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Using the Hazus-MH Flood Model to Assess the Physical and Economic Damages at the City of Minnewaukan, North Dakota, Due to the Expansion of Devils Lake

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USING THE HAZUS-MH FLOOD MODEL TO ASSESS THE PHYSICAL AND
ECONOMIC DAMAGES AT THE CITY OF MINNEWAUKAN, NORTH DAKOTA,
DUE TO THE EXPANSION OF DEVILS LAKE

by

Christina A. Cummings
Bachelor of Science, The Pennsylvania State University, 2008

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota
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2010
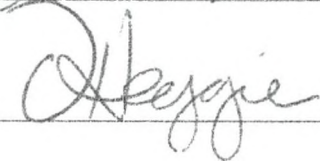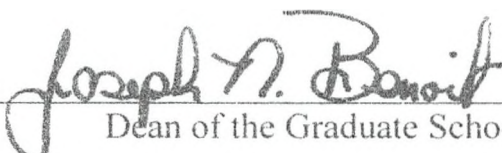
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Department: Geography

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LIST OF ACRONYMS

Acronym	Definition
ASL	Above Sea Level
BFE	Base Flood Elevation
CFS	Cubic Feet Per Second
DEM	Digital Elevation Model
DOT	Department of Transportation
FEMA	Federal Emergency Management Agency
HAZUS-MH	HAZards United States MultiHazard
HUD	Housing and Urban Development
LiDAR	Light Detection and Ranging
NFIP	National Flood Insurance Program
NIBS	National Institute of Building Sciences
OHWM	Ordinary High Water Mark
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WSE	Water Surface Elevation

ACKNOWLEDGMENTS

To Daniel and Mary Cummings, of Lorton, Virginia

ABSTRACT

Flood hazards in the U.S. cause billions of dollars in property damage and disrupt the lives of thousands of people each year. Increased numbers of people continue to move into hazardous zones and the associated increase in capital investment in these zones lead to an escalation in flood losses over time (Cutter and Emrich 2005). Despite local efforts to mitigate flood hazards and federal mandates to regulate development in flood-prone areas, flood damages continue to increase nationally. Terminal lakes have surface water sources such as from rivers and streams, but have no surface water outlets (Newton 2003). Devils Lake, a terminal lake, has risen nearly 25 feet since 1993, more than tripling its surface area (Leistritz et al. 2002). The rising surface water elevation of Devils Lake has destroyed hundreds of homes and commercial buildings, and inundated thousands of acres of productive farmland (North Dakota State Water Commission 2007).

The City of Devils Lake is not the only town battling the rising lake. Surrounding towns in the Lake Region, most notably Minnewaukan, have experienced historic rises in lake level. In 1993, the lake was eight miles from Minnewaukan, and now it is in their backyard. With Devils Lake now at its highest water surface elevation on record, the City of Minnewaukan must develop flood mitigation strategies and identify areas that will require the most immediate assistance if the lake level continues to rise. My study systematically identifies the commercial and residential buildings affected at these

increasing water surface elevations by conducting a site-specific analysis within HAZUS. The HAZUS software is not normally used to calculate terminal lakeshore flooding. However, with the appropriate data, a site-specific analysis on a terminal lakeshore environment is the exception. The purpose of my study is to provide detailed damage estimate information at future water surface elevations, to better inform the City of Minnewaukan in their decision-making processes.

The damage estimation profiles for the City of Minnewaukan at increasing water surface elevations produced expected results. There was an increase in number of buildings damaged and increase in building dollar losses, with each increasing water surface elevation. The commercial and residential buildings affected at these increasing water surface elevations were systematically identified by conducting a site specific analysis and representing building location and dollar loss with graduated symbols in ArcMap. The school becomes completely flooded at WSE 1456 feet. Main Street, at the entrance of the city, becomes impassible at WSE 1457 feet, due to increased flood waters filling the side ditches and spilling onto the road. Because Main Street is one of the major transportation routes into the city and critical infrastructure would be cut off, partial relocation should be considered at WSE 1457 feet. This study met all of its stated objectives and goals, showing that HAZUS functionality can be extended to lakeshore flooding hazards.

CHAPTER I

INTRODUCTION

Flood hazards in the U.S. cause billions of dollars in property damage and disrupt the lives of thousands of people each year. Increased numbers of people continue to move into hazardous zones and the associated increase in capital investment in these zones lead to an escalation in flood losses over time (Cutter and Emrich 2005). Despite local efforts to mitigate flood hazards and federal mandates to regulate development in flood-prone areas, flood damages continue to increase nationally.

Terminal lakes have surface water sources such as from rivers and streams, but have no surface water outlets (Newton 2003). There are only two means of water loss for terminal lakes. The first is evaporation into the air; the second is by underground outflow in the form of ground water (Simpson 1912). A consequence of not having an outlet is the increased concentration of dissolved solids in these lakes over time. Terminal lakes (also called closed lakes, saline lakes, or endorheic lakes) have small enough volumes that the increase in salinity can be observed and measured relatively easily, and can cause an adverse effect on the lakeshore environment (Newton 2003).

One such closed lake where flooding has been particularly devastating is the Devils Lake Basin in northeastern North Dakota. Devils Lake, a terminal lake, has risen nearly 25 feet since 1993, more than tripling its surface area (Leistritz et al. 2002).

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The rising surface water elevation of Devils Lake has destroyed hundreds of homes and commercial buildings, and inundated thousands of acres of productive farmland (North Dakota State Water Commission 2007). In the last 20 years, five Presidential Disaster Declarations have included counties within the Devils Lake region (North Dakota State Water Commission 2007). Since 1993, the flood fight has cost $1 billion to raise roads and protect other infrastructure in the Devils Lake Basin. The lake is just 5.95 feet away from 1,458 feet, the elevation at which it will spill into the Tolna Coulee and the Sheyenne River (Bonham 2010a). More than 450 homes and 650 total structures have been moved or destroyed as a result of the rising lake (Bonham 2010b).

The City of Devils Lake is not the only town battling the rising lake. Surrounding towns in the Lake Region, Churchs Ferry, Penn, and most notably Minnewaukan, have experienced historic rises in lake level. In 1993, the lake was eight miles from Minnewaukan, and now it is in their backyard (Bonham 2010b). With Devils Lake at its highest water surface elevation on record, 1452.05 feet as of June 27, 2010, the City of Minnewaukan must develop flood mitigation strategies and identify areas that will require the most immediate assistance if the lake level continues to rise.

Relocation has been considered as a possible flood mitigation option for Minnewaukan. As Devils Lake rises, there is a point at which relocation of the community may become necessary. Determining when relocation becomes necessary is often a heated topic of local debate. Commercial and residential building losses will increase as the water surface elevation continues to rise. The purpose of my study is to

provide detailed damage estimate information at future water surface elevations, to better inform the City of Minnewaukan in their decision-making processes.

The HAZUS-MH software quantifies the risk for a study area by using GIS to combine flood map hazard layers with national databases; socio-economic data creates a standardized loss estimation and risk assessment methodology (Scawthorn et al. 2006a). It was created by the Federal Emergency Management Agency (FEMA) in the early 1990s for hurricane wind, earthquake, and flood model capabilities. The HAZUS-MH has national databases including demographics, building stock, essential facilities, transportation, and utilities. The generated flood maps and charts will allow the citizens of Minnewaukan to better visualize and understand the potential risks for their town, which can help to inform them in their decision of when and if relocation may become a desirable flood mitigation alternative.

The Flood submodel of the HAZUS model, a natural hazard loss estimation software, will be used to quantify the property and financial impacts of flooding in the City of Minnewaukan, under existing conditions and at a series of potential future lake levels. HAZUS is not normally used to calculate terminal lakeshore flooding. However, with the appropriate data, a site-specific analysis on a terminal lakeshore environment is the exception. Thus, the purpose of my research is to provide objective and quantitative flood loss estimates to the City of Minnewaukan at a range of future lake levels. The first objective of the research is to determine the damage estimation profiles for the City of Minnewaukan at increasing water surface elevations. The second objective is to

systematically identify the commercial and residential buildings affected at these increasing water surface elevations by conducting a site-specific analysis. I will create my own site-specific building inventory using Tax Assessor's data from the Minnewaukan Courthouse Office. This original inventory will be much more accurate than the census block aggregated data included within HAZUS, and takes much more time and effort to create. In particular, I will focus on 1-foot increments from 1452 to 1460 feet water surface elevation. The third objective is to identify the parts of the City of Minnewaukan that are at immediate risk.

This study will allow officials at the local, state, and regional level to plan and make more informed decisions regarding flood mitigation alternatives. The ultimate goal of this study is to reduce risks associated with flooding and to prepare for emergency response and recovery.

CHAPTER II

LITERATURE REVIEW

2.1 Terminal Lakes

Terminal lakes have sources of water from surface runoff, groundwater flow and direct precipitation onto the lake (Newton 2003). There are two major sinks for water in terminal lakes. The first is lake evaporation; the second is underground outflow in the form of ground water (Simpson 1912). Other means of water leaving a lake include transpiration from plants fringing the lake, ground infiltration, or surface outflow through the ordinary high water mark (OHWM). A consequence of not having a surface outlet is the increased concentration of dissolved solids in these lakes over time. Terminal lakes (also called saline lakes, or endorheic lakes) have small enough volumes that the increase in salinity can be readily observed and measured (Newton 2003).

Geography and climate are key conditions that contribute to terminal lakes on various continents. For example, natural factors that affect fluctuations in lake volume and salinity are the average annual temperature and amount of precipitation in the lake region. Australia has the highest percentage of closed basins at 21%, while North America has the least at 5% (Hammer 1986). Furthermore, approximately 17% of Earth's land drains to terminal lakes or seas (de Martonne 1927). Non-polar regions account for 23% but are usually excluded (de Martonne 1927).

The largest saline lake in terms of area and volume is the Caspian Sea. It covers

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an area of nearly 370,000 km^2 and contains more than 78,000 km^2 of water. (David and Goudie 2000). More than one million lakes are small freshwater bodies in the world (David and Goudie 2000). Other well-known terminal lakes include the Great Salt Lake in Utah and the Dead Sea, which lies on the border between Israel and Jordan. The Aral Sea, located in Central Asia, has significantly decreased in size and experienced extremely high levels of salinization. Many other terminal lakes exist in the Middle East, China, and other parts of the world.

2.2 Terminal Lake Hydrology

One of the eastern-most closed lakes in the United States is located in North Dakota, with its sub-humid climate (Langbein 1961). A generalized hydrologic model for a closed lake is:

$$\text{input} + \text{output} = \text{change in storage}$$

A more specific model is:

$$P_{LS} A_{LS} + Q_i - E_{LS} A_{LS} = \pm S$$

(Williams 1996), where P_{LS} = precipitation on the lake surface, A_{LS} = area of the lake surface, Q_i = runoff, E_{LS} = evapotranspiration of the lake, and S = the change in storage. The standard deviation of positive storage change is much greater than the standard deviation of negative storage change, so if there is a significant increase in storage change, it takes a long period of time to evaporate and decrease the total water storage (Williams 1996).

Terminal lake hydrology depends on the lake itself. To illustrate key differences in terminal lake hydrology, I will examine a brief hydrology of the Great Salt Lake. The Great Salt Lake is a remnant of Lake Bonneville, which was created by melting glaciers

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more than 30,000 years ago. Water drained from the lake by a number of rivers and streams. Approximately 12,000 years ago, the ground beneath Lake Bonnesville collapsed and all outflowing streams and rivers were cut off (Newton 2003). Once terminal lake flooding has become established, it perseveres over time (Todhunter and Rundquist 2004).

2.3 Devils Lake Basin

The Devils Lake Basin is a closed basin of approximately 3,810.8 mi^2 that is a sub-basin of the Red River of the North Basin. About 3,320.5 mi^2 of the basin is tributary to Devils Lake, and about 490.4 mi^2 is tributary to Stump Lake. The Devils Lake Basin contributes to the Red River Basin only when the level of Devils Lake is greater than 1458 feet above sea level (asl). The southern boundary of the Devils Lake Basin is made up of moraines that lie between Devils Lake and the Sheyenne River. The eastern, western, and northern boundaries contain poorly defined low divides. The extent of the Devils Lake Basin includes all of Ramsey County, and parts of Benson, Cavalier, Eddy, Nelson, Pierce, Rolette, Towner, and Walsh counties, and the majority of the Spirit Lake Nation.

2.3.1 Geology/Topography

Depositional and erosional features were produced by the last continental glaciation that ended about 10,000 years ago. The geologic features of the Devils Lake Basin are a direct result of glacial thrusting (Aronow 1957). Glacial deposits include outwash deposits, lake deposits, and glacial till; glacial landforms include ground moraines, end moraines, eskers, and kames. Glacial deposits ranged in size from large boulders to miniscule clay particles. The material was deposited as mixtures of different

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sized materials or layers of clay, silt, sand, and gravel. Glacial till and lake sediments cover much of the area of Devils Lake and the basin itself (USGS 2009b). Specifically, clay and till are the dominant sediments on the geologic surface, with silt and cross-bedded sand in parts of the upper basin (Figure 1).
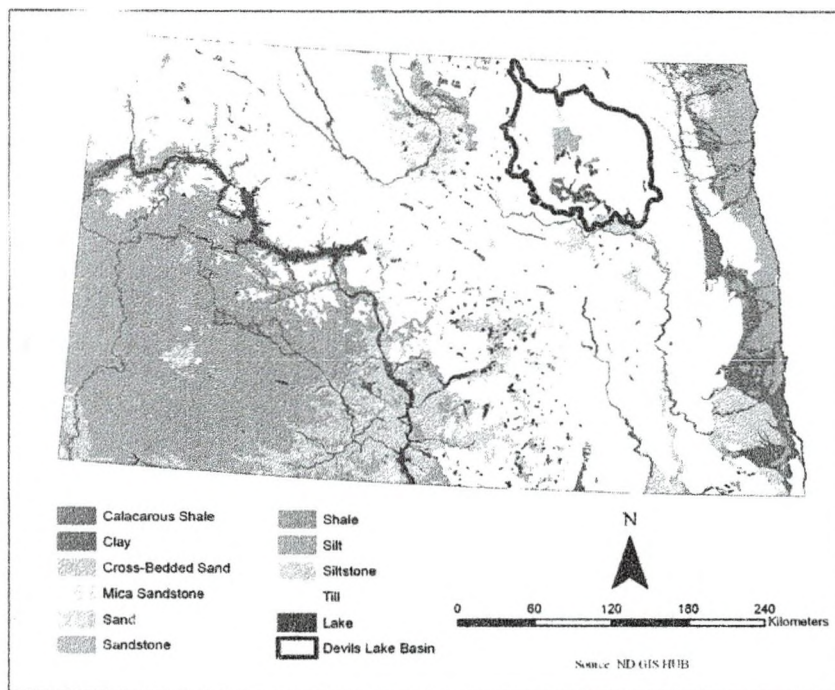
Figure 1. Sediment Types of Geologic Surface in North Dakota.
Source: ND GIS Hub (2010)

The landscape of the Devils Lake Basin has undergone major changes from pre-glaciation to today. The ancient Cannonball River helped form the landscape by creating deep valleys that cut into the underlying shale. During the last glaciation, preglacial rivers were blocked by ice, which resulted in the formation of glacial lakes. Excess water from the lakes carved diversion channels and increased outwash material. The diversion channels and preglacial valleys were formed at different times and contributed to the complexity of the subsurface geology of the Devils Lake Basin (Hobbs and Bluemle 1957). Repeated glacial advances and retreats caused several layers of glacial sediments

to eventually bury the diversion channels and preglacial valleys. Hobbs and Bluemle (1987) state that there have been at least four major glacial events in North Dakota.

The weight of the advancing glaciers resulted in increased ground water pressure in the Cannonball River Valley, which casued excess sediment material to be lifted up in advance of the advancing glacier. Sub-glacial thrusting created a large depression now known as Devils Lake. The build up of thrusted material to the south-southwest direction is currently known as Sully's Hill (Bluemle 1981, 1991). The underlying rock character is soft and shaly. The rocks do not influence the surface of the topography to any marked extent, except where groups of low well-rounded hills or full bodied ridges rise above the plain. For example, Crow Peak, Sully's Hill, and the Blue Hills to the south and east of Devils Lake are "mesa-like remnants" of older and once continuous formations that have eroded away (Simpson 1912). The subsurface geology of the Devil Lake Basin consists of the Pierre Formation, specifically the Pierre Shale (Figure 2).
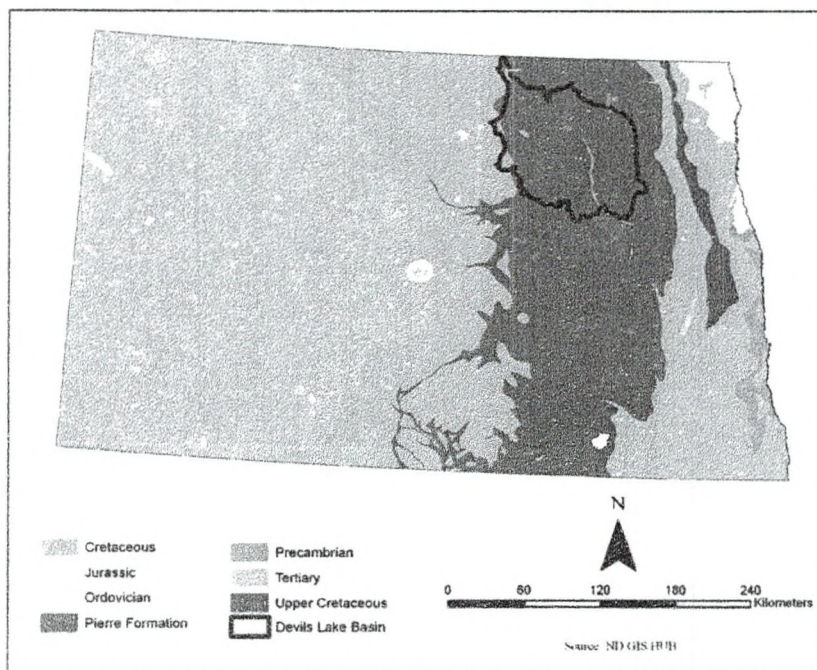
Figure 2. Time Periods of Geologic Bedrock in North Dakota.
Source: ND GIS Hub (2010)

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The Devils Lake Basin is located in the Drift Prairie Plain. The Drift Prairie Plain is a young drift type, which lies within the limits of the latest ice invasion. The slope of the landscape varies from gently undulating through rolling to hilly. The original glacial drift disposition on a nearly level plain contributed to the formation of the landscape (Simpson 1912). The topography is glacial in origin and characterized by slight depressions and numerous prairie potholes.

2.3.2 Climate

The climate of the Devils Lake Basin is characterized as a Dfb climate type in the Köppen classification (Christopherson 2000). Specifically, the region has a warm summer continental climate, with little precipitation and air temperatures that show significant yearly variation. In January, the mean monthly high temperature at Minnewaukan is 16°F, while the mean monthly low temperature is -1°F. In July, the mean monthly high temperature is 79°F, while the mean monthly low temperature is 58°F.

The majority of the precipitation during June, July, and August, comes from thunderstorms. The Devils Lake Basin averages 30 thunderstorms per year (Jensen 1974). For the city of Minnewaukan, average precipitation is 0.58 inches in January, and 3.55 inches in July.

With regards to soil temperature and frost penetration, the average frost depth for the Devils Lake Basin is 3.5 feet, with an extreme depth of 6.5 feet (Jensen 1974). The factors that influence freezing soil depth are winter air temperature, soil properties, and snow cover. Daylength and solar zenith angles are   important in controlling solar

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radiation. Daylength ranges from less than nine hours in December, to more than 16 hours in June.

The climate of North Dakota and the Devils Lake Basin is controlled by three contrasting air masses (Jensen 1974). The maritime polar air mass originates in the Pacific Ocean, and experiences temperature and moisture modification as it crosses the Rocky Mountains; it brings mild and dry weather. The maritime tropical air mass originates in the Gulf of Mexico, and brings warm, moist weather and occurs during the summer months. The final air mass, the continental polar air mass, comes from central Canada, and is associated with bitterly cold temperatures in winter, frequent high wind speeds, and high air pressure. The Devils Lake Basin has a northwest wind direction for 83% of the time. For example, in January the average wind speed is 9.7 mph from the northwest. In July, the average wind speed for the Devils Lake basin is 8.4 mph, also from the northwest direction. The extreme sustained wind speed recorded is 56 mph (Jensen 1974).

