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The Cost-Effectiveness Of Devils Lake Flood Decision-Making: An Economic Case Study Of A Climate Driven Wicked Problem

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THE COST-EFFECTIVENESS OF DEVILS LAKE FLOOD DECISION-MAKING: AN ECONOMIC CASE STUDY OF A CLIMATE DRIVEN WICKED PROBLEM

by

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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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LIST OF ACRONYMS

Acronym	Definition
AMSL	Above Mean Sea Level
CFS	Cubic Feet Per Second
DEM	Digital Elevation Model
DOT	Department of Transportation
FEMA	Federal Emergency Management Agency
LiDAR	Light Detection and Ranging
USACOE	United States Army Corps of Engineers
USGS	United States Geological Survey
FHWA	Federal Highway Administration

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ABSTRACT

The Devils Lake flood is the longest, most expensive terminal lake flood in the history of the United States. In 1993, the Lake had a surface elevation of 433.9 m (1423.7 ft.) above mean sea level. Since that time it has risen 9.3 m (30.6 ft.), inundated 58,275 ha (144,000 acres) of land, and caused an estimated $1.6 billion (2011 USD) in total cumulative economic losses to the region. As a terminal lake in the Devils Lake sub-basin of the Red River Valley Basin, it has no natural outlet below 444.4 m (1458 ft.) and significantly poorer water quality than the rest of the basin waters. This impacts numerous downstream communities across state and national boundaries, making Devils Lake flooding a multi-definitional problem for policy makers on every political level. The economic, environmental, legal, and social ramifications of the State's response, combined with the Lake's unique hydrological features, systematic uncertainty, climactic fluctuation, and socio-political and technical complexity make Devils Lake an ideal case study of a Wicked Problem. Wicked Problems Theory is a subcategory of modern policy thought that is useful in assessing unique environmental and socio-political problems that lack a clear optimal solution or stopping point. This is indicative of the main Devils Lake solution, which consists of a three-pronged mitigation strategy known as Continuing Infrastructural Protection (CIP). Primarily an incremental infrastructural response to protect adjacent lake communities, CIP began in 1994, and has cost nearly $1.3 billion (2011 USD) since that time.

Although CIP was initially predicted to have a positive cost-benefit ratio, statistical data shows that the 18-year cost of CIP is greater than the value of all the property it was constructed to protect. In order to assess how policymakers and domain experts might have determined a more economically efficient solution, this thesis combines the economic concepts of expected and present value into an expected present value (EPV) model within a Wicked Problems framework. This model incorporates the lake level probability and the discount rate as variables, and produces the EPV of all future CIP costs from any point in time over the current course of flooding (1994-2011). Because the discount rate and lake level probability are unknown, the EPV of CIP was simulated under a range of potential discount rates and likely lake level probabilities and compared against the estimated cost of a one-time relocation and buyout of the adjacent Devils Lake communities. The model assumes that the threshold discount rate at which the relocation/buyout alternatives had an equivalent monetary value as CIP reflected the preference of decision-makers for CIP over other alternatives. The results suggested that policymakers preferred short-term solutions with smaller continuing costs over long-term solutions with large one-time costs, despite the fact that the long-term solution was ultimately cheaper in the long-run. Based on an examination of the relevant literature, governmental analysis, and anecdotal evidence, the analysis suggested that flood mitigation decisions were driven by a preference for the present over the future, the possible underestimation of long-term CIP costs, and the human tendency to place a lower priority on the elimination of extreme risks than their statistical probability implies is appropriate. When viewed as Wicked Problem, the results and theory support the conclusion that an 'iterative risk-management framework', as described by the National Research Council, would have likely resulted in a more effective, resilient, and sustainable long-term flood mitigation response.

CHAPTER I

INTRODUCTION

The Devils Lake Flood is possibly the longest, most expensive terminal lake flood in the history of the United States. In 1993, the Lake had a surface elevation of 433.9 m (1423.7 ft.) above mean sea level. Since that time it has risen 9.3 m (30.6 ft.), inundated 58,275 ha (144,000 acres) of land, and, using the projected $194 million economic losses that occurred in 2011 alone as a base (Aakre, Coon, & Hodous, 2011), caused an estimated $1.6 billion in total cumulative losses to the region.

The flooding of Devils Lake has been a problem for policy makers on every political level. On the local level, the threat to homes and farmland has left many in the area wondering what can be done and how they can cope with the enormous costs required to protect their land and livelihoods from the encroaching water. On the state and federal level, the attempts of lawmakers and governmental agencies to design a cost-effective solution to flooding have met little success. The product of their efforts, a strategy known as Continuing Infrastructural Protection (CIP), has been implemented at an estimated $865 million total cost (1994 USD), yet left many in the region frustrated by its apparent lack of effectiveness in preventing rural and agricultural damages (Anfang & Loss, 2003c; Heitkamp & Johnson, 2011; Heitkamp & Marquart, 2011b). On the international level Devils Lake exists as a sub-basin of the larger Red River drainage basin which, because it flows north into Canada, is subject to the terms of the International Boundary Waters treaty. In the event of a discharge from one basin to the other, the disparity in water quality between Devils Lake and the surrounding basins could have negative impacts on the Sheyenne and Red River of the North Ecosystems, which, until recently, potentially constituted a violation of federal law under the International Boundary Waters Treaty with Canada (Whorley, 2008).

Although the frustration of those most directly impacted by the flooding is palpable, the complex nature of the problem has frustrated almost every person involved with its ability to defy expectations. This complexity has transformed CIP from one of the only politically feasible alternatives with a predicted positive benefit-cost ratio (BCR) into a $1.3 billion (2011 USD) project that protects an estimated $900 million (2011 USD) of at-risk infrastructure. It is not an easy or small problem despite the initial appearance to the contrary. Moreover, a great deal of time, money, and effort has been spent trying to determine the most effective and economically efficient method to prevent the most significant flood damages from happening. Yet, the normal methods that governments use to maximize the potential effectiveness of proposed policies in most cases are not easily adapted to predicting the effectiveness of policies in response to a unique problem like Devils Lake.

In fact, the unique nature of Devils Lake flooding places it in a special category of policy problems that current decision-making frameworks are not equipped to deal with efficiently. "Wicked Problems", as they are referred to in the literature, are characterized by their unique nature, multiple possible problem definitions, technical and social complexity, ability to cause ancillary complex problems, difficulty to model and test, lack of distinct end point, and lack of "good" solutions (i.e. a "good" solution can be defined as one wherein the benefits clearly outweigh the costs of implementation and potential costs of externalities) (Churchman, 1967; Conklin, 2006). The best methods for dealing with wicked problems focus on transforming wicked problems into normative or "non-wicked" problems. This usually involves an examination of wicked problems from a more long-term, holistic, sustainable, and precautious perspective, that places higher values on uncertainty and potential negative impacts.

Viewing Devils Lake from the perspective of a wicked problem is useful in that it examines the decision-making in response to Devils Lake flooding from outside the boundaries of individual agencies or governmental entities. A great deal of analysis has been performed upon the proposed solutions for Devils Lake flooding, yet, this analysis has conformed to the conception of Devils Lake flooding as a traditional problem. Defining Devils Lake flooding as a Wicked Problem will allow for a more holistic assessment of decision-making and its ultimate effectiveness. There are many legitimate metrics in which to assess the effectiveness of the response to Devils Lake flooding, from a socio-political to environmental. However, of chief interest to this thesis, is the economic efficiency of Devils Lake decision-making.

There are five main reasons for focusing on the economic efficiency of Devils Lake decision-making. First, economic efficiency is most simply determined through Benefit-cost and Cost-Effective Analysis (BCA and CEA respectively), both of which have been used to assess the potential impact of proposed Devils Lake mitigation alternatives. Second, a CEA is consistent with the methods used most prominently by state and federal agencies to determine the likely effectiveness of public projects, specifically those that collectively describe CIP. Third, it is the standard method used by the U.S. Army Corps of Engineers (USACOE) and their subsidiaries to assess the potential cost-effectiveness of potential mitigation strategies for Devils Lake. Fourth, a CEA allows for the present value monetary comparison of alternatives with vastly different costs and implementation timelines, shedding light on the critically important discount rate utilized by decision-makers. Lastly, a retrospective CEA of Devils Lake mitigation decisions has never been performed at any level of government, even though CIP has nearly reached its maximum protection level, as determined by the hydrology of the Lake.

Many alternatives were assessed by the USACOE in their attempt to find a cost-effective solution for Devils Lake flooding. However, the Draft Environmental Impact Statement and Final Environmental Impact Statement (DEIS and FEIS respectively) prepared by the USACOE was largely bereft of alternatives that could be considered optimum solutions for a wicked problem; that is, alternatives that would change the problem definition in such a way as to eliminate its Wicked characteristics. An example of such a solution would be the physical relocation of the

City of Devils Lake and adjacent communities, which was never formally evaluated for the Devils Lake Basin but was estimated to cost approximately $1 billion in 1998 (Anfang & Loss, 2003c). This solution “solves” Devils Lake flooding by changing the fact that the city and adjacent communities are currently built within the historical confines of Devils Lake.

This stands in direct contrast with CIP, which is largely focused on holding back the lake water that stands to inundate the priority infrastructure within the cyclical area of the lake. Although an incremental relocation of structures was considered in a CEA performed by Barr Engineering for the USACOE (Barr Engineering Co., 2003b), it was not formally evaluated within the FEIS or even seriously considered by policymakers until at least 2001 (Barr Engineering Co., 2003b; Pearson et al., 2003). Further, a relocation of Devils Lake and the surrounding communities as defined in this thesis, which looks at relocation as a one-time event for the entire community, was never formally considered at any point during flooding.

This thesis uses a CEA to compare CIP from 1994-2011 against a relocation and buyout (wherein private property owners would be offered a fair value for their property in order to incentivize their voluntary relocation; it can be viewed as an alternative relocation scenario). This comparison will shed insight on the decision preference of policymakers in response to Devils Lake flooding. In order to compare these alternatives, this study performs three tasks. The first was to estimate the cost of relocation and buyout of Devils Lake and surrounding communities and total current costs of CIP. The second was to develop an Expected Present Value (EPV) function that takes into account the variables of discount rate and probability (i.e. uncertainty of lake level rise). The third step was the creation of a model to estimate the effects of discount rate and probability. It is essential for the model to take into account the variables of discount rate and probability because of the effect they have on the expected value of future costs. This model will allow for the one-time costs of relocation/buyout, as defined in this thesis, to be compared against the EPV of annual CIP expenditures and how the Expected Total Cost (ETC) of CIP changes by probability and discount rate.

A comparison of the total cost of relocation/buyout with the total actual costs of CIP suggests that relocation/buyout was more cost-effective than CIP until 2002. Given the extent of likely future CIP costs after 2011, as well as the costs of adapting the infrastructure at some future point after the Lake recedes, it is likely that relocation/buyout will prove to be cost-effective far after 2002. Although previous CEA took into account discount rate and probability, the analysis finds that the estimated rate of discount in Devils Lake decision making was substantially higher than the discount rate proposed in previous CEA analysis. This is significant because although relocation was more cost-effective retrospectively, from a standpoint looking forward, the extremely high discount rate used by decision makers caused them to underestimate the long-term cost of CIP. While there are many potential reasons for such a high discount rate, assuming decision-makers acted rationally (that is, they attempted to get the greatest level of flood protection for their money) the implied discount rate in Devils Lake decision-making contributed to a situation wherein the costs of mitigation were ultimately greater than the value of the property it was implemented to protect.

The model's results suggest that a combination of a preference for the present over the future, perception of long-term risk that was less than statistical probability warranted, and uncertainty in estimating the long-term costs of CIP led policymakers to choose CIP over solutions that would have eliminated its Wicked characteristics. The results suggest that a decision-making paradigm that focused on the reduction and/or elimination of long-term risk and emphasized greater caution in dealing with uncertainty would have likely improved the economic effectiveness of the Devils Lake flood response. This is not to say that it would have resulted in a complete relocation of the adjacent structures, but rather that different decisions, with a smaller overall cost, would have been made.

Although certainly not the only method, the 'iterative risk-management framework' suggested for dealing with Climate Change in *America's Climate Choices* (2011) is identified as an ideal decision-making paradigm for Devils Lake flooding and similar Wicked Problems in the future. The framework is explicitly designed around understanding, clarifying, and quantifying the potential impacts of systematic uncertainty in an iterative manner. This continual assessment of a problem's long-term risks, potential impacts and solutions, and uncertainty would likely benefit from the changing perception of risk resulting from recent experience. It would also allow policymakers to more accurately assess potential solutions and their costs by comparing the predicted benefit-cost ratios against the actual benefit cost ratios for a given solution. Finally, we suggest that a wicked problem definition should be rigorously codified to allow for a quick differentiation between potential wicked problems and more normative policy problems. Assuming an 'iterative risk-management framework' would likely produce more cost-effective responses, prioritizing problems by this definition would likely increase operational efficiency; the increase in the initial relatively small costs of research and analysis would be justified by the decrease in large long-term mitigation costs, ultimately increasing the overall budgetary capacity of government agencies.

CHAPTER II

LITERATURE REVIEW

2.1 Devils Lake Background

Devils Lake is both the largest terminal lake and second largest body of water in North Dakota. Located in north-eastern North Dakota, it is a 987,821 ha (3,814 sq. mi.) terminal sub-basin of the Red River of the North Basin. 833,976 ha (3,220 sq. mi) of the total basin (84.4%) drains into Devils Lake, while the remaining basin is tributary to Stump Lake, a small closed basin lake southeast of Devils Lake. The lake level varies considerably from year to year, based upon the precipitation and runoff it receives from the surrounding land. Similarly, the water quality levels are also highly variable, depending on volume and recent precipitation. At high elevations, the water quality improves due to the dilutive effects of increased volume. However, when the Lake elevation is low, it is highly saline from the accumulation of salts and other dissolved solids left from evaporation (U.S. Army Corps of Engineers St. Paul District, 2002).

