that failed to be addressed or was only minimally addressed, both in the wake of the 1993 Great Flood and Minot’s 2011 flood, is why reservoirs were allowed to be filled so near to capacity in the first place. In the case of the Mississippi and Missouri Rivers, reservoirs are needed in order regulate the water level of the rivers year-round for riparian navigation, shipping, and commerce. Additionally, and in the case of Minot, reservoirs provide farmers and cities water for crops and the populace in times of drought. Regardless, of the reasons why reservoirs exist, the policies regarding the regulation of the height and volume of their water levels is something that needs to be examined and addressed in addition to flood protection and mitigation measures. A dam and the resulting reservoir can be a great asset and form of flood protection, but its ability to protect from flooding is negated if the reservoir is already at or near capacity when heavy rainstorms come and continue for a persistent time, forcing large water discharges—record releases in the cases of both the 1993 Great Flood and the 2011 Souris River

Flood. Hickcox noted that “the stage was set for the summer’s floods during the fall of 1992 when much of the region received abundant precipitation. Indeed, in mid-September, 1992, thunderstorms along a stalled cold front caused serious flooding in parts of Iowa, Wisconsin, and Minnesota, an ominous harbinger of 1993’s record floods” (Hickcox 1993: 24). If that was the case, and pre-existing flood conditions were known, why were mitigation and preventative efforts such as levees and pre-emptive discharges not bolstered to a greater extent in the lead-up to the summer months? The 1993 Great Flood also raised the question of “whether human modifications to the natural system made the [flooding] situation worse than it might have been,” noting that “the systematic conversion of wetland and floodplain areas to agricultural land has reduced surface-water storage, causing increased runoff and higher flood stages” (Pitlick 1997: 135). Thus, natural versus man-made mitigation and prevention as well as city and regional planning and expansion into wetland and floodplain areas are policy decisions that need to be examined and possibly revised. Another policy area that could be examined, but which is largely outside a city planner’s or engineer’s control, is insurance coverage for flooding events, as “flood damage isn’t covered by standard homeowners insurance” currently (Siskos 2001: 72). In all the case studies covered in this thesis, a lack of flood insurance by the vast majority of the affected populaces is a common theme.

1997 Grand Forks, ND / East Grand Forks, MN, Red River of the North Flood Case Study

On “April 19, 1997, the Red River, usually about 15 feet deep, crested at a towering 54 feet” forcing “more than 90 percent of the 52,500 residents of Grand Forks” and “all 9,000 residents of East Grand Forks” to flee their homes and businesses (Siskos 2001: 72; Paulus et al 2008: 78). The flood was the result of “record-setting snowfalls during the winter of 1996-97,” during which “more than 100 inches of snow fell across the Red River valley” (Paulus et al 2008: 78). An additional 10 to 12 inches accumulated when “a severe blizzard and ice storm […] struck the region April 4th-6th” (Paulus et al 2008: 78). As temperatures suddenly “rose from an average of 9 °F on April 9th to an average 58 °F on April 18th,” the region’s rivers and streams and became swollen with run off and snow melt (Paulus et al 2008: 78). While both Grand Forks and East Grand Forks took measures to protect the cities from flooding in light of the heavy winter snows, including “raising their existing levees and constructing emergency levees” the efforts were not enough (Paulus et al 2008: 78). “Grand Forks was devastated when temporary levees were overtopped and the entire city flooded. More than 8,000 homes were lost. Economic damage was estimated at $3.6 billion, according to an after-action report” (Setzer 2009: 15). In addition to the flooding, fires, caused by natural gas leaks, destroyed several homes and businesses. “It took nearly a month for the floodwaters to recede enough to allow residents to return home to survey the damage” (Siskos 2001: 73).

However, “the devastation of Grand Forks crystallized state and local support for a comprehensive flood-control program. Since 1997, Grand Forks had a $417-million program for new levees, floodwalls, and improved pumping systems. Funding was 45% federal, 20% state, and 35% local, according to Grand Forks officials” (Setzer 2009: 15). The city was able “to replace its infrastructure without raising taxes” (Siskos 2001: 72). However, many of those affected, “have yet to dig themselves out of the debt they took on to rebuild their homes and their lives. Some residents whose houses survived the flood became victims of its aftermath, as the city’s new flood-prevention program claimed hundreds of homes left standing” (Siskos 2001: 72). Similar cases of incurred financial burdens and worry over the effects new flood mitigation measures will bring are shared by Minotians in the wake of the 2011 flood, especially by those who have already rebuilt but might be affected by the location of future flood prevention measures.

After the devastation of the 1997 flood, the City of Grand Forks took action to prevent a future reoccurrence. "The communities have rebounded and now possess not only adequate flood protection but also a vibrant greenway along the entire length of the river between the two cities" (Paulus et al 2008: 77). In order to affect this, the City of Grand Forks refused to issue building permits to allow "residents of three neighborhoods adjacent to the river, the scene of the worst devastation," to rebuild, "but would purchase [the] more than 800 houses and turn the land into a park for the river to reclaim whenever it flooded," i.e. natural flood mitigation (Siskos 2001: 74). "Homeowners would receive a market price based on the value of their house the day before the flood, as determined by a team of appraisers. Owners who disagreed with the assessed price could appeal" to request receipt of a larger sum (Siskos 2001: 74). As noted by one appraiser handling the buyouts, "people were treated fairly; if anything, there was a tendency to give a higher-than-market price" (Siskos 2001: 74). "The Federal Emergency Management Agency and the cities bought out hundreds of homeowners and relocated them to higher ground. Other owners had their property or portions of their backyards acquired to provide the needed right-of-way," i.e. imminent domain (Paulus et al 2008: 79).

While the price given for the homes may have been fair, the "displaced homeowners walked into an inflated housing market, in which the average sales price for new and existing homes in Grand Forks jumped from $67,000 before the flood to $80,000 by October, 1997, and peaked at $100,000 two years later" (Siskos 2001: 74). Similar circumstances were faced by Minotians following the 2011 flood as the Bakken oil boom brought thousands of oil workers to the region, backed by the deep pockets of their companies, driving up rent and home prices and creating a housing demand which exceeded the available supply for the next several years. Only recently in 2015, with the drop in the price of oil creating a slow in the oil boom, has the supply caught up with the demand. However, as housing and rent prices fall, those who purchased homes following the flood are finding it increasing difficult to break even when life's circumstances force them to sell, which is not so uncommon as oil workers leave the town and service members of the nearby Minot Air Force Base, home to approximately 8,000 airmen, move on to their next duty station.

In addition to the home buyouts, the "$409-million project to reduce [future] flood damage in the cities, involved constructing 28 miles of levees, 17,000 lineal feet of floodwalls, 22 road and railroad closures, and 23 pump stations. New diversion channels for coulees on both the Grand Forks and the East Grand Forks sides of the Red River convey flows around the cities during floods" (Paulus et al 2008: 77). "The project encountered many challenges, including poor soils," which was often the reason for acquiring better land for levee construction further away from the Red River's banks. Other challenges included acquiring homes which had not been deemed total losses or in some cases even flooded, and dealing with "areas of historical importance requiring special attention, extreme weather conditions, and short construction seasons" (Paulus et al 2008: 77). "On January 31, 2000, the project cooperation agreement for the construction of the East Grand Forks-Grand Forks Flood Damage Reduction and Recreation Project was signed by representatives of the Corps and both cities;" almost eight years later, in November, 2007, ten years after the flood, the project was finally completed (Paulus et al 2008: 79-80).

The result of the project was permanent and meaningful flood protection for both cities. "The project reliably protects against the 250-year flood, which would discharge 136,900 cfs.

[…] Moreover, the top-of-levee profile is based on a discharge of 169,000 cfs, which is slightly larger than the 500-year event, which would discharge 161,000 cfs" (Paulus et al 2008: 80). The same meaningful protection that now exists in Grand Forks, North Dakota and East Grand Forks, Minnesota needs to be realized in Minot, North Dakota, but getting there, especially in the same time frame, will be no easy task, and the city may already be behind the power curve. Ground breaking on the flood protection project for Grand Forks and East Grand Forks did not occur until three years after the initial flood; in comparison, Minot did not break ground on the first phase of its flood protection project until September, 2015, slightly over four years after flood waters receded.

2005 New Orleans, LA Hurricane Katrina Flood Case Study

"When Hurricane Katrina struck land 75 kilometers to the southeast of the city" of New Orleans "on 29 August 2005, a six meter storm surge caused levee failures and flooding in over 75 percent of the city" (Green et al 2007: 315). "The levees that surrounded New Orleans breached at 53 different sites contributing to the death of 1,800 people and left tens of thousands of residents homeless" (Francis 2015: 2). The neighborhoods of New Orleans East, the Upper Ninth Ward, and the Lower Ninth Ward were hit particularly hard, because

> like most areas of New Orleans, a substantial portion of these neighborhoods are below sea level. […] The Lower Ninth is estimated to be 1.2 to 1.8 meters below sea level" and flood water heights "of over 3.5 meters" were reported "in some areas along Florida Street in the north of the Lower Ninth Ward. […] Flooding in the Upper Ninth Ward started north of St. Claude Avenue and increased to 3.5 meters along Florida Avenue and in [the] Desire Neighborhood, a flood height about 2.5 meters above sea level (Green et al 2007: 315).

While some houses in the Upper and Lower Ninth Wards were moved from their foundations by the hydrodynamic force of water set upon them when the levees breached, Green, Bates, and

Smyth in their report, the product of "an extensive field study of damage and recovery" conducted by "Cornell University, Columbia University, and the University of Illinois-Urbana-Champaign," using a sampling of approximately 3,800 residential plots, found that "the majority of structures in the Upper and Lower Ninth Ward, although heavily flooded, were structurally undamaged" (Green et al 2007: 312-316). This differed from the initial findings contained within a report compiled by FEMA.

> FEMA, in its direct inspection of Orleans Parish, found 107,379 houses with flood damage. Approximately 3,500 of these flood-damaged units were in the Lower Ninth Ward and Holy Cross. FEMA's assessment indicates that 82 percent of the residential units in the Lower Ninth Ward sustained severe damage or were destroyed. These estimates included both structural damage and non-structural flood damage to homes, making it difficult to assess the recoverability of these neighborhoods from the FEMA reports alone (Green et al 2007: 315).

Specifically, the joint-university study found that

> throughout the Upper and Lower Ninth Ward, 75 percent of the existing structures surveyed in October 2006 had either no or minor structural damage. Moreover, vacant lots—many from post-storm demolition—were limited to 9 and 22 percent of the plots in the Upper and Lower Ninth, respectively. Heavy structural damage was primarily limited to the northwestern corner of the Lower Ninth Ward, linked to two significant levee breakages along the Industrial Canal during the early morning of 29 August 2006. […] An estimate of heavy structural damage in the northern section of the Lower Ninth Ward would, at most, be 54 percent of the housing stock (Green et al 2007: 317).

While water levels did rise to as much as 3.5 meters above sea level in some areas as previously stated, "nearly 60 percent of the structures" in the Lower Ninth Ward "were elevated on foundation piers. Floods that did not exceed the height of these piers typically left both house and property undamaged" (Green et al 2007: 317-318).

If the report from the joint-university study was correct, recovery was possible in these areas; however, the universities' research found that "recovery throughout the city has been stymied by a host of interrelated factors […] foremost among these issues are levee reconstruction, flood insurance coverage, labor shortages, and an overwhelmed service sector" (Green et al 2007: 322).

> Residents' access to recovery capital is also a critical factor in the speed at which recovery occurs. Because rebuilding after a hazard event is up to the individual owner, outcomes depend heavily on access to resources. […] The present system works best for well-insured single family homeowners, who tend to rebuild on the same site. Reconstruction of owner-occupied homes requires tremendous resources, pay outs on building, home contents and flood insurance policies, as well as access to personal savings and to credit. Income and access to capital are, therefore, crucial determinants of the capacity to return and begin rebuilding (Green et al 2007: 326).

While "approximately 54 percent of the homes" in the Lower Ninth Ward, which lies within the 100-year flood plain, "were owner occupied," and thus required to carry flood insurance coverage, those renting were not required to carry insurance, and most rental insurance policies do not cover flooding. Additionally, and similar to Minot's 2011 flood, those homes falling "outside of the designated (100-year) flood-plain […] were not required to have flood insurance," yet in the case of both floods, the water's reach far exceeded the boundaries of the predicted 100-year inundation (Green et al 2007: 327). While federal home repair grants are a possibility for those homeowners not carrying flood insurance to enable repairs, the process can be taxing, and the wait for the funds long, causing some residents to just give up hope for rebuilding and reoccupying their homes.

While "initially […] a moratorium" was placed "on rebuilding in heavily flood areas such as the Lower Ninth Ward until their viability was proven" the "New Orleans' Director of the Office of Recovery management, Dr. Edward Blakely, announced that the Lower Ninth Ward would be an initial target for heavy investment as a revitalization node" (Green et al 2007: 311). Thus, repairing homes, creating higher, stronger new levees, and bolstering old levees was chosen over home buyouts and creating a greenway buffer for future flood mitigation in most areas, unlike the solutions presented by city and regional planners and engineers in the last three case studies. "The Army Corps of Engineers completed the $14 billion project to rebuild" the levee system in the summer of 2012 (Gratz 2013: 26). The course of action to repair the levee system and rebuild homes, especially in the Upper and Lower Ninth Ward areas, was chosen primarily due to the fact that the "vulnerability to disaster events is greatest for low income and minority communities," and community leaders recognized that it was important "to avoid strategies that exacerbated social and economic inequality" (Green et al 2007: 330). Time will tell if the additional man-made flood protection improvements will be enough when the next large storm surge occurs, or if pursuing natural flood mitigation measures would have been a better course of action. Some view the choice to not create greenways as a "lost opportunity" and believe that the city's "refusal to change the water and power paradigms will condemn New Orleans and other flood-prone cities to continued devastation from floods" (Gratz 2013: 27). In tackling the problem of flood recovery, repair, and future prevention, Minot's city leaders and planners are having to weigh similar courses of action—balancing home buyouts, the creation of greenspace, and the locations of new levees and pumping stations to protect critical infrastructure with residential and commercial rebuilding activities.

2009 Fargo, ND / Moorhead, MN Red River of the North Flood Case Study

"The Red River has exceeded flood stage in 48 of the past 109 years and in every year from 1993" with the "exception of 2012" (Zeman 2015: 25; Bergeron 2012: 30). On March 27, 2009, the river crested at 40.8 feet but was contained in Fargo by" close to "3 million sandbags," which continued to hold the water at bay as it "lingered for weeks" (Zeman 2014: 25; Kaiser 2009: 6; Guarino 2013). "With little more than a week's notice, an army of federal, state, and local resources, along with sandbag-packing volunteers, built a maze of temporary dikes atop existing levees to withstand the onslaught of the rising Red River" (Setzer 2009: 15). "The town avoided devastation due to a combination of small but crucial flood-control projects after the 1997 flood, as well as an extremely quick mobilization in advance of this flood" (Setzer 2009: 15).

"After the 1997 floods, plans were developed for a $161 million upgrade for Fargo, but local opposition and a lack of funding stalled it" (Setzer 2009: 15). Fargo's city engineer at the time, Mark Bittner, estimated that "if the planned $161 million South Side Flood Control Project had been implemented in time, the city probably would have needed only 10 of the 50 miles of temporary earthen and sandbag levees it erected" (Kaiser 2009: 6). One of the main reasons for the delay in beginning construction was waiting on "the Federal Emergency Management Agency" to "redefine the 100-year flood" (Kaiser 2009: 6). Furthermore, action was stalled until the Army Corps of Engineers completed "a $5.4 million feasibility study to identify a comprehensive plan for permanent flood control throughout the area" (Kaiser 2009: 6).

After the 2009 narrow miss, "mitigation strategy design work" finally "began" (Zeman 2014: 25). Both Fargo and Moorhead have completed "efforts to remove most homes and other structures from low-lying areas" and have "invested millions to build levees and other protections," Fargo having spent $100 million since the 2009 flood," and Moorhead having "spent more than $88 million" (Guarino 2013). In 2013, the City of Fargo recommended "that all residents obtain flood insurance this spring" so that residents would be better prepared should the worst happen in the future (Guarino 2013). Additionally, Fargo and Moorhead city leaders and residents urged "Congress to help fund a $1.8 billion diversion channel around the area of both cities, saying such a project presents the greatest protection against what appears to be consistent flooding each spring" (Guarino 2013). "The proposed flood diversion project would include a 26-mile levee around Fargo. A dam across the Red River would divert water away from the cities and into a staging area, a floodplain of 100-year old farmsteads" (Zeman 2014: 25). Specifically,

> two staging areas" would be created "upstream to temporarily store up to 200,000 acre-feet of floodwater. The […] development of the staging areas would affect an estimated 33,390 acres of land, 387 dwellings, and 421 other structures on rural farmsteads and in two small communities, it would require 10 miles of tie-back levees and placement of control structures on two rivers and a creek (Bergeron 2012: 30).