2.3.3 Hydrology

Devils Lake is divided into a series of bays: Main Bay, Creel Bay, Six Mile Bay, West Bay, Mission Bay, East Bay, Black Tiger Bay, and East Devils Lake (Figure 3). Devils Lake and Stump Lake are both terminal lakes, with each lake occupying the lowest points within their closed basins (Wiche and Pusc 1994). Neither lake has a surface outlet, so there are only two means of escape for water. The first is evaporation into the air; the second is by underground outflow in the form of ground water (Simpson 1912).Within Devils Lake and Stump Lake, the loss of lake water is almost entirely by evaporation.

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"Devils Lake is characterized by broad, shallow, and irregular bays, that are connected by 'narrows' and entered by many 'points', from which radiate several long narrow arms, the whole producing a strikingly irregular form with great extent of shoreline. It belongs to that class of lakes, numerous in the northern United States, formed during the retreat of the glacial ice in the irregular depressions left in the block and partly filled valley which had been eroded in the bed rock during pre-glacial times. In some of the bays, notably those having a general north and south trend, the valleys may have been deepened somewhat by the erosive action of the ice and thus resemble in origin the Finger Lakes of New York State" (Simpson 1912).
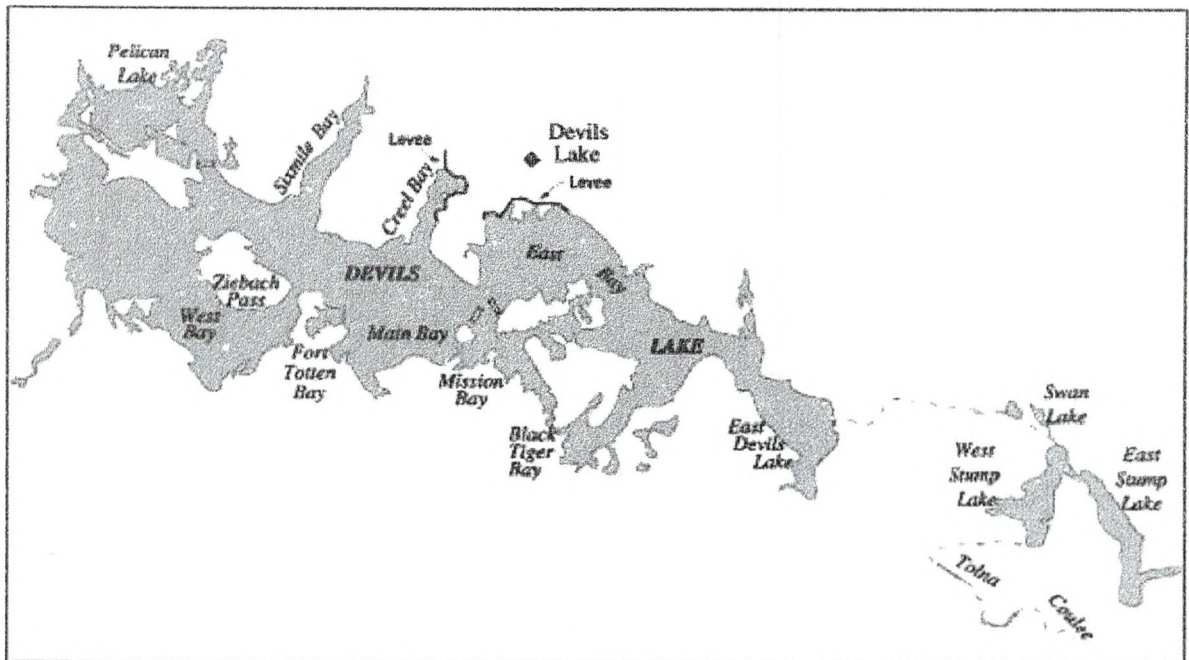
Figure 3. A Map of Devils Lake and its Bays. Source: USGS (2010)

Devils Lake has a highly irregular and lengthy shoreline. The lake bed is comprised of boulders and cobbles incrusted with a white alkaline deposit, and includes gravel and sand that stretches down to the water's edge in a series of belts. As for the water content of the lake, the waters may be termed alkaline and include magnesium and sodium salts. In 2010, the water depths in Devils Lake range from 25 feet in West Bay to 55 feet in East Devils Lake (North Dakota Game and Fish 2010). Furthermore, the groundwater hydrology of Devils Lake is not yet well understood.

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2.3.4 Lake Level History

Approximately 12,000 years ago, the last continental ice sheet that went through North Dakota began to retreat. Devils Lake has reached extreme water levels multiple times since glaciation. There are varying accounts of the historical lake levels. Since glaciation, the water surface elevation of Devils Lake has fluctuated between 1,453.1 feet to less than 1,400.9 feet above NGVD 1929 (Aronow 1957). The approximate spill elevation into the Sheyenne River is 1,458.0 feet. Later around 3,000 years ago, Devils Lake hit 1,398.0 feet above mean sea level, when the lake became almost completely dry. The natural condition for Devils Lake is either rising or falling, and the lake should not be expected to remain at any elevation for a long period of time (Bluemle 1991). Water levels in Devils Lake have continually fluctuated in response to variable climatic and changing hydrologic conditions (Callander 1968) (Figure 4).

Lake levels in Devils Lake were recorded sporadically from 1867 to 1890 (Figure 4). The U.S. Geological Survey (USGS) established a gaging station on Devils Lake in 1901. From 1867 through 2010, the lake level fluctuated between a minimum of 1,400.9 feet in 1940 and a maximum of 1,451.9 feet in July 2010. On October 1, 1992, the combined volume of Devils Lake was about 590,000 acre-feet and the combined surface area was about 49,000 acres. In May 2006, the lake level was 1,449.2 feet above sea level, about 24.6 feet higher than the level recorded in February 1993 (USGS 2009a).

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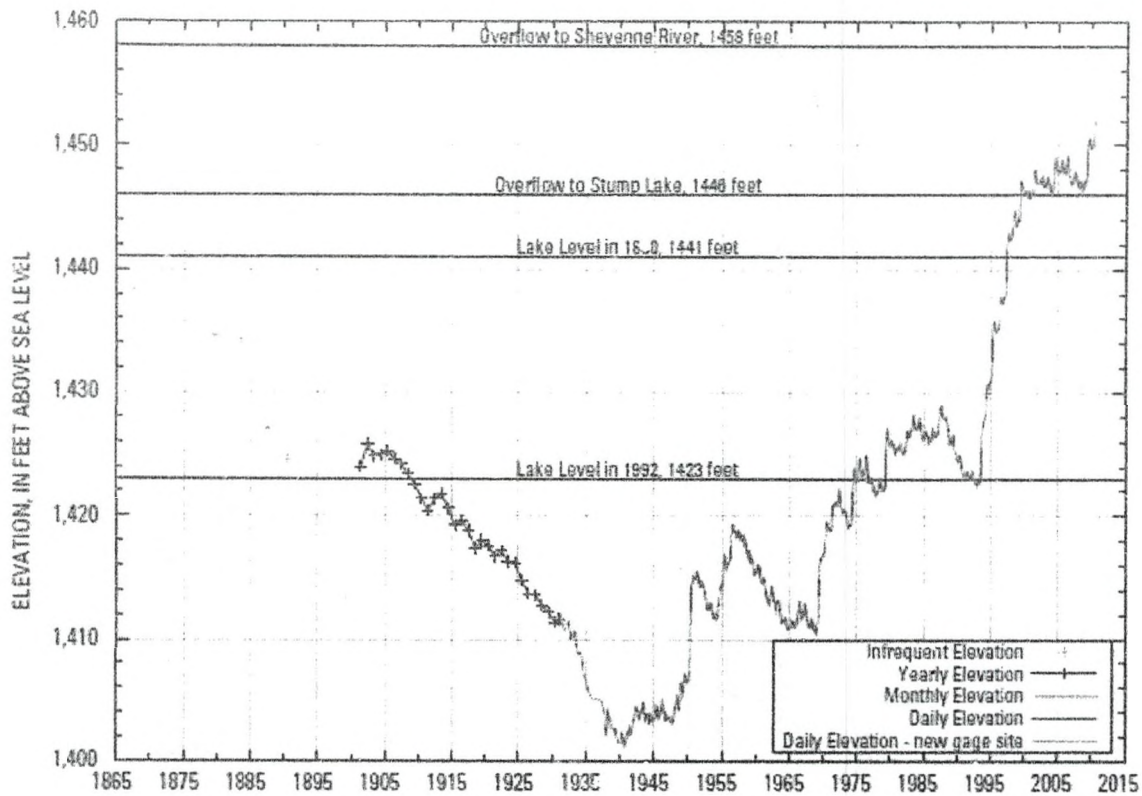
Figure 4. Period of Record Water Surface Elevation (Feet) for Devils Lake, North Dakota. Source: USGS (2010)

Water began spilling from Devils Lake to Stump Lake in May 1999. By September 2009, Devils Lake and Stump Lake had become one continuous water body, with an elevation of 1,447.1 feet and a combined surface area of about 140,000 acres. From 1992 to 2007 the combined volume increased by about 2.3 million acres to 1-foot and the combined area increased by about 91,000 acres (Vecchia 2008). As of August 15, 2010, the lake level is 1,451.8 feet (USGS 2010); Devils Lake and Stump Lake have a combined surface area of 93,112,638 acres to 1-foot (USGS 2010). As of August 15, 2010, Devils Lake covers 163,450 acres (USGS 2010). There are significant differences in lake level elevations from May 1992 to May 2010 (Figure 5). Climate change and other factors pertaining to terminal lakes could explain these differences.

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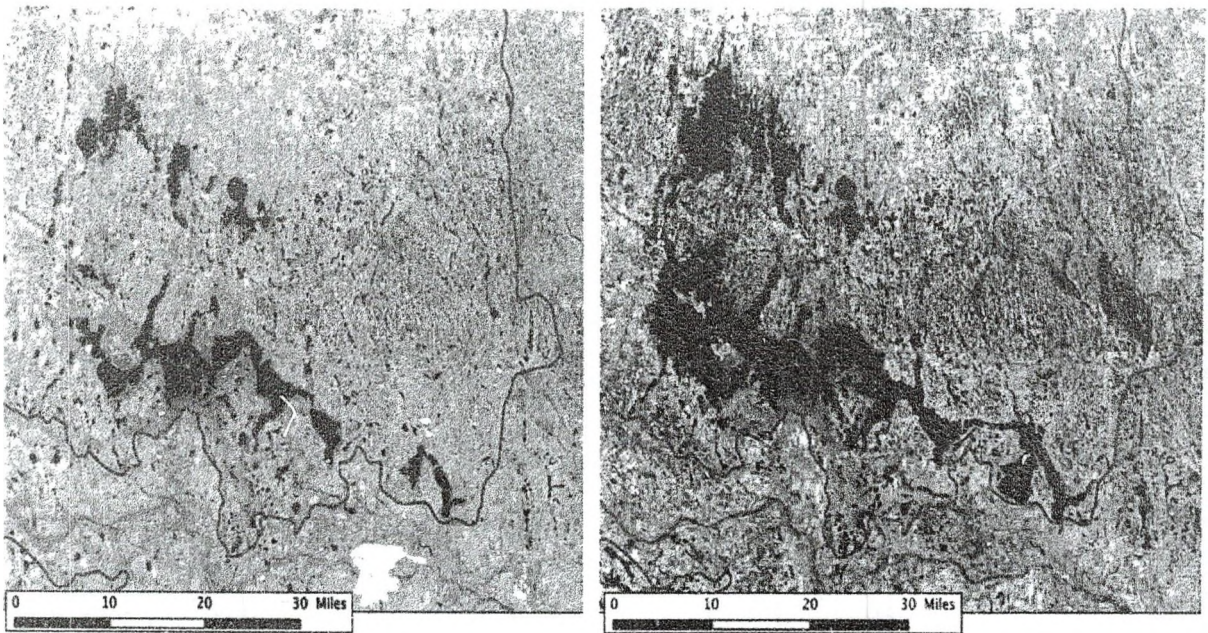
Figure 5. Left: NDSWC Landsat Image of the Devils Lake Basin taken May 13, 1992. Source: ND State Water Commission (1992). Right: NDSWC Landsat Image of the Devils Lake Basin taken May 15, 2010. Source: ND State Water Commission (2010)

2.3.5 Basin-Wide Direct Flood Damages

Federal, state, and local organizations have invested large amounts of money on infrastructure protection in the Devils Lake region (Table 1). The following estimates are from 1994 to what is intended to be spent through 2011, and were distributed in a North Dakota State Water Commission (NDSWC) Devils Lake Flood Tour Memorandum by Aakre and Coon (2010).

Table 1. An Estimation of the Total Direct Damages in the Devils Lake Region from 1994 into the 2011 Season. Source: NDSWC Memorandum Aakre and Coon (2010).

Organization	Amount Spent
Department of Transportation	$341,702,941
Devils Lake Levee	$172,987,729
Federal Emergency Management Agency	$44,400,000
Devils Lake Outlet	$42,000,000
US Army Corps of Engineers	$26,215,000
Rail Repair	$25,672,737
Housing and Urban Development	$3,000
Total	**$655,978,407**

Of the $341.7 million spent from 1994 and allocated through 2011 by the North Dakota Department of Transportation, $175.2 million was spent on the state and county road system, $14.6 million was spent on the Bureau of Indian Affairs, and $151.5 million is allocated on new construction in the 2010 – 2011 season (Aakre and Coon 2009). The Devils Lake levee money, approximately $172.9 million, is being spent to raise the levee to 446.53 meters (1,465 feet) above mean sea level. FEMA has been an important partner in battling the rising lake. The FEMA money spent, approximately $44.4 million, is involved with the purchase and/or relocation of structures, and relocation of Ramsey County rural sewer pipes (Aakre and Coon 2009). The Devils Lake Outlet money,

approximately $42 million, has been spent on increasing its pumping capacity from 100 cubic feet per second (cfs) to 250 cfs by the end of 2010 (Aakre and Coon 2009).

The U.S. Army Corps of Engineers, another key partner in battling the rising lake, has contributed approximately $26.2 million to the outlet, emergency operations, hazard mitigation, the Devils Lake water supply, the Ramsey County sewer system, and maintaining roads acting as dams (Aakre and Coon 2009). Rail repair money, approximately $25.6 million, has been used to raise the railroad to the already surpassed level of 1,449 feet above mean sea level. Significant problems are expected for the Burlington Northern Santa Fe and Canadian Pacific Railway when the lake hits 1,460 feet above mean sea level, which could result in completely re-routing trains around the Devils Lake region (Aakre and Coon 2009). The U.S. Department of Housing and Urban Development (HUD) money, approximately $3 million, has been used in coordination with the Community Development Block Grant in the Devils Lake region since 1995 (Aakre and Coon 2009).

2.4 Minnewaukan

2.4.1 City History

There have been two towns by the name of "Minnewaukan" in North Dakota. One was originally located in Ramsey County; the second is my study site in Benson County. In the early 1880s, a small town was settled along the western shore of Devils Lake. Minnewaukan was a major steamboat landing; the Minnie H., built by Captain Edward Herman, played a vital role in the economic prosperity of the Devils Lake region from 1883 to 1908 (Figure 6). The Minnie H. was a 110-foot steamboat, that drew 3 ½ feet of water.
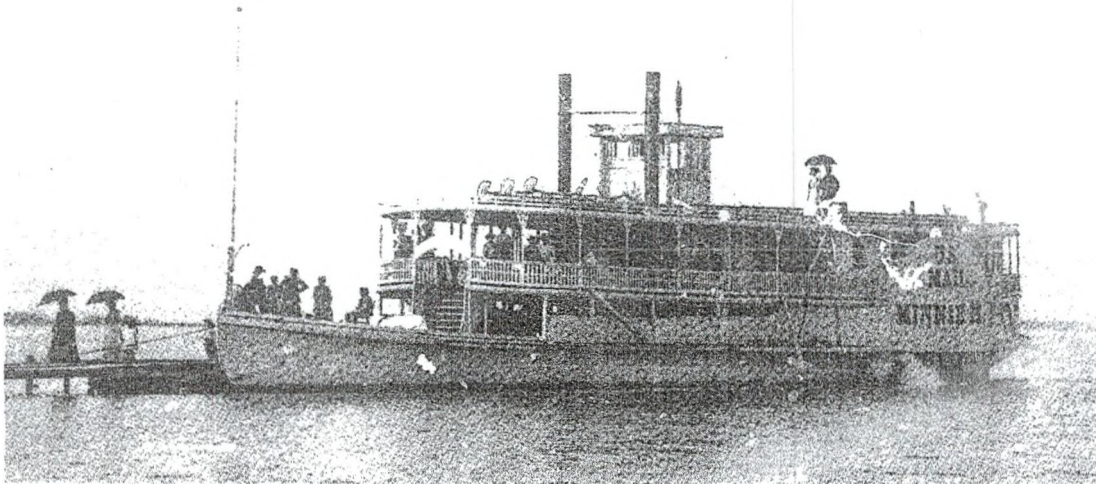
Figure 6. The Minnie H. Docked at Devil Lake, North Dakota. Source: Minnewaukan History Book Committee (1983)

The steamboat was named after Captain Herman's only daughter, Minnietta Herman. It delivered freight, mail, and passengers between Devils Lake, Fort Totten, and Minnewaukan three times a week, and many other locations along the lake. The Northern Pacific Railroad track was strategically built out to and along the steamboat docks, where freight could be unloaded from cars to boats. The dock was located to the east of the present northeast edge of Minnewaukan and was large enough to drive out to the end and turn around with a horse and wagon. Later, in 1909, low water levels and decreased demand forced Captain Herman to permanently dry dock the Minnie H. (Minnewaukan History Book Committee 1983). A replica of the Minnie H. is visible for public viewing in Devils Lake, near the intersection of N.D. Highway 20 and U.S. Highway 2.

Minnewaukan included a number of homes and business establishments, as well as a general store that was operated by B.S. Brown. The townsite was platted a mile south in 1884 and given the Native American name of the lake (Williams 1966). As a result of this new townsite, the previous steamboat settlement was deserted by 1886. A post office

was established in "Minnewaukon" on March 12, 1884, with Thomas Ware as the first postmaster. Due to popular demand, the official spelling of the town was changed to Minnewaukan on August 2, 1909, by Postmaster James Cubbison. He was the first Benson County Register of the Deeds and also operated a drugstore in town (Williams 1966).

The name Minnewaukan is based on the Sioux or Dakota word for Devils Lake, "Mini Waukon Chante." There are a couple translations for "Mini Waukon Chante." One is "water of bad spirits" (Wick 1988). Another translation is "the heart of enchanted water" or "mysterious water" (Williams 1966). However, the most common translation is "Spirit Lake." White settlers literally interpreted it as Mini (water) waukan (spirit) chante (bad); hence the name Bad Spirit or Devils Lake. The word "bad" referred to the saltiness of the water and its unsuitability for drinking. Spirit referred to mirages often seen across the water. Native Americans have no devil in their belief system (Williams 1966). Minnewaukan had a peak population of 564 people in 1920 (Williams 1966). As of 2008, the population was 295 people, with a 7.2% decrease since 2000 (U.S. Census Bureau 2008).

2.4.2 Flood Damages

Rising lake levels have presented a huge challenge to maintaining the regional road system (Figure 7). U.S. Highway 81 was recently moved from running through the City of Minnewaukan to one and a half miles west of town. Construction due to road raises, and detours are expected when traveling in the Lake Region. For example, a 20-minute trip between the City of Devils Lake and Minnewaukan has turned into a 1-hour

journey, because of pilot vehicles leading convoys through construction zones (Bonham 2010a).