Since glaciation, the elevation of the Lake surface above mean sea level (amsl) has fluctuated between 426.7 m (1,400 ft.) and 444.4 m (1,458 ft.) (Aronow, 1957). Devils Lake naturally overflows into Stump Lake at 440.9 m (1446.5 ft.) and eventually the combined lake overflows into the Tolna Coulee at 444.4 m (1458 ft.) (U.S. Army Corps of Engineers St. Paul District, 2002). Although the current rise in lake level is consistent with historical fluctuations, such increases are unprecedented in the time after European settlement. Since 1900 the Lake level had only surpassed 435.9 m (1430 ft.) once prior 1993. While data before 1890 is limited, the original survey of the Stump Lake area conducted between 1881 and 1883 placed the surface elevation of Stump Lake in the range of 432.8 m (1420 ft.) and 434.3 m (1425 ft.), some three to five meters higher than its maximum recorded level in 1940 (United States Geological Survey, 2010b). There is further anecdotal evidence from the journals and writings of Joseph Nicollet, who explored the Devils Lake area in 1839 that describes the area between Devils and Stump Lake as big, deep coulees stating “These are dry at the moment but in time of high water seem to receive water from Devils Lake.” (Bray & Bray, 1976).

With the exception of the time period prior to 1890, Devils Lake was much lower than it is currently, ranging between a record low of 427 m (1,400.8 ft.) m in 1940 and 435.5 m (1,428.8 ft.) in 1987 (United States Geological Survey, 2007). From its lowest point in 1940, the Lake slowly rose until 1956, fell until 1968, rose again to its peak in 1987, and finally declined to the most recent low point of 433.6 m (1422.6 ft.) in 1993 (North Dakota State Water Commission, 2010). Since that point, however, the Lake has risen 9.02 m (30 ft.) over the past 18 years reaching a maximum recorded surface elevation of 443.3 m (1,454.39 ft.) on June 27th, 2011. An immense increase in surface area has accompanied the rising surface elevation. In 1992 Devils Lake covered 18,942 ha (46,807 acres). At its highest point in 2011, the Lake covered an estimated 77,217 ha (190,807 acres), an increase in surface are of 407.6 percent (United States Geological Survey, 2010c). Figures 1 and 2 are images from the Landsat 5 Thematic Mapper, illustrating the change in surface area of Devils Lake from 1993 to 2010.

2.2 Historical Devils Lake

The Devils Lake Basin’s abundant food and water resources, and central location between the forested areas in the east and south (near current day Sully’s Hill) and the Missouri, James and Sheyenne Rivers, has made the Lake a focal point for prehistoric and early inhabitants of North Dakota (North Dakota State Water Commission, 2010). Although European fur traders were known to have operated in the area as early as 1800, the first permanent settlement of Fort Totten was not built until 1867, when it was constructed on the south shore of the Lake (North Dakota State Water Commission, 2010). Despite the existence of this military outpost, white settlement did not begin in earnest until 1882 with the impending construction of the St. Paul,

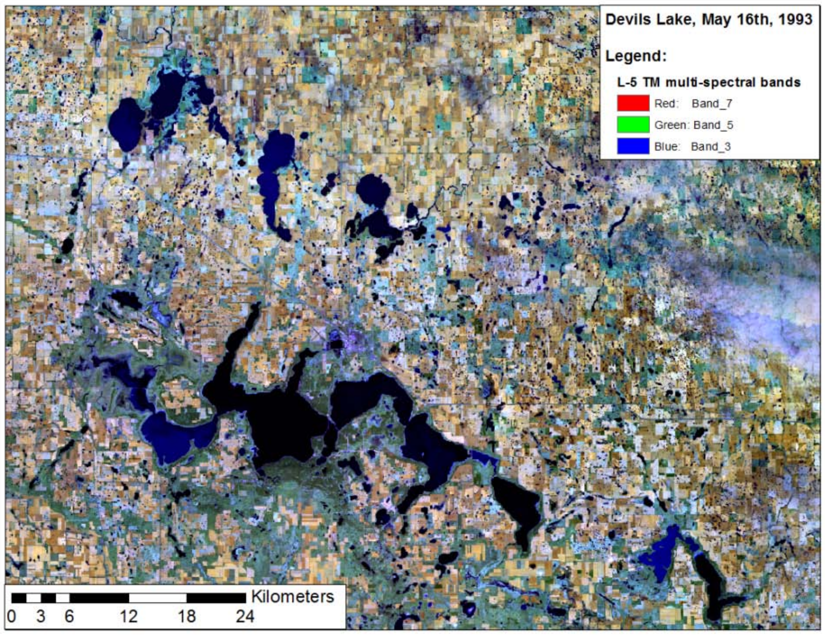

Figure 1. Devils Lake on May 16th, 1993. This image is a composite of scenes 3126 and 3127 and uses a 7-5-3 band combination in order to highlight surface water in a near true-color. The elevation of the Lake on this day was 433.78 m (1423.09 ft.) above mean sea level. In this image the Lake has a surface area 18,374 ha (45,404 acres) and approximate volume of 725.6 million m^3 (588,600 acre feet) (NASA Landsat Program, 1993a; NASA Landsat Program, 1993b).

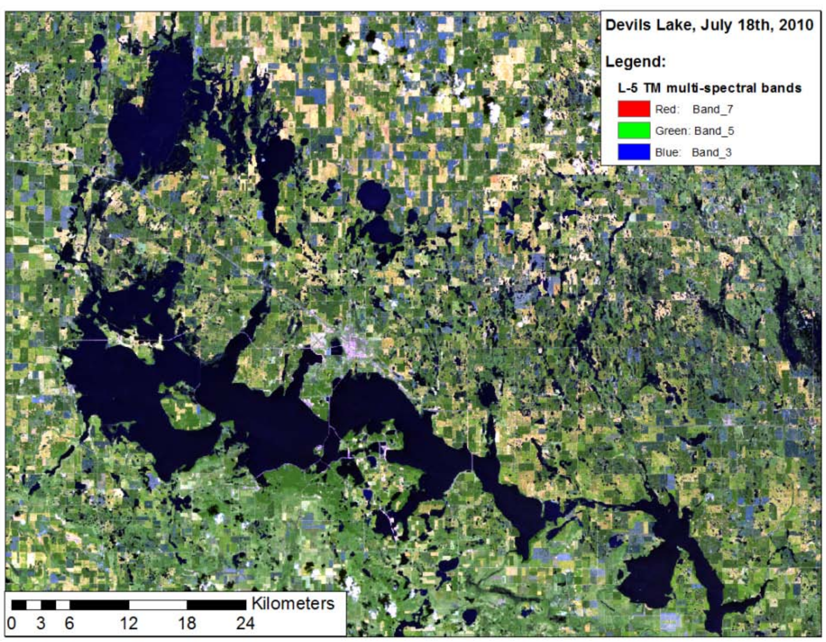

Figure 2. Devils Lake on July 18th, 2010. This image is a composite of scenes 3126 and 3127 and uses a 7-5-3 band combination in order to highlight surface water in a near true-color. The elevation of the Lake on this day was 442.52 m (1451.85 ft.) above mean sea level. In this image the Lake has a surface area 66,549 ha (164,445 acres) and approximate volume of 3.6 billion m^3 (3,100,000 acre feet) (NASA Landsat Program, 2010a; NASA Landsat Program, 2010b).

Minneapolis and Manitoba Railway (now the Burlington Northern) heading west from Larimore, ND. Within 20 years the entire basin had largely been settled. While the depression of the 1920's and 1930's resulted in outmigration from the area, which in turn has caused the disappearance of many of the small settlements initially founded in the basin, much of the original settlement pattern persists to this day (North Dakota State Water Commission, 2010).

2.3 Geology of Devils Lake

The geologic features of the Devils Lake basin were created in the aftermath of continental glaciation (Hobbs & Bluemle, 1987). Located on the eastern edge of the larger Williston basin, it is underlain by Paleozoic and Mesozoic rock deposits that dip westward toward the center of the Devils Lake basin, with cretaceous Pierre Formation Shale and Sandstone deposits as well. There are a total of six Quaternary formations consisting of glacial deposits, and other deposits related to glaciation are found in Ramsey County, with southern most parts of the basin characterized by landforms resulting from glacial thrusting (Hobbs & Bluemle, 1987). This glacial thrusting formed the large irregular depression marking the plain of modern day Devils Lake and its glacial precursor Lake Minnewaukan (Hobbs & Bluemle, 1987). Prior to glaciation, the area was dominated by the Cannonball River Valley. Over time, the valley filled with saturated sediments that were eventually carved out by the advancing glaciers. These glaciers increased the groundwater pressure of the Cannonball River sediments which was lifted up into the advancing glacier, resulting in the excavated depression that we know as Devils Lake. The excavated sediments were deposited to the south-southwest of the depression forming Sully's Hill (United States Geological Survey, 2010d).

Underlying much of the Devils Lake Basin is the Spiritwood aquifer system. This system is an extensive buried-valley aquifer that stretches southeasterly from the Canadian border to the South Dakota border (Wiche & Pusch, 1994). This system ranges from about 1 to 10 miles wide and 30 to 300 feet thick, and is confined by lake deposits and glacial till approximately 100 to 200 feet in thickness and of minimal permeability (Wiche & Pusch, 1994). The lack of permeability of the overlying sediments prevents this aquifer from yielding enough water to be of practical use for water supplies. According to the *Hydrology of Devils Lake Area, North Dakota*, a ND State Water Commission Water Resources Investigation report "…drilling indicates wells within the system range from 150 feet below land surface on top of Devils Lake Mountain to several feet above land surface near Devils Lake (Wiche & Pusch, 1994)."

2.4 Devils Lake Hydrology

Devils Lake is bounded by poorly defined low divides on all sides with the exception of the southern boundary, which is comprised of a series of recessional moraines that lie between Devils Lake and the Sheyenne River (Wiche & Pusch, 1994). The main sub-basins within the Devils Lake Basin are the Edmore, Starkweather, Calio, Mauvais, and Little Coulees (Wiche & Pusch, 1994). Prior to 1979 and the construction of Channel A, these coulees and the principle streams flowed through the interconnected chain of lakes north of Devils Lake consisting of Sweetwater Lake, Morrison Lake, Dry Lake, Mikes Lake, Chain Lake, Alice Lake and Lake Irvine. These lakes then flow downstream through Big Coulee into Devils Lake (Wiche & Pusch, 1994). After 1979, the Ramsey and Cavalier County Water Management Boards constructed Channel A which connects Dry Lake to Six Mile Bay on Devils Lake (Wiche & Pusch, 1994), consequently altering the discharge pattern of the Lake. As a result, most of the runoff into Devils Lake flows from the upper basin through either Channel A or Big Coulee, with a small quantity of overland inflow from drainage areas adjacent to the Lake (Wiche & Pusch, 1994).

2.5 Devils Lake Climate

Devils Lake is characterized primarily by its continental climate consisting of relatively brief, hot summers, and long, cold winters (North Dakota State Water Commission, 2010). The Devils Lake Basin receives approximately 43.18 cm of precipitation annually, three fourths of which occurs between April and September (North Dakota State Water Commission, 2010). The remaining precipitation that falls after September generally contributes to spring runoff responsible for recharging the Lake. The Lake tends to fluctuate with climatological variability, but the response is not immediate. The natural hydrology of the basin tends to distort the hydrologic response to precipitation, resulting in historical incidences of rapid decreases in lake level following periods of relatively high precipitation (North Dakota State Water Commission, 2010). The most notable characteristic in this regard is the large number of wetlands in the northern basin, as well as the small chain of 16 lakes directly north of Devils Lake. The water storage of the upper basin essentially counteracts the effects of increased precipitation by containing water that would otherwise drain into Devils Lake. Conversely, Devils Lake increases more significantly than normal in spring months when a high snowpack preceded by a wet fall quickly melts while the ground is still frozen, resulting in larger than normal inflows into Devils Lake (North Dakota State Water Commission, 2010).

Since 1993 the historical annual precipitation falling in the basin has been inordinately high for the region, averaging over 55.88 cm annually (U.S. Army Corps of Engineers St. Paul District, 2002). These conditions have been further exacerbated by a 40 percent annual reduction in average evaporation (U.S. Army Corps of Engineers St. Paul District, 2002), largely caused by increased cloud cover and slightly cooler spring temperatures. This increase in precipitation is likely related to the increased activity resulting from the El Nino effects that have been observed since the late 1970's (United States Geological Survey, 2010a). This increased activity is greater than at any other time in the 20th century and has increased both the frequency of storms bearing moisture from the Gulf of Mexico across the Devils Lake Basin and the number of wet years in the basin (United States Geological Survey, 2010a).

2.6 Prehistoric Water-Level Fluctuations

As stated previously the elevation of the Lake surface above mean sea level has fluctuated between 426.7 m (1,400 feet) and 444.4 m (1,458 ft.) since the end of glaciation (Aronow, 1957). Prior to the recent onset of flooding in 1993 the Lake level had not exceeded 435.9 m (1430 feet) in the past 100 years(United States Geological Survey, 2007), while previous research estimates the last time Devils Lake exceeded 438.9 m (1440 feet) was approximately

8,500 years ago (Bluemle, 1981; Wiche & Pusch, 1994). Later radiocarbon analysis on lake soils indicates that Devils Lake overflowed into Stump Lake some point in the past 1,800 years (Wiche & Pusch, 1994).