This plan has brought criticism from some residents, with one saying, "you can't build a dike that is going to make someone else flood," but perhaps that is just what the city needs (Zeman 2014: 25). Yet, there are numerous landmark legal cases in which eminent domain has been used to take property from a few for the benefit of the community as a whole, and there is provision for this practice in the Fifth Amendment to the U.S. Constitution—"nor shall private property be taken for public use, without just compensation" (Bill of Rights 1791).

Though unpopular with some, Congress finally did approve "authorization for up to $846.7 million in federal funds for a diversion project in the Red River Valley" when it passed the Water Resources and Development Act in May, 2014, and the president signed it into law on June 10, 2014 (Jackson 2014; Zeman 2014: 25). Now that federal funding has been approved, Fargo and Moorhead city leaders, state officials, and the Army Corps of Engineers have decided to move forward with the plan (Jackson 2014). More importantly, the Water Resources and Development Act "also makes changes to how future projects can seek funding and sets specific time and cost limits for studies on potential projects. It eliminates unnecessary Corps reviews and speeds up environmental reviews for potential projects" (Jackson 2014). These new rules, if enforced, would be a step in the right direction for meaningful flood protection in North Dakota and elsewhere as this and previous case studies have all shown significant time delays in meaningful flood protection actually being delivered to citizens due to governmental bureaucracy and red tape. In the case of the Fargo-Moorhead metropolitan area, it means protection for 209,000 people from a 500-year flood event (Bergeron 2012: 30). While engineering and financial reviews are indeed a necessary part of such a large undertaking to ensure that a quality product is delivered at the lowest cost, such efforts must not unnecessarily impede the timeline for delivering meaning flood prevention and protection, as doing so could subject communities to repeat flooding events before project completion.

2011 Assiniboine and Red River Basins and Winnipeg, Manitoba, Canada Flood Case Study

Flooding which occurred in the Assiniboine River Basin (ARB) and Red River Basin in Canada in the spring and summer of 2011 and the Canadians' actions taken to prevent, mitigate, and combat the flood waters provide insight into the June, 2011 Minot flood and perhaps to what actions could have been done better or differently. As can be seen from Figure 3 below, the Souris River has its headwaters in Cedoux, Saskatchewan, just southeast of Regina, and flows southeast into North Dakota. After passing through Minot, the Souris flows northeast back into Canada joining with the Assiniboine River at Treesbank, Manitoba on its way east to Winnipeg.

Figure 3: Depiction of the Souris, Assiniboine, and Red River Basins (2014).

Because of this, the Canadians in Winnipeg had to deal with similar record water height levels and volumetric flow levels seen in Minot during the summer of 2011.

"In the spring and early summer of 2011, the ARB experienced an extreme flood that was unprecedented in terms of its duration and the volume of water involved" (Brimelow et al 2015: 1268). "The frequency, timing, and severity of heavy precipitation events over the ARB" in the lead up to the June, 2011 flood "were critical because they increased soil moisture (2010 warm season), the winter snowpack (winter of 2010/11), and subsequent spring runoff in 2011" (Brimelow et al 2015: 1258). To give an idea of the scope of the increase in water volume flowing through the Souris and Assiniboine Rivers in 2011, consider this: "In 2011, the Souris basin contributed ~ 45% to the ARB's annual discharge, which is about 20% greater than the average" (Brimelow et al 2015: 1253). Put another way, "the accumulated discharge in 2011 was over 5 times greater than the mean annual discharge" (Brimelow et al 2015: 1254). Furthermore, "In April and May," 2011, "area-averaged precipitation amounts were 130% and 170% above average, respectively" for the ARB, and in June they were "near 150% above average" (Brimelow et al 2015: 1256).

"The impacts of the 2011 flood over the ARB were widespread and costly. [...] Almost 5.5 million hectares of farmland did not produce crops in 2011 because of flooding. Additionally, critical infrastructure, such as roads and bridges, sustained significant damage, and over 7,000 people were displaced" (Brimelow et al 2015: 1250). That being said, Winnipeg was better prepared to handle the flood, having built extensive flood control infrastructure "following a devastating flood in 1950" (Durn & Goel 2001: 356). Specifically, the city of Winnipeg is "protected by the Red River Floodway, the Shellmouth Reservoir, the Portage Diversion, and earthen dykes along the Red, Assiniboine, and Seine Rivers within the city" (Durn & Goel 2001:

356). “To prevent frequent flooding along the Assiniboine River downstream of Portage la Prairie,” including in Winnipeg, “the Portage diversion, completed in 1970, was constructed to divert water to Lake Manitoba” (Brimelow et al 2015: 1253). This, combined with the Shellmouth Reservoir, “are used to regulate the Assiniboine River flows entering the city of Winnipeg,” and it was these features, plus some tough decisions by city and regional leaders and engineers, which spared the city more extensive flooding than Minot experienced in the summer of 2011. “The Portage diversion was operated for a record 126 days and was required to function above its design capacity for a record 31 days between early May and late June 2011” (Brimelow et al 2015: 1251). When it was discovered that not even this effort plus “weeks of frantic work to shore up dikes downstream at a cost of $25 million” would be enough to stop the “predicted peak flows of more than 52,000 cfs,” Manitoba’s Minister of Emergency Measures, Steve Ashton, weighed “two options: do nothing and risk a blowout of the dikes,” in which case “the waters of the Assiniboine would swamp 500 square kilometers and 850 dwellings,” or “do our own release […] with the express aim of flooding out as much as 225 square kilometers and 150 homes. […] I wouldn’t say it was an easy decision, but when it came down to it we just couldn’t risk an uncontrolled breakout” (Gatehouse 2011: 26).

In the end, the flooding “cost the province at least $200 million (Canadian)” in 2011, and “over the past decade, Manitoba has already spent $1 billion (Canadian) on flood-control measures” (Gatehouse 2011: 27). Had the City of Minot and/or the state of North Dakota invested similar amounts of money and performed adequate upkeep maintenance on its own man-made flood prevention structures in Minot prior to 2011, perhaps they too would have only faced a $200 million bill after the flood. Rather, a near $1 billion cost estimate has been currently assessed, not to mention that meaningful and lasting flood protection will cost infinitely more in today's dollars rather than if they had moved to invest in adequate, increased protection after the 1969 and 1976 floods. A diversion project, such as the one currently under construction in the Fargo-Moorhead area and the ones already existing in Grand Forks / East Grand Forks and Winnipeg, has recently been discussed as an option; it seeks to straighten out the river's course at two different locations between two points so as to minimize the amount of inundation that could occur in the city due to the river's winding course. Unlike some of the aforementioned diversion projects, the plan for Minot's diversion project still goes through the middle of the city rather than circumventing the city by utilizing existing farmland and open areas. While not necessarily a best practice in all flooding cases, as it was not a solution found in all the case studies, diversion does seem to be the standard in the region. Obviously, the greater the amount/degree of diversion, the greater the protection afforded, but with greater distance away from the city comes greater expense due to additional construction costs.

Emergency Management, Resiliency, and Adaptive Capacity Policy Review:

David McEntire, a commonly cited and subject matter expert in the field of emergency management theory, stated in a 2004 paper presented at a FEMA conference that

> History […] teaches that our nation can be affected from various agents including floods, earthquakes, tornadoes, power outages, computer failures, chemical spills, riots, terrorism, and even space shuttles breaking up on reentry into the atmosphere. […] All disaster research should reflect different needs at the local or state level. […] We cannot control hazards; we can only limit our degree of vulnerability (or risk) to natural, technological and civil events. […] Vulnerability, unlike hazards, is undoubtedly the only thing we really have control over in the disaster equation (McEntire 2004: 10-11).

In order to effectively limit this degree of vulnerability, "it has become paramount for regions to plan for the unexpected, particularly when it comes to Mother Nature. […] It's a fact that artic ice is melting and the sea level is rising, which leads to higher flood waters and more precipitation" (Heaton 2013). "An assessment of vulnerability is important in resilience management because it contributes to increased situation awareness, promotes the development of adaptive capacity, and also gives the organization tangible objectives to work towards" (McManus et al 2007: 10). For this reason, this thesis is examining what Minot's vulnerability to flooding will be through ArcGIS modeling once proposed additional flood protection/mitigation measures are completed. A vulnerability assessment will give the city's government, as well as its citizens, a reality check for what it is doing right and will suggest areas for improvement with regard to flood prevention and protection. It is the tool which provides the vector for additional actions and improvements.

"By studying the crisis preparedness actions taken before natural disasters" and by "understanding the results of these actions, […] future leaders can plan for disasters, which could increase the overall outcome of the disaster and increase the numbers of lives saved," reduce the scope and extent of damage, and reduce "the overall costs associated with the aftermath of the disaster […] including man power, supplies, and property damage" (Francis 2015: 4). In addition to taking an active role in preparing for a crisis and responding during a crisis, those in positions of power, whether elected or appointed, need "to show strong executive leadership and must be engaged throughout the recovery to ensure that the work is completed" (Francis 2015: 12). For state and local leaders, "maintaining the sustainability of supplies, manpower, and communication can make all the difference in the face of disaster" (Francis 2015: 16). When a crisis or disaster occurs, "leaders do not have the luxury of being able to go back in time and change a decision or its outcome;" therefore, "proper preparedness is key to overcome the obstacle circumstance" (Francis 2015: 19).

"The key element is to have a plan; […] a crisis preparedness plan, also known as a crisis management plan, is a necessity to ensure a community is ready for a crisis" (Francis 2015: 19). City and regional leaders and planners must "identify those events that are foreseeable and consider how they might cope with the outcomes that they cannot foresee" (McManus et al 2007: 8). "Emergency management experts and sustainability planners say it's important to begin planning for a changing paradigm" and to take "a holistic approach to disaster planning" (Heaton 2013). This is because "no one can predict when a crisis will strike or the destruction that a" disaster "will cause;" thus, "having crisis preparedness plans and ensuring that one has the right tools, supplies, and people in place are necessary to be successful" when preparing for, responding to, and cleaning up/rebuilding after a disaster (Francis 2015: 34).

"The first step of any crisis preparedness plan is to state the goal or outcome that one hopes to obtain and to begin the coordination of available resources" (Francis 2015: 19). In the case of a flood prevention, the goal is to be able to control the path and rise of water though the use of dams, levees, flood walls, canals, etc. If these preventative control measures become inoperable, damaged, or fail outright, the goal is to mitigate the resulting effect to the greatest extent possible. Initial coordination of resources during a flood involves securing equipment, such as heavy machinery, stockpiling supplies prior to the event, including food, clean water, fuel, sand bags, etc., and ensuring there exists the right staffing levels, both in terms of numbers and skill levels. Civic leaders might task their engineering, public works, and parks personnel with building sand bag walls and constructing earthen berms as well as recruiting volunteer help from the community to expedite the tasks to be done. The key is for leaders "to be familiar with their people by knowing their strengths and weaknesses;" in "knowing these personal qualities, leaders can adequately assign tasks to complement their followers' strengths and ensure the right people are in the right job at the right time" (Francis 2015: 20). Ideally, the right "supplies and personnel" would be identified and in place before a crisis began (Francis 2015: 21). Other efforts might involve talking with community leaders up-stream and down-stream, especially to those who are responsible for flood control and mitigation measures. Key elements would include coordination of water releases from dams and coordination in warning the public to move themselves and property to higher ground and to shore up defensives around their homes. Additionally, leaders must seek out and be informed of weather and stream gauge data to best predict the path and effect of additional water volume from rainstorms and snowmelt in order to adjust plans and mitigation efforts accordingly to provide the best protection for the community.

In addition to preparation, another key component before, during, and after a crisis is communication. This is perhaps the most important and farthest reaching component of the five Cs commonly referenced in emergency preparedness literature—compassion, continuity, communication, common sense, and confidence (Francis 2015: Abstract). Establishing and maintaining "open lines of communication […] among governors and federal, state, and local leaders as well as the public" and ensuring that these lines of communication "provide factual information not only to the first responders but also all those affected" is essential in a crisis. Especially in today's technological world of social and news media, some of which is at times sensational in nature, leaders need "to ensure that only the facts are being provided and that no one is adding to the chaos of the environment that could lead to additional harm" (Francis 2015: 21). "They are the public face for" their state or local community "and as such need to use the media to their advantage" (Francis 2015: 31). Communication also enables leaders and decision-makers to reach the soundest conclusions in times of crisis, drawing not only their own knowledge and experience, but also on the knowledge and experience base of a variety of subject-matter experts. "Elected leaders," especially in times of crisis, should "surround [themselves] with individuals that can be trusted and who have prior experience in crisis preparedness" (Francis 2015: 89).

Additionally, communication is critical because it forms the backbone of coordinating efforts among different city departments, various state and federal agencies, and volunteers. Focus on "the local emergency manager may always get most of the attention, […] but this should not take place at the expense of disregarding the assistance of state and federal officials, diverse government departments, businesses, humanitarian organizations and citizen volunteers" (McEntire 2004: 10). Of particular importance when planning for and responding to a natural disaster is having a clear understanding of the level and expediency of support one can expect from sources outside the local, city government. In a resilience management report from 2007 authored by McManus et al, it was noted that local government "organizations all appeared to have expectations of other organizations, including emergency services, government agencies, and civil defense, that were disproportionate with the support these organizations could reasonably offer" (McManus et al 2007: v). Having this realistic expectation also extends beyond government organizations to the commercial and service sectors. For example, after the 2011 flood in Minot, local hardware stores and the then single 'big-box' home improvement store in the town had great difficulty keeping construction supplies at levels which could keep up with the demand, thus extending the amount of time it took for residents and the city to complete cleanup and repair efforts. Similarly, following ice storms in many areas of the country, it sometimes takes days or even weeks for power company line crews to restore electricity to all areas. Leaders and residents must adequately understand these limitations as it applies to their city and larger regional area and be prepared to operate and survive until the gap in services and supplies can be closed following a disaster.

In addition to forming a plan of action prior to a crisis occurring and establishing lines of communication, leaders also should continually review, revise, update, and exercise their plans in order to discover weaknesses, shortfalls, and inefficiencies that could cost time, lives, money, and property in a crisis. Leaders should "plan for a crisis all year round; […] crisis preparedness is not a one-time thing to think about (once) and never to think of it again, it is something that should be planned, reviewed, worked through, and revisited all year round" (Francis 2015: 89). Leaders and employees at all levels should contribute to after-action reports following actual crises and disaster response exercises in order to find best practices to incorporate within their own field/department as well as within the larger plan as a whole. By sharing these lessons learned within one's own field/department and with other agencies, one also builds continuity, another one of the five Cs. Having a solidly-built continuity can allow not only for the training of newer personnel within one's own field/department, but also across fields/departments, enabling sound action to still take place should members in leadership positions or those possessing key skills or expertise be killed, incapacitated, or unavailable/unable to communicate or act in an emergency. "Enabling the continued operation of organizations, in and following crises, significantly impacts on the medium to long term recovery and health of the wider community" (McManus et al 2007: 1). To this end, it is important that an organization's decision-making processes and ability to take action be flexible and able to function at the lowest possible level, i.e. decentralized control and execution without a rigid hierarchy, as is sometimes found in government and other organizations, while still operating in harmony with the efforts of other departments and organizations within the scope of the overall response plan. Having a response force containing individuals who understand the larger plan, their individual role within the plan, and how their actions affect the roles and actions of others is key to an effective response and the success of the overall plan. "Quality of leadership and the degree of empowerment through to lower levels in an organization is increasingly seen as a critical facet of an adaptive organization's culture" (McManus 2007: 68).

Together, the actions of planning, communication, conducting exercises, coordinating resources, reflecting on and incorporating lessons learned, and building continuity, help to shape a community's, state's, or nation's adaptive capacity, that is to say, resilience and the ability to respond to crises. "Adaptive capacity is similar to or closely related to a host of other commonly used concepts, including adaptability, coping ability, management capacity, stability, robustness, flexibility, and resilience" (Smit and Wandel 2006: 286-287). It is "a measure of the culture and dynamics of an organization that allow it to make decisions in a timely and appropriate manner both in day-to-day business and also crises" (McManus et al 2007: 2). Furthermore, "local adaptive capacity is reflective of broader conditions. At the local level, the ability to undertake adaptations can be influenced by such factors as managerial ability, access to financial, technological and information resources, infrastructure, the institutional environment within which adaptations occur political influence, kinship networks, etc." (Smit & Wandel 2006: 287). Adaptive capacity involves taking into consideration a "diversity of issues and functions" including

> hazard and vulnerability analysis, land-use planning, engineering, planning, training, exercising, community education, grant acquisition, budgeting, warning, evacuation, sheltering, fire suppression, emergency medical care and triage, search and rescues, mass fatality management, media relations, disaster declaration, donations management, debris management, critical incident stress management, etc. (McEntire 2004: 10).