Also, transportation safety issues have arisen. Visibility problems occur on long stretches of dusty road raises. Miles of roads have water on both sides of the road instead of grassy ditches to catch out of control vehicles. Threats of wave-related erosion are a chronic problem, and wind-blown sprays cause ice build up on the roads. For example, in April 1998, a Soo Line Railroad derailed north of Minnewaukan when Devils Lake floodwaters damaged a rail bed. In June 1999, another train accident occurred because of the softened rail bed (North Dakota State Water Commission 2001).
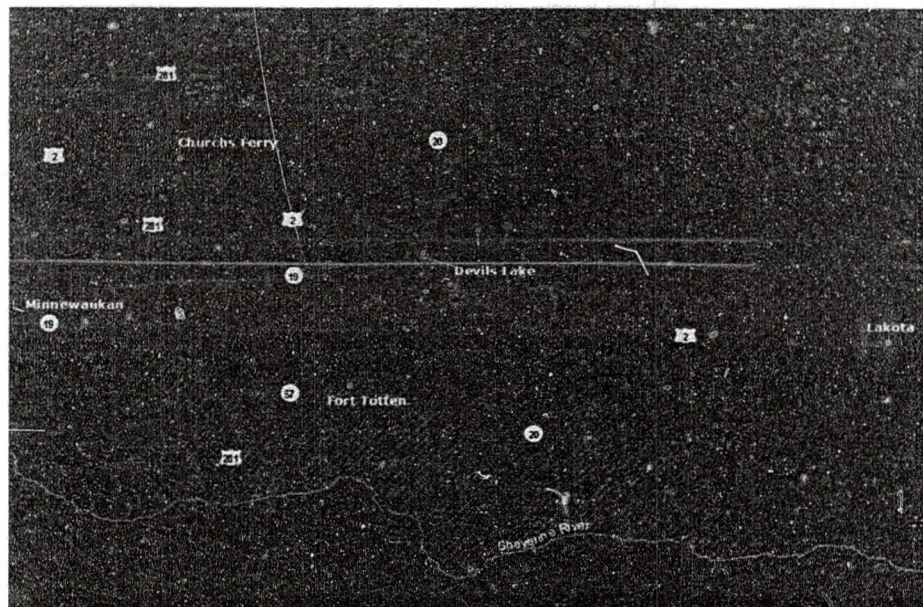
Figure 7. Devils Lake and the Regional Road System.

The Minnewaukan City Council conducted a survey of property owners in the city during May 2010. Some 44% of property owners are experiencing water-related problems in their home. Furthermore, 42.3% of property owners said they plan to leave Minnewaukan if the lake continues to rise. Of these, 40% have a special federal flood

insurance endorsement that allows people within the closed Devils Lake Basin to receive money to help them move before taking on water in their homes (Bonham 2010c).

Currently, homeowners in Minnewaukan pay approximately $1,450 of property taxes annually on a $100,000 home. The survey conducted by the Minnewaukan City Council stated that about one-third of the 34 families who want to stay in Minnewaukan are willing to pay an average of $500 more annually in property taxes, in order to remain in the city (Bonham 2010c).

There are multiple options for the City of Minnewaukan, before relocation becomes necessary. Earlier in 2010, the City of Minnewaukan received a $55,000 Community Development Block Grant through the North Central Planning Council in Devils Lake to build an 800-foot-long, 3-foot-high barrier to protect the Minnewaukan Public School. The dike is necessary because Devils Lake has already consumed the school's football field, basketball court, a softball diamond, and is now threatening the school parking lot. The City of Minnewaukan also received a $300,000 federal grant to move the water tower. The water tower is located on lake-threatened ground near the school parking lot.

Countless meetings have been held to discuss options for the city and to hear residents' opinions about the rising water. Some alternatives brought up at the meetings in Minnewaukan were to build a dike protecting the city, buyout individual homes and property, and to relocate the city (North Dakota State Water Commission 2001).

2.4.3 Relocation

Building-specific studies may be possible for owners of large companies and facilities, but private homeowners are left to make important mitigation decisions based

on limited knowledge of potential losses (Kunreuther 2001). Numerous structures, mostly residential buildings, have been directly affected by rising lake levels in the Devils Lake region (Leistritz et al. 2002). Buildings and their residents have been relocated with funding provided by the National Flood Insurance Program (Leistritz et al. 2002). It has been estimated that 90% of the relocated homes have a higher market value after relocation than before. Homeowners often use relocation as opportunity to start over and enhance their property (Watts & Associates 1998). The rising water of Devils Lake has forced the relocation of the town of Churchs Ferry in 2003. Currently, Minnewaukan is fighting to avoid that same scenario (Figure 8).

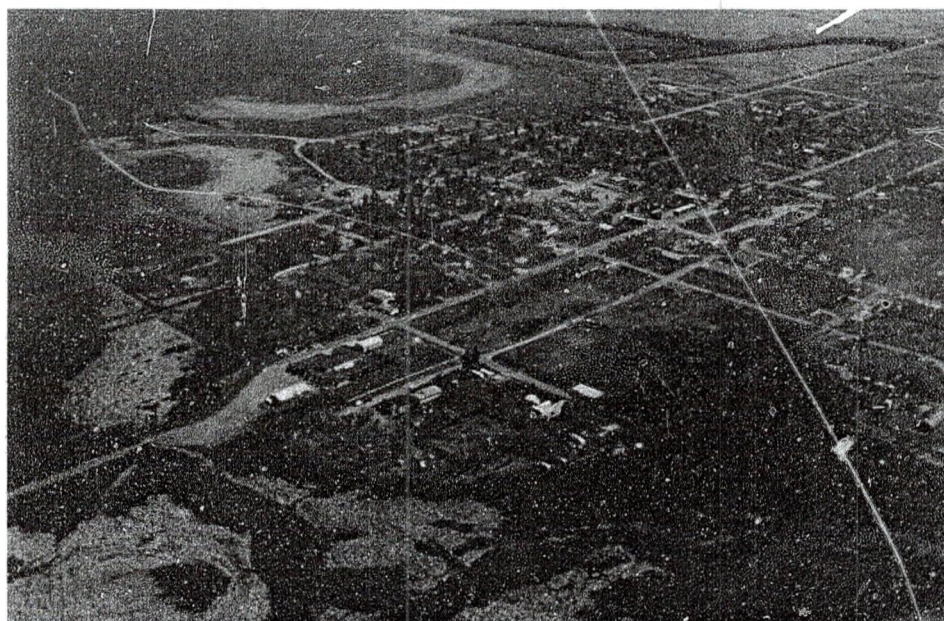Figure 8. An Aerial View of the City of Minnewaukan taken May 2010. Source: City of Fargo (2010)

The idea of partial relocation of Minnewaukan has been introduced. The U.S. Army Corps of Engineers is in the process of conducting a study to determine the cost-benefit ratio of a partial move (Bonham 2010d). Mayor Trish McQuoid and the City Council are in collaboration with Governor John Hoeven to come up with financial

means through state and federal programs to move a portion of the city to higher ground. The possible site is an area of land above 1,460 feet west of the relocated U.S. Highway 281. The possible site is approximately a mile west of town (Bonham 2010c).

If the partial relocation were to happen, that would open the door to developing new infrastructure because the "no building below 1,460 feet" rule would not apply there. Rita Sialoch, a city council member, stated that it would be ideal to build a new school, residential housing, a hotel, convenience store, gas station, recreational vehicle park, mobile home park, and other businesses to serve the community and tourists for the fishing and bird watching industry, if the funds were available and partial relocation were to happen (Bonham 2010c).

2.5 Flood Hazard Mitigation Strategies

2.5.1 Flood Insurance

The Flood Disaster Protection Act of 1973 and the National Flood Insurance Reform Act of 1994 mandate the purchase of flood insurance as a condition of Federal or Federally related assistance for acquisition and/or construction of buildings in Special Flood Hazard Areas of any community. The purchase of flood insurance on a voluntary basis is frequently prudent even outside Special Flood Hazard Areas (FEMA 2004). The requirements under the Disaster Mitigation Act of 2000 indicate that state and local jurisidictions must calculate the possible risks and potential damage that could occur in a flood event, in order to keep mitigation funds.

In September 1999, the National Flood Insurance Program (NFIP) implemented a closed basin lake flood insurance endorsement. This replaced the temporary waivers it had been using to handle the continuous lake flooding. Four of nine Devils Lake area

NFIP participating communities opted to remain eligible for the closed basin lake flood insurance endorsement. Furthermore, Minnewaukan is designated an Area of Special Consideration in the scientific and engineering report entitled the "Flood Insurance Study, Benson County, North Dakota and incorporated areas" dated December 20, 2000. The communities of Benson County, Minnewaukan, Creel Township, and Devils Lake adopted a strict floodplain management regulation, which controlled development below an elevation of 1,460 feet amsl (Connor and Klapprodt 2002).

There are 20 homeowners in Minnewaukan who have a special flood insurance endorsement that the federal government approved in the 1990s for property in the enclosed Devils Lake Basin. This endorsement allows buyouts before homes are innundated with water (Bonham 2010c). Minnewaukan's Harlow Co-Op Elevator and Seed Company is one example of a business that took a federal flood buyout (Bonham 2010c).

2.5.2 Proposed Mitigation Options

There have been multiple proposed mitigation options for Devils Lake. The State of North Dakota is spending about $16 million to expand the original 2005 $26 million Devils Lake Outlet (Bonham 2010b). The debate is over water quality, increased water capacities downstream, and expected opposition resulting in legal challenges. Other proposed options include a controlled outlet from Stump Lake to the Sheyenne River via the Tolna Coulee, a controlled outlet from East Bay to the Sheyenne River via the Tolna Coulee, and a new west-end outlet (Bonham 2010a). This west-end outlet would cost approximately $40 million, and would be comparable to the existing state outlet. Todd Sando, the Assistant State Engineer, stated that "the water quality is higher in the west

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end of Devils Lake, with quality decreasing as it moves east." (Bonham 2010a). Todd Sando, the Assistant State Engineer, also added that the cost of a controlled outlet on the west end would likely be much higher than on the east end (Bonham 2010a).

2.6 The HAZUS Model

2.6.1 The History of HAZUS

HAZUS-MH stands for HAZards U.S. MultiHazard. HAZUS-MH is software originally developed by FEMA in the early 1990s (Schneider and Schauer 2006) as a method for estimating earthquake losses. It consists of an inventory database, ground motion model, and building/lifeline models. HAZUS was enhanced in 1997 when FEMA began expanding it to examine earthquake, flood, and hurricane hazards. Before the release of HAZUS-MH, the HAZUS Earthquake model was used by more than 1,700 users nationwide (Schneider and Schauer 2006).

Many software engineers have contributed to the development of HAZUS, including FEMA, the National Institute of Building Sciences (NIBS), user groups, four technical oversight committees, and three primary contractors. NIBS organized a project oversight committee, also known as the Flood Committee, to provide technical guidance and to assist in selecting consultants to carry out the methodology and software development. The flood model includes methods for assessing riverine and coastal flooding damage to buildings, transportation, and utility lifelines, agricultural areas, vehicles, debris generation, and shelter requirements (Schneider and Schauer 2006). The flow velocity and flood warning effects are also taken into account.

Schneider and Schauer (2006) describe how the software itself has gone through multiple changes. HAZUS-MH is currently programmed in both C++ and Visual Basic to

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run the flood, hurricane, and earthquake models. The database format was changed to MS-Access. This is also referred to a relational database using Microsoft SQL Server. The GIS platform was upgraded to ESRI's ArcGIS. The Spatial Analysis extension is used for raster computations required by HAZUS. Currently, developers are working on supporting Internet applications within ArcGIS.

A Flood Information Tool was released in 2002, prior to the Flood Model. This tool is used during a Level 2 Analysis and consists of a toolbar that can be added into ArcMap. It calculates the extent, depth, and elevation of flooding in riverine and coastal areas. The tool also processes ground elevations, flood elevations, and floodplain boundaries into a format required for the Flood Model to compute damage loss (Scawthorn et al. 2006a). For technical support, FEMA provides multiple training websites, user support groups, and a toll free number for assistance. Typical users of HAZUS include federal agencies, local and state agencies, academic institutions, and private companies; the number of HAZUS users is increasing (Schneider and Schauer 2006).

2.6.2 Flood Model Development

The development of the flood model took place in two phases. The first phase was a review of existing flood loss estimation studies, models, and data. The second phase was a new concept methodology (Figure 9). First, a DEM is combined with stream discharge data (Figure 9-a), then a flood surface elevation is calculated, providing the areas and depth of flooding (Figure 9-b). Next, the population, residential and commercial buildings, and other structures are layered with the area flood layer (Figure

9-c). Finally, an estimate of damages and losses is produced (Figure 9-d), which assists emergency management officials in response and recovery operations (Figure 9-e).

The second phase of the methodology included testing the algorithms and data in GIS using a Graphical User Interface. After conducting the flood loss review, the advisory committee tested the various concepts that comprised their methodology on six communities. To have a first-class flood model, the advisory determined that the following elements were needed: discharge frequencies, flood depths, U.S. Census Bureau and Dunn & Bradstreet data, depth-damage functions for building, and depth-damage functions for lifelines (Scawthorn et al. 2006a). A few examples of lifelines are water, electric, power, roads, and railroads (Scawthorn et al. 2006b).
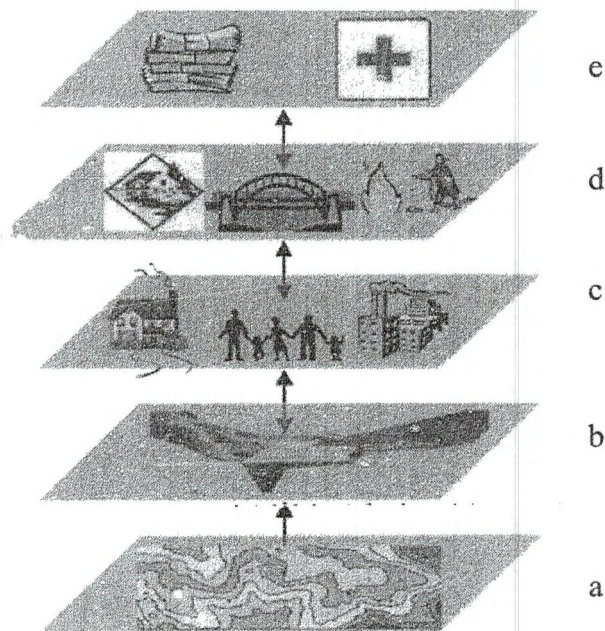

Figure 9. The HAZUS Methodology Diagram. Source: Scawthorn et al. (2006a.)

Scawthorn et al. (2006a) further detailed what they meant by each condition. For example, discharge frequencies should be determined for all river reaches where digital

elevation models and regional regression relations are available. Flood depths should be determined for all river reaches where DEM and Q3 data are available. There are other methods of determining flood depths; however, the methods involve calculations. A user's best bet is to obtain a Flood Insurance Study or a Digital Flood Insurance Rate Map. These can be found on FEMA's Map Service Center Website and can be downloaded for free (Schneider and Schauer 2006). It is beneficial to know the community number. For example, the City of Minnewaukan has a community number of 380240. This information can be looked up on the FEMA website.

Next, the base flood elevations (BFEs) along coastal shore transects are estimated in order to provide reasonable results. Adjustments within the HAZUS Flood Model will have to be made to apply this model to a lakeshore environment. The possible adjustments could be inputting a user-defined depth grid for Devils Lake and developing a more detailed Level 2 Analysis. Issues are anticipated in applying the model to a terminal lakeshore environment.

U.S. Census Bureau and Dunn & Bradstreet data are used to provide suitable flood loss estimations. The Federal Insurance Administration's information is suitable for the depth-damage functions for buildings within the model. The information is based on more than 20 years of losses and is considered the best available damage data. The U.S. Army Corps of Engineers' depth-damage functions are also integrated into the building analysis section. The flood model development also includes depth-damage functions on lifelines (Scawthorn et al. 2006a). These conditions are analyzed by component based modeling, a combination of historical data, and expert opinion (Scawthorn et al. 2006a).

Lastly, the U.S. Army Corps of Engineers AGDAM model is modified within HAZUS-MH to produce results of agricultural damage.

2.6.3 Flood Model Overview

The flood model is split into two types of analysis. The first is flood hazard analysis; the second is flood loss estimation analysis. Scawthorn et al. (2006a) state that the hazard analysis portion characterizes the spatial variation in flood depth and velocity for riverine or coastal flooding conditions. Structural damage to buildings and infrastructure are estimated through the use of depth-damage curves. Depth-damage curves are plots of floodwater depth versus percent damage, plotted for residential and commercial building types, as well as other structural components (Scawthorn et al. 2006b). The depth-damage curves are intended to give audiences a visual perspective of the extent and severity of structural building damage. Depth-damages can be applied to single buildings; however, they are more reliable as predictors of damage for large groups of buildings (Scawthorn et al. 2006b). Direct and indirect economic losses are then computed and put into figures, tables, and map format. Vehicle and agricultural losses are also calculated, along with building damage estimates.

HAZUS-MH includes both Level 1, 2, and 3 Analyses. Level 1 and 2 Analyses are the most common. The first step in a Level 1 Analysis is to acquire a digital elevation model, LiDAR, or equivalent topographic information. DEMs can be obtained from the U.S. Geologic Survey's National Elevation Dataset (http://edcnts14.cr.usgs.gov/website/-store/viewer.htm). The DEM is used to combine stream discharge data to determine a flood surface elevation. The difference between the ground surface and the flood surface provides the boundary and depth of flooding.

The geographic distribution of the population, buildings, infrastructure, agricultural resources, and vehicles at risk within the flood boundary are determined from "inventory data" included within the Flood Model for the entire U.S. The flood model uses data from the built-in databases on general building stock to estimate direct physical damage on a variety of buildings and their contents. It also takes into account exposure of essential facilities and people to flooding, and the direct and indirect economic losses. For utility lifelines, Level 1 Analysis only examines potable water and wastewater treatment plants. Other utilities have to be assessed in Level 2. My study is different because I will input my own data from the Benson County Tax Assessor's Office.

The Level 2 Analysis involves the Flood Information Tool, an extension available in ArcMap. It allows the user to create depth grids and create a further analysis of damage and loss. In order to use the Flood Information Tool, the user has to have a specific set of data. The list of data includes coastal base flood elevations, digitized floodplain boundaries, and ground elevation data in a grid format (Figure 10).

The main difference between Level 1 and Level 2 Analysis is the amount of user knowledge involved. In a Level 1 Analysis users have the capability to produce flood depth grids along any river reach or shoreline in the United State. In a Level 2 Analysis, the Flood Information Tool develops the grid and users are required to have a level of expertise in GIS and the local flood hazard.

Finally, HAZUS is a valuable tool that communicates the importance of natural hazard risks to communities. For example, relocation, improved land use and planning, structural modifications, and warning systems are all potential flood mitigation responses that can make use of the results of the software. FEMA is constantly improving the

software with downloadable patches online and creating updated versions within the three different models. FEMA intends to make HAZUS the standard tool for spatial assessment of hazard costs and the development of hazard mitigation measures in the future.
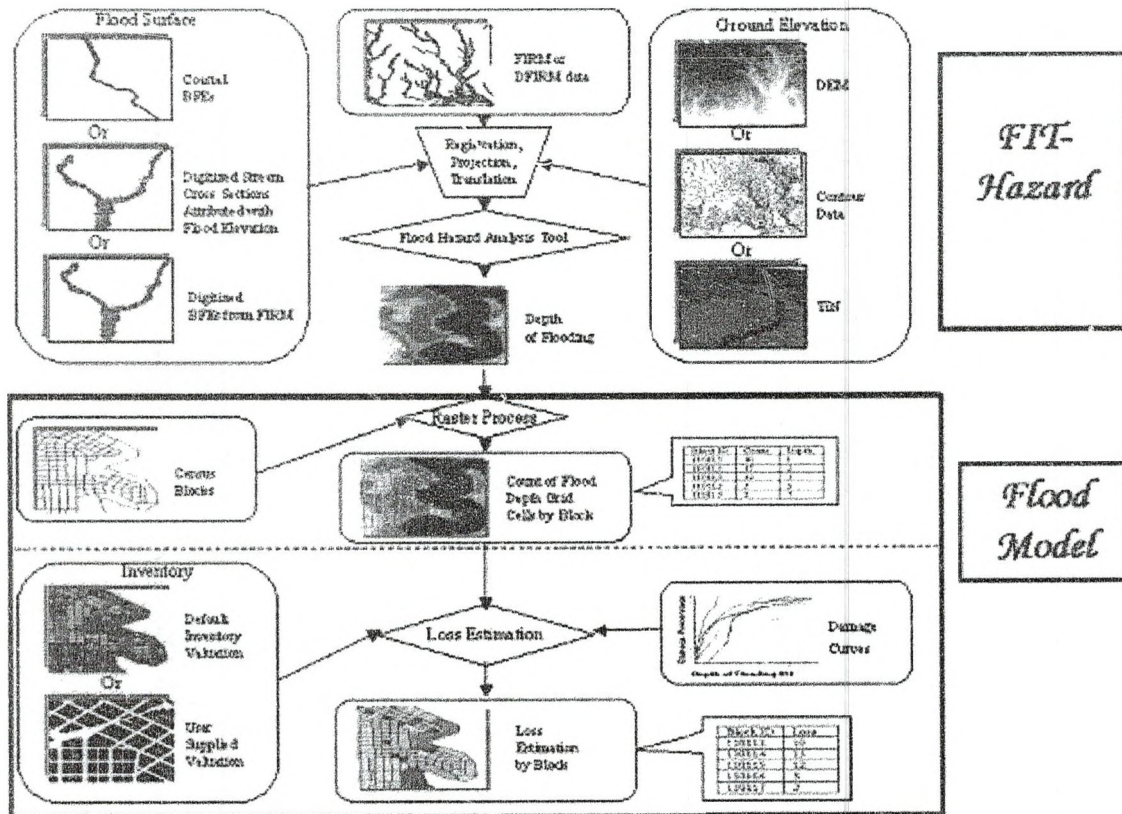

Figure 10. The Relationship of the Flood Information Tool-Hazard with the Flood Model. Source: Scawthorn et al. (2006a).