The cyclical fluctuation of Devils Lake level is also supported in earlier chemical analysis of sediment samples from Devils Lake conducted by Edward Callender. He concluded that Devils Lake rose and fell dramatically between 6,500 and 2,500 years ago with levels low enough between 1,400 and 500 years ago, to allow oak trees to grow on dry surface sediment in what is currently East Stump Lake (Callender, 1968; Wiche & Pusch, 1994). The Lake gradually rose for the next 300 years until the mid to late 1800's at which point it decreased to its most recent low point of 427 m (1400.87 feet) on September 24th, 1940 (United States Geological Survey, 2007). This period of growth between the mid-1500's to late 1800's corresponds to the climate period known as the Little Ice Age (Wiche & Pusch, 1994). Taken together, these studies indicate that Devils Lake has experience large water-level fluctuations between 20 and 40 feet every few hundred years, and that significant increases or decreases in water level, even over relatively short time periods are considered normal for Devils Lake (Wiche & Pusch, 1994). However, despite the normality of extreme lake level fluctuation, the Lake does not often reach the level where it naturally overflows into the Sheyenne River, which last happened between 800 and 1,200 years ago.

2.7 Relation of Inflow to Outflow

The relationship between surface water inflow, precipitation, lake surface area, ground water inflow, evaporation, and storage change defines our current understanding of how the hydrological processes function in the Devils Lake Basin. The U.S. Geological Survey in coordination with the North Dakota State Water commission has studied these factors in relation to their impact on Devils Lake level, in order to create a generalized hydrological model for the DLB. This model is a simple water balance model and was first developed in 1994 by Gregg Wiche of the USGS. A water balance model is:

$$inflow = outflow + storage\ change$$

$$\text{Equation 1: } Q_i + P_{ls}(A_{ls}) + G = E_{ls}(A_{ls}) + S_c$$

Where Q_i is the inflow in acre-feet, P_{ls} is precipitation (in feet) falling on lake-surface, A_{ls} is the lake surface area in acres, G is the ground-water inflow to Devils Lake in acre-feet, E_{ls} is evaporation (in feet) from the lake surface, and S_c is storage change, in acre-feet (Wiche & Pusch, 1994).

A_{ls} is of critical importance to this equation because it is directly related to the amount of precipitation that falls directly onto the lake surface, as well as the volume of water lost through evaporation and transpiration (Wiche & Pusch, 1994). Of these, precipitation falling on the lake surface and evaporation are the primary factors that determine inflow and outflow respectively. This designation is important because it means that the primary factors determining surface area are subject to both climatic fluctuations and the initial conditions of the lake surface at the time of modeling. This makes long-term prediction of lake levels incredibly difficult because the models are based upon both widely fluctuating climate data and a constantly changing initial surface area determined by a highly variable combination of surface area and inflow. However, by effectively quantifying all of the available inflows and outflows of the Lake, the interaction between these variables can be modeled under a variety of conditions.

This water balance model underlies all of the predicted future lake levels that have been generated for Devils Lake and is the key to our understanding of how the Lake operates. Established by Gregg Wiche of the USGS (1994), it characterizes Devils Lake hydrological interactions. Wiche outlines the generalized annual hydrological model as follows:

> 1. In late fall or early winter, the water level in Devils Lake declines to a minimum. After freezup and throughout the winter, the water level rises slightly because of groundwater inflow. Surface-water inflow usually is zero, and precipitation and evaporation usually are minor. Ground-water inflow is minor throughout the year.
> 2. In March through May, snowmelt and rain produce runoff from the basin into Devils Lake. The maximum water level occurs in April or May in drier years and in June or July

in wetter years. In March through May, inflow [sum of Q_i , P_{ls} (A_{ls}), and G] exceeds outflow [E_{ls} (A_{ls})] and the water level rises (positive S_c).
3. Sometime in April through July, outflow exceeds inflow and the water level begins to decline (negative S_c). The minimum water level occurs in late fall or early winter. Then the cycle is repeated. (p. 17-18)

The model was verified against the historical lake level, replicating the observed lake levels very closely. There are instances when the generalized model produced does not apply, such as the dry years of 1934, 1935, and 1937 where the inflow during March through May did not exceed the outflow capacity of the Lake, resulting in a decline in lake level (Wiche & Pusch, 1994). Overall, the historic water-level fluctuations indicate that the water-level in 1932, 1954, and 1971 differ significantly from the generalized model, due to larger than normal increases in precipitation (Wiche & Pusch, 1994).

Generally, precipitation falling on the surface of Devils Lake is the largest contributor to annual inflow (Wiche & Pusch, 1994). The only exception to this rule occurs in instances when tributaries to the Lake flood, producing surface-water inflow greater than the Lake surface precipitation. Consequently, Devils Lake experiences a large annual variability of inflow due to the highly variable annual fluctuations in precipitation, and the inconsistency of Devils Lake's surface through the year (Wiche & Pusch, 1994).

While the Lake level generally fluctuates in response to climatic variability throughout the basin and larger region, the distinctive hydrologic characteristics of the basin can distort the generalized response. This occurs under certain conditions when the potholes and lakes of the upper basin retain more water than normal, as was the case between 1991 and 1992 prior to the onset of flooding. The spring of 1992 saw large increases in annual precipitation and cloud cover, and lower than normal annual temperatures and evaporation, yet Devils Lake did not experience any appreciable increase in lake-level(United States Geological Survey, 2007). Satellite images from August 15th, 1991 and August 1st, 1992 (Figure 3) show nearly identical lake-levels for Devils Lake and despite being late in the fall when declining lake levels are generally observed (and in this case were observed as normal), the images clearly show Mike's Lake, Lake Alice, and Lake Irvine were completely dried up by 1992 after having decreased in size since 1988 (NASA Landsat Program, 08/15/1991a; NASA Landsat Program, 08/15/1991b). However, on August 1st, 1992 Lake Irving, Lake Alice and Mike's Lake covered 1,612 ha (3,983 acres), 1,391 ha (3,437 acres), and 1,029 ha (2,543 acres) respectively, collectively covering some 4,032 ha (9,963 acres) (NASA Landsat Program, 08/01/1992a; NASA Landsat Program, 08/01/1992b).

Despite instances like those in 1991 the generalized hydrologic model accurately describes the level of Devils Lake under most conditions and provides a benchmark for inflow under various conditions. Under normal precipitation and evaporation, about 68,900 acre-feet are required to maintain the "standard" lake level of 434.3 m (1,425 ft.) (Wiche & Pusch, 1994). It is interesting to note that this hydrologic model was developed in order to understand the needed inflow to stabilize Devils Lake lake-levels, which had been decreasing to the point where policy makers discussed alternatives to increase inflow into what at that time was a lake on the verge of drying up.

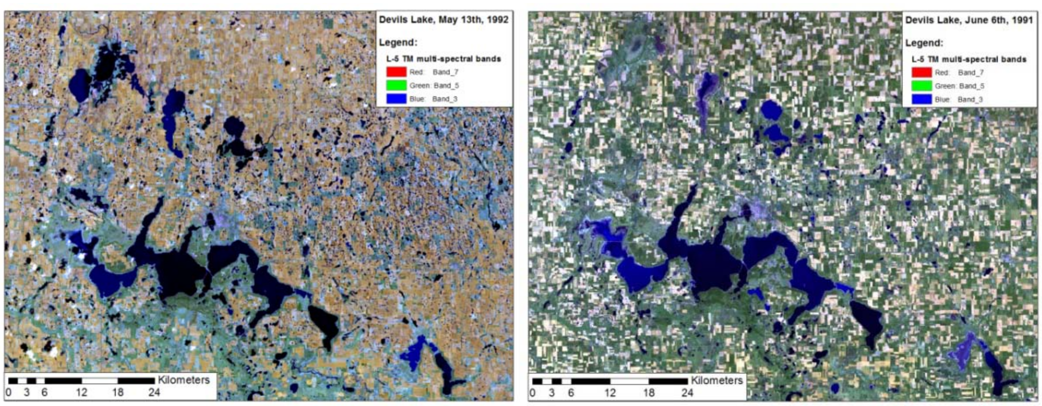

Figure 3. Devils Lake in 1991 and 1992. These two images compare DL in 1991 and 1992, and illustrate the degree to which the upper basin water volume increased. The upper basin bodies in the left image (1992) are clearly more developed than the same bodies in the right image. It was only after the upper basin lakes had become saturated that the main body of Devils Lake began to increase.

2.8 Future Lake Level Predictions and Flood Mitigation

In 1994 the City of Devils Lake began implementing a continual infrastructural mitigation strategy designed to combat the rising lake levels. Since that time the funds for the expensive and protracted flood mitigation have come largely from Federal emergency flooding monies, of which Devils Lake has taken the largest share through 2010. In response to this unique flood situation, federal and state governments have expended a great deal of time and effort attempting to develop more proactive long-term flood mitigation strategies.

Despite this, the proactive implementation of mitigation efforts has been difficult to achieve because of federal regulations dictating how to perform benefit-cost analysis of proposed projects and policies. Until 2007, the U.S. Army Corps of Engineers could not justify projects that had a negative benefit-cost ratio as determined by standard methods. A crucial variable in their methods involves the probability of future lake level rise in Devils Lake. While the USGS began producing future lake level probabilities as early as 1995, these analyses were infrequent and highly uncertain, due to the nature of the Lake. Because of the Lake's unique nature and complex inputs, it is incredibly difficult to predict long-term lake levels, and as such, the probabilities of future lake levels are highly uncertain. It is also difficult to determine the accuracy of the models because of the volatile nature of the Lake's fluctuations.

Despite the difficulties involved in predicting future lake levels, the predictions produced by Aldo "Skip" Vecchia of the USGS constitute the best available understanding of the future lake levels for the entirety of the Devils Lake flood. They combine an annual lake-volume model with a statistical water mass-balance model (WMB) to compute the total volume (mass) of water stored in Devils Lake due to precipitation on the Lake surface, evaporation from the Lake surface, and inflow to the Lake from the drainage basin. The WMB model generates seasonal lake volumes on the basis of seasonal precipitation, evaporation and inflow. Autoregressive moving average models were used to model the annual mean lake volume and the difference between the annual maximum lake volumes.

The models are verified against historical annual lake-level changes from 1901 to the most recent year of the model. The annual lake-volume model closely reproduced the statistics of the recorded lake-level for this time except for the skewness coefficient, which was less skewed than the data indicates because of unrealistically large lake-level declines (Wiche & Vecchia, 1996a). The statistical water mass balance model requires as inputs seasonal precipitation, evaporation, and inflow data, which showed no significant trends from 1950 to 1993, and thus were treated as stationary for the model in question (Wiche & Vecchia, 1996a).

A comparison of the two models illustrates that WMB model's upper exceedance levels increase more rapidly than do the upper exceedance levels in the annual lake-volume model. This variance is driven by the fact that the WMB model closely matches the hydrology of the Lake, and thus bases future lake levels more on the inputs into the system than on an extrapolation of the historical recorded levels, and thus is superior in its predictive ability (Wiche & Vecchia, 1996a). Although specifically for the 1996 frequency analysis, the lack of differentiation between the models, and the discussion within each of the previously mentioned future lake-level probability estimates, indicates similar issues with each iteration of lake-level analysis (Vecchia, 2002; Vecchia, 2008a; Wiche & Vecchia, 1995; Wiche & Vecchia, 1996a; Wiche & Vecchia, 1998; Wiche, Vecchia, Osborne, & Fay, 2000).

2.9 Environmental Impacts

Environmental impacts analyses resulting from Devils Lake mitigation efforts have almost exclusively centered on the negative impacts that would likely be experienced downstream in the event of a natural overflow from Devils Lake into the Sheyenne River (Anfang & Loss, 2003c). Because of its terminal nature, Devils Lake has historically had a lower water quality levels than the surrounding basin because of its low volume, the high influx of dissolved solids from overland flooding, and the concentrating effect of evaporation (Aronow, 1957; United States Geological Survey, 2010b; United States Geological Survey, 2010d). When the Lake is low, the water quality deteriorates considerably, and when the Lake rises, the increased volume generally tends to dilute the presence of major ions and dissolved solids, nutrients, and trace elements within the Lake (North Dakota Water Science Center, 2005).

Further, although there is a consistent surface-water connection between the Devils Lake sub-basin and the larger Red River Basin near the north end of the DL basin, the actual lake does not connect with the larger Red River Basin at levels below the natural overflow elevation of 444.4 m (1458 feet). Consequently the biota within the aquatic ecosystem is cut off from that of the rest of the larger basin in all but the most statistically unlikely of instances. Taking into account the dilutive effects of the increased volume of water, the ND State Water Commission in cooperation with the U.S. Army Corps of Engineers has found that rising lake levels do not pose health risks to the native biota of the Lake or the Red River Basin. Most of the native wildlife in the DL basin is associated with water and wetlands, and as such the increased lake levels have improved the Lake's viability as a natural breeding area for a number of migratory waterfowl species, as well as the predators that thrive on them (Anfang & Loss, 2003c). While this tremendous increase has benefited some species, it has not been so extensive as to pose a threat to the existence of other endangered species including the bald eagle, whooping crane, gray wolf, piping plover, and western prairie fringed orchid (Anfang & Loss, 2003c).