Thus far, this literature review has discussed resilience theory from largely a scientific/engineering and governance/policy perspective. This was probably due in part to my background as a mechanical engineer and to my interest in flood mitigation from an engineering perspective. It is worth noting, though, that the term 'resilience' encompasses more than just these two viewpoints. The meaning of the word resilience has developed over time "through the sciences, humanities, and legal and political spheres," eventually passing from "mechanics […] to ecology and psychology" and "from there it was adopted by social research and sustainability science" (Alexander 2013: 2707). "Resilience has a long history of multiple, interconnected meanings in art, literature, law, science, and engineering" (Alexander 2013: 2710). As such, this literature review will now briefly discuss resilience as it applies to the social aspects of disaster preparedness. In early literature, "the most common uses" of the word "were to describe leaping, jumping, or rebounding" (Alexander 2013: 2708). However, recovering from a disaster should be more than just rebounding or returning to a previous state of existence and preparedness as doing so leaves communities open to history, circumstances, and events repeating when the next disaster hits. "In developing the concept of resilience as a 'bounce forward' notion [in the social context of the term …], it implies a means of 'limiting poverty (by conserving and developing resources) and vulnerability (by reducing risk to people and assets),'" which involves more action to be taken than just a return to or the maintaining of the status quo (Alexander 2013: 2712).

Some academics and practitioners in the field of emergency preparedness and disaster response and mitigation believe the term "resilience is being used as little more than a fashionable buzz-word," noting that "merely adding a new term will not change the ability to understand and tackle problems connected with poverty, vulnerability, marginalization, and the riskiness of life" (Alexander 2013: 2713-2714). In 2009, Hornborg argued that "resilience thinking consistently relies on the assumption that the social order is based on consensus, while the neoliberal capitalist system involves dispossession and exploitation, in ways that are inimical to the acquisition of safety and robust defenses against hazards" (Alexander 2013: 2714). While this may oftentimes be true, I believe this viewpoint of resilience to be narrowly focused. Rather, "resilience should be transformed from a mainly descriptive concept ('what is done') into one which includes a normative agenda ('what ought to be done')" (Weichselgartner & Kelman 2015: 250). As public servants, city, state, and federal officials, from planners, to engineers, to disaster and emergency response coordinators and beyond should be focused on not only ensuring the preservation and restoration of essential basic structures and functions, but on how such structures and functions could be improved upon (Weichselgartner & Kelman 2015: 251). Resiliency literature from a geography standpoint focuses largely on this, "integrating the natural environment, the built environment, and society" (Weichselgartner & Kelman 2015: 251).

> Resilience rests on the abilities to: (1) anticipate and deal with the impacts of natural hazards; (2) adapt to change; and (3) be proactive and self-determining, rather than just reactive and outside-determined. […] This descriptive expansion moves the concept more toward the social sciences and philosophy—with the normative consequence that is has to deal with equity, power, justice, and social capital, thus increasing complexity. […] Based on vulnerability and development geography, the ability to be resilient is never distributed homogenously within and through social groups. Instead, this ability is largely determined by social, economic, and cultural factors, and, because the minority of a society often holds control over the decision-making for the majority, these factors may often be beyond society's control. […] Poverty, corruption, and exploitation can also be highly resilient (Weichselgartner & Kelman 2015: 252).

"The increase of resilience among some people often means the increase of vulnerabilities for others" (Lizzarralde et al 2015).

> To this end, while resilience may be important to support and maintain systems in a desirable state, it may also maintain a system in an undesirable state, making recovery or transformation difficult. […] An extensive knowledge system exists with regard to

> dealing with disaster impacts and adapting to changing environments, which is frequently not considered by researchers and not applied to maximum effect by decision-makers in policy and practice. […] Improving physical [infrastructure] resilience without adequately addressing social resilience illustrates short-term thinking in dealing with a longer-term future (Weichselgartner & Kelman 2015: 252, 259).

In order to combat this, the United Nations International Strategy for Disaster Reduction (UN-ISDR) authored the "10 essentials for making cities resilient" which, relevant to this discussion, include the

> participation of citizen groups and civil society. Building local alliances. Ensuring that all departments understand their role in disaster risk reduction and preparedness. Providing incentives for homeowners, low-income families, communities, businesses, and the public sector to invest in reducing the risks they face [and] identifying safe land for low-income citizens and upgrading informal settlements, wherever feasible (Weichselgartner & Kelman 2015: 254-255).

Lastly, "after any disaster, ensuring that the needs of the affected population are placed at the center of reconstruction, with support for them and their community organizations to design and help implement responses, including rebuilding homes and livelihoods" (Weichselgartner & Kelman 2015: 254-255). Furthermore, the Organization for Economic Co-Operation and Development (OECD) stated/recommended the following with regard to social resilience: "1) Identify the economic base and the social and economic drivers specific to the region to increase its resilience; 2) strategic choices have to be locally led; and 3) build trust, increase accountability of policy-making and improve (the) capacity of administrations" (Weichselgartner & Kelman 2015: 256).

City of Minot officials and residents could benefit greatly by taking some of these recommendations to heart and applying them to the 2011 Flood recovery efforts and plans for future disaster recovery prevention, response, and recovery. As the historical examples of flood prevention and recovery in the United States demonstrated, a large portion of the responsibility for flood mitigation efforts, both financially and physically, rest with the local community. If the citizens of Minot and its leaders want meaningful flood protection, they need to take ownership of making that a reality—"strategic choices have to be locally led" (Weichselgartner & Kelman 2015: 256). Furthermore, Minot, especially between the years of 2011 and 2013, had a unique set of circumstances which inhibited more so than aided the recovery efforts of citizens due to the Bakken oil boom. Citizens faced competition for affordable local housing and building materials and supplies due to the influx of oil workers from out-of-state. Rent and housing prices skyrocketed. The city could have done a better job of "identifying the economic base and the social and economic drivers in the region to increase resilience" and streamline recovery efforts (Weichselgartner & Kelman 2015: 256). Lastly, the city's actions in building some of the earthen dikes, in order to combat the 2011 Flood, sent waters into neighborhoods where the natural topography of the land would probably not have otherwise sent it. Many of the home owners in these neighborhoods did not have flood insurance because the elevation of their home was high enough so as to not require it. While perhaps necessary to combat the flood, had a plan of action been pre-conceived and on hand prior to 2011 rather than being solely reactionary in nature, homeowners might have made different decisions regarding flood insurance coverage and made those decisions early enough for the policies to actually take effect. (Most policies do not go into effect until thirty or more days after the insurance application is signed). A pre-conceived and agreed-upon plan for action between citizens and city leaders would have "built trust and increased accountability of policy-making and improved capacity" (Weichselgartner & Kelman 2015: 256).

Seeking to make "changes in the system to better deal with problematic exposures and sensitivities," at all levels and across all fields/departments "reflects adaptive capacity" (Smit & Wandel 2006: 287). In discussing the City of Minot's and other agencies' actions before, during, and after the June, 2011 flood, this thesis has investigated the city's and the region's preparedness and current level of adaptive capacity. In the remaining segments of this paper, the City of Minot's current crisis management plan and proposed additional flood mitigation measures will be reviewed, modeled, and analyzed, concluding in an assessment of just how well the city/region is currently prepared to respond to another major flooding event and in a set of recommendations for further improvement in the area of disaster and crisis response.

Literature Review Closing Thoughts and Observed Best Practices

By understanding how emergency management, flood mitigation and prevention, and disaster response has evolved in the United States over the past two centuries, and by incorporating the best practices and lessons learned from major flooding events in the United States and Canada since 1889, citizens across North America, in cooperation with local, state, and federal governments, can find the best course forward for meaningful flood protection for their communities. A few best practices became apparent in completing the literature review and case studies. First, "Living with Water," or natural mitigation, strategies "could drastically reduce the subsidence of" a "city's soil, save money, and create new public amenities" (Gratz 2013: 27). These strategies are not meant to replace traditional man-made flood control measures such as levees, dikes, dams, and pumping stations, but rather are meant to work in harmony with them. "The Living with Water strategies would not replace the pumping system but would supplement and balance it, thus easing the strains already on it" (Gratz 2013: 28). It is an augmentation of "civil engineering with water-managing urban design" (Russell 2015: 91). Second, "community efforts to build awareness of the solutions" for meaningful and lasting flood protection "are key to generating funding support for such ambitious plans," especially as the case studies have shown that local funding for cleanup, repairs, and future prevention and mitigation efforts typically accounts for a third or more of the overall cost, and that local and state funding combined typically account for 50% to 60% (Gratz 2013: 28). Cities in flood plains need to realize that federal tax dollars are not going to be enough to pay for the needed protection, and that most federal programs involve a local or state matching component to funding. While unpopular, this means that taxes and fees may need to be raised, not for all time, but at least temporarily, to cover the cost for adequate flood protection. As the old adage goes, 'you get what you pay for.' Lastly, but perhaps most important, the timely sharing of information between various agencies and across county, state, and country borders was identified as being key to an effective mitigation strategy and disaster response. Leaders and workers at all levels as well as citizens at large need to be aware of the decisions being made upstream and downstream in order to wage the most effective fight again rising floodwaters. Having sound and agreed-upon policies, processes, and continuity in place pre-event allows for more timely, coordinated, and predictable actions during the event and post-event, which can greatly reduce the amounts of property damage and loss of life. With this in mind and with an ArcGIS analysis of the topography, flood stream gauge readings, and proposed additional flood protection in Minot, North Dakota, this paper seeks to identify the best course of action to take forward to make meaningful flood protection in Minot a reality in the near future.

Chapter 3: Methods

The research relies on a detailed case study of events in Minot, North Dakota related to the flood and its aftermath. Policy information from several governmental levels was sourced (federal, state, and local) pertaining to current flood management techniques and policies in Minot, Ward County, and North Dakota in general. The policies and plans were thoroughly reviewed, compared to, and contrasted with each other, particularly in the areas of consistency and agreement between the plans to the likelihood of future flooding and the actions to be taken pre-event, during the event, and post-event. Local land use changes were identified using public documents and agency-derived information from sources such as the Minot Planning Department, state floodplain managers, and FEMA, then mapped in ArcGIS 10.1. An ArcGIS model was constructed using stream gauge data from the June, 2011 flood and mathematical interpolation to correlate flow rates with resulting water levels. The propagation of flood waters was then modeled on a contour map in ArcGIS against different flood countermeasures with varying protection ratings based on the maximum volumetric flow rate the defenses could accommodate. Finally, policies derived from the literature as incorporated within an ideal flood management system or best practice, particularly those in place and found to be effective in other major North Dakotan cities, were compared to the strategies being implemented in Minot, and discussed in light of the model results and local issues.

Chapter 4: Analysis

Review of Crisis Preparedness (Crisis Management) Plans for Minot, North Dakota:

The responsibility and organization of emergency and disaster preparedness in Minot, North Dakota and the surrounding areas falls primarily to the state and Ward County, where the city of Minot is the county seat. Ward County has developed hazard mitigation plans for all twelve cities within its boundaries, and in doing so, has ensured that each city and the county as a whole is in compliance with the Disaster Mitigation Act (DMA) of 2000.

> DMA 2000 established a requirement that in order to remain eligible for federal disaster assistance and grant funds, local and state governments must develop and adopt hazard mitigation plans. On February 26, 2002, the Federal Emergency Management Agency (FEMA) published an Interim Final Rule (IFR) that set forth the guidance and regulations under which such plans are supposed to be developed (Hazard Mitigation Plan 2013: 1-1).

Since the DMA requirement was levied, Ward County has gone through a few iterations of the plan. The most current version of Ward County's Hazard Mitigation Plan was revised in May, 2013. In addition to the Hazard Mitigation Plan, Ward County also provides its residents resources and information pamphlets on a variety of topics including emergency preparedness tips for schools and workplaces, families and senior citizens, flooding, severe summer weather, severe winter weather, as well as emergency shelter information, warning systems, weather forecasts, and a telephone notification alert system called City Watch for which residents and businesses of Ward County can sign up to be warned of impending or current disasters. (To review this information, please see http://www.co.ward.nd.us/156/Emergency-Disaster-Preparedness). The county partners with the North Dakota Department of Emergency Services to participate in emergency and disaster preparedness conferences, training, and exercise events. (The current training and exercise event calendar can be viewed at http://www.co.ward.nd.us/159/Training-Exercise-Links). Each city's individualized hazard mitigation plan is laid out in a separate section of the Hazard Mitigation Plan for Ward County, North Dakota. The provisions of Minot's plan are organized in section twelve of the report. The State of North Dakota has provisions for disaster response and planning in its Multi-Hazard Mitigation Plan, which covers all areas of the state. Like the county's mitigation plan, the state's plan has been revised several times since the requirement to have a plan was levied by the DMA; the most current version of the plan is dated 2014. Finally, the City of Minot itself has an emergency information section on the city's website (http://www.minotnd.org/181/Emergency-Information) covering disaster and preparedness information, much like the county's emergency management website. These mitigation documents/sources will be discussed in the remainder of this segment of the thesis, with particular emphasis on measures for flooding and heavy rainfall.

Ward County Hazard Mitigation Plan for Minot

Ward County's Hazard Mitigation Plan for Minot begins by citing the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) database, which identified "94 weather-related hazard events [...] in the city of Minot since 1993, including" eight floods or flash floods and three significant rain or heavy rain events (Hazard Mitigation Plan 2013: 12-2 & 12-3). A few pages later, the report identifies presidential disaster and emergency declarations for the City of Minot for the year range of 1957 through 2012 in which flooding was identified twelve times, ground saturation was identified twice, and severe rain storms were identified four times. The report further quantified that in three of the twelve flooding instances, snowmelt played a contributing factor (Hazard Mitigation Plan 2013: 12-3). The county's plan covers dam and levee failures within the context of its flood hazard planning and chooses to exclude a shortage of critical materials as a hazard, but rather to consider it as a vulnerability (Hazard Mitigation Plan 2013: 12-5). It was “determined that all sources of flooding should be treated in the same profile, as the effect on the area was generally the same, regardless of the source of origin of the flood or the frequency of which each source of origin might occur. Flooding sources considered include: snowmelt, dam release (controlled) or failure (uncontrolled), and excessive rain events” (Hazard Mitigation Plan 2013: 12-20 - 12-21). The flooding section of the county’s report states that “the area drained by the Souris (River) is 9,112 square miles. Stream length in the state is 357 river miles” (Hazard Mitigation Plan 2013: 12-21). Because of the winding course the river takes through Ward County and the City of Minot in particular, “the total length of the channel is approximately twice the length of the valley through which it flows” (Hazard Mitigation Plan 2013: 12-22). Thus, a flooding event on the Souris has the ability to inundate the farms, homes, and businesses of Minot to a greater extent than other cities in the state through which a river flows, such as the Red River at Grand Forks and the Missouri River at Bismarck and Mandan which, in comparison, follow more or less straight courses through those cities. “Minot has significant areas of one percent annual chance of floodplain adjacent to its corporate limits, as well as areas within its limits. Large portions of the city fall within the .02% annual chance floodplain;” reference Figure 4 on the next page for an illustration from Ward County’s Mitigation Plan demonstrating this (Hazard Mitigation Plan 2013: 12-22).