2.6.4 Previous HAZUS Applications

Research in HAZUS is rapidly expanding to a wide variety of groups. Collaborations between emergency management organizations and universities are becoming increasingly common. Graduate students, emergency services management,

government, and private industry are proving its capabilities through research questions, case studies, and detailed projects.

With regards to the earthquake module, a case study was conducted on Salt Lake County, Utah, that involved a parcel-scale updated methodology to provide building loss estimates for individual homeowners (Moffatt and Cova 2010). It indicated that parcel-level loss estimation techniques provided the necessary information to the homeowner's mitigation decision making.

A multi-year study addressed the risks of an earthquake impacting New York City. Factors like soil information and detailed building inventory were created and/or updated. For example, more than 37,000 buildings were geo-coded from the NYC Mass Appraisal System to specific tracts in Manhattan, with a lesser level of detail in the surrounding region. The soil data was assembled for the New York, New Jersey, and Connecticut area. This HAZUS study produced several earthquake scenarios and their probable consequences (Tantala et al. 2005).

With regards to the flood module, the state of Wisconsin conducted a 100-year flood risk and loss estimate for the entire state. Wisconsin Emergency Management implemented a HAZUS flood analysis in one-fourth of the state's 72 counties. More than 30 users received training from the POLIS Center in Indianapolis, Indiana, at Emergency Management Headquarters in Madison, Wisconsin, and a planner received training at FEMA's Emergency Management Institute in Emmitsburg, Maryland. The State of Wisconsin plans to conduct a second statewide assessment with an updated HAZUS methodology and incorporation of local data, to produce reports, tables, and maps with greater accuracy (FEMA 2005).

The University of Iowa Department of Geography and Johnson County Emergency Management Division of Homeland Security collaborated to provide alternative routes to navigate around the county, in the event of an upcoming flood. The project was in response to forecasts that the Iowa River would meet or exceed record flood levels set in 1993. The HAZUS-MH maps, data, and statistics were used to understand the severity of possible flood damages and to reduce risks in the event of a pending flood. Johnson County Emergency Management Services ran a flood analysis, and then intersected the HAZUS flood boundaries with the local GIS road system and elevation data. This indicated which roads would be closed when the flood occurs, and gave Emergency Management Services a "heads up" to start preparing alternative transportation routes for citizens. HAZUS allowed Emergency Management Services to prioritize efforts and reach as many people as possible (FEMA 2009a).

Jessica Lowther analyzed default data included within HAZUS and compared it to user-supplied building and inventory data for a tornado strike on the Arkansas Tech University campus (FEMA 2009b). She collaborated with the Arkansas Department of Emergency Management. Together, Arkansas Tech University and the Arkansas Department of Emergency Management contributed Level 2 user-supplied data sets for input into CDMS and HAZUS.

Results indicated the tornado models showed more variation than originally predicted. For example, the Level 1 data showed that the majority of the building count was concentrated in one census block, while the Level 2 data showed the building count was concentrated in a neighboring census block. Overall, the project demonstrated that a

Level 2 Analysis, that included user-supplied data, produced more precise results, which

ultimately lead to more efficient hazard mitigation planning (FEMA 2009b).

CHAPTER III

DATA AND METHODS

3.1 Data Sources

I used three main data sources to compile the database that was input into HAZUS and ArcGIS 9.3.1 to produce the lake level elevation maps from 1452 to 1460 feet. The data sources were the December 2008 U.S. Army Corps of Engineers Minnewaukan Structure Elevation sheet, the 2010 Real Property Assessment Book for the City of Minnewaukan, and more than 200 Individual Property Cards from the Benson County Tax Assessor Office. All of the above data were provided by Ellen Huffman, the Tax Assessor for the City of Minnewaukan. The December 2008 U.S. Army Corps of Engineers Structure Elevation sheet, in paper format, is the result of a survey and provides the most current and reliable structure elevation data for the City of Minnewaukan. Attribute for each record in the dataset includes: Structure, Building Type, Address, Street Name (Physical Address), Ground Elevation, First Floor Elevation, and Notes (Figure 11).

A	B	C	D	E	F	G	NOTES	H	I
Entry #	Structure	Building	ADDRESS	ROAD	Ground Elevation	First Floor Elevation	NOTES		PHOTO NM
17	712	House	240	8 AVE. N	1459.84	1462.44			IM004008.JPG

Figure 11. A Sample of the U.S. Army Corps of Engineers Structure Elevation Dataset.

The 2010 Real Property Assessment Book for the City of Minnewaukan, in Notepad digital format, also provides the most up-to-date information regarding residential, commercial, and other buildings. The 2010 Real Property Assessment Book includes the following attributes: parcel ID, address street name, address city, address zip code, farm value, commercial lot, commercial building, residential lots, residential building, total value, assessed value, and elderly citizen and veteran discount (Figure 12). For the purpose of my study, I concentrated on residential and commercial buildings, and assessed value.

			FARM VALUE	COM LOT	COM BLDG	RES LOT	RES BLDG	TOTAL VALUE	ASSD VALUE	TAXABLE VALUE	SR-CITZN VET-SERV
45 0001 10871 000	AVG./ACRE-					2,230	-3,428	45,658	22,829	2,055	
	MWC 5										
	FM	RA									
311 W AVE N	NW	CA									
MINNEWAUKAN ND 58351	EX	TA									
LOTS 4, 5 & 6 BLK 26 ORIGINAL MINNEWAUKAN CITY											

Figure 12. A Sample of the 2010 Real Property Assessment Book for the City of Minnewaukan.

A sample record from the 2010 Real Property Assessment Book is shown in Figure 12. The name of this property is Parcel ID 45-1-10871. In this example the residential lot has a value of $2,230, while the residential building has a value of $43, 428. The total value of both the residential lot and residential building is $45,658. The assessed value is 50% of the total value, which for this example is $22,829. The taxable value is $1,033 times the mill rate. The mill rate is the dollars in taxes paid by the owner to Benson County. For this property, the taxable value is $2,055. Other factors that contribute to county tax collections include a 9% tax on residential buildings and 10% tax on commercial buildings. Notice that the farm value, commercial lot, commercial

building, senior citizen and veteran service discount slots are left blank. This property, Parcel ID 45-1-10871, is strictly a residential property. For the database, the key factors I complied were the building value (residential or commercial), and assessed value.

The Individual Property Cards took the most time and effort to retrieve information from. The property cards were in paper format, and only viewable in the Tax Assessor's Office in the Benson County Courthouse in Minnewaukan. This involved multiple trips out to Minnewaukan to scan the paper property cards into a digital format, so this information could later be organized into a database. The database was eventually sent out to FEMA, the U.S. Army Corps of Engineers, and anyone requesting it in the Devils Lake GIS Coordination Group. The information I used from the property cards were: square footage, number of stories, foundation type, basement, notes, property card link, and property card pages (Figure 13). Interior Detail, Use, and Construction provided valuable information, but were not categories in my database.

Figure 13. A Sample of Page 2 of One Individual Property Card.

3.2 Database

The database started as a blank Microsoft Excel spread sheet and then converted

into a Microsoft Access geodatabase that included FEMA's Minnewaukan footprint data,

Benson County Tax Assessor property card data, 2010 Real Property Assessment Book

for the City of Minnewaukan, and the December 2008 U.S. Army Corps of Engineers

Structure Elevation (Table 2).

Not all of the property cards provided all of the above information, which is common for a site-specific analysis. It is extremely rare to have all the attributes for your data in ready-to-use form. Estimations were calculated to fill in the missing gaps in the database. The property cards were an invaluable source of information with regards to building statistics, and contributed to the accuracy of the lake level elevation maps from 1452 to 1460 feet. However, there was an assigned methodology for calculating missing gaps in first floor elevations (first floor height), area (square feet), and building value that was created by Jesse Rozelle, a Risk Analyst/GIS Coordinator in FEMA Region VIII.

To calculate gaps in the first floor elevations (first floor height), the user must derive the elevation above sea level in feet for the exact point of all structures using the "extract values to points" tool in ArcGIS Toolbox. The field is called LiDAR Elevation in the database. Then, the rows that do not have first floor elevation values are highlighted. To compute the first floor elevations when there is no recorded value, the user must add the number of feet above the ground for that foundation type to the elevation value from the LiDAR. All of the buildings in Minnewaukan had a foundation type of 4, representing basement, to account for worst-case scenario at different lake level elevations (Jesse Rozelle, personal communication, July 6, 2010). HAZUS-MH estimates the first floor elevation to be 4 feet above the ground (FEMA 2009c). Therefore, the LiDAR elevation point is calculated and 4 feet is added to the elevation of the structure for the new first floor height. To differentiate which first floor elevations are calculated and which ones were U.S. Army Corps of Engineers elevations, a new column called "Computed First Floor" was created, with a Yes or No as the text.

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Table 2. Names of the Columns in the Database.

OID_1	INSIDE1465	GPSX
OBJECTID_1	IDENTIFIER	GPSY
PARCEL ID	INSIDE1450	NUMBEROFST
ADDRESS_ST	TOWNSHIP	CONSTRUCTI
ADDRESS_CITY	SECTIONS	QUALITYTYP
ADDRESS_STATE	QUAD	FFEDELT
ADDRESS_ZIP	FIELDDATA	ESTBASEMENT
DWELLING_SQ_FOOTAGE	QUADNAME	FFE
NUM_OF_STOR	QUADRANTS	FFE_HAZUS
FOUNDATION	LIDARNODAT	GROUNDELEV
FOUNDATION_TYPE	CHECK1465	DIRECTION
Basement2	X	BASEMENT
GROUND_ELEV	Y	FUELSTORAG
FIRST_FLOOR_ELEV_29	CHECK1450	GARAGE
FIRST_FLOOR_ELEV_88	BUILDINGNU	LTH
CONTENTS_COST	UNIQUE	WTH
BUILDING_TYPE	SOURCETHM	GARAGETYPE
NOTES2	ACRES	GARAGETTA
PROPERTY_CARD_LINK	OID	FAIRMARKET
NUM_OF_PROPERTY_CARDS	ID_1	FLOODINSUR
Sqft2010	BUILDING_1	RELOCATEDF
Lidarelev	STRUCTURE1	RELOCATEDH
ComputedFirstFlr	STRUCTURE	POLICYAMOUNT
ComputedArea	RESIDENTIAL	NOTES
SqFt2010Int	OCCUPANCY	LAT
ComputedValue	DESIGNLVL	LNG
BSMTSqFt	SUBDIVISON	SEWER
ComptdContent	ROAD	PUBWATER
ID1	AVEST	WELLS
OBJECTID_12	TOWNSHIP_1	SECTION
OBJECTID	CITY	DATMOD
ID	COUNTY	DATESURVEY
COMMENT	SLN	IdTest
INSIDEDL	STATE	Shape_Leng
NOLIDAR	ZIP	Shape_Area
NOORTHO	BUILDINGTY	Elevation

Gaps in area (square feet) are calculated by joining my database to the FEMA Minnewaukan Footprints database. The databases are joined by selecting a common identifying field, which is owner's last name. Then FEMA Minnewaukan Footprints database is now combined with my database, and box show attributes in the list is checked. After selecting the field owner's last name om the database and keeping all records, the spatial join is complete. The user now calculates geometry by selecting square feet for all the building structures. The footprint derived square footage is labeled "SqFt2010" in the database. Records that do not have values are highlighted and populated with the new square footage values from the new computed column (Jesse Rozelle, personal communication, July 6, 2010).

A comparison is done between the property card square footage and footprint derived square footage. These values are different because the property card square footage only included the building, not attics, garages, patios, etc, and the method of measurement varied depending on the structure. The property card square footage is kept in the database for record, but the footprint derived square footage is used for the economic analysis.

To calculate gaps in the building value, the user must follow a detailed description listed in the HAZUS Flood Technical Manual, Section 14-2. Building values are often the most difficult gaps to calculate. The formula is:

Building value per structure = Structure square footage * (value per square foot, adjusted for Consumer Price Index * county modification factor) (FEMA 2009c).

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The structure square footage is derived from the SqFt2010 column. The value per square foot is derived from page 384-385 of the HAZUS Flood Technical manual (Table 3). The Means Cost/SF (2006) and Root Square Means average costs per square foot for each HAZUS occupancy type. The 2006 values are converted to 2010 using an inflation adjustment tool (U.S. Bureau of Labor Statistics 2010). To use the CPI calculator, the original value for the occupancy, the original price date, and the current year are entered. All of the occupancies followed this methodology, except RES1 (Single Family Dwelling). The RES1 formula is:

RES1 Building Value = ((SqFt2010 * (cost per SF adjusted for Consumer Price Index * County Modification factor)) + (BsmtSqFt * (Basement Cost per SF adjusted for CPI * County Modification Factor))

Table 3. The Default Full Replacement Cost Models. Source: HAZUS Flood Technical Manual (FEMA 2009c).

HAZUS Occupancy Class Description		Sub-category	Means Model Description (Means Model Number)	Means Typ Size	Means Cost/SF (2006)
OCC Code	OCC Description	OCC sub-class			
RES1	Single Family Dwelling	See Table 14-2			
RES2	Manufactured Housing	Manufactured Housing	Manufactured Housing Institute, 2004 average sales price and size data for new manufactured home (latest data available)	1,625	$35.75
RES3A	Multi Family Dwelling – small	Duplex	SFR Avg 2 St., MF adj. 3000 SF	3,000	$79.48
RES3B		Triplex/Quads	SFR Avg 2 St., MF adj. 3000 SF	3,000	$86.60
RES3C	Multi Family Dwelling – medium	5-9 units	Apt, 1-3 st. 8,000 SF (M.010)	8,000	$154.31
RES3D		10-19 units	Apt., 1-3 st. 12,000 SF (M.010)	12,000	$137.67
RES3E	Multi Family Dwelling – large	20-49 units	Apt., 4-7 st., 40,000 SF (M.020)	40,000	$135.39
RES3F		50+ units	Apt., 4-7 st., 60,000 SF (M.020)	60,000	$131.93
RES4	Temp. Lodging	Hotel, medium	Hotel, 4-7 st., 135,000 SF (M.350)	135,000	$132.52
RES5	Institutional Dormitory	Dorm, medium	College Dorm, 2-3 st, 25,000 SF (M.130)	25,000	$150.96
RES6	Nursing Home	Nursing home	Nursing Home, 2 st., 25,000 SF (M.450)	25,000	$126.95
COM1	Retail Trade	Dept Store, 1 st	Store, Dept., 1 st., 110,000 SF (M.610)	110,000	$82.63
COM2	Wholesale Trade	Warehouse, medium	Warehouse, 30,000 SF (M.690)	30,000	$75.95
COM3	Personal and Repair Services	Garage, Repair	Garage, Repair, 10,000 SF (M.290)	10,000	$102.34
COM4	Prof./ Tech./Business Services	Office, medium	Office, 5-10 st., 80,000 SF (M.470)	80,000	$133.43
COM5	Banks	Bank	Bank, 1 st., 4100 SF (M.050)	4,100	$191.53
COM6	Hospital	Hospital, medium	Hospital, 2-3 st., 55,000 SF (M.330)	55,000	$224.29

Some of the properties were tax exempt. This posed a challenge because any property that is tax exempt did not have square footage, basement area, foundation type, etc. listed. Another challenge was that most of the addresses in the 2010 Real Property Assessment Book were listed as P.O. Boxes. For the study, physical addresses were

needed. The spatial join in ArcMap 9.3.1 solved this issue, and resulted in P.O. Boxes matched with Physical Addresses. After I input all the U.S. Army Corps of Engineer Structure Elevation data, the Tax Assessor Property Card information, and Tax Assessment Book information, the database was ready for QA/QC. The database was QA/QC-ed in Microsoft Access geodatabase format by FEMA (Jesse Rozelle, personal communication). Next, I imported the geodatabase as a user-defined table in HAZUS. The user-defined tables convert the Microsoft Access geodatabase columns into data that HAZUS recognizes and uses to conduct the flood analyses. I assigned the fields with the database column names. Most of these were self-explanatory, except that contents cost was calculated as 50% of the building value. For example, PARCEL_ID represents a property's Parcel ID. ADDRESS_ST, ADDRESS_CITY, ADDRESS_STATE represent the property address in street, city, and state.

3.3 The HAZUS Model

The first step is to download HAZUS MR4 Patch 1 from FEMA (2009e), then download HAZUS MR Patch 2 from FEMA (2009f). These patches fix more than 66 bugs when HAZUS-MH MR4 first came out. Then the user clicks on HAZUS-MH and creates a study region. I named the study region "Minnewaukan1452" and added in an optional description. The Flood Hazard Type was selected. The aggregation level was set to Census Block. This defines the procedure and level of geographic detail by which the study is defined. Next, the state of North Dakota was selected, with a county selection of Benson County.

Then, I selected two Census Tracts – 3800594100, with 60 selected blocks, and 38005956600, with 2 selected blocks for the analysis, then hit finish. The Minnewaukan footprints shapefile was added in the "Show Map" section to determine which Census Blocks contained city buildings. The goal is to keep the study region as small as possible for quicker processing. HAZUS then created the study region. The software indicates the overall progress with aggregating the study region in one bar and the specific entities in a second bar, shown simultaneously. HAZUS aggregates 13 types of study region data (FEMA 2009d). Now the region aggregation is successful. The user must "Open a region" and select the newly created study region with the correct hazard to have it opened up in ArcMap 9.3.1. There will be a HAZUS-MH Toolbar added into ArcMap 9.3.1, that contains: Inventory, Hazards, Analysis, and Results. There is a Study Region Wizard and Switch Hazard option in ArcMap as well.

After the study region was set up, I closed HAZUS and opened up Microsoft SQL Server 2005, SQL Server Management Studio Express. Then I connected to the server, clicked on Databases, then right-clicked New Query. Next, I cut and pasted the following code (Figure 14) and hit Execute. The command(s) were completed successfully; the query was executed successfully.