However, flooding does have some negative environmental impacts. The states of North Dakota and Minnesota have identified over 300 sites that exhibit significant natural and/or cultural values around Devils Lake and within ¼ mile of the Sheyenne River (U.S. Army Corps of Engineers St. Paul District, 2002). These sites along the Sheyenne River, as well as the adjacent natural areas and downstream communities, are faced with the greatest risk of significant environmental damages from Devils Lake flooding, especially in the event of a natural overflow scenario through the Tolna Coulee (Anfang & Loss, 2003b).

Under a natural overflow scenario (which differs from a catastrophic natural overflow scenario characterized by the absence of significant preemptive action from the state or federal government to prevent a natural overflow's occurrence or limit its potential impact) it has been estimated by the Army Corps of Engineers and USGS that the discharge through the Tolna coulee could reach approximately 396.4 m^3 per second, or 14,000 cubic feet per second (cfs), with erosion. The discharge would remain above 339.8 m^3 per second (12,000 cfs) for 19 consecutive days, and could carry approximately 718,682 m^3 (25,380,000 cubic feet) of material into the Sheyenne River (Anfang & Loss, 2003b). This would drain approximately 5.58 x 10^{11} liters (452,231.40 acre feet) from lake, lowering it by 48.8 cm (1.6 ft.).

While the DL community would benefit greatly from the significantly reduced water level, downstream communities along the Sheyenne would be severely damaged by the sudden and severe influx of water. Valley City, ND is currently at the greatest risk of significant damage from a catastrophic natural overflow through the Tolna Coulee. Although the city is currently protected to a depth of 6.24 m (20.5 ft.) by levees (Nowatzki, 2009), a flow of the magnitude predicted by the U.S. Army Corps in the event of a catastrophic natural overflow would be double the highest recorded river crest for the Sheyenne River, which occurred during the spring of 2009. That year, the Sheyenne River experienced unprecedented levels of flooding, peaking at a maximum depth of 6.3 m (20.59 ft.) and 224,836 lps (7,940 cfs). This flow, despite being only half of what would come through the Tolna Coulee in a catastrophic natural overflow scenario , is still five feet higher than flood stage for the Sheyenne River at Valley City (which occurs at river elevations of 15 feet or higher (Dalrymple, 2009)). While the specific depth of the Sheyenne at this flow rate is not known, it would certainly overtop the current levee system, especially considering that such an overflow would likely occur during the spring when the Sheyenne River already flows between 28.3 m^3 per second (1,000 cfs) and 169.9 m^3 per second (6,000 cfs) (North Dakota State Water Commission & U.S. Army Corps of Engineers St. Paul District).

The environmental and socio-economic concerns are not limited to a natural or catastrophic overflow scenario. Much has been written about the potential environmental risks associated with an emergency outlet from Devils Lake into the Sheyenne River. Although it is commonly accepted that the native biota of the Devils Lake Basin and the Red River Valley were not widely studied or well known, it is equally accepted that the proximity of the two basins makes the inter-basin transfer of native biota, or, more importantly, of potential biota of concern (of which there is not a complete list), highly likely (Peterson & Gathman, 2002) . The impacts of a potential biota survey were established in the 2002 biota transfer studied completed by Peterson Environmental Consulting Inc. and despite gaps in the knowledge of present species, as well as the absence of knowledge concerning the presence (or lack thereof) of invasive species within Devils Lake, they concluded that it was highly unlikely that downstream habitats would suffer substantially from an inter-basin biota transfer. A limited biota survey conducted in 2005 refrained from making any statement of potential risk despite failing to identify any potential species of concern within Devils Lake that had not already been exposed to the Red River Basin through other avenues (Arroyo, 2005).

2.10 Benefit-Cost and Cost-Effective Analysis.

Benefit-cost analysis (BCA) has been used by the United States since 1900 and has been widely used in assessing the impact of various mitigation alternatives proposed for dealing with Devils Lake flooding (Hyman, 2008). While BCA's consider many criteria, economic efficiency was the primary criteria used in determining the best mitigation alternatives in response to Devils Lake (Anfang & Loss, 2003c). Like all benefit-cost analysis, the methods utilized by the USACOE to determine a given alternative's potential effectiveness hinges upon how future risk is treated. Generally, a benefit-cost analysis evaluates two major dimensions in assessing risk consisting of the assessment and quantification of risk, and the determination how much risk is acceptable (Tietenberg & Lewis, 2009). In the USACOE Final Environmental Impact Statement on Devils Lake (2002) the USACOE assumes a stochastic method of predicting future lake level rise, as this has been the primary method utilized by Wiche and Vecchia since 1994 to predict future lake levels (Vecchia, 2002; Vecchia, 2008a; Wiche & Pusch, 1994; Wiche & Vecchia, 1996a; Wiche & Vecchia, 1998; Wiche, Vecchia, Osborne, Wood, & Fay, 2000).

The USACOE does not make an individual assessment of acceptable risk when dealing with Devils Lake, as the necessary guidelines for government projects are outlined by Congressional statute. Normally, the USACOE recommends projects with the greatest demonstrated net benefit in any given situation (Anfang & Loss, 2003c), however, pursuant to Public Law 108-7 Congress removed this traditional requirement opting to require the USACOE to fully describe their justification for the emergency outlet with a full benefit-cost analysis (Anfang & Loss, 2003c). This removed the requirement of net benefit, which all available information indicates would only occur in the event of a natural overflow of Devils Lake into the Tolna Coulee (Anfang & Loss, 2003b; Barr Engineering Co., 2003a; Barr Engineering Co., 2003b). Although the likelihood of this event occurring is very small, the USACOE Final EIS (2003) makes it very clear that such an outcome is not acceptable, and consequently, all alternatives should be viewed more as insurance policies than as direct investments.

Because the USACOE is not in charge of making the final decision regarding which mitigation strategies will be implemented, the Final EIS is largely absent any evaluation of the acceptable level of risk, and rather recommends alternatives likely to avoid the greatest possible damage to the identified areas of priority within the basin (Anfang & Loss, 2003c). Apart from funding studies necessary to understand the flooding situation at critical times, and levee increases to protect the City of Devils Lake and surrounding priority infrastructure, the USACOE was not involved in the creation of the West End Devils Lake outlet into the Sheyenne River. Even though the USACOE did not provide funding for the outlet, they, alongside several other state and federal agencies, have spent considerable sums (usually from emergency funding sources) on infrastructural protection (to date the USACOE, FEMA, DOT, DOI, NDDOT, and ND State Legislature have all spent considerable monies on infrastructural protection).

Regardless of which agency shouldered the financial cost of a given infrastructural protection effort, all of the expenditures were spent on incremental infrastructural protection at levels capable of protecting the at-risk features to the highest possible near-term surface elevation, instead of the maximum possible lake elevation (Anfang & Loss, 2003c). In terms of benefit-cost analysis this illustrates a preference for long-term approaches. This perspective is completely in line with a high-risk aversion mindset that characterizes the current policies regarding environmental problems and natural hazards (Tietenberg & Lewis, 2009).

For most benefit-cost analyses, long-term interest rates on government bonds are used as a measure of the cost of capital, adjusted by a risk-premium dependent on the specific nature of the alternative suggested. This is done to discount the estimated cost of a given alternative in order to make it more accurately reflect the current present value of all costs that might occur at a future point in time (Tietenberg & Lewis, 2009). It is also a measure of the long-term value of a given project's present cost, thus allowing for effective comparison of policy alternatives with differing lengths of effectiveness (Tietenberg & Lewis, 2009). As of 1992, with a few exceptions, the U.S. Office of Management and Budget standardized the discount rate used within benefit-cost analysis in order to eliminate bias in the choice of discount rate. While a standard discount rate allows the cost of a project's necessary capital to be considered independent of economic fluctuations, in cases involving long-term risks that are unknown or poorly understood (like those characteristic in long-term natural hazard mitigation projects) a standard discount rate is generally ill-suited to describing the future value of costs given the real long-term risks involved. In such instances, a benefit-cost analysis with a standard discount rate (which is determined by long-term bonds and not by any objective determination of risk) will not necessarily define the efficient allocation of capital (Tietenberg & Lewis, 2009).

In addition to the aforementioned instances involving unknown or poorly understood risks, the effectiveness of benefit-cost analyses also relies heavily upon the estimated future cost of a given action. This leaves benefit-cost analyses open to error in cases characterized by substantial differences between the estimated costs prior to implementation and the actual costs upon completion of a project. Tietenberg addresses this issue in "Environmental and Natural Resource Economics" by citing Robert Haveman's study (1972) of USACOE major water projects. Haveman's study found that nearly half the projects in question had realized costs that deviated from the projected costs by plus or minus 20 percent. This study points to a key flaw in using benefit-cost analyses in long-term hazard mitigation. In instances where scientific uncertainty is so great as to systematically bias the results, such as predicting future climate conditions, the future benefits of a given project is almost always underestimated (Tietenberg & Lewis, 2009). This is a primary criticism of the benefit-cost analysis performed on Devils Lake mitigation alternatives, as a comparison of the future predicted lake levels reveals a great deal of discrepancy between the probabilities of reaching various surface elevations at different points in time. Although the chosen alternatives to mitigate Devils Lake flooding were not selected solely upon their cost-effectiveness, the inability to adequately assess the future likelihood of events has definitely impacted the economic efficiency of flood mitigation efforts.

The inability to accurately assess the benefits and costs of a given mitigation strategy in instances like Devils Lake is directly relevant to the analysis in this thesis, as the question being tested is inherently an economic one: How do we more accurately assess the economic efficiency of mitigation alternatives when dealing with the uncertainty associated with climate-driven natural hazards? The answer to this question stands to have far-reaching implications because it will impact the debate surrounding climate change and the related natural hazards that stand to be exacerbated by it. Though Devils Lake may not be of the same scope as climate change, the lessons we learn in dealing with Devils Lake help us weigh the benefits and costs of future, climate-driven hazard mitigation policies more appropriately given the length of the potential negative impact, and how likely a decision stands to be effective over time.

2.11 Principles of Benefit-Cost and Cost-Effective Analysis

Benefit-cost analysis is a crucial element in setting any policy. According to the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies, which were originally established in 1983 and updated in 1992 by the Office of Management and Budget, the Federal objective of water and related land resources project planning is to contribute to the national economic development consistent with protecting the nation's environment in accordance with all applicable Federal planning requirements and executive orders (Council on Environmental Quality, 2010; Office of Management and Budget, 1992; Watt, 1983).

The purpose of a benefit-cost analysis on governmental projects is to determine how well a given project meets the established Federal objectives as set in the aforementioned guidelines (Watt, 1983). Pursuant to these guidelines, all water and related land resources project plans shall be formulated to alleviate problems and take advantage of opportunities in ways that contribute to this objectives, primarily by contributions to national economic development (NED) that result in increases in the net value of the national output of goods and services, expressed in monetary units (Watt, 1983). These net value of national goods and services consist of both direct net benefits that accrue in the planning area and rest of the nation, and increases in the net value of those goods and services that may or may not be marketed (Watt, 1983).

Whether a given project will meet Federal objectives as described by these criteria is dependent on two factors, namely the type of economic analysis performed on all reasonable alternatives and the assumptions underlying the economic analysis being performed. The EPA recommends assessing the impacts of environmental policy using a benefit-cost analysis (BCA), economic impacts analysis (EIA), or distributional analysis. Each analysis looks at the proposed effects of a given policy from a different perspective. BCA focuses on the net social impacts to the localized area and/or society in general; an EIA examines impacts on industry, governments, and non-profit organizations; and a distributional analysis examines the effects on affected sub-populations with a particular emphasis on low-income, minority, and children populations (National Center for Environmental Economics, 2010).

For water projects in response to Devils Lake flooding both EIS and distributional analyses are inappropriate. Because of the low number of affected individuals (the immediate lake area has a population of approximately 12,000), lack of disproportionately impacted minority populations (nearly $80 million has been spent over the course of flooding on the small Lakota community of Minnewaukan (approximate population: 400 persons)), and absence of major environmental risk apart from flooding (the water is not clean, but poses no detrimental health risk (Anfang & Loss, 2003a; Arroyo, 2005; U.S. Army Corps of Engineers St. Paul District, 2002)) there is no justification for a distributional analysis that is focused on any of these areas. Further, the lack of significant economic damages outside of the agricultural and transportation sector of the regional economy (Aakre et al., 2011) combined with the fact that the City of Devils Lake is not a major center of industry or government within the region makes EIA inappropriate as well.

This leaves BCA as the analysis of choice. For Devils Lake, the USACOE utilized a model based upon the benefit-cost ratio (BCR) of the net benefits of potential alternatives (Anfang & Loss, 2003c). This was done by evaluating the benefits of alternatives under four potential future scenarios, the probability of which were determined by the traditional stochastic approach as directed by the USACOE. This approach is based on the probability of hydrologic events and the resulting damages and projects benefits that would ensue (Anfang & Loss, 2003b). Very few of the mitigation strategies assessed by the USACOE had positive BCR's. While this would normally prevent any federal action (and did prior to 2001), pursuant to Public Law 108-7 Congress removed the traditional economic justification requirements for an emergency outlet (i.e. positive net benefit) so long as the justifications for an emergency outlet were described and the benefits and costs fully delineated (Anfang & Loss, 2003c; Anfang & Loss, 2003d) .

The second factor that impacts whether a proposed project will meet federal guidelines is the assumptions used in discounting future costs and benefits. When considering federal action, the discount rate is generally defined as the rate at which society as a whole is willing to trade off present for future benefits or costs (Bellas, 2004; Tietenberg & Lewis, 2009). Because the costs and benefits of the assessed alternatives are spread out over the course of flooding, the future cost of these benefits must be discounted in order to reflect their value to society in the present. These alternatives were categorized into different groups of "Most Likely Action Flood Protection Strategies" (MLAFPS) based upon the most appropriate type of response required. For example, if a road had to be raised, it would most likely continue to be raised as the flooding continued (Anfang & Loss, 2003c) (p.5-36). Additionally, the example road would be raised if the Lake surface exceeded an elevation that was within 1 ft. of the “design[ed] level of protection” which was defined separately for each flood protection measure (Anfang & Loss, 2003c) (p. 5-36).