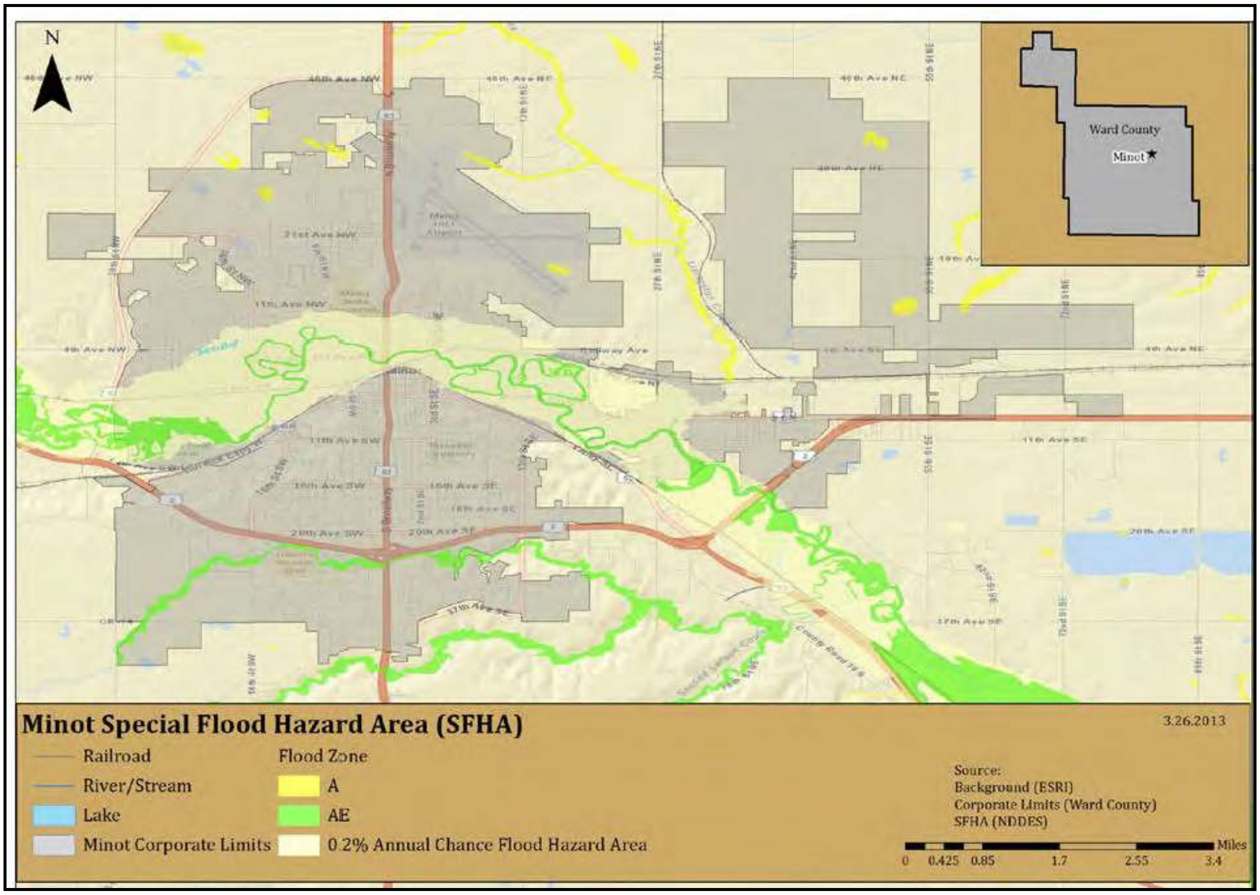

Figure 4: Minot Special Flood Hazard Areas (Hazard Mitigation Plan 2013: 12-23).

Thus, the county's plan adequately identifies flooding as an issue for the city of Minot, and states that

> a balance must be reached between the four aspects of floodplain management which are: structural works designed to modify the flood itself, regulatory functions which may reduce susceptibility to flood, emergency preparedness actions which may reduce susceptibility to flooding, and emergency preparedness actions which minimize a flood's effects during a flood event (Hazard Mitigation Plan 2013: 12-25).

It does not, however, go into any procedures or step-by-step playbook for how to utilize these four aspects before, during, or after a flooding disaster. Rather, the report lists a number of still-remaining vulnerabilities which need to be addressed. First in this list of vulnerabilities, the report noted that

> a series of naturally occurring coulees […] channel water toward the Souris. […] Flows of water through these coulees have measured three feet or more during localized heavy rain (6-9 inches in 3 hours). This type of flooding has washed out roads, breached culverts, and damaged bridges. Adding to these phenomena, as the water flows down through the coulees it picks up a great deal of debris and deposits it into the river, compounding the flood hazard (Hazard Mitigation Plan 2013: 12-25).

Periodic clearing of debris would be a prudent mitigation measure. The city could organize a mixture of city crews and volunteers to clear the river of trash and natural debris such as downed tree limbs as well as to clear drainage grates of trash, leaves, and other natural and man-made materials to prevent backups, reduce the amount of standing surface water, and generally allow better drainage flows.

Second, the report states "Both hydrostatic and hydrodynamic forces can cause serious damage, including complete destruction, of non-mitigated structures. Utility systems, such as HVAC systems, water and sewer lines, and electrical systems, can be compromised, damaged, or destroyed by flood waters, even if not completely inundated" (Hazard Mitigation Plan 2013: 12-26). While construction recently began in the fall of 2015 to give additional flood protection to the city's water treatment plant, no other projects for protection or layers of redundancy in providing services have thus been started or pursued. The report later goes on to list critical assets including the water treatment plant, the civic center, city hall, the police department, and other structures, many of which would still be held at threat in a major flooding event (Hazard Mitigation Plan 2013: 12-53). Furthermore, "While the majority of Minot's critical assets fall outside of any mapped flood hazard area, it is notable that the majority of critical assets that lie within this hazard area are shelters or medical facilities" (Hazard Mitigation Plan 2013: 12-61). Tying into this same train of thought, the report also stated that "flooding could impact transportation routes in and around the city, and could result in delays in receiving supplies and decreased ingress and egress" (Hazard Mitigation Plan 2013: 12-26). In light of these findings, it would seem prudent for the city to stockpile supplies necessary before, during, and after a major flooding event such as pre-filled sandbags, backup generators, fuel to run the generators, vehicles and machinery (so that efforts to evacuate residents and combat the flood could continue), medical supplies, and temporary shelters (such as trailers) in order to allow for the continued operation of government and other services until additional help and supplies could be brought into the city. Establishing agreements with local big-box vendors such as Menards and Home Depot, as well as with local rock quarries, lumber and hardware stores to keep in stock a predetermined level of key supplies to aid in the building of temporary flood-mitigation devices before and during the flood and to aid in rebuilding immediately after the flood would also be sensible, if corporate leadership would be agreeable to approving such an arrangement. Similar agreements could also be reached with local hotels as a means to augment providing shelter.

Third, the report notes that "Floods which result in more severe damages originate primarily from snowmelt in the Canadian portion of the Souris River Basin and have occurred seven times since 1969," yet the report makes no mention as to the communication links or processes in place which are critical for coordinating dam releases, even though these releases played a major role in the severity of the flooding in June, 2011 (Hazard Mitigation Plan 2013: 12-26). A key component to this effort would be to foster improved relationships with and between the Saskatchewan Watershed Authority, the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, and local and state authorities who control dam releases and movable floodwalls, and who coordinate disaster mitigation and response efforts. While these relationships already exist, communication among the entities needs to continue to be exercised and improved upon. Seven major flooding events on the Souris since 1969, with damages totaling in billions of dollars, should be evidence/justification enough to work for such a goal.

Perhaps most alarming is the report's statement that "based on the available data, flooding occurs less than once every five years in the city of Minot. Therefore, […] the probability of a future occurrence of flooding is low" (Hazard Mitigation Plan 2013: 12-27). However, further into the document, in a "Summary of 2008 Ward County Hazard Mitigation Plan Risk Assessment Data" the report states that the frequency of flooding is likely, and that its severity could critically impact the city (Hazard Mitigation Plan 2013: 12-51). These two statements seem to be conflicting in nature as to the likelihood and risk associated with a flooding event. Statements like this reflect a lack of a shared mental model regarding the problem and could produce as a result a lack of a sense of urgency to adequately address vulnerabilities and protect the city and its residents from inundation. The city, the county, and the state need to work to keep Minot's recovery and meaningful flood protection moving along in the same way that Fargo-Moorhead and Grand Forks-East Grand Forks did following major floods in those cities. As it stands now, Minot may be behind the timeline of the bar set for a timely recovery and response by its peer cities, or put bluntly, it appears that adaptive capacity/resiliency efforts in Minot are stunted. "The city does not currently have either a continuity of operations/continuity of government (COOP/COG) or a disaster recovery plan" (Hazard Mitigation Plan 2013: 12-72). Furthermore, "Minot utilizes the framework established by the county and state government for technical assistance, and relies on the state and federal governments for funding" (Hazard Mitigation Plan 2013: 12-72). Developing continuity of operations, continuity of government, and disaster recovery plans, as well as furthering technical assistance and funding capabilities at the local level, would improve Minot's overall preparedness and ability to function in a crisis.

Negative aspects and room for improvement aside, Minot and its leaders are doing some things right. “The city maintains a listing of residents who will need additional assistance with evacuations, so that proper planning and timing can be ensured” (Hazard Mitigation Plan 2013: 12-71). “The city is working with the county to be a part of the Emergency Operations Plan, which will provide some framework for emergencies and disasters in the city” (Hazard Mitigation Plan 2013: 12-72). Also, “The city does have a comprehensive plan as well as an evacuation plan” (Hazard Mitigation Plan 2013: 12-72). Lastly, the city does have two schools, Jefferson Early Childhood Center/School and Jim Hill Middle School, predesignated as shelter locations. Maintaining these abilities while improving upon relationships with county, state, federal, and Canadian agencies, and continuing to develop “capability and capacity for disaster recovery and hazard mitigation” at the local level will serve to benefit Minot when the next flooding event occurs (Hazard Mitigation Plan 2013: 12-72).

State of North Dakota Multi-Hazard Mitigation Plan

The State of North Dakota Multi-Hazard Mitigation Plan mirrors many of the same aspects discussed in the Ward County Hazard Mitigation Plan, thus duplicate information will not be repeated in this section. The two reports differed in that the state report claimed that there had been eight occurrences of flooding resulting from snowmelt in the Canadian portion of the Souris River Basin since 1969 instead of the seven claimed by the Ward County report (AMEC 2013: 5.92). The state’s report also noted that “in most major floods (involving the Souris River), more than 90% of the dollar damages are incurred in Minot. Other areas are primarily affected by agricultural losses” (AMEC 2013: 5.92). While both residential home and business losses and rural agricultural losses can be costly, it is worth noting that the flooding of rural areas affects fewer structures and fewer citizens and thus has a lower damage cost overall; thus, perhaps it would be prudent to allow these areas to flood first in the case of a major inundation event. This is not to say that a farmer would have to lose his/her land to imminent domain, the land would still be workable for agriculture the majority of the time. In exchange for these tracks of land acting as flood abatement, the city or the county could assist with the cost of farm insurance or pay outright for crop losses when flooding occurs as such an action would be less expensive overall than the cost of recovering from an inundation in the residential and commercial areas of town.

The state report also noted that “River channel obstructions and stream bank erosion occur in many areas along the Souris River and its tributaries” (AMEC 2013: 5.92). Such conditions can wreak havoc on flood defenses if not properly addressed. Along the Souris River within the boundaries of Ward County are ten levees, eight of which were constructed by the U.S. Army Corps of Engineers (USACE), but then turned over to a public sponsor (i.e. the county and the city) for operations and maintenance. The other two were locally constructed and remain locally operated and maintained (AMEC 2013: 5.96-5.97). “Under the Levee Safety Program, USACE conducts levee inspections (routine, periodic, and special event). During these inspections, deficiencies may be identified such as unsatisfactory culverts, non-compliant vegetation, encroachments, and animal burrows” (AMEC 2013: 5.94). Inspection ratings for eight of the ten levees were not available for the state’s report, however, the ratings for two levees, Sawyer West and Sawyer East, were listed in the report and were found to be unacceptable and minimally acceptable, respectively, according to an April 26, 2012 inspection (AMEC 2013: 5.96-5.97). These findings echo what was said by Schramm in the literature review regarding the general overall state of Minot’s levees:

> the responsibility of levee maintenance falls to the city, [and] Minot's levees have been found deficient because standards have changed or circumstances have occurred over the years that place the levees in need of fixes. For instance, erosion around storm sewer outfalls or inside of river banks, growth of trees on or near the dikes and encroachment by residents through fences or buildings can result in deficiencies (Schramm 2015: 8).

Thus, levee maintenance is a definite area for improvement in the county's plan.

The report also noted that in the thirteen years between 2000 and 2013, four flood events and fifteen flash flood events have occurred in Ward County resulting in $100,538,000 and $6,514,000 in damages respectively (AMEC 2013: 5.112 & 5.115). Only 2,915 Ward County homes and businesses had flood insurance policies as of January 31, 2013, and the number of claims between 1978 and 2013 totaled 1,022 with $68,250,781 paid out to policy owners (AMEC 2013: 5.126). As such, Ward County was assessed to have a high loss rating with $9,773,000 in total losses and 42 properties having had a repetitive loss, i.e. properties which have flooded on more than one occasion (AMEC 2013: 5.128 & 5.131). While many residents in Ward County are required to carry insurance based on where their home is located, the city, county, and state would be wise to continue information campaigns advocating for other residents to voluntarily obtain flood insurance coverage, especially residents whose homes lie just outside the areas required to carry coverage by nature of the floodplain map.

Similar to the "2008 Summary of Ward County Hazard Mitigation Plan Risk Assessment Data," the 2013 state report assesses the vulnerability rating of a 1-percent chance by riverine flood as moderate to high for Ward County; this is contrary to the finding of a low probability of a future flooding occurrence in Minot listed in the county report, as previously mentioned. The state report is also enlightening in that it quantifies the amount of acreage, population, and property value currently provided protection by the 0.7 square miles of levees in Ward County: 446 acres, 1,184 people, and $89,164 in property value (AMEC 2013: 5.122). This pales in comparison to the capabilities in Grand Forks and Cass Counties where the cities of Grand Forks and Fargo are located. Cass County has 24 square miles of levees and is able to protect 15,044 acres and Grand Forks County has 34 square miles of levees and is able to protect 21,813 acres. Ward County's flood defenses have significant room for improvement in the level of flood protection they provide residents through the expansion of levees and other flood control measures. The state seems to realize this and is moving to correct issues, though it may take longer than for similar projects it has helped fund and construct in Cass and Grand Forks Counties:

> Flood control projects in the basin include Lake Darling Reservoir and levees at Velva, Sawyer, and Minot. Another flood control project is the Souris River Basin Project, which consists of flood storage in the Alameda and Rafferty Dams in Saskatchewan, a gated spillway at Lake Darling, upgraded levees at Sawyer, Renville County Park, and six subdivisions between Burlington and Minot, structural and non-structural measures for rural residents along the Souris, modifications of U.S. Fish and Wildlife structures in the Upper Souris and J. Clark Salyer National Wildlife Refuge, and a flood warning system (AMEC 2013: 5.92).

To a greater extent than the county report, the state report identifies that adverse weather conditions in Ward County, be it winter weather or heavy rains, as well as natural disasters, such as flooding, could result in "the disruption of the critical material supply system" for material and infrastructure such as electrical power, transportation fuels, heating fuels, medical supplies, and adequate food, water, and shelter (AMEC 2013: 5.286). The report goes on to say that "The public has come to rely upon utility, communication, and fuel services for everyday life and basic survival" and that "during a widespread or complicated outage" or disaster, "services may be down for days or even weeks" (AMEC 2013: 5.286 & 287). Thus, the practice of prestaging supplies by the city, county, and state prior to a crisis starting, and the aforementioned governing bodies encouraging residents to be prepared with their own survival kits/supplies to meet basic needs for a few days should a crisis occur, would be wise. Additionally, state and local governing bodies in North Dakota typically put out radio and television advertisements for residents to be prepared just prior to the start of the winter months; however, tailoring a similar message for other times of the year would be appropriate.

The state outlined a number of these recommendations and others in the mitigation strategy section of the report. Specifically, the areas of data digitization, public education, insurance education, basin-wide water management planning, floodplain map modernization, and property acquisition, relocation, elevation and flood-proofing as well as flood-proofing critical facilities were identified as having room for improvement or needing further action as related to flood prevention and mitigation. Facility-hardening and security, as well as improved warning systems, were also listed as mitigation actions for other disaster and crisis areas, but not to flooding. Additionally, Ward County was not necessarily listed in all of these areas, but given the historical evidence and other findings above, perhaps it should be included in the state's next revision of the Multi-Hazard Mitigation Plan (AMEC 2013: 6.2 - 6.37). In the mitigation implementation section of the report, the state identified FEMA's Hazard Mitigation Assistance (HMA) grant programs, the Hazard Mitigation Grant Program (HMGP), the Pre-Disaster Mitigation (PDM) Program, Flood Mitigation Assistance (FMA), the National Flood Mitigation Fund (NFMF), the Silver Jackets Program, the Community Assistance Program (CAP), the Community Rating System (CRS), the Building Code Program, Community Development Block Grants (CDBG), the Public Assistance Section 406 Program, and various aspects of the National Flood Insurance Program (NFIP) as being vehicles for accomplishing improvement in the above areas through collaboration and communication (AMEC 2013: 7.3 - 7.17). Of particular interest in this list is the Silver Jackets Program, a North Dakota program "primarily focused on the communication [between] and collaboration of agencies for the coordination, enhancement, and streamlining of flood-related solutions" (AMEC 2013: 7.12). This will be of great importance moving forward, as over four years have already passed since the 2011 flood, with few physical improvements for flood prevention and mitigation having been put in place as of the time this thesis was written. The next section will discuss the future flood prevention and mitigation measures proposed for Minot and will evaluate their effectiveness.