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```
if exists (select 1
        from  sysobjects
        where  id = object_id('absv_UDEFlty')
        and   TYPE = 'V')
  drop view absv_UDEFlty
go


create view absv_UDEFlty as
select
  hz.UserDefinedFltyId, [Name], Cost, hz.Occupancy,
  --hz.NumStories,
  'Rise'=case
    when hz.Occupancy like 'RES%' and hz.NumStories = 9 then 'S' -- RES1, RES2
    when hz.Occupancy like 'RES3%' and hz.NumStories between 1 and 2 then '1' --
RES3A, RES3B, RES3C, RES3D, RES3E, RES3F
    when hz.Occupancy like 'RES3%' and hz.NumStories between 3 and 4 then '3' --
RES3A, RES3B, RES3C, RES3D, RES3E, RES3F
    when hz.Occupancy like 'RES3%' and hz.NumStories >= 5          then '5' -- RES3A,
RES3B, RES3C, RES3D, RES3E, RES3F
    when (hz.Occupancy not like 'RES%' or hz.Occupancy in ('RES4', 'RES5', 'RES6'))
and hz.NumStories between 1 and 3 then 'L' -- non-RES
    when (hz.Occupancy not like 'RES%' or hz.Occupancy in ('RES4', 'RES5', 'RES6'))
and hz.NumStories between 4 and 7 then 'M' -- non-RES
    when (hz.Occupancy not like 'RES%' or hz.Occupancy in ('RES4', 'RES5', 'RES6'))
and hz.NumStories > 7 then 'H' -- non-RES
    else cast(hz.NumStories as char(1)) -- anything else, take the first char
  end,
  --fl.FoundationType
  'Basement'=case
    when fl.FoundationType = 4 then 1 -- basement
    when fl.FoundationType in (1, 2, 3, 5, 6, 7) then 0 -- no basement
    else -1 -- error
  end,
  BldgDamageFnID, ContDamageFnID, FirstFloorHt, FloodProtection
from
  hzUserDefinedFlty hz, -- UserDefinedFltyId, Occupancy, NumStories
  flUserDefinedFlty fl -- UserDefinedFltyId, FoundationType
where hz.UserDefinedFltyID = fl.UserDefinedFltyID
-- select * from absv_UDEFlty
go
```

Figure 14. A Microsoft SQL Server 2005, SQL Server Management Studio Express Query.

The user must define the type of Flood Hazard. I selected Riverine because of the customized depth grids provided by FEMA. The Minnewaukan database is then ready to be imported into HAZUS-MH as a User Defined Table. I clicked on Inventory, then right clicked on User-Defined Facilities. I selected Import, navigated to the Minnewaukan Table geodatabase, clicked on Minnewaukan Table, then hit OK. Next, I had to match up the Target Fields with the Source Fields (Table 4).

Table 4. Assigned Fields with Database Column Names.

Target Field	Source Field
Name	OWNER_LAST_NAME
Address	ADDRESS
City	CITY
State	STATE
ZipCode	ZIP
Occupancy	OCCUPANCY
Foundation Type	FOUNDATION_TYPE
First Floor Height	FFE_HAZUS
Latitude	LAT
Longitude	LNG
NumStories	NUMBER_OF_STOR
DesignLvl	DESIGNLVL
Cost	BUILDING_VALUE
Contents Cost	CONTENTS_COST
Area	DWELLING_SQ_FOOTAGE

After matching up the Target Fields with the Source Fields, HAZUS "thinks" for a while and imports the database into the User-Defined Facilities table. Now is a good time to click Save. Now the user must import the Flood Depth Grid with corresponding lake level elevation. I clicked Hazard, User Data, Depth Grids, then browsed to the

corresponding data path where the depth grids are located. This attaches the Depth Grid with the study region. Then I clicked Set Parameters to Feet and a 100-year return period. Next, I clicked Hazard and created a new scenario. This allows the user to select the grid and save the selection. Next, I clicked Hazard, Riverine, and Delineate Floodplain with a single return period. Now the depth grid is integrated into the study region and is showing varying depths and lake extent at Minnewaukan.

To derive statistics, I clicked Analysis, Run, and only selected the User Defined Facilities. Then I clicked on Results, View Current Scenario Results by, and clicked on the name of the scenario. Next, I clicked on Results, User Defined Facilities, and opened the table. Then I selected Building Loss U.S. Dollars, and clicked Map. From there I right-clicked on the User Defined Facilities personal geodatabase and exported the data into a shapefile. Then selected the building dollar loss column and left-clicked Statistics. From there, I took the sum of building dollar losses and incorporated that number into my analysis. The same process is followed for number of buildings damaged. Next, I clicked on Properties, Symbology, Quantities, Graduated Symbols. There I selected the value as BuildingLossUS and nominalization as none. This same process was repeated for the rest of the increments from 1452 to 1460 feet.

CHAPTER IV

ANALYSIS AND DISCUSSION

4.1 Lake Level Inundation Maps

The location of each damaged building is shown in a series of maps depicting a

systematic increase in lake level from WSE 1452 to 1460 feet (Figure 15). Graduated

symbols, in the form of purple circles, were used to depict the location and amount of

building dollar loss on a map overlaid with the ESRI 2009 World Imagery and the

FEMA-delineated WSE flood depth grid in ArcGIS 9.3.1. This provides a spatial

perspective of Minnewaukan (Figure 15a) and the surrounding Devils Lake region

(Figure 15b). I produced the City of Minnewaukan and surrounding Minnewaukan region

maps for each WSE elevation from 1452 to 1460 feet.

WSE 1452 feet (Figure 15a) shows that the highest building dollar losses are

located on the northern part of the city, with low building dollar losses on the eastern part

of the town. Critical infrastructure includes the school, courthouse, grocery store, etc. At