The MLAFPS for communities and cities, state facilities, rail lines, and roads, consisted of incremental protection involving levee and/or transportation route elevation increases, while the MLAFPS for rural areas was residential structure relocation and loss of property. A total relocation of all at-risk propert was considered, but the USACOE relocation estimate was approximately $1 billion as of 1999 (Anfang & Loss, 2003c) (p. 5-24) and an extensive search has failed to find the report in which this cost was estimated. However, in summarizing the report, the USACOE reports that the costs on the whole would not vary greatly from the value of the buildings or infrastructure, which was the basis for the relocation estimates produced in this thesis (Anfang & Loss, 2003d) (p. B-1).

After organizing the alternatives into MLAFPS the damages were evaluated based upon the elevation-damage and corresponding benefit-cost relationship between the cost of feature protection at a given elevation and the likelihood that the Lake would achieve a surface elevation greater than, or equal to, the action level of that feature (Anfang & Loss, 2003d). The discounted costs were amortized over the 50-year planning period to produce an annual equivalent value, by a discount rate formula based upon the average yield on long-term government securities (Office of Management and Budget, 1992; Powers, 2003; Tietenberg & Lewis, 2009). This rate is chosen because of the temporal displacement characterizing the costs and benefits in water projects. Although alternatives analyzed have benefits that accrue over a very long time period, they are achieved at the expensive of typically large, short-term costs (Powers, 2003).

As of 2003, the USACOE discount rate was 5.875%. This is much lower than the standard Treasury rate of 7% mandated by the Office of Management and Budget in BCA of other governmental projects and policies. Typically, the lower the discount rate used in a BCA analysis, the more equivalent the real value of future money is to the present value of money, resulting in an increased likelihood that a project will have a positive CBR (Powers, 2003). However, because the USACOE calculates future benefits and costs using real dollars, which have already been adjusted to eliminate the effects of inflation, and then discounts them using a nominal rate, which has not been adjusted for inflation, they tend to underestimate the present value of future benefits and costs. This tends to increase the likelihood that a water project will not have a positive CBR (Powers, 2003; Tietenberg & Lewis, 2009).

While the net impact of this inconsistency is unknown, the choice of discount rate is crucial in assessing the present value of future costs and benefits, especially in regards to environmental and natural resource projects where the benefits often consist of non-marketable goods that are difficult, if not impossible, to quantify (Council on Environmental Quality, 2010). In cases like this, discounting is especially important because of the rationale behind discounting in economic analysis. In reflecting the present value of future costs/benefits, discounting reflects how individuals or decision-making groups (i.e. governments, organizations, etc.) value economic resources. Economic literature is replete with evidence that suggests humans value immediate or short-term resources more than those obtained in the long-term future (Bellas, 2004; Callan & Thomas, 1996; Chapman, 1999; Harris, 2006; Horowitz, 1996; Newell & Pizer, 2003; Simon, 1959; Stern, 2008; Tietenberg & Lewis, 2009; Weitzman, 1994). The effect this has is referred to as the time-preference (National Center for Environmental Economics, 2010; Tietenberg & Lewis, 2009), time discount rate (Newell & Pizer, 2003; Nordhaus, 1999; Norhaus, 2007; Weitzman, 1998), or pure rate of time preference (Stern, 2008; Weitzman, 1998) because it discounts future costs simply because they are in the future.

Another justification for discounting is to eliminate the impact of inflation. As a sustained increase in the price of goods over a long period of time, inflation decreases the relative buying power of capital from one year to the next, preventing their comparison in real monetary values. Real monetary values differ from nominal values in that they have been adjusted to eliminate the effects of inflation, whereas nominal values reflect the value of a dollar that has not been adjusted for inflation (Bellas, 2004). In addition to inflation there is also the opportunity cost of capital, which is equal to the full cost of the highest valued alternative to any decision (Chapman, 1999). This is often viewed as the expected return that a capital expenditure would have achieved if invested in a comparable financial security (Bellas, 2004).

In the case of Devils Lake, given the Corp's use of the average rate of return on long-term government securities for the discount rate, the opportunity cost of a water project to prevent flooding would be equal to the return on investment in long-term government securities of the money that would be spent on a given water project. Comparing the expected long-term monetized benefits of the capital required for a water project against the expected long-term yield of a comparable amount of capital invested in long-term government securities is another simple method to assess the cost-effectiveness of a proposed water project. This is known as the real cost of capital and generally has a greater discounting effect than the time-preference because unlike the time preference, it compares the productivity of capital rather than the difference between a dollar's worth of services consumed in the present and the future consumption made possible by the return on investment (Bellas, 2004).

The final rationale for discounting, especially when performing a BCA on a public project concerning natural hazard mitigation, is that public projects and policy carry considerable uncertainty and risk. For any public project, there is uncertainty surrounding its full impact on the majority of the affected populace, as well as the net impacts of any externalities that may result from government policy (Apel, Aronica, Kreibich, & Thieken, 2009; Kunreuther, 2008; Vecchia, 2008a). There is also the risk that the benefit of a policy will not be fully realized, or will fail to be effective, which Devils Lake illustrates exceptionally well. An emergency outlet had been discussed as a potential alternative to prevent catastrophic flooding from Devils Lake, but suffered from the uncertainty surrounding the risk that it might not be effective due to regulatory constraints and future climate fluctuation. Given the possible lake surface elevations of DL, the size constraints of the Sheyenne River (through which any outlet would run), and water quality restrictions on the flow into the Sheyenne, from a 1994 perspective, an outlet could have been built that would have significantly decreased the maximum surface elevation, justifying its moderately-high short-term costs. Conversely, it is also possible that water quality constraints could have prevented significant releases of DL water into the Sheyenne River, or that the Lake would suddenly reverse its recent trends by drying up, thus making any expenditures on an outlet worthless (Vecchia, 2008b).

It is even possible to imagine a scenario wherein an outlet could significantly decrease the maximum lake surface elevation without preventing a catastrophic rise that would flood both Devils Lake and Valley City, making the outlet effective but just as worthless as the scenario wherein it wasn't. Even in a case like Devils Lake where the probability of large future lake level fluctuations was low, the inability to assess the accuracy of these probabilities further increases the risk involved in any public expenditure on a policy or project. It is the perception of risk that drives discounting in this case, and because it is typically based upon our best assumption of a given event's probability of occurrence, it is highly subjective (Chapman, 1999). Like time preference, risk and probability can only really be known after they have been observed, that is, after a decision has been made and an event with multiple outcomes and varying risks has played itself out (Bellas, 2004).

The discount rate is any and all of these things at once, and only after it has been quantified through a comparison with another alternative in equivalent monetary terms can we know the actual rate and the possible reasons for it. When comparing the expected value of a public project's future costs and benefits great care must be taken to choose a rate that is based upon justifiable and reasonable assumptions of the most appropriate time preference, future productivity, and risk and probability. In this thesis, we are not interested in setting a discount rate, but rather in utilizing the full knowledge of the actions taken by policymakers in response to

Devils Lake flooding in order to determine what the real discount rate actually was between chosen alternatives.

2.12 Wicked Problems and Policy Analysis

From a public policy perspective Devils Lake flooding is a unique and incredibly difficult problem to address. At the most basic, the Government of the United States has never dealt with a decadal terminal basin flood in its entire history. The only analogue that exists is the moderate increase in lake level that occurred as a result of increased precipitation in the Great Salt Lake (GSL), Utah between 1980 and 1985 (Campbell, 1998). From 1980 to 1985 the surface level elevation of the Great Salt Lake rose approximately 3.65 m (12 ft.), to its highest point in recorded history (Utah Division of Water Resources, 2009b). Having suffered an estimated $240 million in flood damage, with weather experts predicting no immediate change in upcoming weather patterns, the Utah State Legislature allocated $71.7 million dollars to fund a flood control plan to pump water out of the GSL (Utah Division of Water Resources, 2009b) .

Between April 10, 1987 and June 30, 1989 the new flood protection system pumped 3.37×10^{12} liters (2.73 million acre-feet) from the Great Salt Lake. The pumps accounted for approximately 0.6 m (2 ft.) of the total 1.82 m (6 ft.) drop in surface elevation between 1987 and 1989 before they were shut down in June of 1989 (Utah Division of Water Resources, 2009a). By that time the uncharacteristic variations in precipitation that caused the dramatic increase had reverted back to normal levels, and pumping was no longer needed. Given the declines in precipitation that occurred after 1985, it is highly likely that the Lake would have naturally returned to normalcy without the pumps (Campbell, 1998).

The flooding of the Great Salt Lake between 1980 and 1985 illustrates the inherent difficulties in mitigating climate driven hazards through infrastructural mechanisms. At the time, the state legislature had no reason to believe that the massive inflows prompting the substantial increases in lake volume would change, leading them to invest considerable monies on the construction of a pump to empty the Lake. In hindsight, however, such expenditures were not necessary as the Lake would have decreased in size through the natural mechanism of evaporation. Given that the majority of the water was lost through evaporation, the action taken is more appropriately viewed as an insurance policy for reducing the potential long-term risks rather than a solution to the immediate problem. Further, although the pumps are still being maintained in case of future flooding, news sources report that the high latent salinity of the area has significantly degraded the pumps past the point of operability (McMillian, 2010).

While the Great Salt Lake dwarfs Devils Lake in terms of surface area (approximately 621,597 ha (1.5 million acres) versus 77,217 ha (190,807 acres) in 2011 for DL), and affected population (1.2 million people in the Salt Lake Area versus approximately 21,000 for DL), the observed and potential damages are comparable[1] (Aakre et al., 2011; Utah Division of Water Resources, 2009a) . On a per capita basis, however, the damage from Devils Lake flooding is nearly 44 times larger due to the much more rural nature of the area. Additionally, GSL expenditures were relatively small when compared to the observed damages and the number of people affected by the action, whereas the opposite is true in the case of Devils Lake. This fact is incredibly important in understanding the policy formation process in DL because regardless of the alternative, federal involvement is needed to obtain the funding necessary for implementing it.

Although certainly analogues, the specifics of the social, environmental, and political complexities characterizing these two floods reveal a great many differences between them. In the case of GSL flooding, lake surface elevation increases and the damages they caused were experienced over a short time span of little over two years. While the costs of the solution were not insignificant, they were manageable at the state level, and did not have any ancillary impacts on "downstream" communities. Comparatively, the economics of Devils Lake flooding require a large number of government stakeholders at every level to be involved in mitigation. This alone results in much greater federal involvement (and political complexity) than the GSL flood.

[1] The direct damages from Great Salt Lake flooding through 1985 were estimated at $240 million, while total damages from DL flooding through 2010 are estimated to be approximately $190 million. The potential costs of ancillary damages in both instances were estimated to be nearly $1 billion.

However, it is the geomorphology of the basin that has the greatest impact on political complexity. Unlike the GSL, the elevation of the DL region prevents substantial volumes of water from being transferred from the Lake. Moreover, as a sub-basin of the Red River of the North, water from Devils Lake invariably finds its way into waters that cross state boundaries and eventually national boundaries, requiring interstate involvement as well as international involvement with the Canadian National Government and the Provincial Government of Manitoba. Although these stakeholders are greatly concerned about the transfer of water across basin boundaries, they are also concerned with the moral and economic ramifications involved in a natural overflow event which would have catastrophic impacts on Valley City, ND (Kempf, 2006).

The social complexity characterizing Devils Lake flooding places it into an entirely different realm of policy problems, known as "Wicked Problems". Wicked problems were first defined by C. West Churchman in 1967 as "…social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing (Churchman, 1967)." Recent scholarship expands upon this definition by characterizing wicked problems as being unique and novel, lacking clear boundaries, having no right or wrong solutions and no clear stopping point (Conklin, 2006).

The uniqueness of the problem and lack of clear boundaries and finishing points exacerbates the issues involved in addressing wicked problems. Namely, because they are poorly understood and unique it is difficult, if not impossible, to effectively predict how effective a given solution will be at addressing direct and indirect impacts of the wicked problem (Conklin, 2006). In dealing with myriad stakeholders, it is also oftentimes difficult to effectively communicate the complex information characterizing the problems and proposed solutions (as well as the various secondary impacts of those solutions) among the stakeholders involved (E. P. Weber & Khademian, 2008). This not only leads to confusion about the true nature of the problem, it also contributes to competing problem definitions, contention between stakeholders, the inability (or conflict regarding how) to measure the costs and benefits of proposed alternatives against one another, and ambiguity as to which policy arena is best suited for making the necessary policy decisions on a given wicked problem (Van Bueren, Klijn, & Koppenjan, 2003).

For example, in the case of the GSL, the state had a clear problem (GSL was flooding from uncharacteristically large cyclical fluctuations in precipitation), it had clear geophysical and socio-political boundaries (the immediate area surrounding the Lake under the state legislature's authority), and it had a clear solution that posed no additional impacts (drain the Lake with big pumps and send the water into an adjacent low area with no economic value). While it is an analogue because it is a terminal lake flood, the similarities end there. Devils Lake has no clear solution (infrastructural protection is short-term, ad-hoc, and does not address the main causes of flooding, and draining the lake cannot be effectively accomplished because of the minimal capacity of the Sheyenne River to hold additional water); it has no clear stopping point (the cyclic nature of lake flooding will invariably cause dikes to be rebuilt to stop future flooding, infrastructural protections do not eliminate downstream impacts of natural overflow, and much of the infrastructure will have to be taken down upon decrease in lake level); has many far-reaching impacts (threatens downstream communities and environments); numerous stakeholders (ND and MN state governments, 10 federal agencies, a Tribal Reservation, 21 counties, 3 major cities, the Government of Canada, and Province of Manitoba); and lacks a clear stopping point (there is currently no solution in place that eliminates the problems posed by DL flooding nor is it clear that the current alternative will prevent the catastrophic downstream impacts that could potentially occur).