ArcGIS Analysis of Proposed Flood Prevention Measures

As previously discussed, the City of Minot, in partnership with Ward County, the State of North Dakota, and the U.S. Army Corps of Engineers has developed an improved flood protection plan consisting of the bolstering of existing levees, the construction of movable floodwalls, and the 27th Street and Maple Diversions. A visual depiction of these features is provided in Figures 5 and 6. Additionally, Figure 6 provides an estimated timeline for completion for each element of the new flood protection measures. The two diversions straighten the flow of the Souris River through Minot and aid in reducing the likelihood of flood waters reaching neighborhoods north of the diversions. The floodwalls should provide additional protection for Minot's commercial downtown district up to the 9,600 cfs flow rate recommended by FEMA and is what Minot's leaders, planners, and city engineers believe is needed locally (Flood Plain Options 2012). In theory, the floodwaters would pass through the city and eventually be allowed to expand out in rural, less populated areas, much of which is currently farmland. The next two towns downstream of Minot, Logan and Sawyer, are mostly situated further back from the river's banks and are better able to naturally mitigate flooding. The next major town further east still, called Velva, has its northern border along the river's edge and could face flooding if waters did not spread out enough in the uninhabited farmlands prior to the town. For this reason, Velva, with the help of the state and county, is also seeking to implement additional flood protection measures. After Velva, the river turns north to head back into Canada and passes near, but not though, other small, rural towns, nowhere close in population to Minot's approximately 50,000 residents. The river's waters are eventually allowed to expand into a natural wetlands, the J. Clark Salyer National Wildlife Refuge, in northern, central North Dakota. Using ArcGIS and flood protection shapefiles from the City of Minot GIS Department, along with contour and floodplain modeling previously done as part of a GSP 532 class, this thesis analyzes the effectiveness of the proposed new flood measures and the level of protection provided. It calculates effectiveness when flow rates reach the 9,600 cfs for which the protection measures were designed, the 14,800 cfs average that Minot has seen in historical flooding, and the peak 26,900 cfs flow rate seen in the June, 2011 flood, where the term 'effectiveness' describes the degree to which homes would be inundated due to areas on the other side of the floodwalls reaching or surpassing what the USGS and the city consider to be a major flood stage (1555 feet MSL) should the floodwalls be topped and the waters overflow. It should be noted that this assumes that the floodwalls and levees do not breach due to an overflow event. This thesis does not go into the engineering calculations required for this to happen as such equations require knowledge of bedrock and soil composition, the type/strength of concrete used in constructing the floodwalls, the depth of foundations for such structures, as well as many other factors that were not available at the time this thesis was written and for which the designs might be proprietary to the engineering firms involved in the construction of the new flood defenses. Once such information is available, it is something which should definitely be considered in a follow up vulnerability assessment, because from an engineering standpoint, having water on both sides of a floodwall could significantly degrade structural stability. It is for that very reason that the foundations of hydroelectric dams extend significantly not only vertically down into the riverbed and bedrock but also laterally into the sides of the surrounding canyon walls or riverbank. If similar structural support is not considered in the design criteria and provided for in the finalized product of Minot's new flood prevention measures, a floodwall breach could occur in a future flood, thereby undermining the protections promised/provided by the city. A flowchart for the ArcGIS analysis processes can be found in Appendix A. A detailed, step-by-step procedure for performing the ArcGIS analysis can be found in Appendix B. ArcGIS screenshots modeling the inundation resulting from the June, 2011 Flood and the inundation resulting from various water heights can be found in Figures 7 through 12. Table 1 provides a listing of water levels corresponding to various flood stages, flood defenses, and volumetric flow rates. Table 2 provides a comprehensive look at the increase in inundation area as the water level rises.

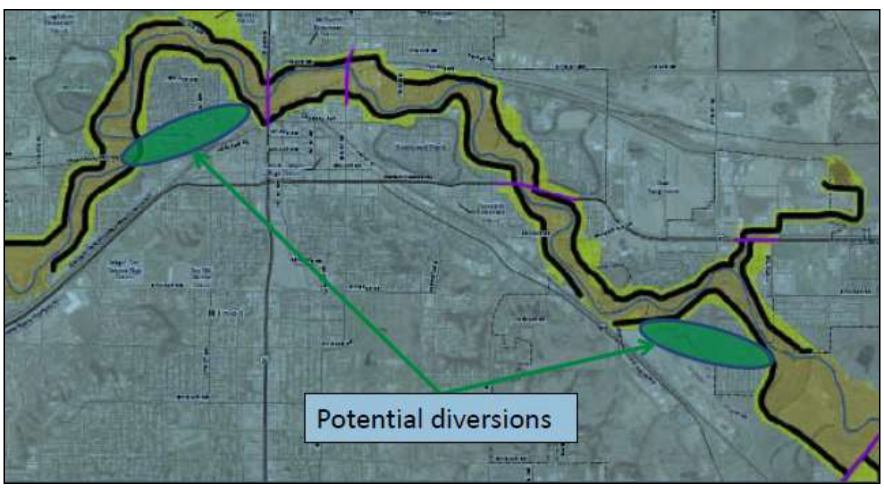

Figure 5: Potential Souris River Diversions in Minot, North Dakota (BARR et al 2012: 17).

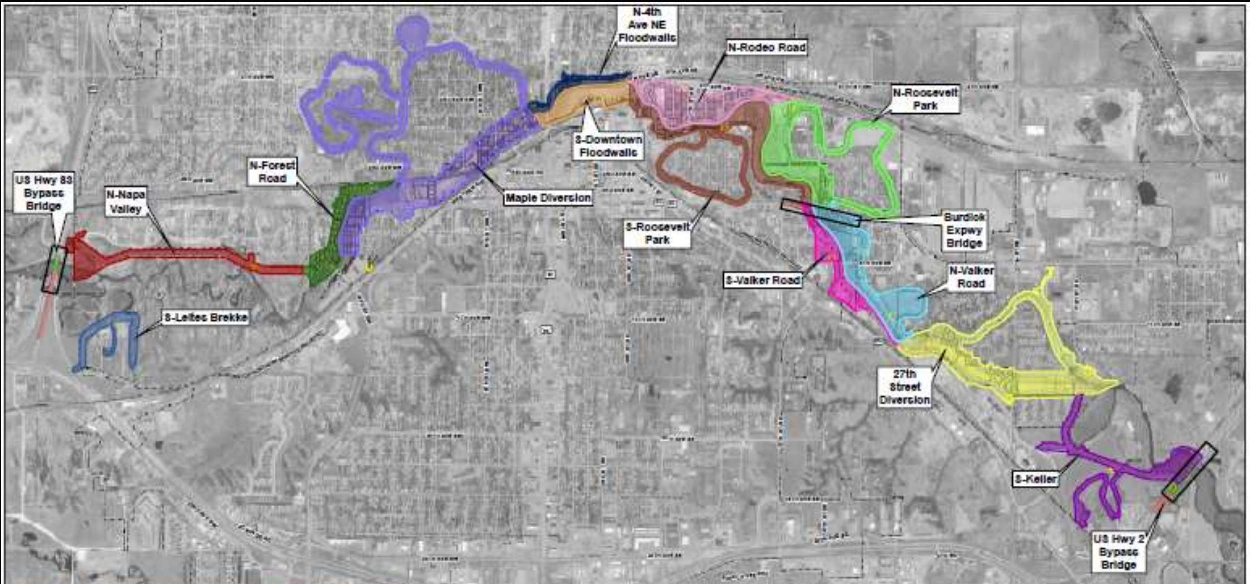

TABLE 1: SUMMARY OF SUBPROJECTS AND ESTIMATED TIMELINE (MINOT REACHES) [1] Description		Projected Time Frame (Fiscal Year)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Opinion of Cost (2012 Dollars)
Feasibility Investigations and Design During EIS Timeframe (Minot Reaches)		2014-2017 [2]													$35.4 M
Lands and Easements (Minot Reaches) [3]		2014-2023													$86.9 M
Subprojects (Minot Reaches)	N – 4th Avenue NE Floodwalls	2014-2016													$26.4 M
	CP Rail Bridge	2014-2019													$5.3 M
	Hwy 83 Bypass Bridge	2015-2018													$5.4 M
	Hwy 2 Bypass Bridge	2015-2018													$6.3 M
	Maple Diversion	2015-2019													$103.9 M
	N – Forest Road	2017-2018													$8.3 M
	N – Napa Valley	2018-2019													$18.3 M
	Burdick Expressway Bridge	2018-2020													$9.3 M
	N – Rodeo Road	2019-2020													$12.0 M
	N – Roosevelt Park	2019-2020													$24.2 M
	S – Roosevelt Park (Zoo)	2020-2022													$38.9 M
	27th Street Diversion	2020-2023													$94.5 M
	N – Valker Road	2023-2024													$17.6 M
	S – Valker Road	2023-2024													$13.2 M
	S – Downtown Floodwalls	2023-2025													$10.0 M
	S – Keller	2024-2025													$6.7 M
	S – Leites Brekke	2024-2025													$8.0 M
Subtotal [1]															**$530 M** [4]

Figure 6: Summary of Minot Flood Protection Subprojects and Estimated Completion Timeline (BARR & Ackerman-Estvold 2013: 3).

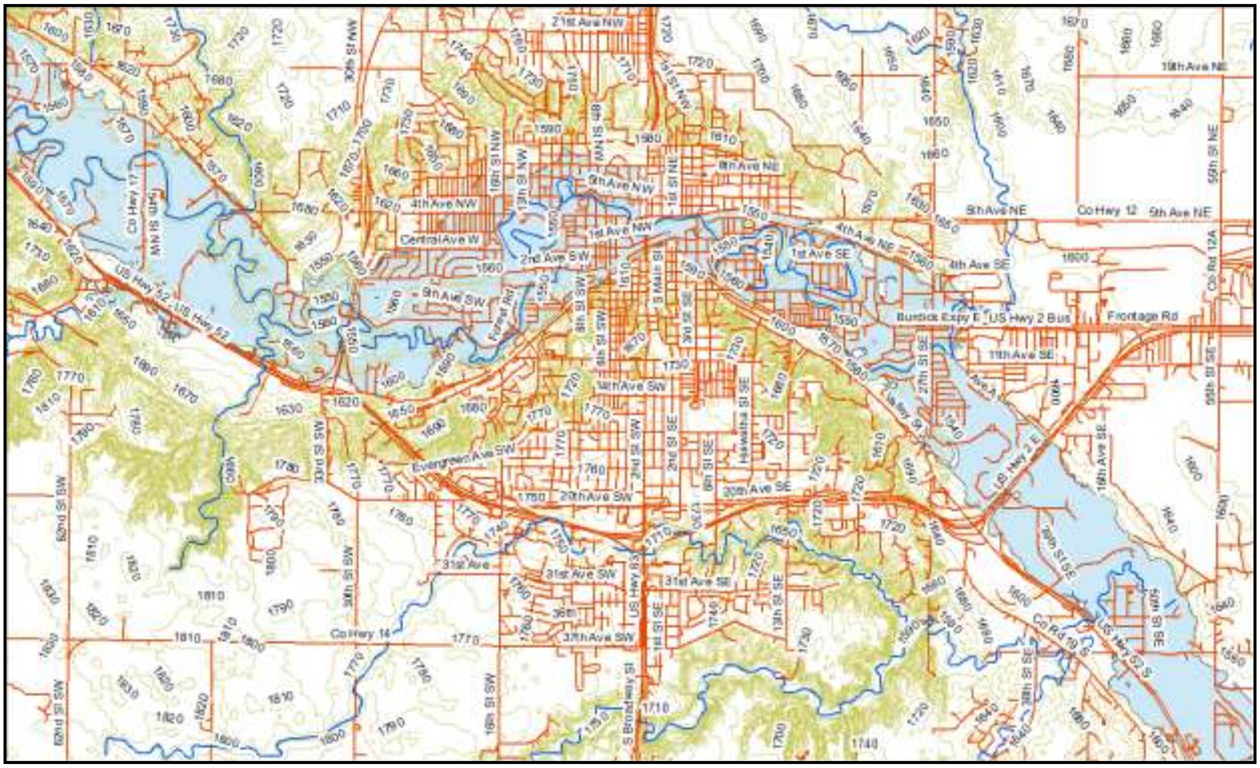

Figure 7: Projection of June, 2011 Flooding in Minot, ND.

Figure 8: Projection of the Extent of Inundation with the Water Level at 1540 Feet MSL.

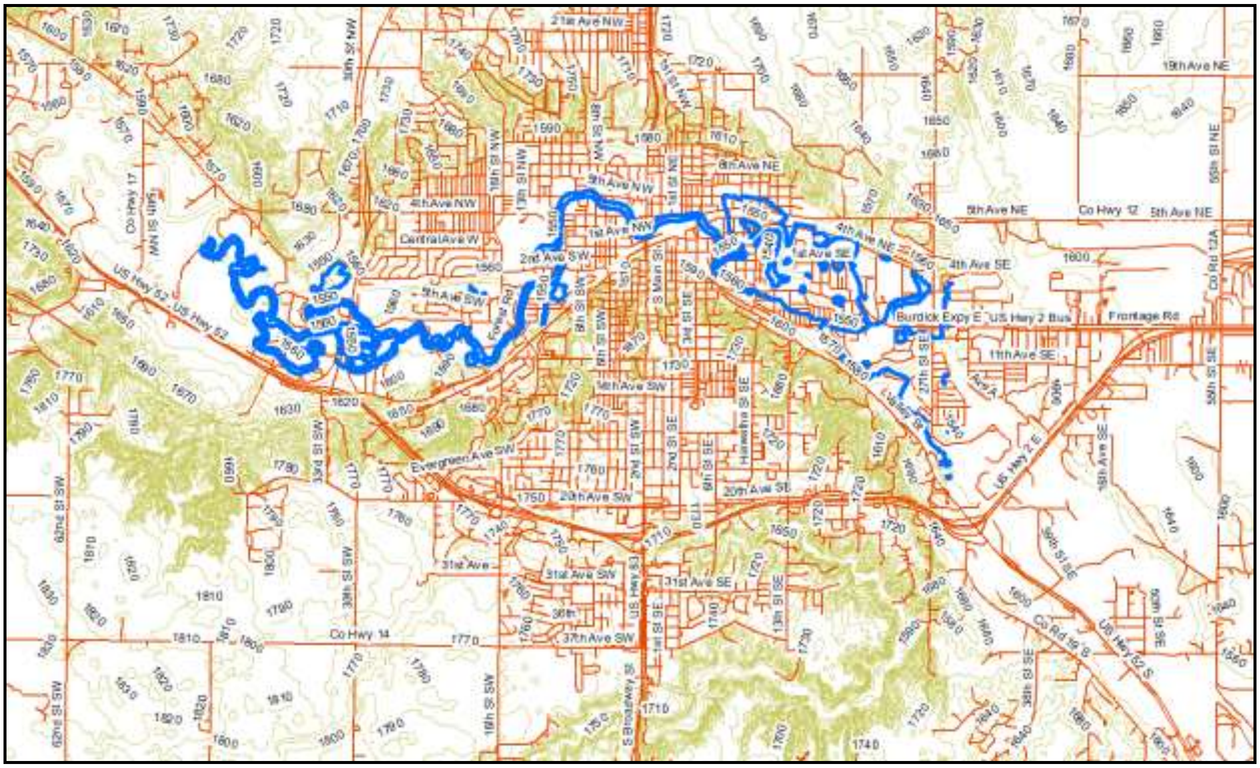

Figure 9: Projection of the Extent of Inundation with the Water Level at 1550 Feet MSL.

Figure 10: Projection of the Extent of Inundation with the Water Level at 1560 Feet MSL.