WSE 1452, the critical infrastructure is intact, and Main Street is in good condition. The

zoomed-out view of the surrounding Minnewaukan region at WSE 1452 feet (Figure 15b)

indicates the low depths surrounding Minnewaukan, with a unique shoreline north and

south in Benson County. WSE 1453 feet (Figure 15c) shows that there is an increase in

number of buildings damaged and distribution of building dollar losses throughout the

northern and northwestern parts of the city. All critical infrastructure is intact and Main Street is still in good condition. The zoomed-out view of the surrounding Minnewaukan region at WSE 1453 feet (Figure 15d) indicates a slight increase with the low depth and increased variation in the unique shoreline north and south in Benson County. WSE 1454 feet (Figure 15e) shows the north-northwestern part and eastern shore of the city has an increased number of buildings and building dollar loss. Water is starting to gather on the southern part of the city as well. Critical infrastructure is intact, but rising water is threatening the school. Main Street has more water along the road ditches, but is still in good condition. The zoomed-out view of the surrounding Minnewaukan region at WSE 1455 feet (Figure 15f) shows another increase from the previous shoreline and more areas of gathered water in the farm fields to the north and south of the City of Minnewaukan.

WSE 1455 feet (Figure 15g) shows a significant increase in building dollar losses and buildings scattered throughout the north-northwestern, eastern, and southern parts of city, compared to previous results for WSE 1454 feet. WSE 1455 feet is the first elevation where Devils Lake starts to encircle and close-in on the city. Critical infrastructure is intact; however, the school parking lot is now flooded. Main Street is still trafficable, but has increased amounts of water along the side ditches. The zoomed-out view of the surrounding Minnewaukan region at WSE 1455 feet (Figure 15h) indicates a significant increase the shoreline irregularity and the outer parts of Devils Lake encompassing more land. WSE 1456 feet (Figure 15i) shows an increase in the number of buildings damaged and that Main Street connecting to Highway 281 is surrounded by water. This is vital because Main Street is one of the major transportation roads for the

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City of Minnewaukan. Although there are increased amounts of water off Main Street at the entrance of Minnewaukan, Main Street is still trafficable. The northwestern and southern parts of the city show the most new building dollar losses; however, building dollar losses are occurring at all sections where water is infringing on the core of the city. All critical infrastructure, except the school, are intact. The school becomes submerged at WSE 1456 feet. The zoomed-out view of the surrounding Minnewaukan region at WSE 1456 feet (Figure 15j) shows a noticeable increase in the shoreline, extending farther west, with the City of Minnewaukan beginning to form a peninsula.

WSE 1457 feet (Figure 15k) shows another increase in building dollar loss and number of buildings damaged. The map shows that Main Street is completed submerged at the entrance of the city. This cuts off a major transportation route, a point where partial relocation of the city becomes necessary. Devils Lake continues to encircle the city, with new and expanding water showing up on the southern side of the city. All critical infrastructure are intact, except the school. The zoomed-out view of the surrounding Minnewaukan region at WSE 1457 feet (Figure 15l) indicates a shoreline increase to the west of the City of Minnewaukan and north where a gap exists in the farmland. WSE 1458 feet (Figure 15m) shows a significant increase of water submerging larger sections of Main Street and a significant increase in building dollar loss and number of buildings along the south and southeastern parts of the city. Critical infrastructure is in good condition, except the school. Since Main Street is submerged, there is no easy transportation in and out of the city to reach the critical infrastructure. Partial relocation becomes an especially necessary option at WSE 1458 feet. The zoomed-out view of the

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surrounding Minnewaukan region at WSE 1458 feet (Figure15n) shows the westward expansion of the Devils Lake shoreline. It shows shallow depths taking up more farmland north of Minnewaukan and encircling more land around the city itself.

WSE 1459 feet (Figure 15o) shows that Main Street and nearby farm fields are now part of the lake. There is a significant increase in the number of buildings damaged and building dollar losses at all corridors of the city. All critical infrastructure is either cut-off from transportation access or submerged. Partial relocation is a highly recommended option at WSE 1459 feet. The zoomed-out view of the surrounding Minnewaukan region at WSE 1459 feet (Figure 15p) shows a more defined lake area immediately south of Minnewaukan and straight north near the pocket of farmland. WSE 1460 feet is a worst-case scenario for Minnewaukan. At WSE 1460 feet (Figure 15q) Minnewaukan becomes an island, nearly completely surrounded by Devils Lake. All critical infrastructure is either cut-off from transportation access or completely submerged. Partial relocation is a highly recommended option at WSE 1460 feet. There is the maximum building dollar loss and number of buildings damaged at every corridor of the city. The zoomed-out view of the surrounding Minnewaukan region at WSE 1460 feet shows a solid lake expansion westward, swallowing more acres of farmland and causing relocation to become necessary for Minnewaukan (Figure 15r).