Addressing wicked problems is complicated and requires non-traditional problem solving methods and strategies (Conklin, 2006). The need for outside the box solutions, collaborative stakeholder mechanisms, flexible strategies, and the necessity for more robust and fundamental problem definitions is well defined in the literature (Churchman, 1967; Conklin, 2006; Lazarus, 2009; Palmer, Smith, Willetts, & Mitchell, 2007; Van Bueren et al., 2003; E. P. Weber & Khademian, 2008). Further, the importance of understanding a given wicked problem in a variety of disciplinary contexts is crucial for developing the communication and problem-solving relationships needed to address wicked problems, especially those driven by climate change and other complex systems with poorly understood interactions characterized by high levels of uncertainty (Lazarus, 2009).

Fundamentally, from a philosophical perspective, the actions of government officials during the course of DL flooding, and of government in general since the Mississippi flood of 1927, there can be no doubt that there is a normative societal expectation that government has a moral imperative to take action to mitigate the damaging effects of Devils Lake flooding. Given this moral imperative, the purpose of this thesis is to utilize cost-effective analysis and recent historical flooding trends and mitigation expenditures in order to shed light on the possible ways in which mitigation might be accomplished in a more efficient and/or effective manner.

CHAPTER III

DATA

3.1 Background

An examination of the previous BCA's using the stochastic future lake level methods as described at length by Vecchia and Wiche (1995, 1996, 1998, 2002, 2004, 2008) shows that CIP was one of a small number of alternatives with a positive cost benefit ratio (CBR) over the 50 year planning period utilized by the USACOE and its subsidiaries (Anfang & Loss, 2003b; Anfang & Loss, 2003d; Barr Engineering Co., 2003b; Cox, 2007; Pearson et al., 2003). Assuming an equal benefit for each alternative, the statistical data suggests that CIP was not the most efficient option over the course of flooding. Figure 4 illustrates the estimated costs of relocation and buyout, the actual total cost of CIP, the annual and cumulative future costs of CIP, and the change in lake surface elevation over the course of flooding.

The costs of relocation and buyout include the cost of previous CIP expenditures for each year. Although the relocation becomes prohibitive by 2002 it stays at an approximately equivalent monetary value until 2005, which suggests that relocation was a viable alternative for the first 11 years of flooding. In terms of the relationship between total CIP costs and a buyout, it was still more economical in the long-run to buyout the private property in Devils Lake until 2010. The base data shows that the largest annual expenditure occurred in 2010 and was 25.7% of the total CIP cost.

With the exception of 2000, no annual expenditure was ever greater than 8.1% of the total cost of CIP while the average annual CIP cost was only 5.9% of the total. Buyout and relocation were also much greater than the annual expenditures, with the percentage of annual CIP to buyout costs maxing out at 30.1% and annual CIP to relocation maxing out at 19.7%.

The percentage of annual costs to buyout and relocation averaged 11.2% and 5.7% respectively. All of these costs (except future cumulative CIP, which decreased) increased with lake surface elevation.

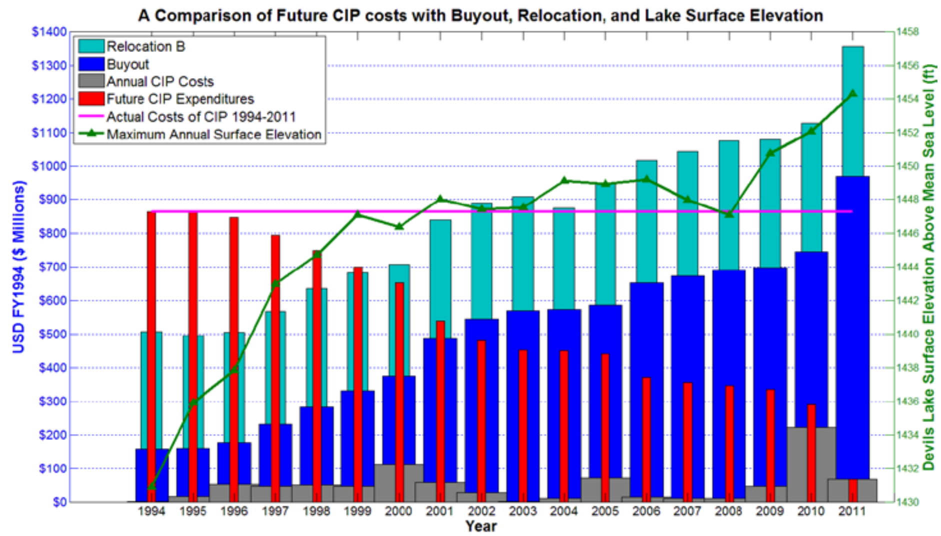

Figure 4. A Comparison of Future and Total CIP Costs with Buyout, Relocation, and Lake Surface Elevation over time.

These relationships, especially between the estimated cost of relocation and buyout and the total cost of CIP, are notable because had dramatic action been taken early in the onset of flooding, a great deal of money would have been saved providing the same benefit as CIP. The problem with this fact is that it is only observable in hindsight. The breadth of official reports, academic literature and anecdotal evidence indicates that the perceived risk of a near-term catastrophic overflow (which would require the maximum protection level of CIP) was extremely low for much of the course of flooding. Further, the likelihood that the Lake would reach catastrophic overflow levels within the next 50 years was also incredibly low. How the perceptions of low risk and the far-off nature of a catastrophic overflow impacted the predicted CBR of CIP and influenced decision-making is the driving force behind the scholarly inquiry described in this thesis.

3.2 Overview

The data used in this model comes from a variety of different sources ranging from the City of Devils Lake, the State of North Dakota, and U.S. Federal agencies. The data consists of the most accurate and best information available as of May 2011. A thorough description of the data being used is important because the results of this model hinge upon their validity. This section describes how the annual costs of CIP, and the one-time costs of a relocation and buyout of Devils Lake, ND were estimated. It will also describe the pertinent assumptions behind the estimates wherever necessary, as well as any methods used to manipulate or adjust the data.

3.3 Actual CIP Expenditure Data

Actual CIP expenditures are defined as expenditures spent in the Devils Lake Basin to mitigate or remediate the damage caused by Devils Lake flooding. These expenditures were spent or allocated between the years of 1994 and 2011 on projects consistent with the three-pronged approach delineated by the Devils Lake Basin Joint Water Resource Board and North Dakota State Water Commission's Devils Lake Basin Water Management Plan (Conner & Noone, 2006 Devils Lake Basin Water Management Plan). The actual CIP expenditures for Devils Lake were compiled from a variety of sources, specifically DL levee expenditures were provided by Project Managers Bonnie K. Greenleaf and Bill Csajko from the USACOE (2010), and infrastructural mitigation and other flood mitigation expenditures came from *The Report of the Federal Interagency Devils Lake Working Group* (2010), the *Devils Lake Flood Infrastructure Expenditure (1994-2011)* memo by Michael Noone of the State Water Commission (2010), and the *Report of the Devils Lake Basin Technical Review Team* (ND Department of Emergency Services, ND State Water Commission, & U.S. Army Corps of Engineers, 2010). Major CIP expenditure data was also obtained from the *Devils Lake, North Dakota, White Paper* produced by the U.S. Army Corps of Engineers (2009).

Public Assistance funding was collected by ND Department of Emergency Services Public Information Office of Cecily Fong (2010)(Fong, 2010)(Fong, 2010)(Fong, 2010)(Fong, 2010), and Farm Service Agency (FSA) and flood compensation payments from agencies under the auspices of the U.S. Department of Agriculture (USDA) were collected by Program Specialist Dale Ihry of the ND Farm Service Agency and FSA Farm Program Specialist Jim Jost of the ND State FSA office (Ihry & Jost, 2000; Ihry & Jost, 2011). Further supplementary expenditure data detailing some cost-share payments and other state/federal costs was obtained from the ND State Water Commission's Water Resource Program Administrator Carolyn Merbach (2011). All costs were cross-referenced whenever possible, in order to prevent double counting or overlap resulting from disparate sources. While almost all of the data was reported in FY expenditures, some data was not available in itemized format. This data consisted of total monies spent over a given time frame (these expenditures comprised only a small amount of the total CIP expenditures) and for consistency, was amortized over the number of years wherein the Lake level increased.

Because of the difference in timing of the various reports' estimates of CIP expenditures, there were instances where sources disagreed about the amount of a given expenditure. In these cases, preference was given first to the sources with the most specific and detailed estimates, and second to the source that was closest in time to when the expenditure occurred. Finally, newer estimates of total expenditures were given preference over older estimates, but were viewed in conjunction with one another in order to detect how the totals changed over time and any discrepancies between the sources. The expenditures were cross-referenced across all available sources in order to eliminate any potential double-counting of expenditures and ensure that the data was as accurate as possible. The annual CIP expenditures reported in this thesis are believed to be more comprehensive than any available and are consistent with all current and previous reports of total CIP expenditures to date. The annual expenditures on CIP are represented in Table 1.

CIP expenditures in Table 1 are presented in three different ways. First, they are shown in nominal value, which is consistent with reported value in other sources. Second, they are presented in fiscal year 1994 dollars which reflect the same annual costs but in terms of the present day 1994 value with the effects of inflation removed. The third way the expenditures are presented is in fiscal year 2011 dollars, in order to illustrate CIP expenditures in terms of their present value as of the writing of this thesis. For the sake of continuity, all of the costs and monetary values reported in this thesis are reported in fiscal year 1994 US dollar value.

Table 1. Total CIP Expenditures by All Agencies 1994-2011

Year	Annual Devils Lake CIP Expenditures (nominal USD)	FY 1994 Annual Devils Lake CIP Expenditures	FY 2011 Annual Devils Lake CIP Expenditures
1994	$1,346,021	$1,346,021.00	$2,030,705.58
1995	$17,189,117	$16,707,821.72	$25,275,591.85
1996	$54,744,866	$51,615,649.46	$78,306,542.44
1997	$49,672,524	$45,756,077.95	$68,981,662.20
1998	$55,148,274	$49,987,289.24	$74,864,118.92
1999	$52,925,883	$46,917,474.61	$70,715,757.29
2000	$132,095,506	$113,117,991.59	$172,697,174.58
2001	$70,152,925	$58,392,314.29	$88,699,757.24
2002	$33,660,222	$27,569,061.48	$41,400,016.27
2003	$2,154,900	$1,724,355.04	$2,608,656.82
2004	$12,602,573	$9,812,318.70	$14,913,288.85
2005	$93,127,233	$70,043,241.51	$107,305,121.53
2006	$19,384,395	$14,112,928.80	$21,601,080.17
2007	$14,950,448	$10,579,992.40	$16,143,500.51
2008	$14,745,401	$10,434,886.66	$15,488,415.04
2009	$67,190,792	$45,559,120.40	$70,576,507.21
2010	$333,479,288	$222,499,752.82	$338,814,956.49
2011	$101,000,000	$67,387,918.39	$101,000,000.00
Total	$1,125,570,368	$863,564,216.06	$1,311,422,852.98

3.4 Relocation and Buyout Estimate Data.

The estimated cost of a buyout of Devils Lake priority infrastructure was determined using the True and Full assessed value of all residential and commercial property in Devils Lake according to the Devils Lake City Assessor's office[2] (Martinson & Wolf, 2010) , the reported relocation costs of the cities of Fort Totten, Minnewaukan, and St. Michael, North Dakota in the Devils Lake Infrastructure Protection Study (Barr Engineering Co., 2003d), the estimated cost of federal aid highway construction as reported by the U.S. Federal Highway Administration, and

[2] Because the Devils Lake City Assessors Office does not assess the value of non-taxable and public property, the value of public property in Devils Lake was determined using the Devils Lake City Assessors estimate of its total worth. According to Donna Wolfe, the value of public property is approximately 50% of the true and full assessed value of all private property in the Devils Lake City limits.

the cost of residential and commercial road construction for the city of Grand Forks, North Dakota.

While only a single buyout alternative was estimated, the relocation estimates were split based upon whether major transportation routes would be relocated around the maximum lake elevation (445.9 m (1463 ft.)) or maintained in their current location. Relocation A assumes that the major roadways would be relocated along with Devils Lake (and other remaining communities), which would be placed in the closest area to the current location of the communities above the maximum lake elevation. Relocation B assumes a similar relocation of all the communities above the maximum lake elevation but assumes that the major transportation routes will remain in the current location.

The difference between these two scenarios impacts has the greatest impact on the City of Devils Lake. For the communities of Ft. Totten, St. Michael, and Minnewuakan, relocation/buyout is relatively easy as the south end of the basin is a much higher elevation. Minnewaukan, for example, could be relocated to the west of Highway 281, less than a mile from its current location. Similarly, Ft. Totten and St. Michael could be relocated with 2-5 miles of their current location. More importantly, these relocations would not require any additional roads or alterations to major transportation routes. Devils Lake on the other hand, would need to be relocated between 8 and 10 miles from its current location, and, depending on which relocation scenario is chosen, would need additional roads and alterations to major transportation routes. The specific distances required in each scenario will be described in greater detail later in the chapter.