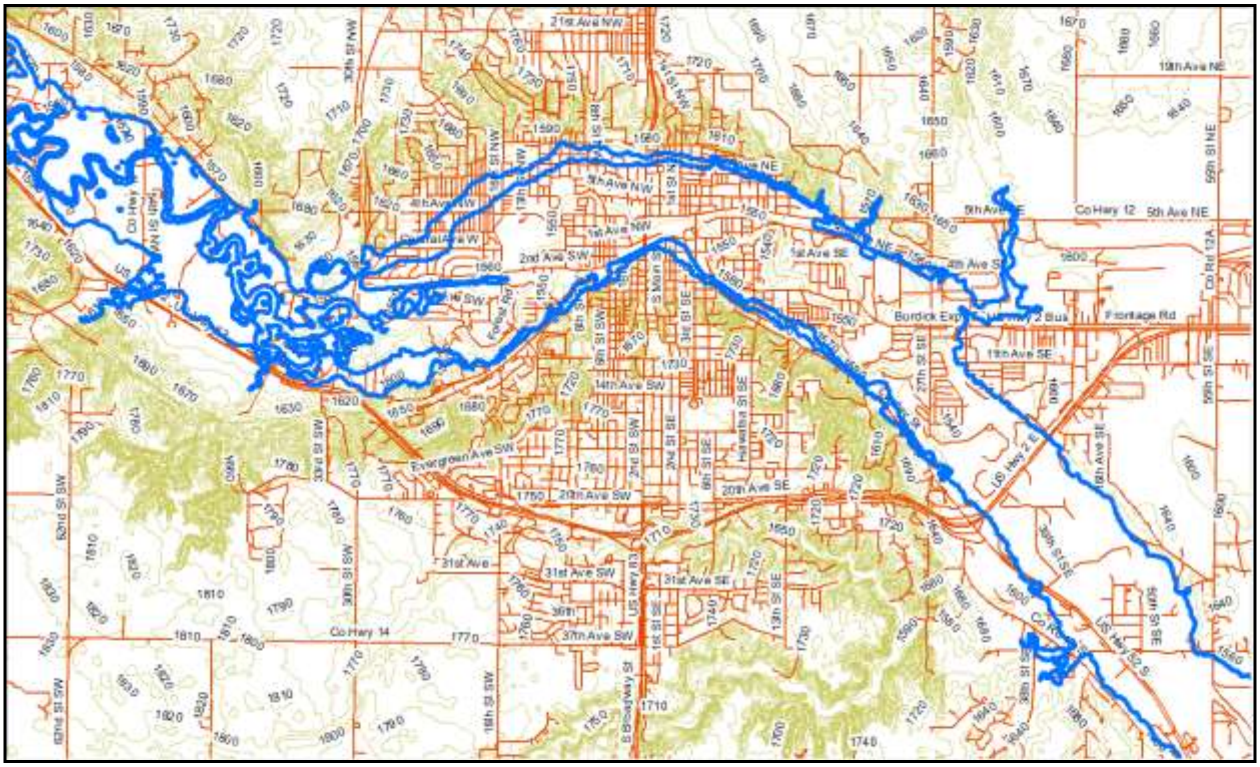

Figure 11: Projection of the Extent of Inundation with the Water Level at 1570 Feet MSL.

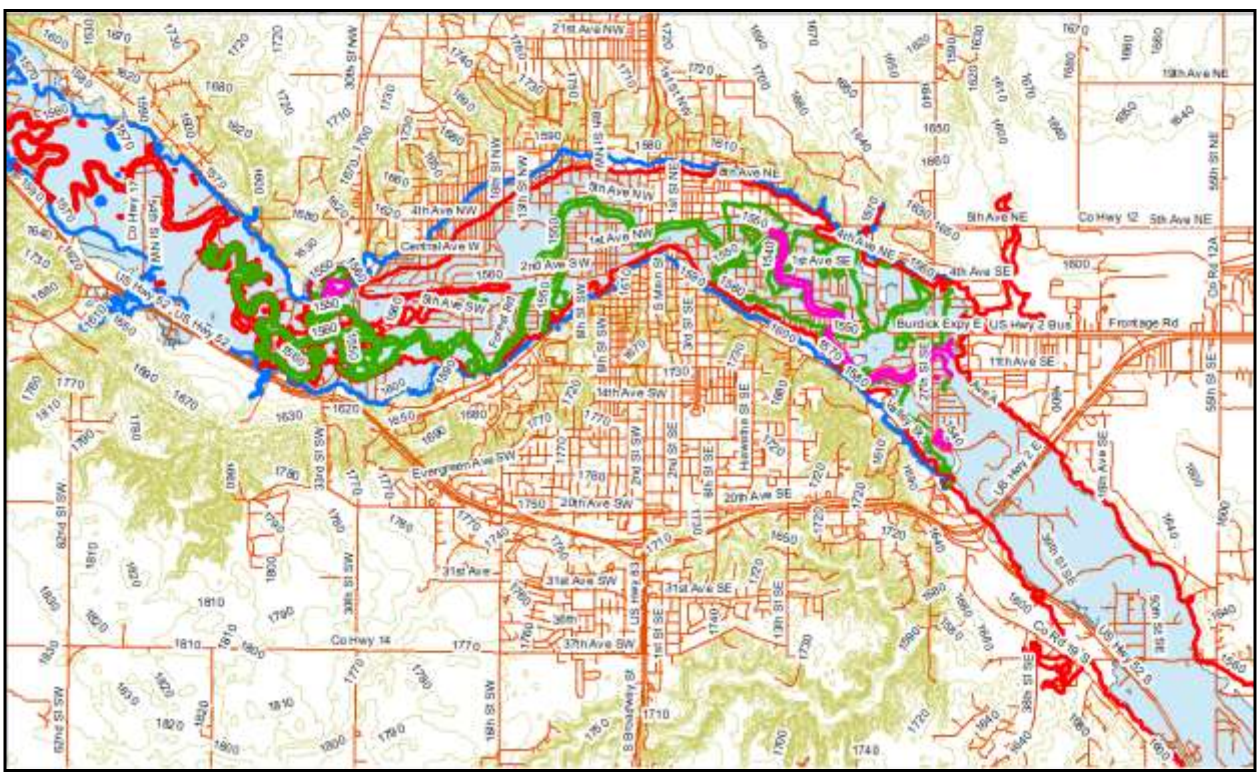

Figure 12: Projection of the Extent of Inundation at 1540 Feet MSL (Magenta Outline), 1550 Feet MSL (Green Outline), 1560 Feet MSL (Red Outline), and 1570 Feet MSL (Blue Outline) Compared to the Extent of June, 2011 Flooding (Light Blue Shading) in Minot, ND.

Flood Category or Flood Protection Description	Water Level (Feet MSL)
Action Stage	1548
Flood Stage	1549
Moderate Flood Stage	1551
Major Flood Stage	1555
June 2011 Flood Defenses vs. 9,600 cfs Flowrate	1566.75
June 2011 Flood Defenses vs. 14,800 cfs Flowrate	1567.61
June 2011 Flood Defenses vs. 26,900 cfs Flowrate	1569.37
9,600 cfs Rated Flood Defenses vs. 14,800 cfs Flowrate	1550.85
9,600 cfs Rated Flood Defenses vs. 26,900 cfs Flowrate	1552.62
14,800 cfs Rated Flood Defenses vs. 26,900 cfs Flowrate	1551.76

Table 1: Scenario-Based Comparison of Water Levels

Contour Elevation (Feet MSL)	Approximate Area of Inundation (Acres)
1540 (Contour Line in ArcGIS)	56
1550 (Contour Line in ArcGIS)	920
1560 (Contour Line in ArcGIS)	4141
1570 (Contour Line in ArcGIS)	4158
1548	747.2
1549	833.6
1551	1242.1
1555	2530.5
1566.75	4152.47
1567.61	4153.94
1569.37	4156.93
1550.85	1193.79
1552.62	1763.9
1551.76	1486.9

Table 2: Approximate Area of Inundation for Given Contour Elevations

City of Minot Feature / Landmark	Elevation (Feet MSL)
Roosevelt Park Zoo	1536
Roosevelt Park Public Swimming Pool	1546
Homes nearest the southern river bank by Roosevelt Park	1534
Home Sweet Home Gift Shop	1552
Homes on northern river bank on 4th Ave NW east of Broadway (US-83)	1552
Oak Park	1534
Homes on northern river bank on 4th Ave NW west of Broadway (US-83)	1550
Amtrak Train Station	1548
Minot Public Library / City Hall / Police	1553
Water Treatment Plant	1560
Starving Rooster Restaurant	1560
Sweet and Flour Bakery	1551
Souris River Brewing Co. & Restaurant	1551
Lamplighter Bar & Bottle Shop	1549

Table 3: Elevations of Various Minot Features and Landmarks from GPS

Analyzing the data in Figures 8 thru 12 and in Tables 1, 2, and 3, one can infer that the key to flood control in Minot relies on keeping water levels near, or ideally below, 1550 feet MSL as the area of inundation increases exponentially above this level. It is for this reason that post-flood, FEMA recommended that the ground floor of homes be raised to at or above the 1551 feet MSL considered a moderate flood stage and that city building officials should not issue building permits for blueprint plans that do not meet or exceed this elevation level (as previously discussed on page 11 of this thesis). This analysis verifies that the proposed construction of 9,600 cfs flood defenses should be sufficient to counter a major flood in the Souris River Valley and protect most of the residents, property, and infrastructure of the city of Minot, North Dakota, because it contains the water level to 1552.62 feet MSL, below the 1555 feet MSL major flood stage at which the City of Minot and the USGS believe a majority of homes and businesses would start to be affected by widespread flooding. The 14,800 cfs rated defenses would only provide ten additional inches of water level protection against June 2011 level flow rates of

26,900 cfs when compared to the 9,600 cfs rated defenses. Due to the extra construction/material costs that would be associated with achieving this extra ten inches of protection to affect only 277 acres less of inundation area, the City of Minot's choice to pursue 9,600 cfs rated defenses instead of 14,800 cfs rated defenses seems reasonable and fiscally responsible. That being said, it will still be crucial for businesses and residents nearest the river's banks, and particularly on the southern banks, to carry flood insurance and be prepared to fortify structures with sandbags and earthen dikes, as their ground floors reside at or below the 1552.62 foot MSL mark which the new protection is calculated to provide. The level of protection afforded will be increased even more once the two proposed divergences are complete. Note that the GIS files obtained from the City of Minot did not yet contain a model of the river with the divergences completed, thus, the modeling and analysis in Figures 9, 10, 11, and 12 reflect more of a worse-case scenario than would be expected once the divergences are constructed and operational. Also note that the contour elevation map used in the ArcGIS modeling progressed in increments of ten feet between contour lines, thus a more detailed examination of projected inundation areas for water level values between 1550 feet MSL and 1560 feet MSL was not possible, aside from mathematical interpolation, but this would be an area for further examination and review in the future should a more detailed elevation contour projection become available. Combined with improvements in capability and capacity of other flood control measures along the Souris River, such as improvements on the Rafferty, Alameda, and Lake Darling Dams, the system as a whole should be able to handle increased rainfall, snowmelt, and the release of larger flow rates from the dams should it be deemed necessary. While physical improvements to the system should prove adequate once completed, there is still room for further adaptive capacity and resilience when it comes to emergency and crisis management and response policy and practice on the part of the City of Minot, Ward County, and the state of North Dakota. Recommended courses of action (COAs) to meet this end and make improvements a reality will be discussed in the next section.

Chapter 5: Conclusions and Recommendations

Based on the findings resulting from the literature review, the emergency management policy review, and the review of the hazard mitigation plans for Ward County and the state of North Dakota, this thesis suggests the following as prudent courses of action, listed in priority order, which could effect the greatest benefit:

1) Develop Continuity of Operations (COOP) and Continuity of Government (COG) for the local city government in Minot, North Dakota. Should a key public employee such as the fire chief or city engineer be unavailable or incapacitated due to a disaster event, procedures and trained back-up personnel need to be able to step in and continue prevention, relief, and recovery efforts. While it is possible that operations could continue without a COOP or COG in place at the city level due to county and state leadership, agencies, policies, and procedures, such action is not likely to be as efficient because of a lack of understanding of the details and inner-workings of the city and its citizens to the same extent. The lack of efficiency, lack of communication, and lack of coordination during an emergency or disaster could ultimately cost additional time, resources, lives, and property damage. Thus, creating a COOP/COG at the local, city level is of the utmost importance and should be given the greatest priority.

2) Complete construction and make operational improvements in capability and capacity on existing dams and levees, as well as on proposed new diversions and floodwalls. Continue to expand and improve upon existing stream gauge, weather monitoring, and

early warning capabilities. Build levels of redundancy in the physical protection of key infrastructure, utilities, and supplies/the supply chain. Make the maintenance and inspection of these assets a priority, i.e. clear fallen debris and non-compliant vegetation, mitigate erosion, discourage and prevent encroachments and animals building burrows on or near flood protection assets. The roles and responsibilities for maintaining existing and new flood protection structures needs to be clearly spelled out and understood by the city, county, state, federal agencies, and citizens alike.

3) Improve upon existing relationships between city, state, and federal agencies, and the Saskatchewan Watershed Authority in Canada. Exercise these relationships, particularly communication. This includes all parties coming to a common shared mental model on whether future flooding in Minot is of low or high probability as well as coming to a consensus on the priority and timeline for the completion of meaningful flood prevention in Minot, ND and the larger Souris River Valley. Take the lessons learned and address limiting factors found in exercises to continually revise and improve upon existing disaster plans.

4) Increase efforts to expand the social aspects of resilience. A multi-faceted approach to resilience focusing on more than just engineering and physical improvements is necessary to maximize readiness and is part of sound emergency preparedness and disaster response policy and planning. Part of this would involve increasing public education efforts regarding emergency preparedness and flood insurance, particularly flood insurance for homeowners in areas where a breach of the newly proposed

floodwalls might have to purposefully be made in the future to minimize the exposure of a larger number of homes to inundation. By engaging the public on these topics, citizens will be better prepared to care for themselves, their families, and their property during a disaster. Additionally, by carrying flood insurance, they and the city will be better prepared for success in recovering from a disaster event by having the necessary funds to conduct clean up and repairs. Even homes not damaged by a flood can be affected if other homes in their neighborhood are left unrepaired/blighted as this figures into property value calculations of all the homes in a neighborhood. Furthermore, water drainage and sewer backups on one property can easily and quickly spread to adjacent properties. Thus, the quicker each home is able to recover from a disaster, the better the overall health of the whole community.

5) Create and maintain adequate levels of critical supplies such as pre-filled sandbags, medicine, fuels, food, water, shelter, generators, etc. so that they are readily available before a disaster or crisis occurs. Not having these critical resources on hand could lead to greater disaster when a crisis occurs. It is possible that modes of communication and transportation might be cut off and remain down for an extended period of time in a disaster event, so getting additional help and supplies into the city might prove difficult. Emergency water pumps and generators need fuel to run, hospitals need various medicines to provide patient care, sandbags take time to fill and stockpile, etc. Thus, being prepared and having these supplies on hand pre-event is critical for actions during the event and post-event. In addition to having these supplies and machinery on hand, sound planning, from the social resilience perspective, requires that there exist a pool of

workers and citizens capable of utilizing them. Organizing and participating in emergency preparedness and disaster response drills incorporating city, state, and federal officials, personnel from nearby Minot Air Force Base, and local citizen volunteers, including but not limited to church groups, Boy Scout and Girl Scout troops, Civil Air Patrol members, search and rescue members, and 4-H club members, could aid in achieving this social resilience goal.

6) Continue to seek, find, and adopt best practices for the region, such as creating diversion channels (already planned), incorporating greenspace and natural flood mitigation to a greater extent where possible, performing home buyouts or using imminent domain if necessary for the benefit of the larger community, etc. Continuing to run vulnerability analyzes is vital so that weaknesses and shortfalls can be identified. The term 'good enough' is not something that should be applied to crisis preparation, response, and mitigation; rather, the city and its citizens should continually strive to improve its capabilities—to enhance its resilience and adaptive capacity.

From the research, modeling, and writing of this thesis, I have learned a great amount about emergency management policy, disaster preparedness and response, adaptive capacity, flood prevention, flood control, and flood recovery, in the United States and Canada and to a lesser extent in Europe. My research has made me a believer in and an advocate for the use of natural flood prevention methods where possible followed closely by diversion methods, because having traveled to Rapid City, Fargo, Grand Forks, and Winnipeg, I have seen these flood mitigation and prevention measures in action, affording their citizens adequate protection. In the case of natural flood prevention, I have appreciated the secondary benefits in the form of recreation—parks, golf courses, and greenspaces—that such an approach to flood mitigation provides, and the value that such features add to a community. Additionally, natural flood prevention methods would be more easily affordable for many of the small North Dakota towns in proximity of the Souris River than larger physical/engineering flood protection methods such as diversions, flood walls, dikes, and dams due to the limited tax base and corresponding limited financial resources at the disposal of these smaller communities. Having lived in Minot, North Dakota for the past four years, I have seen the transformation the town has undergone post-flood and in response to the Bakken oil boom, and I have high hopes for what meaningful flood prevention and sound emergency management policy and preparation could do for this community and its citizens. I believe that the areas encompassed within the 1550 foot MSL contour line in my GIS modeling should eventually be purchased or taken by imminent domain if necessary and turned into greenspaces for natural flood prevention as they lie within the moderate and major floodplains. The most practical course of action in my mind, albeit not the easiest, is to just back away from the river and give it space to ebb and flow as necessary. Time will tell just how effective Minot's newly proposed flood prevention measures will be. Of particular interest, and what I believe should next be pursued, would be an engineering study of the stability of the flood walls if they are topped. In addition to this, I believe the City of Minot and Ward County need to develop sound policies and procedures for what to do if the newly constructed flood walls are topped. Such a situation is very similar to what Manitoba's Minister of Emergency Measures, Steve Ashton, faced in regard to the Assiniboine River flooding in the summer of 2011, as was discussed in the case study, in which he elected to do a controlled breach of Winnipeg's flood defenses in order to guarantee that the fewest number of homes would be impacted, rather than risking an uncontrolled breach which could have affected a greater number of homes, businesses, and citizens. Minot needs to start developing the policies and procedures for such a situation now so that it can evaluate the best location in which to conduct such an operation so that the least number of homes and businesses are affected and so that citizens living within close proximity to this location can prepare as best they can in advance. Such coordination and partnership with citizens is not only prudent, it aligns with sound social resilience theory and practice. Minot's history of flooding over the past century has shown that it is likely waters will rise again in the future. City and county leaders and citizens alike need to recognize this fact and act with an appropriate sense of urgency in order to be prepared before the next flood or other disaster event occurs. They need to take meaningful action to increase capacity, capability, and overall protection. In this way, the city will not only bounce back from the 2011 Flood, it will surge forward, moving past settling for the status quo and in its place aiming to raise the bar of meaningful protection higher.