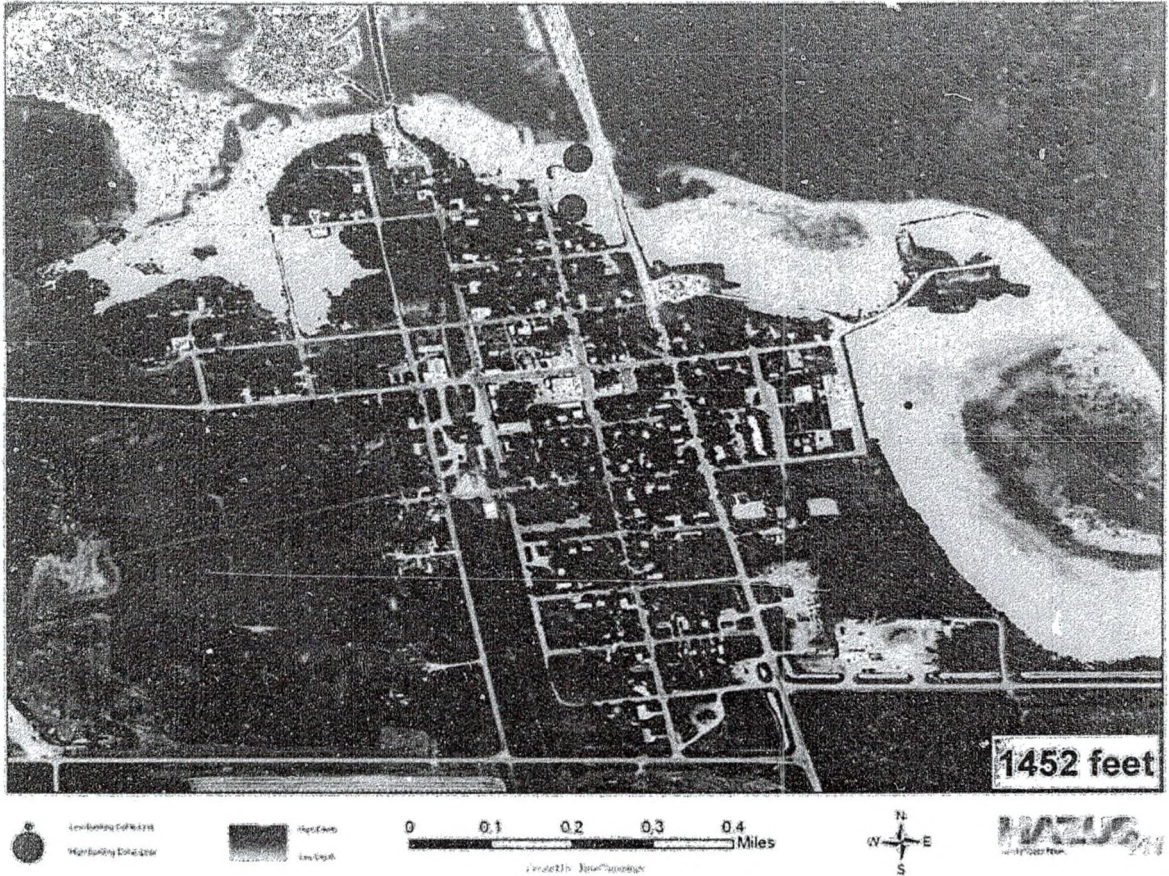
Figure 15a. An Aerial View of the City of Minnewaukan at Devils Lake WSE 1452 Feet.
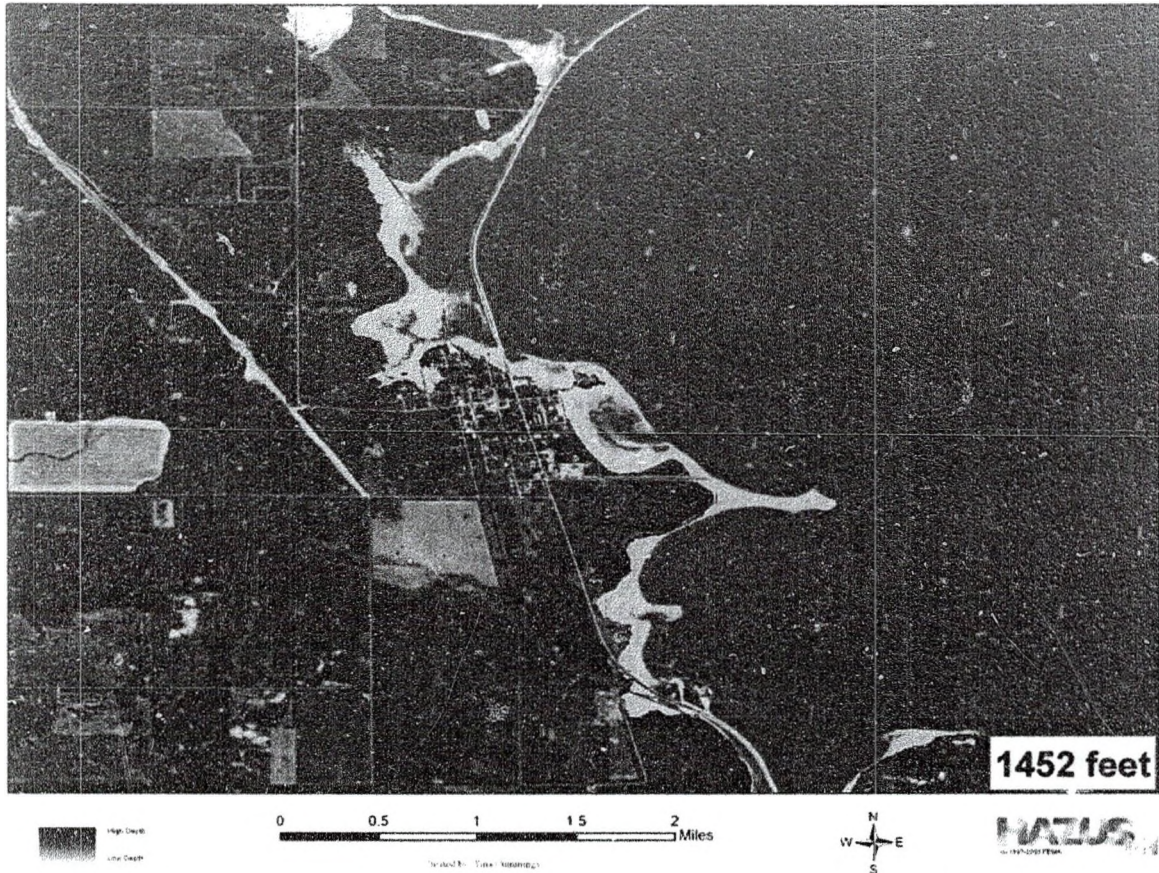
Figure 15b. An Aerial View of the City of Minnewaukan and Surrounding Areas at
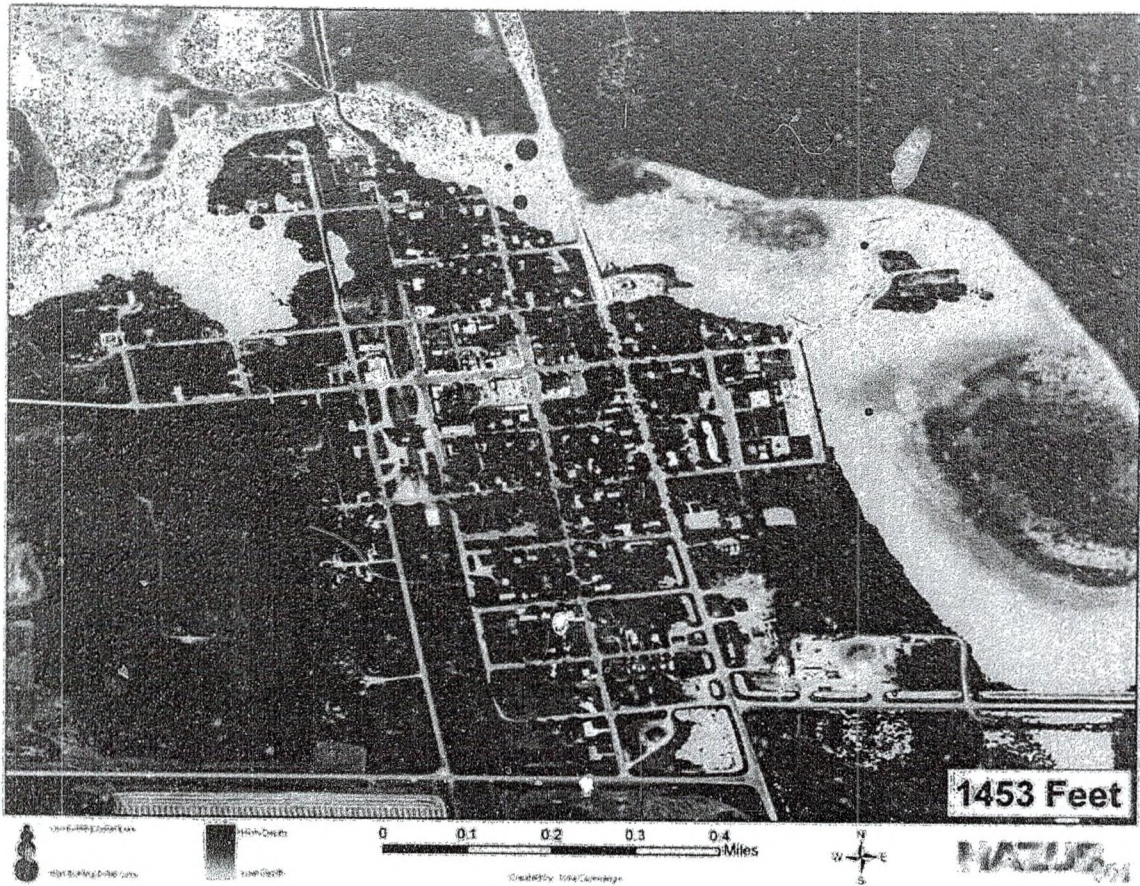Devils Lake WSE 1452 Feet.

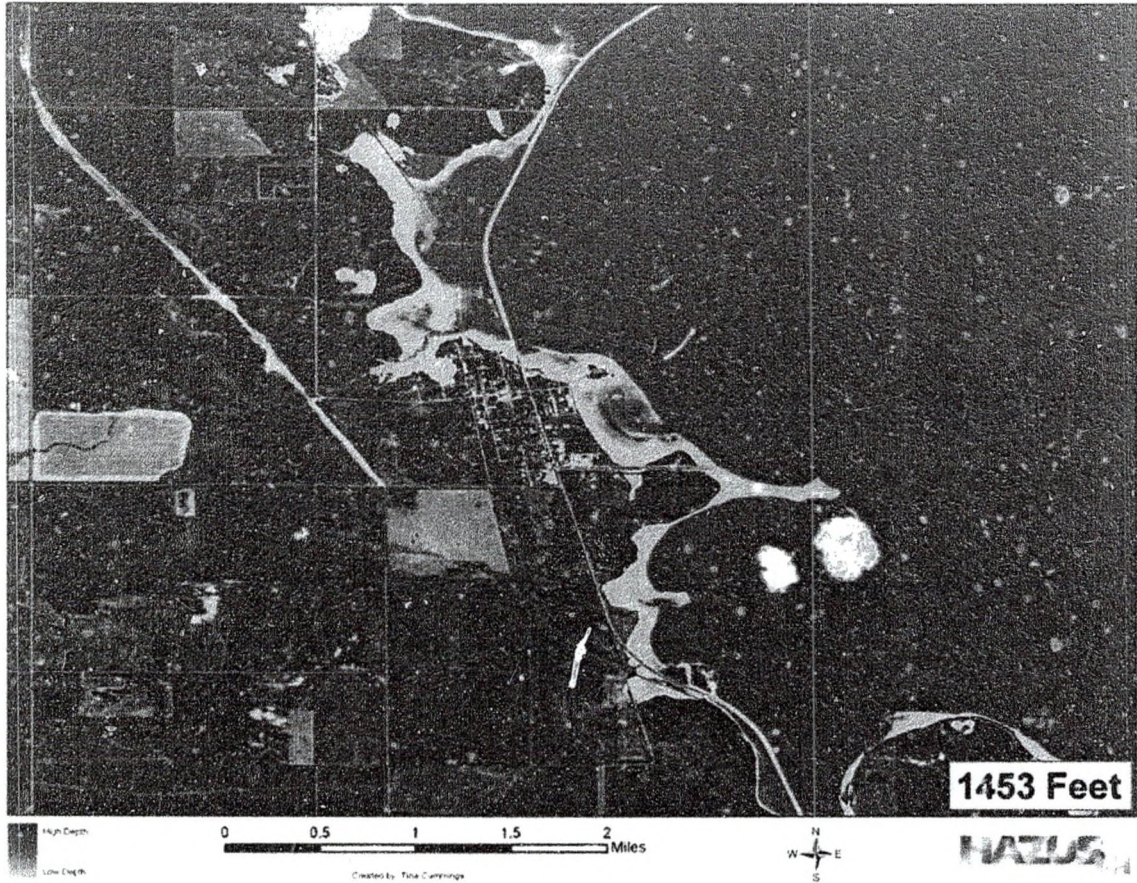Figure 15c. An Aerial View of the　　y of Minnewaukan at Devils Lake WSE 1453 Feet.

Figure 15d. An Aerial View of the City of Minnewaukan and Surrounding Areas at Devils Lake WSE 1453 Feet.
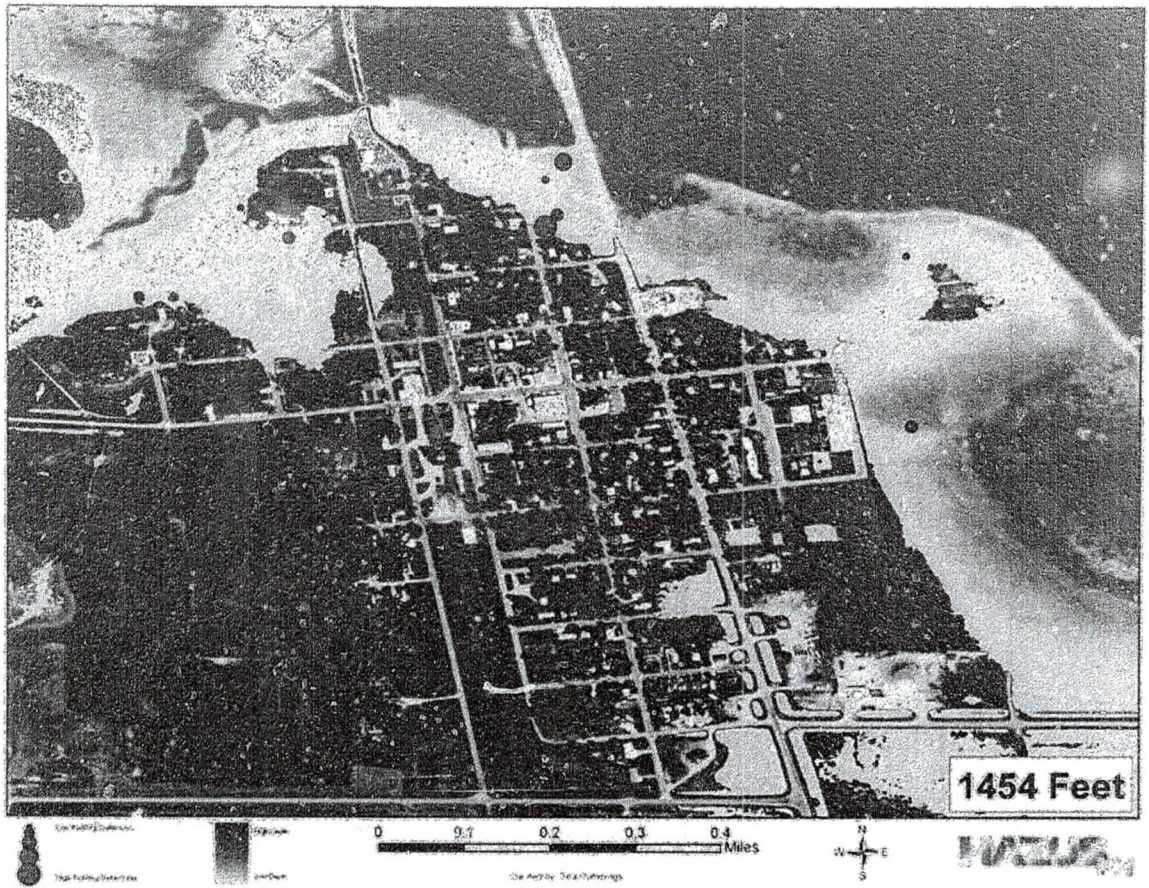
Figure 15e. An Aerial View of the City of Minnewaukan at Devils Lake WSE 1454
Feet.

Figure 15f. An Aerial View of the City of Minnewaukan and Surrounding Areas at Devils Lake WSE 1454 Feet.

Figure 15g. An Aerial View of the City of Minnewaukan at Devils Lake WSE 1455 Feet.

Figure 15h. An Aerial View of the City of Minnewaukan and Surrounding Areas at Devils Lake WSE 1455 Feet.

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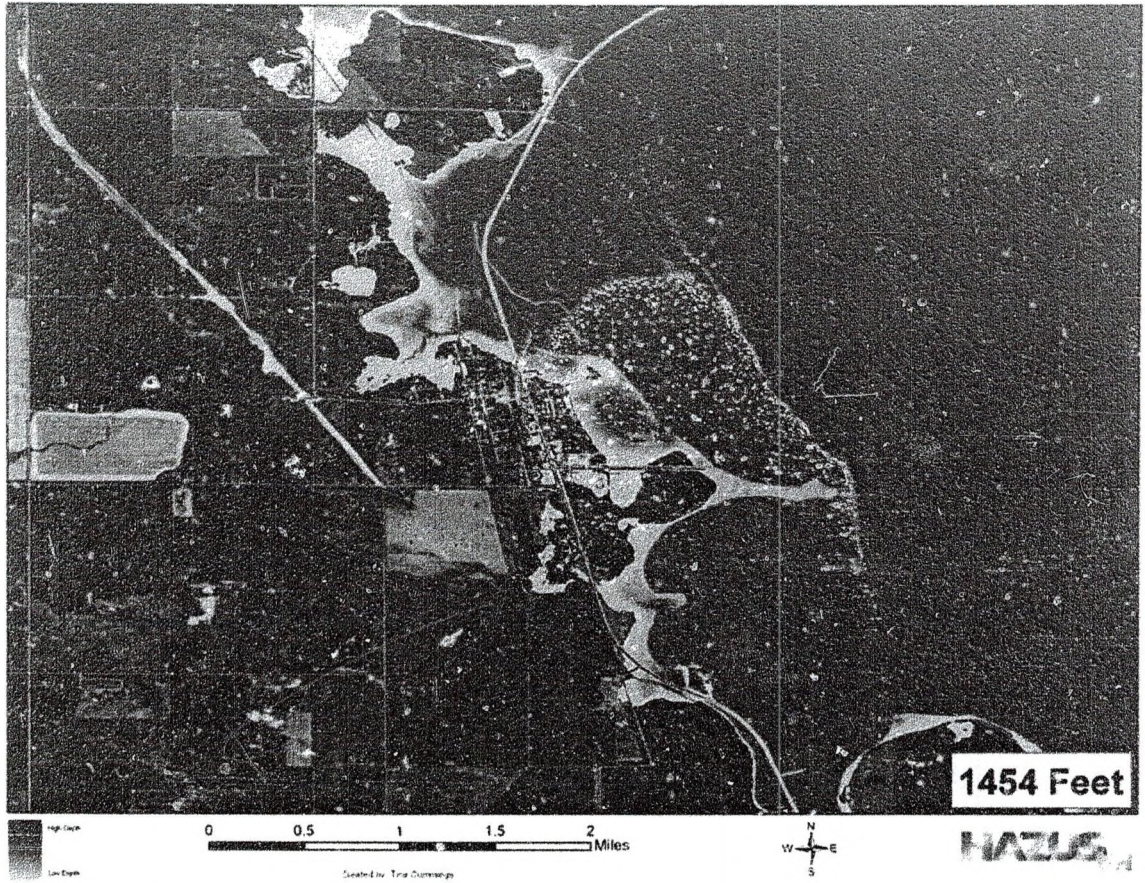Figure 15i. An Aerial View of the City of Minnewaukan at Devils Lake WSE 1456
Feet.

Figure 15j. An Aerial View of the City of Minnewaukan and Surrounding Areas at Devils Lake WSE 1456 Feet.
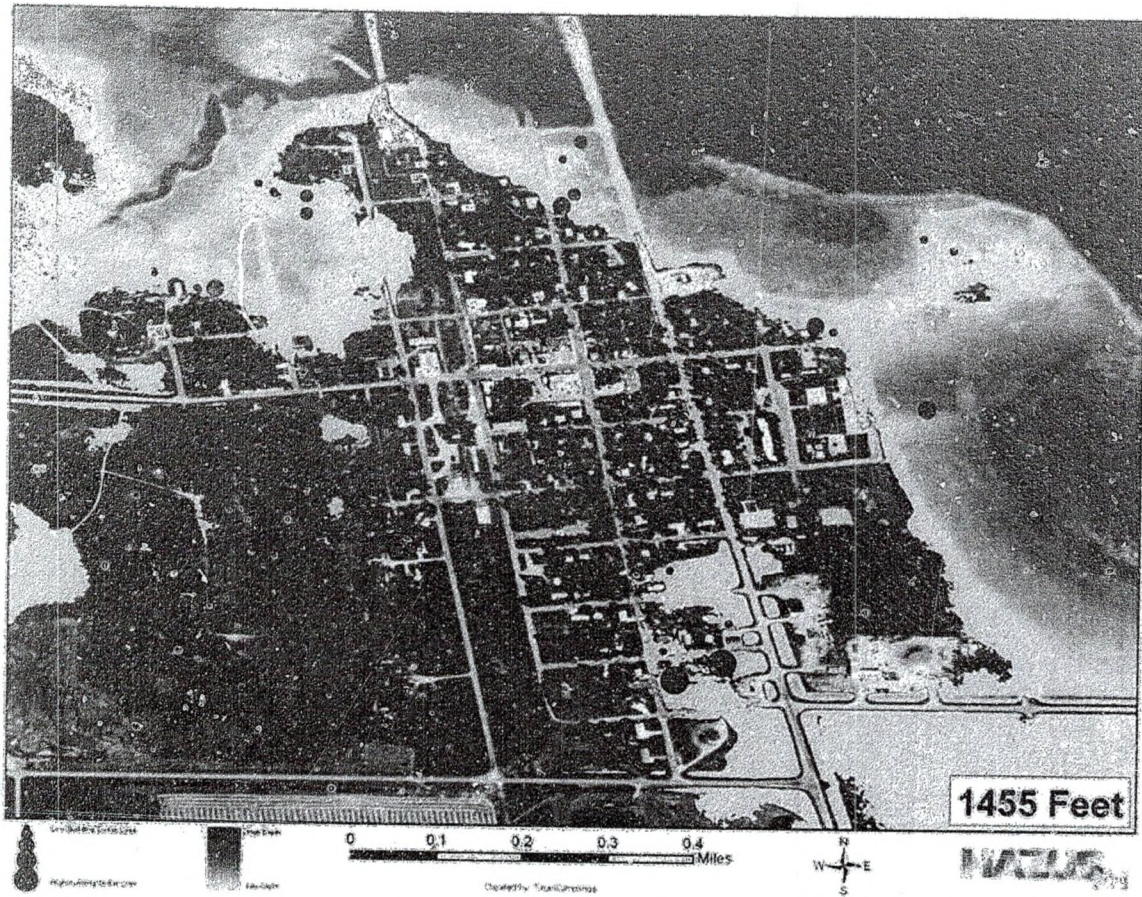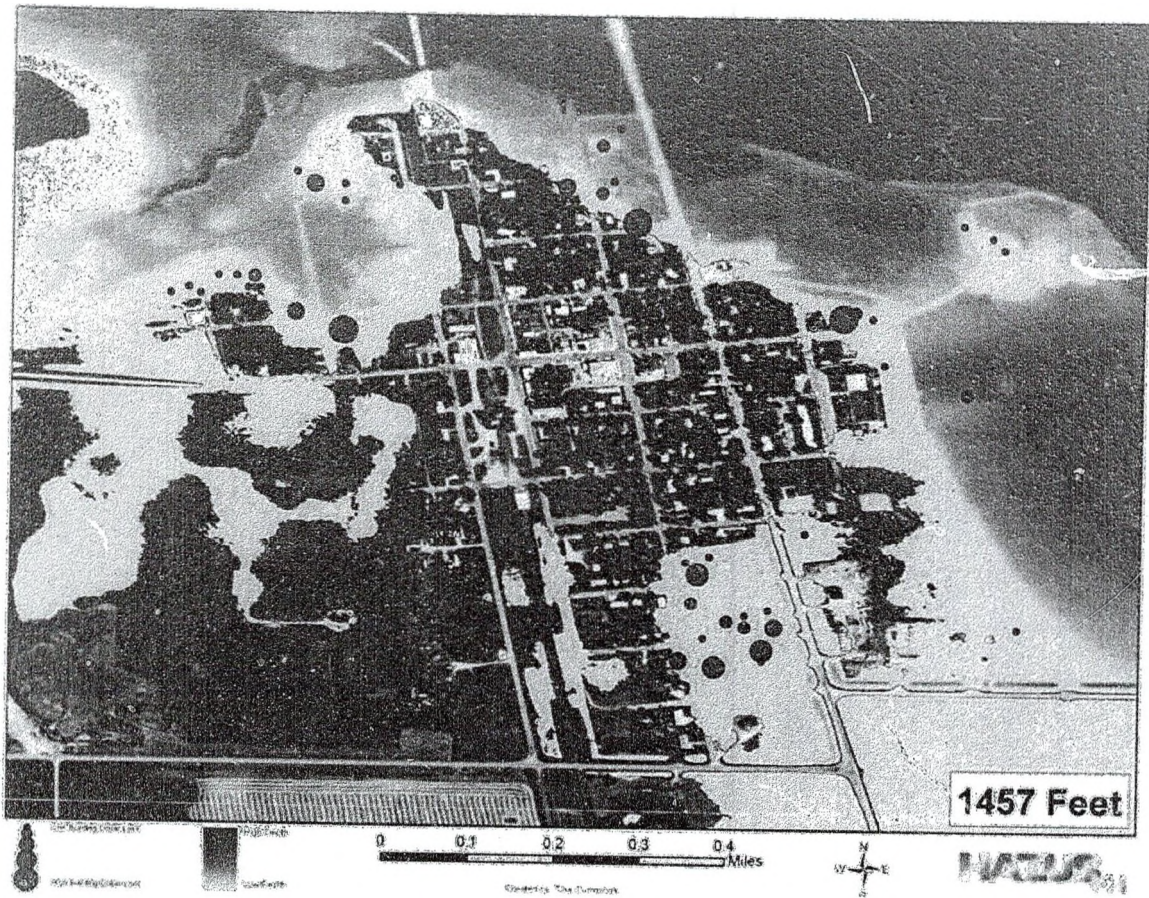
Figure 15k. An Aerial View of the City of Minnewaukan at Devils Lake WSE 1457 Feet.
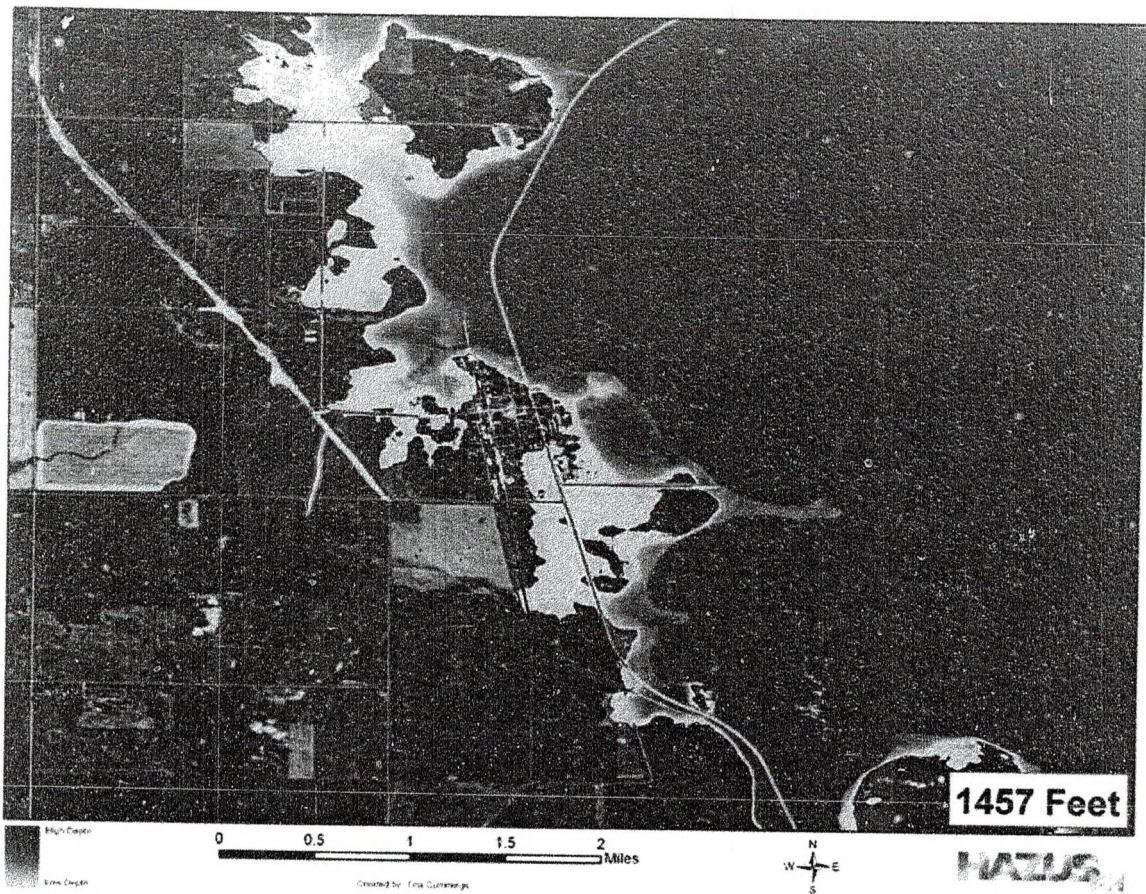
Figure 15l. An Aerial View of the City of Minnewaukan and Surrounding Areas at Devils Lake WSE 1457 Feet.

Figure 15m. An Aerial View of the City of Minnewaukan at Devils Lake WSE
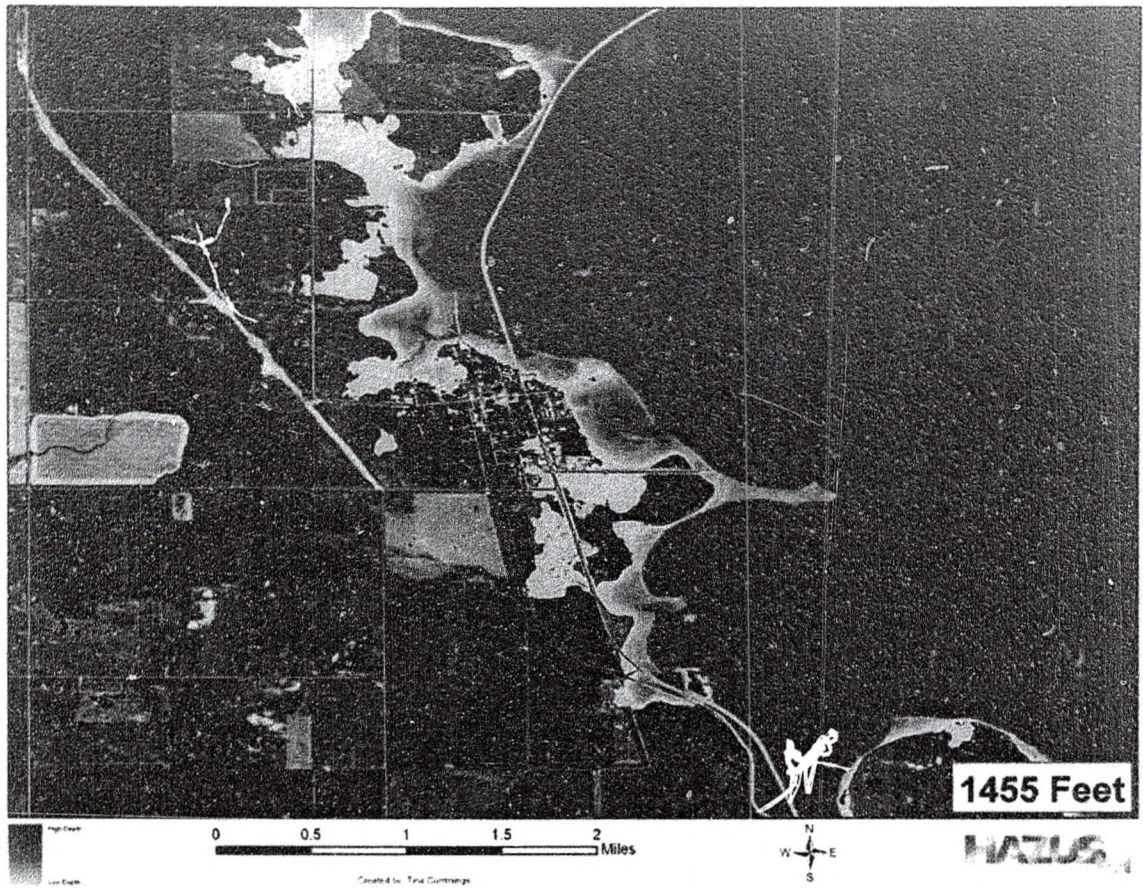1458 Feet.

Figure 15n. An Aerial View of the City of Minnewaukan and Surrounding Areas at Devils Lake WSE 1458 Feet.
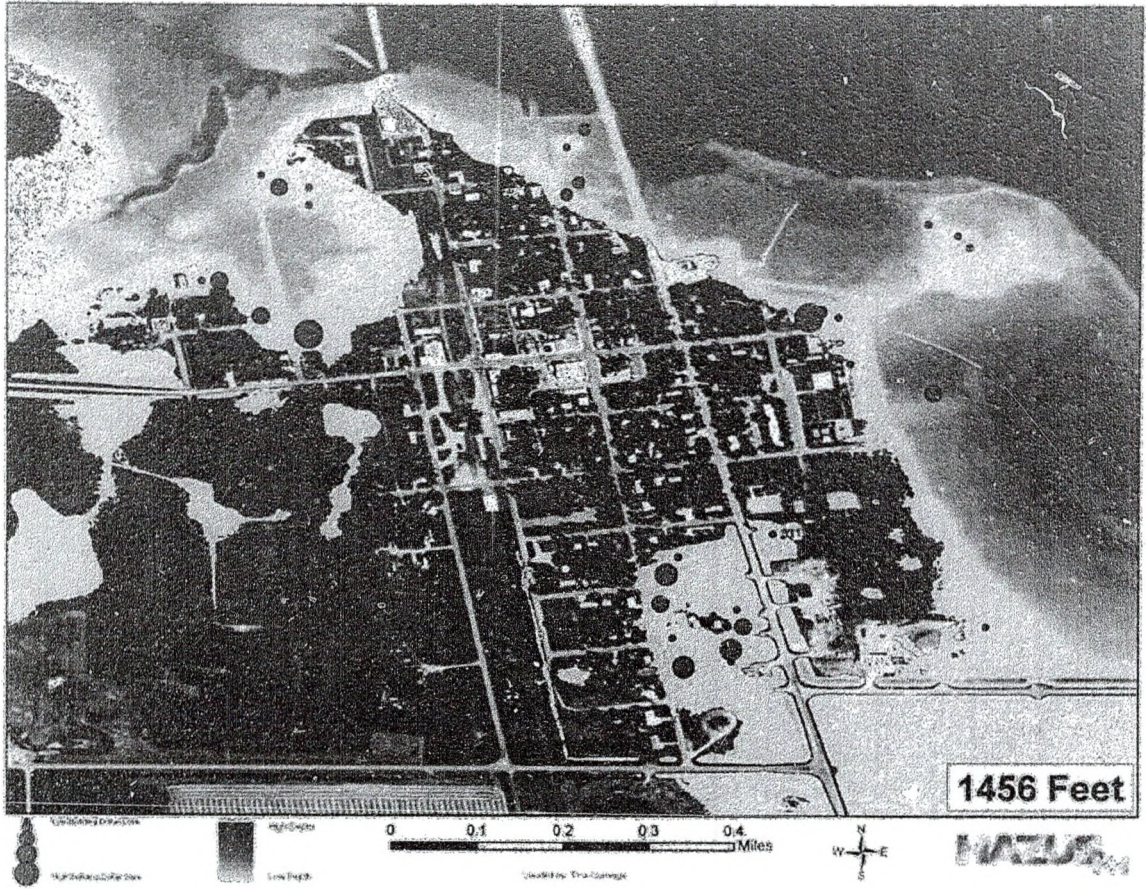
Figure 15o. An Aerial View of the City of Minnewaukan at Devils Lake WSE 1459
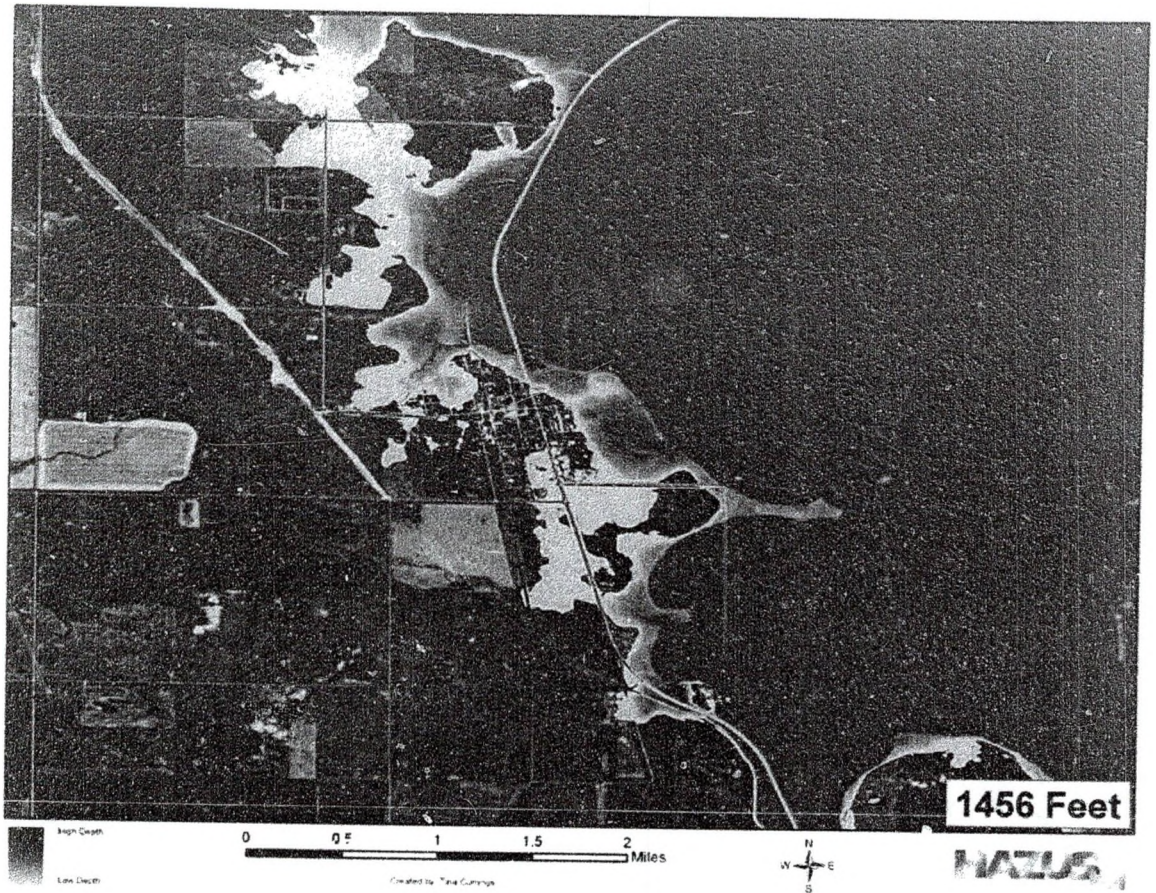Feet.

Figure 15p. An Aerial View of the City of Minnewaukan and Surrounding Areas at Devils Lake WSE 1459 Feet.

Figure 15q. An Aerial View of the City of Minnewaukan at Devils Lake WSE 1460 Feet.
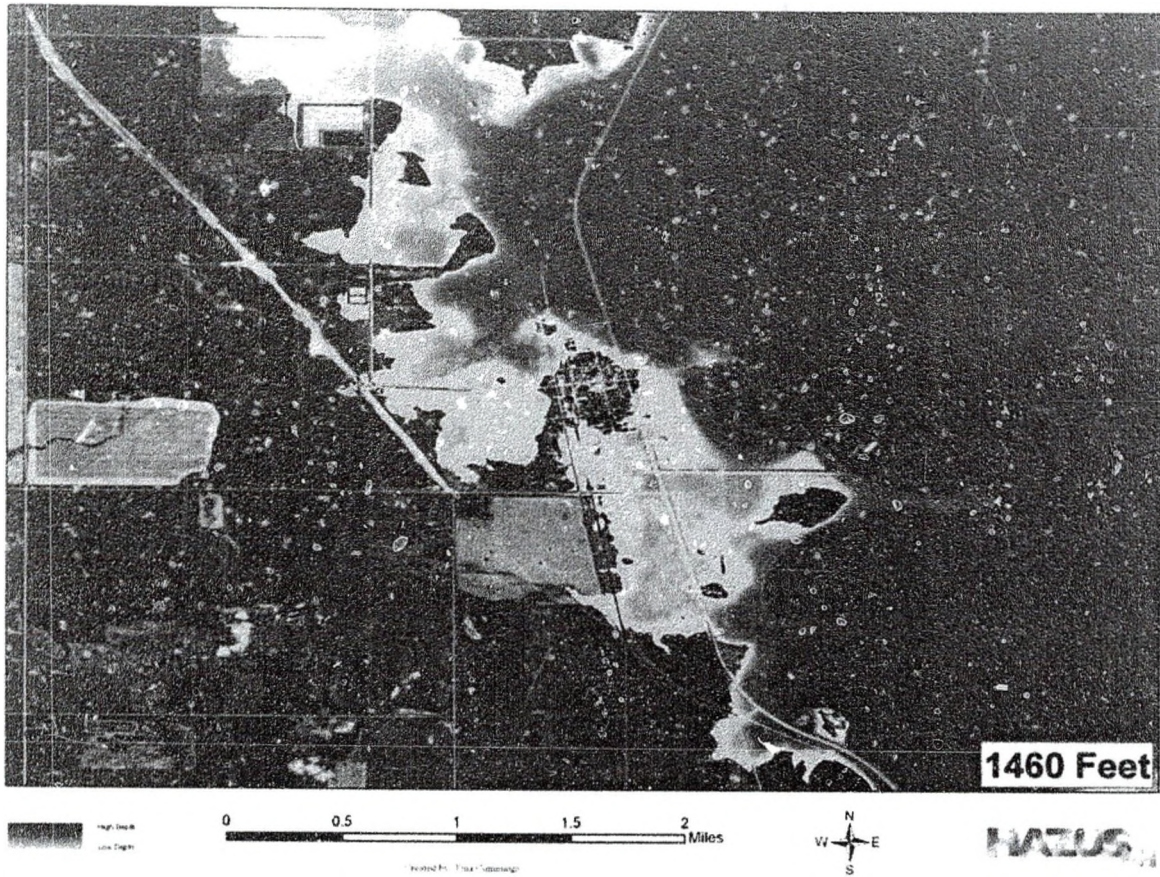
Figure 15r. An Aerial View of the City of Minnewaukan and Surrounding Areas at Devils Lake WSE 1460 Feet.
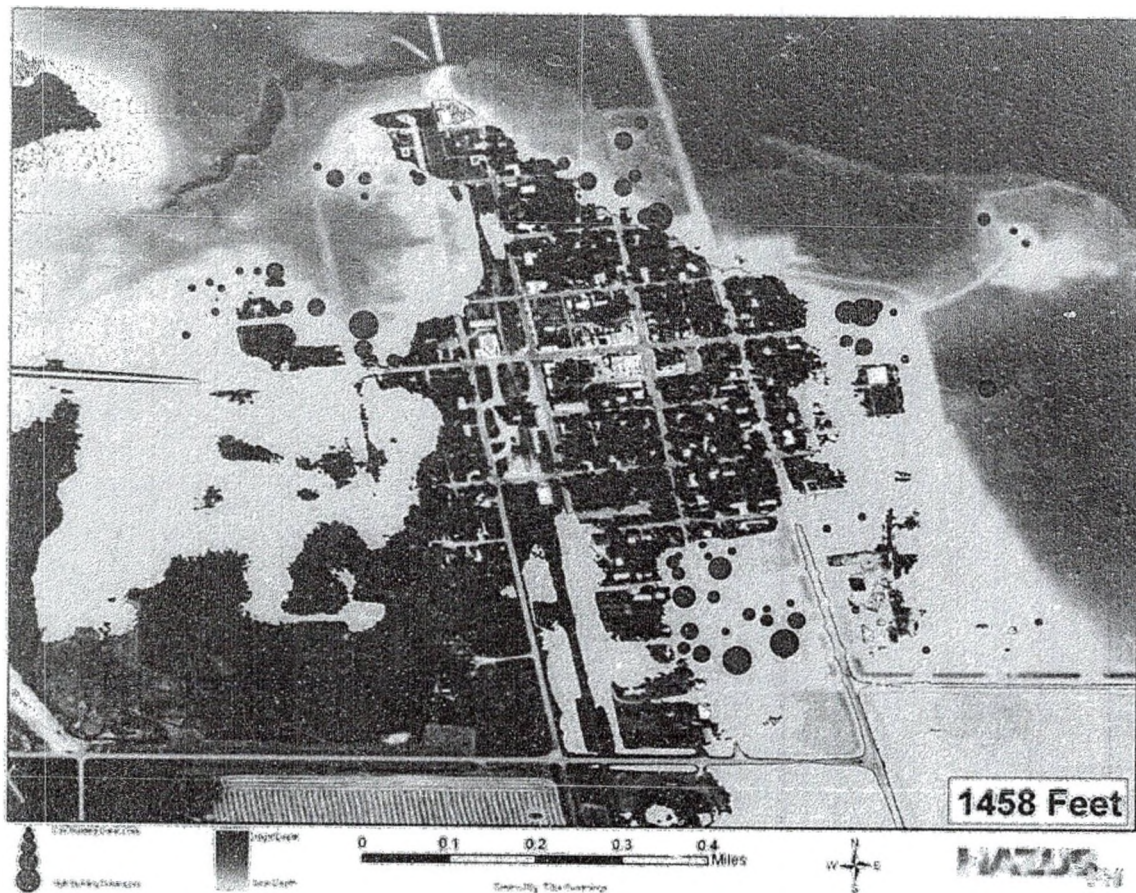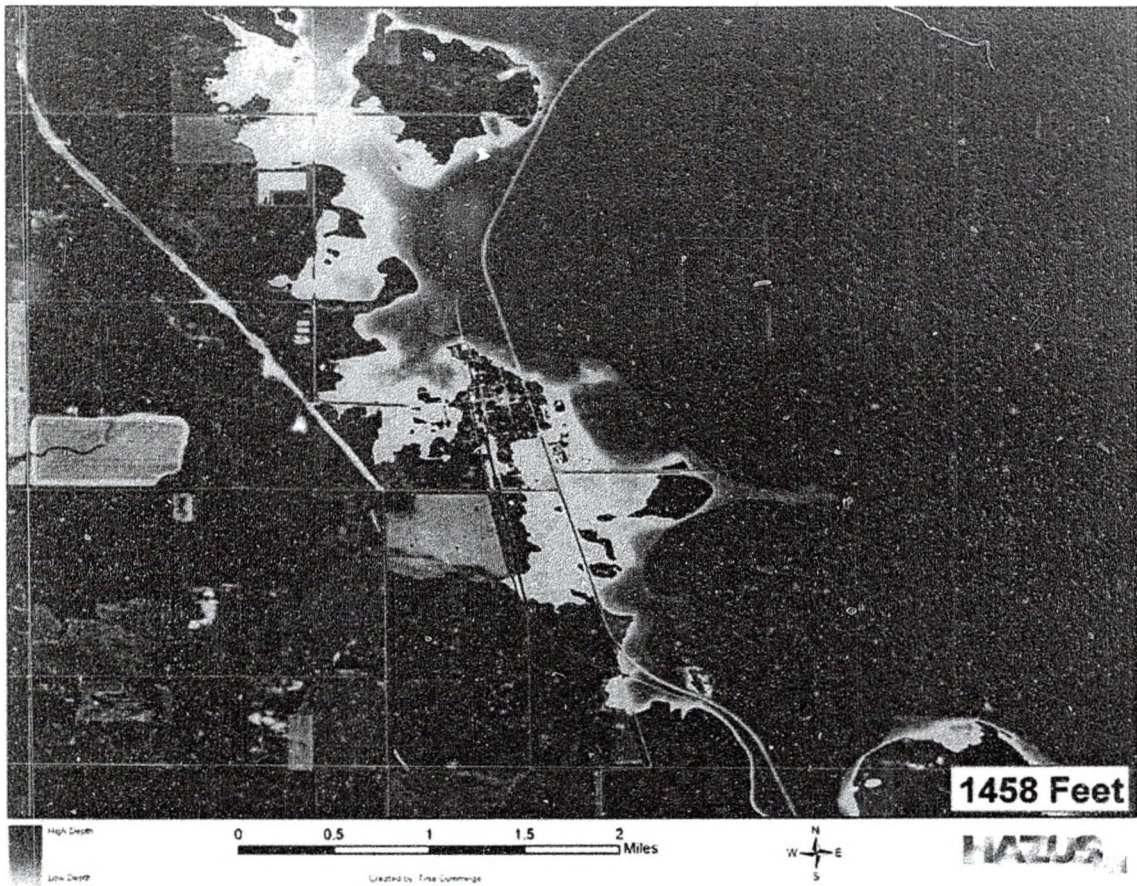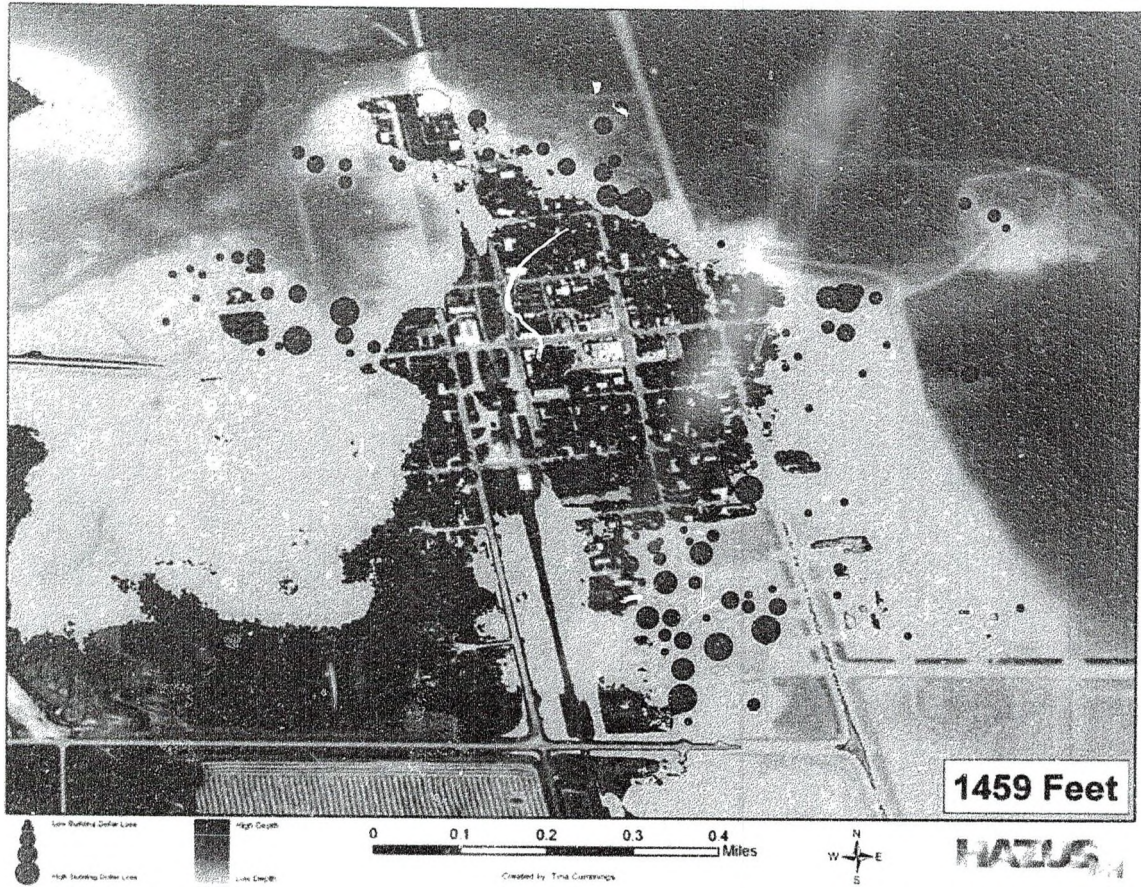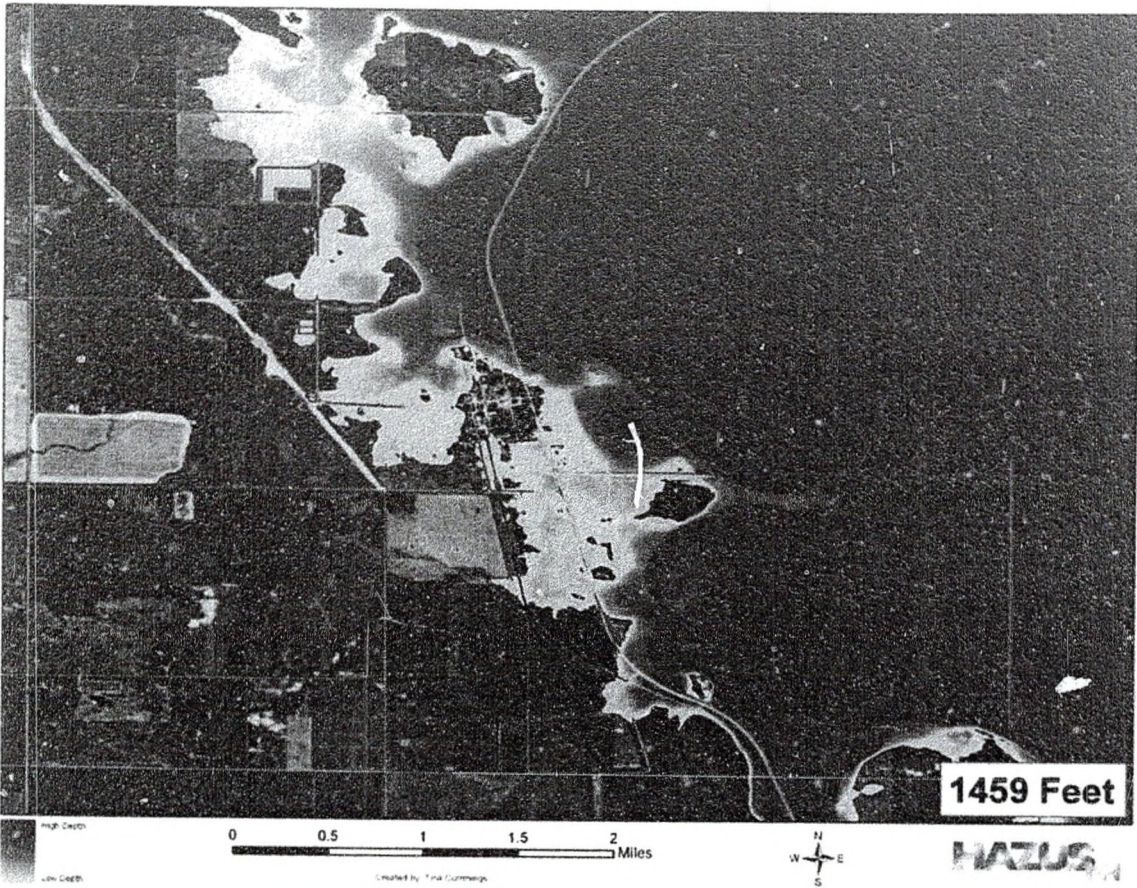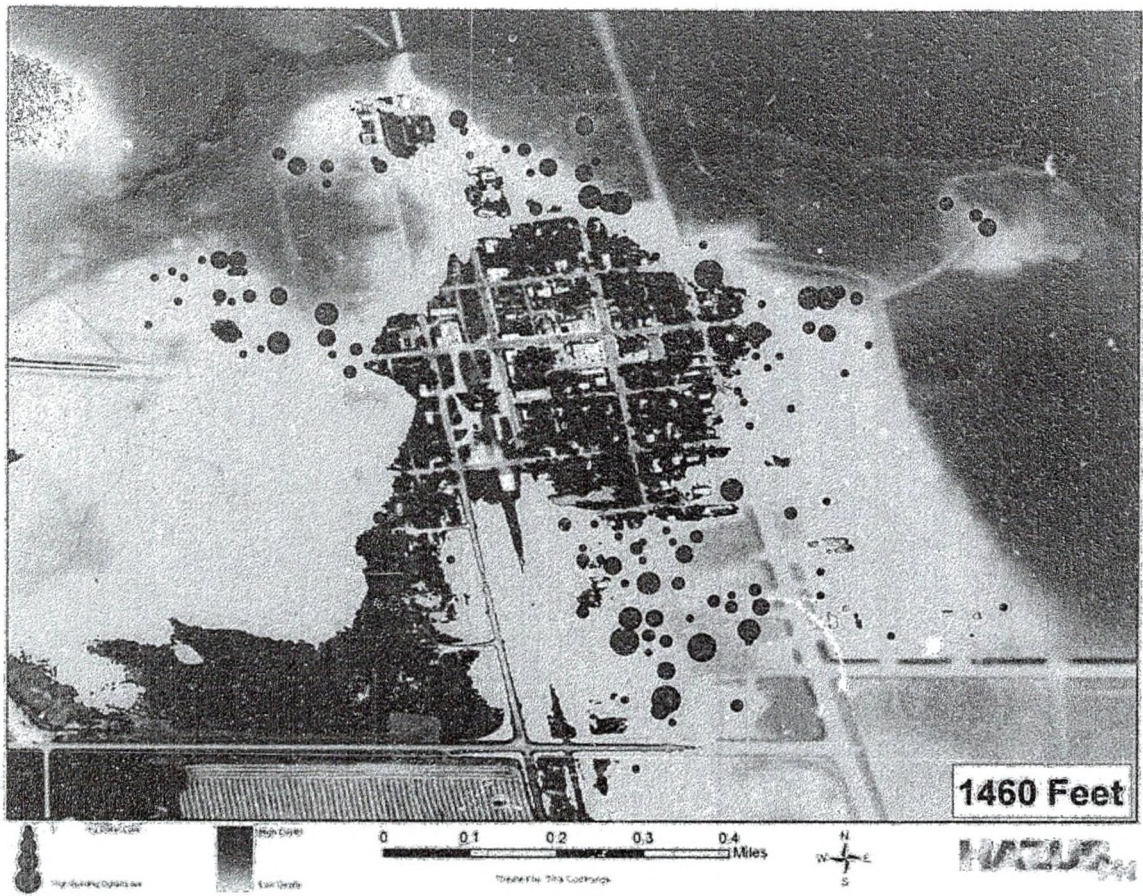
4.2 Damage Estimation Profiles

Two damage estimation profiles display the number of buildings damaged at increasing water surface elevations (Figure 16a) and the building dollar losses per 1-foot increase in water surface elevation (Figure 16b). All building dollar losses are listed from the 2010 Real Property Assessment Book and are in 2010 U.S. dollars unless otherwise noted. The damage estimation profiles produced expected results with each increasing elevation. As Devils Lake water surface elevation rises, the number of buildings damaged increases and greater building dollar losses occur in Minnewaukan.

At WSE 1452 feet, HAZUS calculated that four buildings were damaged with a building economic loss of $1,987 (Tables 5 and 6). At WSE 1453 feet, seven buildings were damaged with a building dollar loss of $4,937, for a difference between WSE 1452 and WSE 1453 of three buildings and $2,950. At WSE 1454 feet, 10 buildings were damaged with a building dollar loss of $20,555. The difference between WSE 1453 and WSE 1454 is $15,618. At WSE 1455 feet, 21 buildings were damaged with a building economic loss of approximately $115,121. There is a significant jump in building dollar losses of $94,566 between WSE 1454 and WSE 1455 feet. At WSE 1456 feet, HAZUS calculated that 38 buildings experienced damage, resulting in a loss of $320,031. At WSE 1457 feet, 49 buildings were damaged with a building economic loss of $489,617. The difference between WSE 1456 and WSE 1457 is $169,586. At WSE 1458 feet, HAZUS calculated that 69 buildings had damage with a building economic loss of $776,534. The difference between WSE 1467 and WSE 1458 is $286,917. At WSE 1459 feet, 98 buildings were damaged with losses totalling $1,309,624. The difference between WSE

1458 and WSE 1459 is $533,090. Finally at WSE 1460 feet, approximately 122 buildings experienced damage, with $1,957,653 in building economic damages. The difference between WSE 1460 and WSE 1459 is $648,029.

With regards to the FEMA property buyout program, FEMA purchases properties at fair market value, even if it is completely destroyed due to flooding. The land is then deed restricted with stipulations that no buildings can be built on that lot. The lot is then usually handed over to the city, county, or state. Many times the lot ends up being used as a park, where if it is flooded there is little to no damage involved. My building loss estimates used assessed values from the Tax Assessor Property Cards, not the market value. FEMA uses the market value when a property is bought out; therefore, the FEMA buyout price would be higher.