Beginning with the True and Full assessed value of Devils Lake, the original data was for the years 1991-2009, and consisted of the true and full assessed, taxable assessed, and taxable value of commercial, residential, and farm land within the Devils Lake city limits. Farm land was equivalent to undeveloped lots. Thus, the total True and Full assessed value for all private property within the city is the sum of the true and full assessed value for all commercial, residential, and undeveloped property within the Devils Lake city limits. For the years 2010 and 2011, the 2009 data was assumed to increase with average rate of inflation over the time of flooding (2.45%). Finally all of the values were converted to 1994 dollars in order to make all of the monetary values constant.

The road estimates were determined from two separate sets of data; the estimated construction cost for a federal aid highway according to the Federal Highway Administration (FHWA) and the 2009 cost of construction for new residential and commercial roadways and services in Grand Fork, ND. Beginning with the highway construction costs, the data combined the design specifications of a Federal Aid highway, with the distance of roads needed in one of two relocation alternatives as described later in this thesis. Using ArcGIS shapefiles describing North Dakota state, federal and local roadways (Kautzman & Bieber, 2010; Nelson & Bieber, 2011; U.S. Census Bureau, Geography Division, Geographic Products Branch & U.S. Department of Commerce, 2011) , the length of roadways needed for the city was determined. Depending on whether the current major transportation routes would be relocated along with the city, the shorted estimated distance of necessary highway was calculated using ArcMap. Altogether, the length of new highway was between 50 and 100 miles depending on the specific relocation area and the location of major transportation routes.

This was combined with the specifications for a Federal Aid Highway as defined by U.S. Department of Transportation (Obenberger, 2011), which are established by the American Association of State Highway and Transportation Officials (AASHTO). Because all Interstate Highways must conform to these standards in order to receive federal funding, they are the same for every state. As a result, even though the vertical composition of federal aid highways came from the U.S. District of Columbia minimum pavement standards, because they are in accordance with AASHTO standards (Klein, 2009) it is safe to assume they are the same for North Dakota. The estimated cost of per-mile highway construction was computed assuming a standard 30.48 cm (12 inch) portland cement concrete base base, 17.78 cm (7 inch) bituminous concrete cap, and a standard 3.7 m (12 ft.) lane width (Klein, 2009; Obenberger, 2011). The state roadmaps were used to determine whether a given road was a two or four lane road, and the widths were adjusted accordingly. Using these specifications, the volume and area of necessary inputs (including common excavation, portland cement, and bituminous concrete) was calculated and then multiplied by the appropriate unit price as reported by the FWHA (Federal Highway Administration, 2006), which produced the cost of construction for one mile of a two and four lane interstate highway. This thesis did not determine the estimated cost of labor because it varied too much to establish valid estimates. It also did not estimate the cost of local county road construction because such data was unavailable. As a result, all of the roads outside of the Devils Lake city limits were estimated using interstate highway specifications.

For commercial and residential roads within the city limits, the data was procured from the Grand Forks City Engineer. It detailed the cost of constructing new roads for additional development in Grand Forks, including the unit cost of sanitary sewers, water mains, road lights, and other public utilities. For residential areas the roads consisted of a 9.4 m (31 ft.) roadway width (berm to berm), a 30.48 cm (12 inch) aggregate base, and 17.78 cm (7 inch) concrete cap. These are exactly the same measurements used in commercial roadway construction with the exception of a 15.5 m (51 ft.) road width (Rau, 2010). The lights were computed at 1 light per 45.7 m (150 ft). The total costs for new roads came to $1,837.27 per meter ($560 per foot) for residential, and $2,352.36 per meter ($717 per foot) in 2009 USD. The length of residential and commercial roadway was measured in ArcMap and multiplied by the unit cost reported by the Grand Forks Engineer (Rau, 2010). The total cost of roadways was then assumed to stay constant and adjusted for inflation for every year back to 1994, in order to give it a constant yearly value.

The method used to determine road relocation costs is similar to the method used for relocation (cost is equal to 100% reported property value) but differs in that the relocation costs of the aforementioned cities only apply to the costs of relocating property that is at or below lake surface elevations of 445.9m (1463 ft.). Because of the small population of these cities and relative value of property at risk, the difference between total private property value and the total value of all property at risk is minimal, amounting to approximately $16 million in 1994 USD. This thesis assumes the cost of relocation/buyout to include all of the property within the Devils Lake City limits. This is because at lake surface elevations greater than 445 m (1460 ft.) Devils Lake becomes an island, stranding a large section of the city and seriously disrupting major transportation within the region. This can be seen in Figure 5.

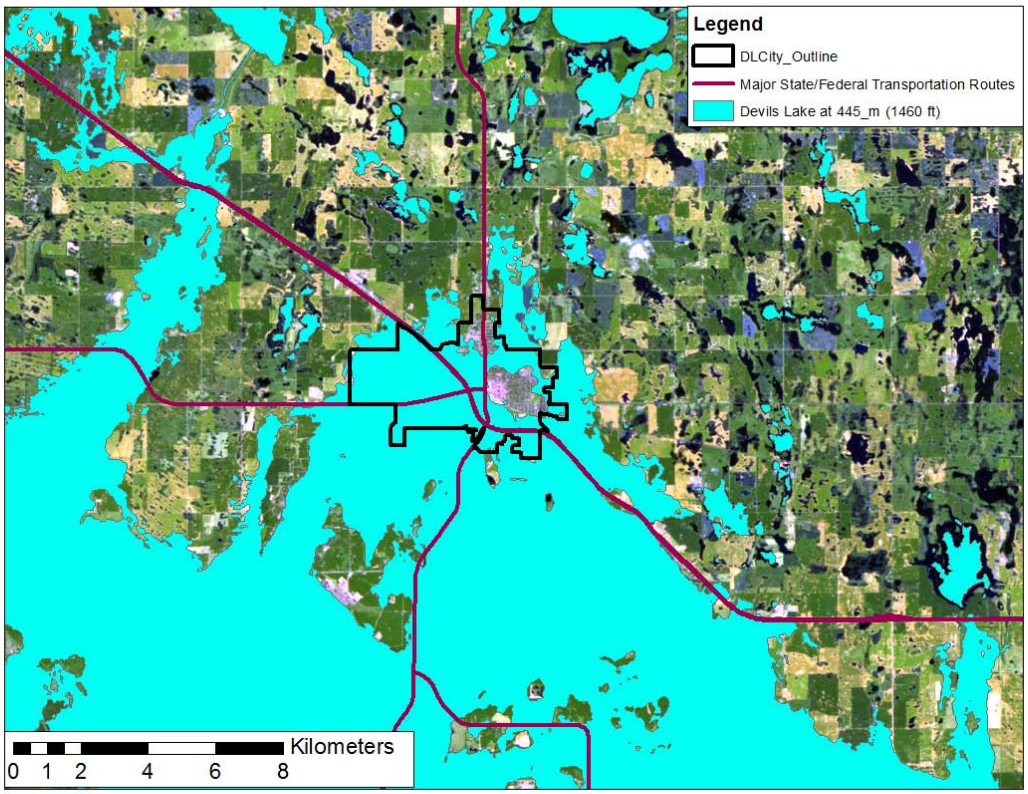

Figure 5. Devils Lake Under No Protection at 445 m (1460 ft.) Elevation.

The costs of a relocation/buyout for Churches Ferry, ND are not included in this total because they have already been bought out by FEMA. The buyout alternative assumes that the federal government, most likely under the auspices of FEMA, would pay individuals at risk from flooding a fair market value for their property (land and improvements) rather than spending capital on infrastructural mitigation. These values are displayed in Table 2.

Table 2. Estimated Buyout Cost of Devils Lake Property Types (Public and Private) (Nominal USD)

Years	True and Full Assessed Devils Lake Private Property Value	Public/non-assessed Devils Lake property value (DL Assessor's Office)
1994	$142,626,731	$71,313,366
1995	$146,465,592	$73,232,796
1996	$151,100,784	$75,550,392
1997	$157,704,371	$78,852,186
1998	$165,572,582	$82,786,291
1999	$168,459,598	$84,229,799
2000	$172,525,034	$86,262,517
2001	$173,586,887	$86,793,444
2002	$176,885,507	$88,442,754
2003	$178,289,351	$89,144,676
2004	$183,636,493	$91,818,247
2005	$196,093,193	$98,046,597
2006	$196,345,128	$98,172,564
2007	$211,239,066	$105,619,533
2008	$221,345,596	$110,672,798
2009	$227,285,786	$116,225,834
2010	$232,859,454	$119,076,009
2011	$238,569,803	$121,996,078

The relocation alternatives were determined under different assumptions pertaining to their possible implementation. This was done to reflect possible methods of relocating the city as well as produce a range of potential values for relocation. The range of relocation costs for DL reflects the difference between a relocation strategy characterized by the decision to maintain current major transportation routes as much as possible and a relocation strategy wherein major transportation routes are relocated above the maximum potential lake elevation of 446.834 m (1466 ft.). Regardless of whether the major transportation routes are moved along with the city, the most likely area for any relocation is illustrated by Figure 6. The Targeted Relocation Area was identified because it would require the least amount of additional roadway under the Relocation A scenario, and is closest to existing transportation routes, minimizing costs of additional roadways for Relocation B. It is also the closest area to the current location of the City of Devils Lake as determined using ArcMap GIS software. This same area was also targeted as a most likely relocation area by Barr Engineering (2003a), because of its proximity and because regardless of the exact site within this area, the land value will not change appreciably.

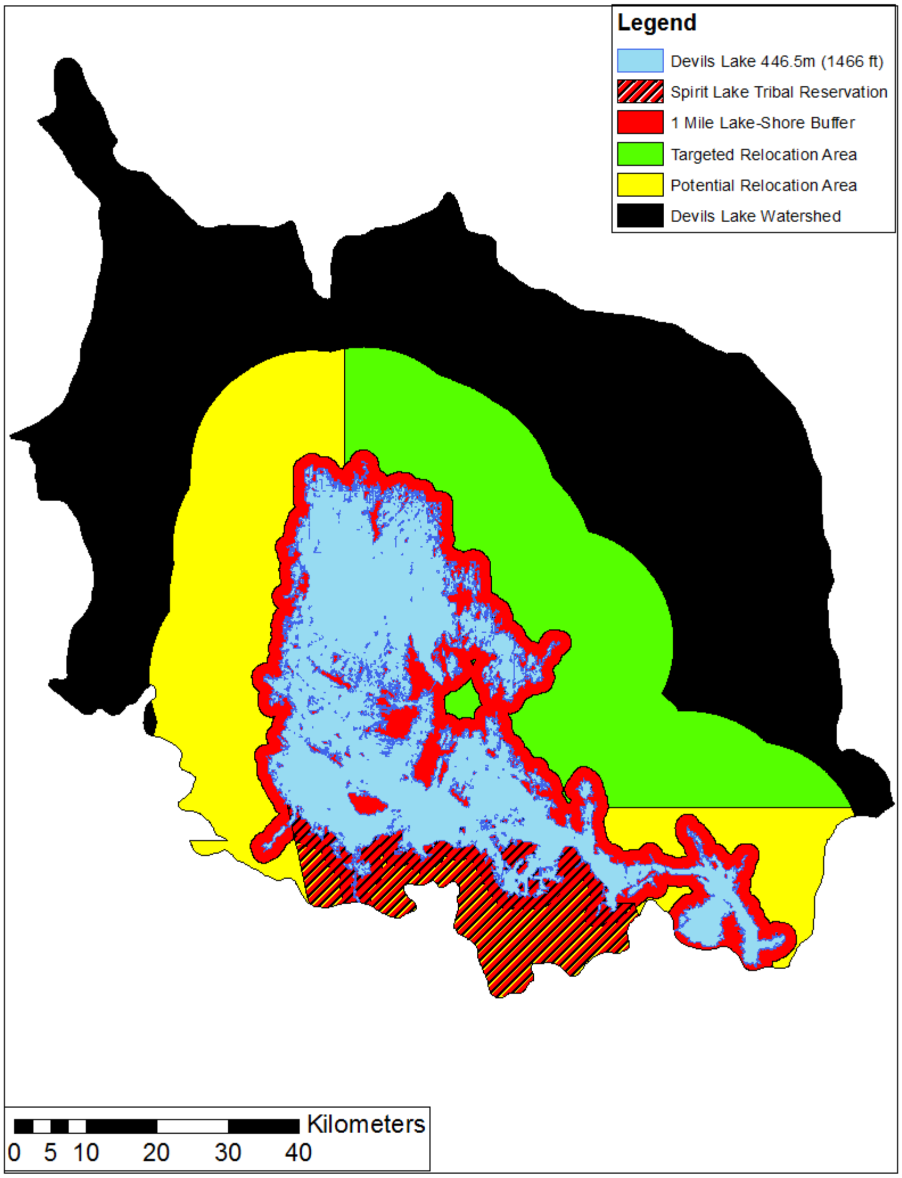

Figure 6. Devils Lake Potential Relocation Zone. In order to calculate relocation costs, a targeted relocation Area (TRA) and potential relocation area (PRA) were identified based upon the distance from the original city location and from existing roadways. The TRA is consistent with the most likely relocation area considered for incremental relocation by Barr Engineering (2003a). Within the TRA and PRA a relocation option would require between 50 and 100 miles of new highways. Using this estimate, a range of potential relocation costs was determined based upon relocating major roadways or maintaining them in their current location.