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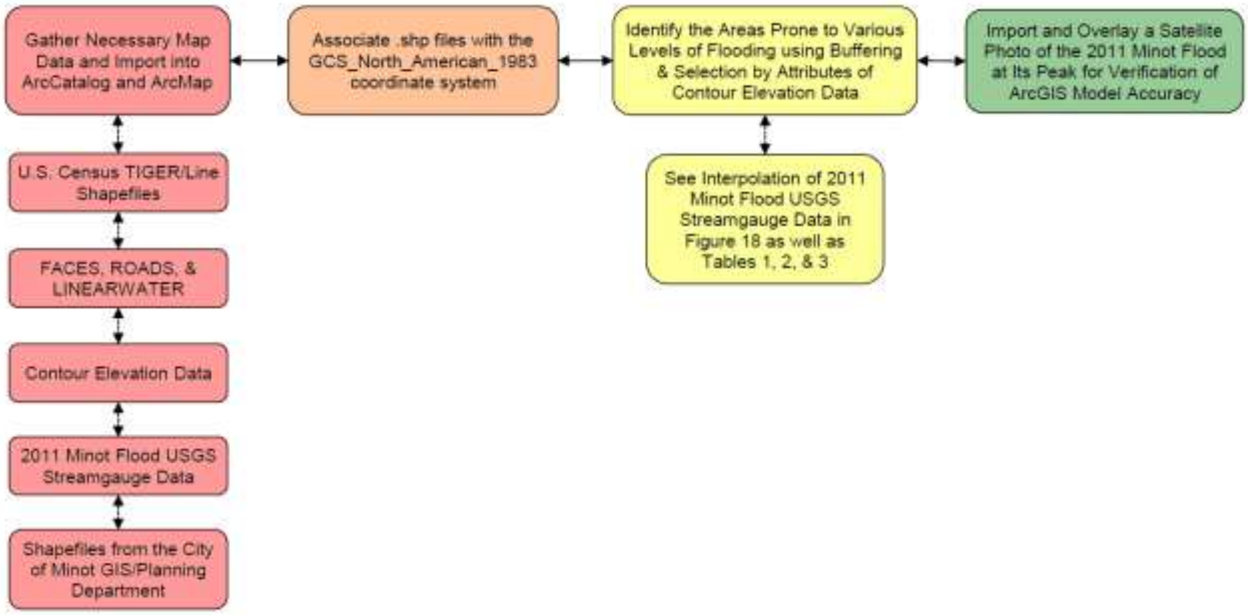
Appendix A: ArcGIS Modeling Flow Chart



Appendix B: Step by Step ArcGIS Modeling Instructions for Re-Creation

The following are step by step instructions of how I performed ArcGIS modeling of the Souris River in Minot, North Dakota. Note, this work was originally done as part of a final project for my fall 2014 Semester GSP 532 class, knowing that the work would be incorporated into this thesis.

Part A: Downloading the Necessary Map Data & Initial Setup in ArcCatalog & ArcMap

1. Copy and paste the following URL into your web browser: http://www.census.gov/geo/maps-data/data/tiger.html.
2. Click the "TIGER/Line Shapefiles – New 2014 Shapefiles" link.
3. Click the "2011" tab.
4. Expand the download menu tab and click on the "FTP Site" link.
5. Open another tab/window in your web browser and copy and paste the following address into the URL field: http://www.census.gov/geo/reference/ansi.html.
6. Click on the "County Subdivision" link.
7. On the page that appears, select "North Dakota" from the drop down menu and click the "GO" button.
8. In the list that appears do a search (Ctrl+F) for "Minot." You should find that the FIPS code for Minot is 53380 and the FIPS code for Ward County is 38101. Return to your other web browsing tab for the FTP Site.
9. Click on the following links: 1) FACES, 2) ROADS, and 3) LINEARWATER and download the zip files corresponding to 38101 (Ward County, ND).
10. Extract the files from the FACES, ROADS, and LINEARWATER zip files you just downloaded.
11. Open ArcCatalog. Connect to the folder where you saved the FACES, ROADS, and LINEARWATER .shp files. For each .shp file, right-click, select properties, and choose the coordinate system GCS_North_American_1983. Close out of ArcCatalog.
12. Open ArcMap and start a new blank map.
13. Click the "Add Data" button and add the FACES, ROADS, and LINEARWATER .shp files to your Table of Contents.

14. Rename the layers to Roads, LinearWater, and Faces. In the Table of Contents, click the "List by Drawing Order" button and arrange the layers in the following order from top to bottom: LinearWater, Roads, and then Faces.
15. Symbolize the Faces layer as Hollow with a Black outline. Symbolize the Roads layer as an Arterial Street of 1.0 width and the color Red Flame. Symbolize the LinearWater layer as a River of 1.0 width and the color Lapis Lazuli.
16. Zoom in on the city of Minot (coordinates -101.297, 48.23) to a scale of 1:50,000. Create a bookmark called "Minot" once you have done this so that you can quickly return to this overhead view of the city later on.
17. In the Table of Contents, right-click on the Roads layer and select Properties. Click on the Labels tab. Check the box for "Label features in this layer." Ensure that the Method field is "Label all the features the same way." In the Text String Label Field make sure that "FULLNAME" is selected. In the Text Symbol field, ensure that Arial is selected as the Font and that the Font size is 8. Click on the "Symbol" button. In the Symbol Selector window that appears click on the "Edit Symbol" button. In the Editor window that appears click on the Mask tab. Select Halo in the Style field and 2.0 for the size. Click OK to close the Editor window. Click OK to close the Symbol Selector window. In the Layer Properties window click Apply then click OK. You should now see some of the major street names labeled on your map of the City of Minot.

<u>Part B: Identifying the Flood Zone / Areas Potential to Flood Using Buffers</u>

1. From the menu bar click "Selection" and then click on "Select by Attributes." Select LinearWater for the Layer field, click or type the following code into place: "FULLNAME" = 'Mouse Riv' OR "FULLNAME" = 'Souris Riv'. The Souris River, also known as the Mouse River, which runs through the center of Minot should now be highlighted Teal.
2. From the menu bar click "Geoprocessing" and then click on "Buffer." Select LinearWater from the Input Features field drop down menu. In the Output Feature Class navigate to the folder for this project and call the file "Souris River Buffer." In the Distance Field type in 100 and select Feet for your units. Click OK. The Souris River Buffer is added to your Table of Contents. Choose a fill and outline cover for the Souris River Buffer layer so as to distinguish it from the other layers. (I used green).

Part C: Importing and Projecting an Image into ArcGIS

1. Add the jpeg image “MinotFloodAerialCoordConversion.jpg” included with the materials for this project to your Table of Contents. You will most likely get a message prompting you to build pyramids, click OK. You will also get a warning saying that the image can be displayed but not project; just hit ok/accept.
2. At this point, I found it easiest to uncheck all the other layers and just focus on the jpeg image layer, but you do not have to turn them off if you do not want to. Make the jpeg image the second to last (one up from the bottom) layer in the Table of Contents (above the Stream Gauge Data layer).
3. Optional Step: Go to the following URL: http://gis.yohman.com/up206a/how-tos/how-to-add-a-google-earth-satellite-image-into-arcmap/ (same as from the first part of Project 5 for this course). You can use this as a reference to jog your memory for how to do aspects of this part of the project (like where the buttons I reference are in ArcGIS). Keep in mind that this time we are not exporting an image from Google Earth into ArcGIS; rather, we are just using Google Earth to pull coordinates to correlate with distinguishable points (intersections, landmarks, etc.) in the jpeg image. I will briefly cover the remaining steps of the process here:
4. Go to Customize → Toolbars→ Georeferencing
5. Open Google Earth. If you do not have this program on your computer you can download it for free.
6. Type “Minot, ND” into the search field in Google Earth.
7. Pick four points in Google Earth corresponding to points near the corners of the jpeg image (make sure Google Earth’s Lat/Long setting is in decimal degrees: Tools → Options → make Show Lat/Long option “decimal degrees”). The points do not have to be the exact corner of the image. (In fact, I would recommend against that as it would involve too much guessing in placing the points). Pick points that will show up well and be easy to find; I used road intersections and the centers of cul-de-sacs (see Figure 13 on the next page). The centers of bridges or large warehouse-type buildings would also work well. Make sure to zoom in to a detailed enough level so that you get accurate coordinates.
8. Go back into ArcMap and from the Georeferencing Toolbar, click the “add control points” button.

Figure 13: Control Point Aim Points.

9. Left-click once at the location in the jpeg image corresponding to the first point you selected in Google Earth, then right-click and select “Input X and Y.” Remember that the X coordinate is longitude and the Y coordinate is latitude. Type in or copy and paste the information from your point in Google Earth to your point in ArcMap. Repeat the process for your other three points. If your image disappears, remember you can right-click on the jpeg layer in the Table of Contents and select zoom to layer to reorient yourself.
10. When you have finished inputting the coordinates for your four points, click on the Georeferencing drop down menu on the Georeferencing Toolbar and select “Update Georeferencing.”
11. Turn the other layers back on (if you choose to turn them off previously). If you have done everything up to this point correctly, your map should look something like this:

Figure 14: ArcGIS Image of the 100 Foot Flood Protection Buffer Zone for the Souris River, Minot, ND with Layers Turned On and Satellite Image Overlay.

As you can tell from the image, the 100-foot flood protection buffer zone on either side of the river was woefully inadequate to protect the town from the flooding that occurred in late June 2011. We are also set up now for modeling a flood animation over the layers you see above in Figure 14. By placing our animation over the other layers, particularly the jpeg image, we can get an idea of just hour accurate the animation is in depicting the scope of the flooding.

Part D: Downloading and Importing Contour Elevation Data

1. Go to http://topotools.cr.usgs.gov/contour_data.php and download the zip file for North Dakota; make sure you save it in the folder with all your other files for this project. Extract all the files from the ND_preliminary.gdb zip folder.
2. Open ArcCatalog and navigate to the folder with all your files. In the Catalog Tree, expand the ND_preliminary.gdb folder and then expand the ND_preliminary.gdb file. In the right pane under the Contents Tab right-click on the Elev_Contours_preliminary file and select "Properties." Ensure the coordinate system "GCS_North_American_1983" is utilized. Close out of ArcCatalog.
3. In ArcMap, click the "Add Data" button and add the Elev_Contours_preliminary file.
4. Order your Table of Contents so that this new layer is at the top.
5. Right-click on the new Elev_Contours_preliminary layer in the TOC, select "properties," click on the General Tab, rename the layer "Elevation Contours," and click Apply.
6. Click on the Symbology Tab, click on the Symbol (line in the Symbol field), in the Symbol Selector window that appears select "Contour, Topographic, Intermediate," change the color to Light Olivenite (5 over and 1 up from the bottom left-hand corner of the color grid), make the width 0.40, and click OK.
7. In the Layer Properties window click Apply and OK. Your map should now look something like this (see Figure 15 on the next page).
8. In the TOC, right-click on the Elevation Contours layer then click "Properties." Click on the Labels Tab. Check the box to turn label features on in this layer, use the method of "Label all the features the same way," and make the Label Field "ContourElevation," click the symbol button, click the edit symbol button, click on the Mask Tab, select Halo and size 2.0, click OK, click OK, click Apply, then click OK. If you zoom in and look at the now-labeled contour lines of the map along the Souris River (specifically at where it crosses US Hwy 83/Broadway), you should see that the contour lines read 1550 feet. 1550 feet is roughly the river bank's elevation during normal/median water levels, when water rises above this level, the City of Minot declares the river to be in Flood Stage (1549 feet is the exact number for this, but for our purposes, 1550 feet will work just fine).

Figure 15: ArcGIS Image of Minot with June, 2011 Flood Image and Contour Map Overlays.

Part E: Gathering/Creating Flood Data for Use in ArcMap (Adding a Table to a Geodatabase)

1. Go to http://nd.water.usgs.gov/floodinfo/souris.html; click on the green circle for the stream gauge just above Minot, ND (USGS 05117500 SOURIS RIVER ABOVE MINOT, ND).
2. Insure that the available parameters for "00060 Discharge" and "00065 Gauge height" are checked. Select "Tab-separated" for Output Format. Select the date range of April 11, 2011 to August 31, 2011. Click the "GO" button.
3. On the table that appears when the page loads, right-click and select "Export to Microsoft Excel." Modify the table so that you have a date/time column in column A, a flow rate column in column B, and a gauge height column in column C (i.e. delete the extraneous columns A, CDT, etc.). Save the Excel file using a Comma Separated Values format to the folder location you're using for this project. (Note: you may need to widen your date/time column so that it actually displays the data. If you are seeing ##### in the cells for that column, you need to widen the column, otherwise when you bring it into ArcMap it will display as <null> rather than giving you the data). You now have water flow rate and water depth information for the period leading up to, during, and after the Minot 2011 Flood in 15 minute increments.
4. Go back to your web browser, hit the back button, and select Graph with Stats as the output for the same date range, and hit the "GO" button. On the page that appears you can see that the 110-year median daily average for water flow rate ranges from about 20 cfs to 280 cfs

and that the 11-year median gauge height (depth) is just 5 feet. The highest flow rate recorded during the period of the flood was 26,900 cfs and the greatest gauge height (depth) was 24.37 feet recorded on June 25, 2011 at 19:45 Central Time (just to give you an idea of how extensive the flooding actually was).

5. As 5 feet is the median gauge height, will we call that our baseline water depth. Knowing this, go back to your CSV Excel File and in cell D1 type the formula "=C1-5" (without the quotation marks). Replicate this formula all the way down column D through cell D13724. If you do not know how to do this quickly, go to http://www.youtube.com/watch?v=TUFV6FeDoTo and watch a quick tutorial (start at 1:43 into the video). We now have the height of the river above the normal median water level in feet for each date/time measurement interval.
6. Now that we have the height of the river above the normal median water level in column D, we can calculate the height of the water above mean sea level (MSL) during the time of the flood by adding the 1550 feet (from Part D Step 8) to the values in column D. In cell E1 type in the formula "=D1+1550" (without the quotation marks). Replicate this formula all the way down column E through cell E13724 (just like you did in the previous step). Save the CSV Excel file.
7. Open ArcCatalog. In the Catalog Tree navigate to the folder where you are saving the files for this project. Expand the ND_preliminary.gdb folder, right-click on the ND_preliminary.gdb file, hover over import, and click on table (single). Click on the folder link button to the right of the Input Rows field and navigate to and select your Excel CSV file (5 fields should populate in the field map). Click on the folder link button to the right of the Output Location field, select the ND_preliminary.gdb file, and click Add. Name your output table "RiverWaterElevation." Click OK. Close out of ArcCatalog.
8. In the ArcMap Table of Contents, right-click on the geodatabase layer (ND_preliminary.gdb), then click "Add Table." In the window that appears, click on "RiverWaterElevation," then click "Add."
9. Right-click on the RiverWaterElevation Table in the TOC and select Open. Change the Alias for each column from Field1 through Field5 to "Date/Time," "Flow Rate (cfs)," "Gauge Height (feet)," "Height above Median Water Level (feet)," and "Water Height MSL (feet)" respectively by right-clicking on the column header (i.e. Field1) and selecting

"Properties." (Once again if you're Field1 values come up as <nulls>, remove the table from the TOC, reopen the Excel CSV file, widen your date/time column, re-save and close the Excel CSV file, and then repeat Part E Steps 7, 8, and 9).

10. Open ArcToolbox. Expand "Data Management Tools." Expand "Fields." Click on "Convert Time Field."
11. Make the following selections as seen below in Figure 16. Note that you will have to physically type in "M/d/yyyy HH:mm" (without the quotes) into the Input Time Format Field. Name the Output Time Field "TimeConversion." Make the remainder of the selections as seen below; when you are finished click OK.