The total cost of the 277 buildings in Minnewaukan was $29,995,969, derived from the property cards in the Benson County Tax Assessor's Office. For WSE 1460, a building dollar loss of $1,957,653 seems a little low. This could be for a number of reasons. One is there is a low cost of living in Minnewaukan. Another reason is when I derived information from the property cards, twenty three property cards were tax exempt. This meant the square footage, foundation type, building cost, etc. were not documented on the property card and therefore had to be left blank. The City of Minnewaukan would experience a building dollar loss of at least $1,957,653 if Devils Lake reached a WSE of 1460 feet.
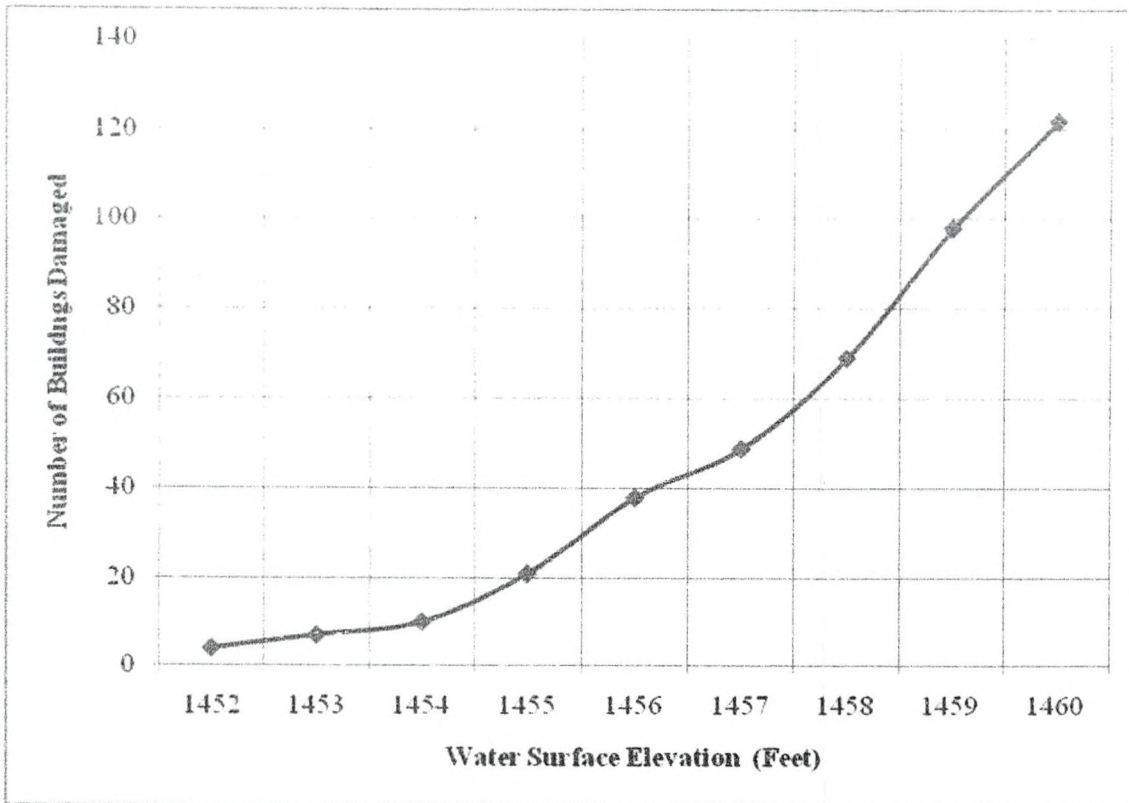
Figure 16a. The Number of Buildings Damaged in the City of Minnewaukan per 1-foot Increase in Water Surface Elevation, 1452 to 1460 Feet.

Table 5. The Number of Residential, Commercial, and Other Buildings Damaged in the City of Minnewaukan per 1-foot Increase in Water Surface Elevation, 1452 to 1460 Feet.

WSE in Feet	Total Number of Buildings Damaged	Number of Residential Buildings Damaged	Number of Commercial Buildings Damaged	Number of other Buildings Damaged
1452	4	2	0	2
1453	7	3	0	4
1454	10	4	0	6
1455	21	9	0	12
1456	38	15	2	21
1457	49	22	2	25
1458	69	40	2	27
1459	98	61	5	32
1460	122	80	6	36

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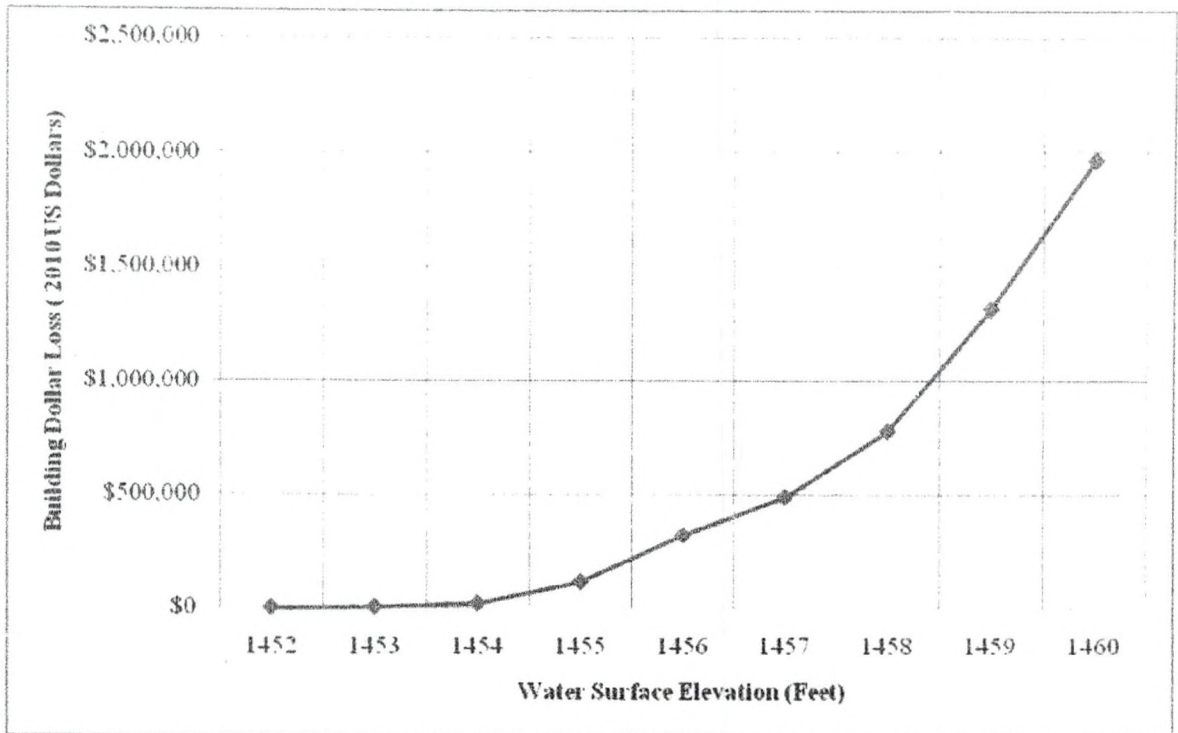
Figure 16b. Building Dollar Loss in the City of Minnewaukan per 1-foot Increase in Water Surface Elevation, 1452 to 1460 Feet.

Table 6. Residential, Commercial, and Other Building Dollar Loss in the City of Minnnewaukan per 1-foot Increase in Water Surface Elevation, 1452 to 1460 Feet.

WSE in Feet	Total Building Dollar Loss	Residential Building Dollar Loss	Commercial Building Dollar Loss	Other Building Dollar Loss
1452	$1,987	$1,987	$0	$0
1453	$4,937	$4,937	$0	$0
1454	$20,555	$9,938	$0	$10,617
1455	$115,121	$86,073	$0	$29,048
1456	$320,031	$265,853	$13,999	$40,179
1457	$489,617	$410,049	$15,829	$63,739
1458	$776,534	$666,813	$17,650	$92,071
1459	$1,309,624	$1,145,372	$27,544	$136,708
1460	$1,957,653	$1,632,887	$44,150	$280,616

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CHAPTER V

CONCLUSIONS

The maps of Minnewaukan and the surrounding region produced in HAZUS show

that the model can be used to examine lakeshore inundation at 1-foot increments from

1452 to 1460 feet water surface elevation. HAZUS can successfully identify areas at

immediate risk, show the number of buildings damaged, and determine the building

dollar losses.

The damage estimation profiles for the City of Minnewaukan at increasing water

surface elevations produced expected results. There was an increase in number of

buildings damaged and increase in building dollar losses, with each increasing water

surface elevation. The commercial and residential buildings affected at these increasing

water surface elevations were systematically identified by conducting a site specific

analysis and representing building location and dollar loss with graduated symbols in

ArcMap. The school becomes completely flooded at WSE 1456 feet. Main Street, at the

entrance of the city, becomes impassible at WSE 1457 feet, due to increased flood waters

filling the side ditches and spilling onto th.   ad. Beca.   Main Street is one of the major

transportation routes into the city and critical infrastructure would be cut off, partial

relocation should be considered at WSE 1457 feet. This study met all of its stated

objectives and goals, showing that HAZUS functionality can be extended to lakeshore flooding hazards.

However, there are limitations to this study. My dollar loss estimates only included building dollar losses at the assessed value, not the market value. Also, within the property card data, some buildings were tax exempt. This means that there is not any information given on assessed value, square footage, foundation type, etc. In addition, the Flood Submodel of the HAZUS Model estimates potential damage. There are going to be discrepancies with any model.

HAZUS can be used to provide accurate and up-to-date information to officials at the local, state, and regional level to assist them in making more informed decisions regarding flood mitigation alternatives. If Devils Lake continues to rise, then the City of Minnewaukan will be prepared and know how to handle certain parts of the city with each increasing water surface elevation.

For future studies, I would like to incorporate a HAZUS study on the Sheyenne River and downstream communities. In particular, I would like to incorporate a site specific analysis of Valley City and what effect a spillover would have on the Sheyenne River in that region. The techniques utilized in the Minnewaukan site specific analysis can also be applied to other more general lakeshore hazards studies. For example, there are multiple lakes in Minnesota where cabin development has increased, without controlled management in the event of lakeshore flooding. These cabins are significantly increasing in market value and being built in locations without proper flood protection.

For future studies, I would analyze a specific lake in Minnesota and propose land

management and lakeshore development guidelines around that lake.

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