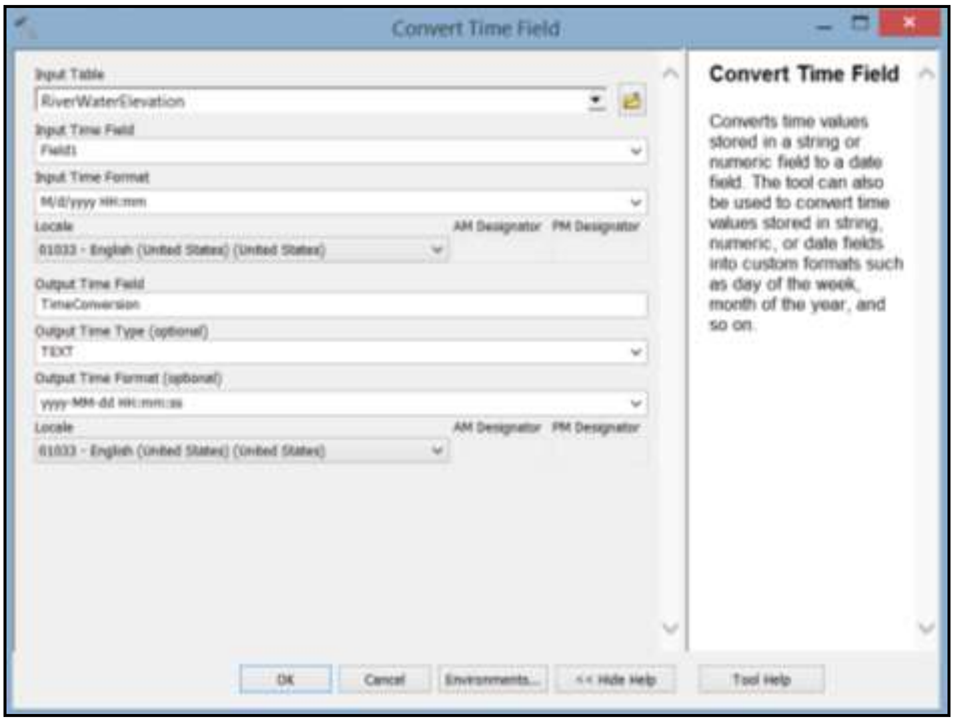


Figure 16: Screen Capture of ArcGIS Convert Time Field Window.

12. We have now created a "TimeConversion" column in the "RiverWaterElevation" Table that ArcMap can actually read/understand.

<u>Part F: Performing and Projecting a Selection by Attributes to Model Minot's June 2011 Flood</u>

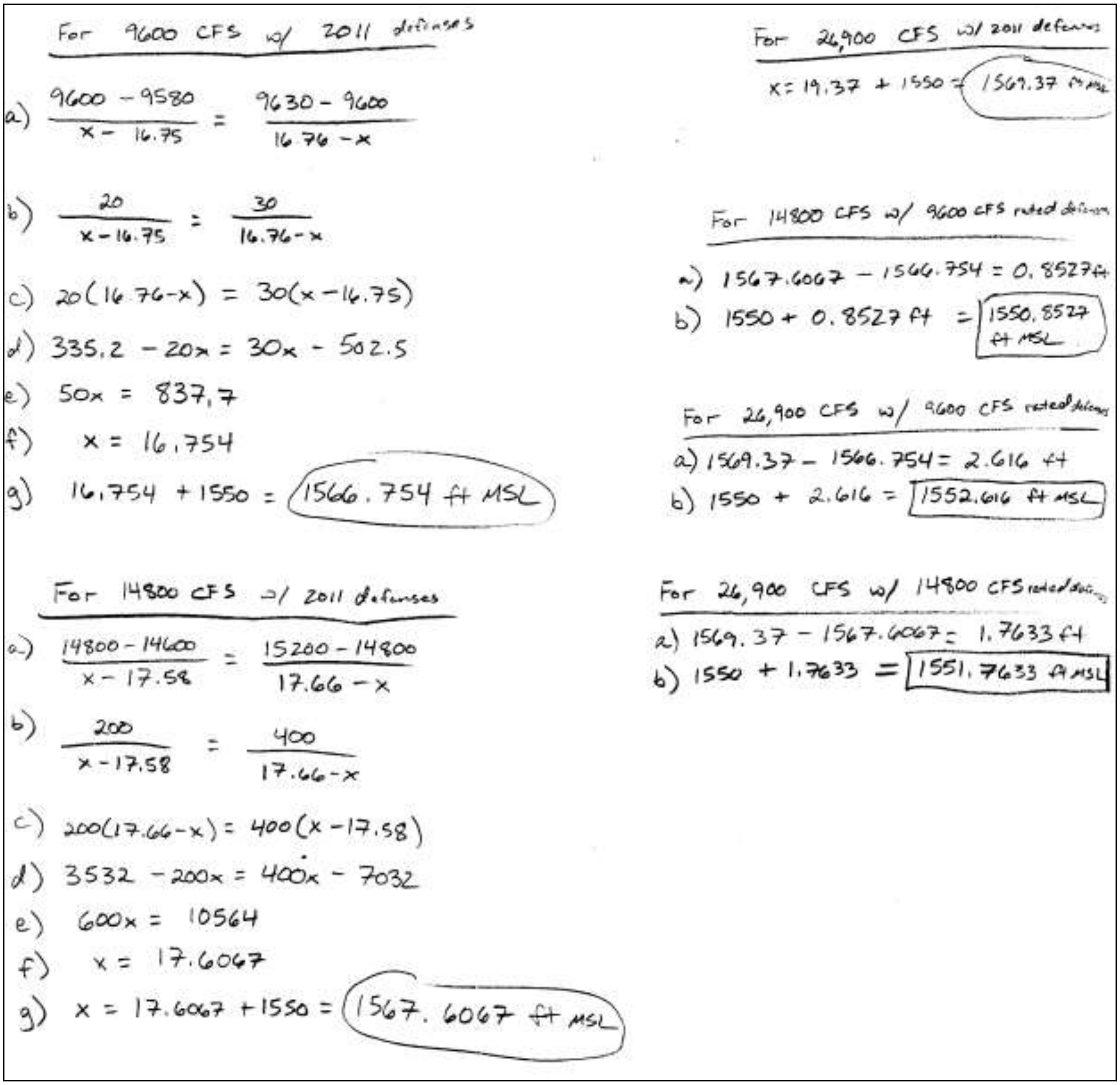
1. In the TOC, right-click on the "RiverWaterElevation" table and select Open.
2. Right-click on the header "Water Height MSL (feet)" and select Sort Descending. You should find that the greatest water height MSL that the flood waters reached was 1569.37 feet

at 19:45 on 6/25/2011 (this corresponds to the 26,900 cfs flow rate and 24.37 feet gauge height mentioned in Part E Step 4). Close out of the table.

3. On the menu bar click “Selection,” then click “Select by Attributes.”
4. In the window that appears, select the “Elevation Contours” layer in the Layer Field drop-down menu. In the Method Field ensure that “Create a new selection” is selected. Next, type or click the following formula into the equation field: “ContourElevation <= 1569.37” (without the quotation marks). Click Apply, then click OK.
5. Right-click “Elevation Contours” in the TOC and select Properties. In the window that appears click on the Selection tab. Ensure that the Show selected features: “with this symbol” is selected. Click on the symbol shown/previewed in the field (beneath the words “with this symbol”). Symbolize the selection as a River of width 3.0. Click OK to close out of the Symbol Selector window. Click Apply, then click OK to close out of the Layer Properties window. Your final product should look like this (see Figure 17 on next page).
6. The resulting model depicts fairly closely the actually flooding that occurred in June, 2011 in Minot, ND. As you can see, the 1569.37 foot selection on some areas on the map (look to the bottom left) do not match up to the flooding seen in our jpeg graphic overlay. The reason for this is the accuracy of the map/contour data being slightly off and not including the changes in elevation in certain areas due to the creation of earthen dikes by the city (to protect key areas). These earthen dikes forced water into neighborhoods and other areas that might not have otherwise been flooded (as you can see was the case with homes on 30th Street SW and 27th Street in SW Minot).
7. Export your map as a jpeg file and save it in the folder you used for the other files for this project using the naming convention of STUDENTIDgradprog.jpeg.

Figure 17: ArcGIS Image Showing Modeling of the Extent of the June 2011 Minot Flood in Comparison to the Satellite Image Overlay.

8. Part F steps 3 thru 5 were repeated to produce the screen shots in the Modeling and Analysis Section of this report based on the following calculations / interpolation of June 2011 stream gauge data from the “RiverWaterElevaton” table mentioned in Part F step 1 (see Figure 18 on the next page).
9. Flood inundation areas were approximated using the Measure Area tool in ArcGIS and hand clicking around the perimeters of the layers produced using a selection by attributes of the contour elevation layer for 1540 feet, 1550 feet, 1560 feet, and 1570 feet respectively within the boundaries of the clipped flood inundation area provided in the City’s GIS files.


For 9600 CFS w/ 2011 defenses

a) $\frac{9600 - 9580}{x - 16.75} = \frac{9630 - 9600}{16.76 - x}$

b) $\frac{20}{x - 16.75} = \frac{30}{16.76 - x}$

c) $20(16.76 - x) = 30(x - 16.75)$

d) $335.2 - 20x = 30x - 502.5$

e) $50x = 837.7$

f) $x = 16.754$

g) $16.754 + 1550 =$ 1566.754 ft MSL

For 14800 CFS w/ 2011 defenses

a) $\frac{14800 - 14600}{x - 17.58} = \frac{15200 - 14800}{17.66 - x}$

b) $\frac{200}{x - 17.58} = \frac{400}{17.66 - x}$

c) $200(17.66 - x) = 400(x - 17.58)$

d) $3532 - 200x = 400x - 7032$

e) $600x = 10564$

f) $x = 17.6067$

g) $x = 17.6067 + 1550 =$ 1567.6067 ft MSL

For 26,900 CFS w/ 2011 defenses

$x = 19.37 + 1550 =$ 1569.37 ft MSL

For 14800 CFS w/ 9600 CFS rated defenses

a) $1567.6067 - 1566.754 = 0.8527$ ft

b) $1550 + 0.8527$ ft $=$ 1550.8527 ft MSL

For 26,900 CFS w/ 9600 CFS rated defenses

a) $1569.37 - 1566.754 = 2.616$ ft

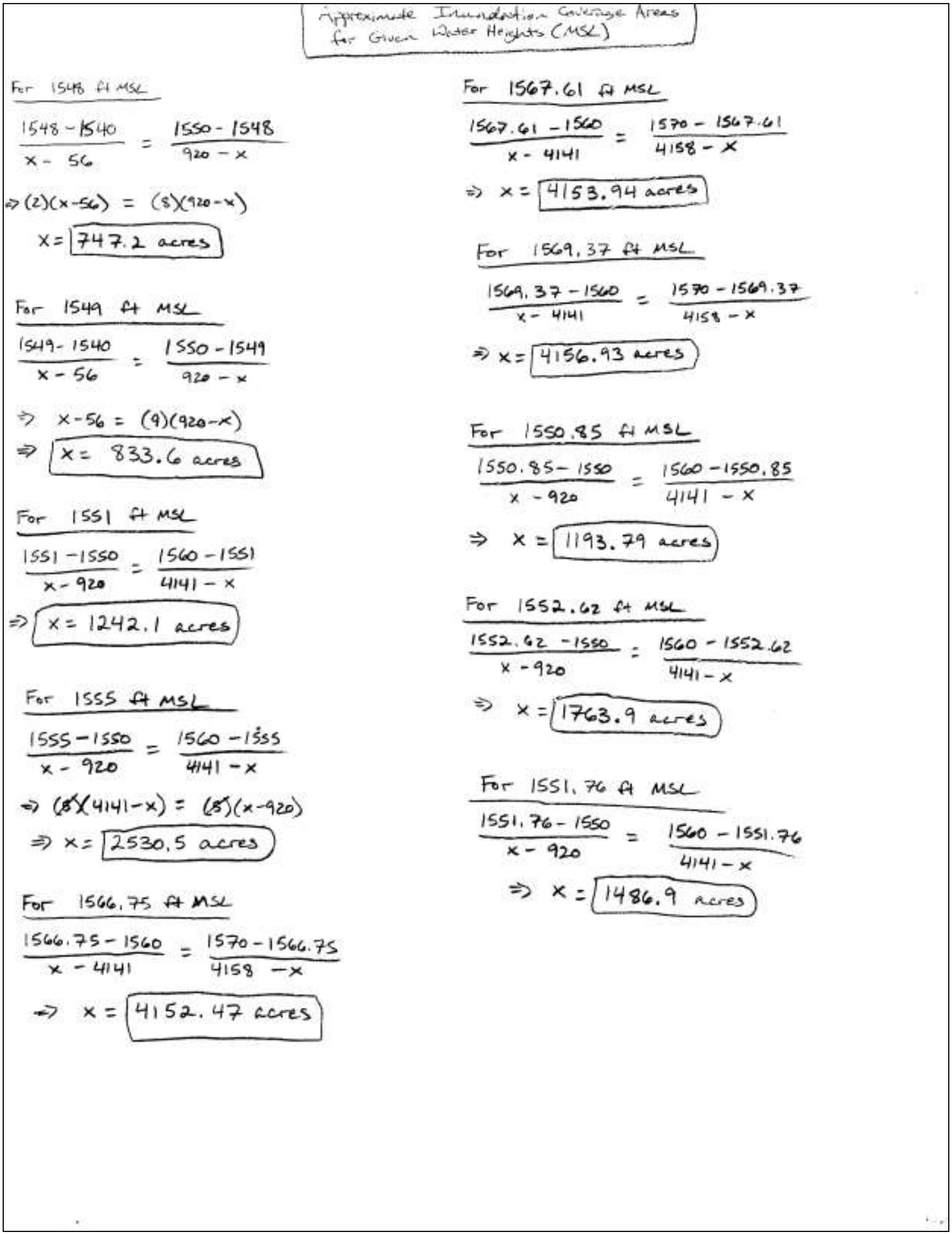
b) $1550 + 2.616 =$ 1552.616 ft MSL

For 26,900 CFS w/ 14800 CFS rated defenses

a) $1569.37 - 1567.6067 = 1.7633$ ft

b) $1550 + 1.7633 =$ 1551.7633 ft MSL

Figure 18: Calculation / Interpolation of June 2011 Stream Gauge Data for Modeling and Analysis of Proposed Flood Defense Effectiveness.



Approximate Inundation Coverage Areas for Given Water Heights (MSL)

For 1548 ft MSL

$$\frac{1548-1540}{x-56} = \frac{1550-1548}{920-x}$$

$$\Rightarrow (2)(x-56) = (8)(920-x)$$

$$x = \boxed{747.2 \text{ acres}}$$

For 1549 ft MSL

$$\frac{1549-1540}{x-56} = \frac{1550-1549}{920-x}$$

$$\Rightarrow x-56 = (9)(920-x)$$

$$\Rightarrow \boxed{x = 833.6 \text{ acres}}$$

For 1551 ft MSL

$$\frac{1551-1550}{x-920} = \frac{1560-1551}{4141-x}$$

$$\Rightarrow \boxed{x = 1242.1 \text{ acres}}$$

For 1555 ft MSL

$$\frac{1555-1550}{x-920} = \frac{1560-1555}{4141-x}$$

$$\Rightarrow (5)(4141-x) = (5)(x-920)$$

$$\Rightarrow x = \boxed{2530.5 \text{ acres}}$$

For 1566.75 ft MSL

$$\frac{1566.75-1560}{x-4141} = \frac{1570-1566.75}{4158-x}$$

$$\Rightarrow x = \boxed{4152.47 \text{ acres}}$$

For 1567.61 ft MSL

$$\frac{1567.61-1560}{x-4141} = \frac{1570-1567.61}{4158-x}$$

$$\Rightarrow x = \boxed{4153.94 \text{ acres}}$$

For 1569.37 ft MSL

$$\frac{1569.37-1560}{x-4141} = \frac{1570-1569.37}{4158-x}$$

$$\Rightarrow x = \boxed{4156.93 \text{ acres}}$$

For 1550.85 ft MSL

$$\frac{1550.85-1550}{x-920} = \frac{1560-1550.85}{4141-x}$$

$$\Rightarrow x = \boxed{1193.79 \text{ acres}}$$

For 1552.62 ft MSL

$$\frac{1552.62-1550}{x-920} = \frac{1560-1552.62}{4141-x}$$

$$\Rightarrow x = \boxed{1763.9 \text{ acres}}$$

For 1551.76 ft MSL

$$\frac{1551.76-1550}{x-920} = \frac{1560-1551.76}{4141-x}$$

$$\Rightarrow x = \boxed{1486.9 \text{ acres}}$$

Figure 19: Calculation / Interpolation of Approximate Inundation Coverage Areas (in acres) for Given Water Heights (in feet MSL).