Relocation costs for Devils Lake were estimated using a combination of data. Similar to the buyout alternative, it began with the true and full assessed value of DL residential and commercial property from the Devils Lake City Assessor's office (Martinson & Wolf, 2010) and the relocation costs of the cities of Fort Totten, Minnewaukan, and St. Michael. The Devils Lake city assessor also estimated the value of all non-assessed private and public property within Devils Lake, which in combination with the true and full assessed values provides an accurate estimate of all property within DL.

The costs of new residential and commercial roadways within the city limits were estimated using commercial and residential roadway construction costs and specifications for the City of Grand Forks, ND in 2009. Approximately 90 miles from Devils Lake, Grand Forks is an ideal analogue for Devils Lake. It has also undergone major infrastructural construction for new residential and urban areas in past years, providing the very recent cost estimates for this type of construction. The costs of city roadways also included the necessary infrastructure to provide city services, including sewer, water, storm-sewer, utility and public lighting, and were adjusted for the rate of inflation for every year back to 1994 to accurately express the likely change in value over that time. The value of the land needed to be purchased in the event of relocation was determined using the maximum recorded value of cropland for the basin according to the USDA Agricultural Census data.

Altogether, the estimated cost of a buyout consisted of the true and full assessed value of all Devils Lake private property plus the estimated relocation cost of all structures in St. Michael, Ft. Totten, and Minnewaukan. Relocation A consisted of the true and full assessed value of all private property in Devils Lake, the Devils Lake City Assessors estimate of the value of public and non-assessed property in Devils Lake, the cost of relocating approximately 60 miles of additional interstate highway, the value of all commercial and residential roadway in Devils Lake, and the value of necessary land for relocation. For the model, we assume a distance of 60 miles for the relocation of major roadways, which would be built along current transportation corridors in order to avoid disrupting agricultural land. This was the distance of road relocations needed to reach the closest area above the maximum lake elevation within the Devils Lake potential relocation zone. Relocation B consisted of the same costs, with the exception of the 60 miles of relocated highway. Instead of relocating major transportation routes, Relocation B assumes that major routes are maintained. It does include the estimated cost of 28 miles of highway needed to connect the closest relocation site above the maximum lake elevation to current transportation routes. The only difference between A and B is one scenario builds new roads above flood levels, and the other maintains current roadways as much as possible.

The range of estimated relocation costs is consistent with the few previous relocation estimates. The Army Corps did a cursory estimate of the cost of relocating the city in 1996 (MN & ST PAUL, 1996) and again for the Final Devils Lake Integrated Planning Report and Environmental Impact Statement, they placed the cost of relocation at $1 billion (2002 USD) without any explanation as to how this estimate was determined (Anfang & Loss, 2003b). The data compiled by this thesis suggests the cost of relocation was between $575.6 million and $846.3 million in 1994, and $709.2 million and $1.04 billion in 2002.

The costs of relocation and buyout include the cost of previous CIP expenditures for each year. Although the relocation becomes prohibitive by 2002 it stays at an approximately equivalent monetary value until 2005, which suggests that relocation was a viable alternative for the first 11 years of flooding. In terms of the relationship between total CIP costs and a buyout, it was still more economical in the long-run to buyout the private property in Devils Lake until 2010. Using this data, this thesis has developed a model that takes into account the impacts of discounting and future lake level uncertainty in order to describe how policymakers compared the future costs mitigation alternatives in decision-making, and how the process might be adjusted to produce more efficient outcomes in similar situations in the future.

CHAPTER IV

METHODOLOGY

4.1 Overview

This thesis examines the economics of government decision-making in response to Devils Lake flooding in order to determine the efficacy of the policy known as Continuing Infrastructural Protection or CIP. It began with an assessment of the damages to property and productivity within the region from flooding, the largest damages occurring within the agricultural sector. The damages were calculated using the net profit of various commodities grown in the region as determined by the reported acreages for Benson, Nelson, Ramsey, and Towner ND Counties as reported by the University of Minnesota Farm Financial Database (FINBIN) (University of Minnesota Center for Farm Financial Management, 2009) and National Agricultural Statistical Service (NASS) (United States Department of Agriculture, 2011)) (United States Department of Agriculture, 2011).

The damages from lake flooding are not spread evenly across the region. As a result, the severity of the flood damages has a strong geospatial component. The location of flooding was determined by developing a chronological time series of the Lake between 1991 and 2011 and a 3m and 1m digital elevation map (DEM) of the DL basin. The 3m digital elevation data came from the USGS (United States Geological Survey, 2009), while the 1m digital elevation data was provided by the International Water Institute LiDAR data (Kaliki, 2011; Skarphol, Deutschman, & Fischer, 2009a; Skarphol, Deutschman, & Fischer, 2009b; Skarphol, Deutschman, & Fischer, 2009c; Skarphol, Deutschman, & Fischer, 2009d) .The chronological time series was created using Landsat TM5 images of Devils Lake from SRTM's 3126 and 3127 between 1991 and 2011(NASA Landsat Program, 1991 - 2011).

The Landsat images were used in conjunction with the ND GAP Analysis land classification map from 2005 (Strong, Sklebar, & Kermes, 2005) and DEM's to determine both the extent of historical and potential future flooding and the location of various types of property within the flooded area. The Landsat images were also used, in conjunction with the USGS DL surface-area/elevation table (United States Geological Survey, 2011), to verify the accuracy of DEM's in producing accurate estimates of lake surface area at future potential lake elevations. This information was useful in developing a clear description of the current and possible extent of lake flooding, as well as the costs of flood damages and mitigation. The development of a model that would estimate the economic impact of Devils Lake flooding is a worthy endeavor that should be explored more fully at a later point in time. However, this area of inquiry is not fully pursued in this thesis. This line of research ultimately led to the question of how best to assess the cost-effectiveness of CIP in addressing Devils Lake flooding, which has since become the focus of this thesis.

The novel element of this thesis is the cost-effectiveness model (CEM) used to compare CIP with a buyout and relocation of DL in terms of their real expected present value in any given year from 1994-2011. The sources for the yearly CIP expenditures and inputs used to determine the estimated costs of a buyout/relocation of Devils Lake were described in the previous chapter. In total, the data consisted of reported CIP expenditures from relevant government (i.e. Federal, State, and Local) sources from 1994-2011, and the estimated cost of a relocation/buyout of Devils Lake for each year between 1994-2011as determined from commercial and residential property values reported by the DL City Assessor, road construction costs as reported by the Federal Highway Administration, and the costs of new service infrastructure (sewer, water, lights, etc.) as reported by the Grand Forks City Engineer.

Using a CEM to reflect the expected present value (EPV) of future CIP expenditures, we will assess the overall effectiveness of the Devils Lake CIP strategy as it compares to buyout and relocation alternatives. This comparison is useful as it illustrates how CIP over 18 years of flooding compares to mitigation alternatives that have the same benefit as CIP expenditures, but at a greater one-time cost.

The reason we utilize this type of model for our analysis is because it is a derivation of the standard method for conducting benefit-cost analysis of proposed federal agency projects and/or policies (Kohyama, 1992; Office of Management and Budget, 1992; Watt, 1983). A derivation of this method was also used to evaluate the present value of future benefits of various flood mitigation alternatives in Appendix B of the United States Army Corps of Engineers (USACOE) Devils Lake, North Dakota Final Integrated Planning Report and Environmental Impact Statement (Anfang & Loss, 2003b).

Our method differs from the method utilized by the USACOE in that it assumes each alternative to have the same benefit, that is, they preserve the value of priority at risk from DL flooding, which can be viewed as the damages avoided[3].

4.2 Cost-Effectiveness Model

The CEM in this thesis compares the expected present value of CIP expenditures against the real value of a buyout and relocation of Devils Lake for 1994-2011. We assume that all of the alternatives have the same benefit in order to focusthe comparison on the respective costs of each alternative. All monetary values have been converted to fiscal year 1994 U.S. dollar values to eliminate the effects of inflation. Since CIP expenditures are spread out over 18 years of flooding they are not expressed in equivalent dollar amounts. Thus, we need to calculate the present value (*PV*) of future CIP expenditures for the beginning year before a lake increase occurs. The present value of a future expenditure in any particular year, PV_t can be written as a function of a future cost (*C*), a discount rate (*d*), and the year when the cost occurs (*t*).

[3] We do not consider downstream damages to be a part of the damages avoided because none of the expenditures for any of the elements comprising CIP can be considered to prevent downstream damages. While some CIP expenditures, most notably those spent on an outlet, could potentially prevent a natural overflow from Devils Lake into the Sheyenne River, monies spent on an outlet will not absolutely prevent such an overflow from occurring, as, depending on regional climactic conditions, the Lake could naturally overflow regardless of whether an outlet is present (Vecchia, 2002; Vecchia, 2008a).

$$\text{Equation 2:} \qquad PV_t = \frac{C_t}{(1+d)^t} \qquad with\ d \geq 0$$

In this equation, when a future cost and time period are fixed, the present value of a future cost is a decreasing function of the discount rate. That is, the larger the discount rate; the smaller the present value of a future cost will be. This relationship exists because the value of money changes with time. With a positive *d*, the negative relationship implies that the value of a dollar today is greater than the value of a dollar one year from now. As such, before the values of two costs that occurred at different times can be compared, they must be adjusted to reflect the change in the value of money that occurred in the time between them.

The discount rate is the key variable in this function because it is subjectively determined by assumptions concerning the relative importance of present to future costs and the inherent risks associated in capital investments. When predicting the present value of a future project, an "appropriate" discount rate is generally based upon a combination of the project's most likely results and the historical trends of various economic measures, like inflation or interest. The justifications for choosing a discount rate notwithstanding, when it is used in a present value function in a predictive fashion, it does not reflect the real rate of change between the present and future values of a cost, only the rate assumed to reflect the most likely difference between the present and future values of a cost (Bellas, 2004; National Center for Environmental Economics, 2010). Further, because of the multitude of rationales for discounting, and the inability to quantify them, the discount rate cannot really be observed. It can, however, be inferred or estimated by comparing the costs of a decision in hindsight after a cost occurs and all the other variables are known.

In the case of DL flooding the real rate at which policymakers discounted the future costs of CIP over the one-time costs of relocation/buyout is not observable, even though the fluctuating CIP costs have been incurred in each of the previous 18 years. Therefore, the *PV* equation needs to be extended as follows to take all future years into account to better fit the circumstances of describing Devils Lake:

$$\text{Equation 3:} \qquad PV = \sum_{t\,=\,1,2,\ldots 18}^{t} \frac{C_t}{(1+d)^{t-1}}$$

$$with\ 0 \leq\ d \leq 1$$

This modified equation gives the present value (*PV*) of all future annual CIP expenditures (C_t) in the starting year of the model, where $t = 1$. This model still fails to take into account the fact that future CIP costs are dependent upon future lake level rise, which is uncertain and difficult to predict accurately. The probability that the current CIP level will be exceeded by a future lake elevation must be considered in order to correctly estimate the present value of a future expenditure under uncertainty.

To incorporate the uncertainty issue in the model, equation (2) can be further modified based upon the concept of expected value in Economics. The expected value of a given alternative is the sum over outcomes of a policy's present value determined by a given decision outcome's probability of occurrence (Tietenberg & Lewis, 2009). The idea is based upon the principle that, in a set of all possible outcomes, the value of any single outcome is proportional to its likelihood of occurring. For example, for a set with two possible outcomes (e.g. a coin flip), the expected value of either result is equal to the full value assigned to either outcome multiplied by the 50% chance each will occur. If the value of both outcomes is $1, their expected value is $0.50.

In the context of Devils Lake flooding we are interested in the expected value of future CIP costs. CIP is based upon the likelihood that the Devils Lake surface elevation will exceed the action level of the designed protection elevation of the infrastructural protection for the features identified by the USACOE. The action level is a foot below the designed protection level of any given feature's infrastructural protection, or CIP level. The likelihood that CIP level will be exceeded shall be referred to as the exceedance probability, which, for a given year t, is P_t. Because the CIP level varies by feature and CIP costs have been incurred in every year of flooding, the CIP level is assumed to be equal to the Lake surface elevation when the Lake is greater than 435.9 m (1430 ft.). Although the total possible number of potential lake levels cannot really be known, the model assumes that the total number of possible lake levels is equal to the number of model runs performed by the USGS when predicting future lake levels (i.e. 10,000).

The model also assumes that exceedance probability is equal to the likelihood that a given future lake level greater than the current level of CIP will be greater than or equal to all possible lake levels. The reason for this is based upon the difference between the probability a given lake level will occur and the probability the Lake level will increase. Whereas the probability of any single lake level is proportionate to the number of times it occurs over 10,000 traces, the likelihood that the Lake level will increase is proportionate to the sum of all lake levels greater than the current lake elevation. Therefore, the exceedance probability is proportionate to the sum of all lake levels greater than or equal to the current CIP level over 10,000 possible future lake levels based on the current lake elevation and expected inflow for Devils Lake.

Initially, our model will be run for exceedance probabilities between 10% and 100%, in order to assess the sensitivity of the model to probability. The final model ultimately assumes the exceedance probability for any of the features identified as part of the CIP policy is between 90% and 100% for any given year. Regardless of the range of probabilities chosen (whether 10% - 100%, or 90% -100%), for an alternative with an annual exceedance probability of P_t and fluctuating annual costs C_t, over t time periods, the expected value or EV_t is:

Equation 4: $$EV_t = p_t * C_t$$

Combining the multiple time period *PV* and *EV* equations will produce a function that results in the expected present value of future annual costs over multiple time periods. The expected present value (*EPV*) of future mitigation costs *C*, over *t* time periods is:

Equation 5: $$EPV = \sum_{t=1,2,\ldots 18}^{t} \left(\frac{EV_t}{(1+d)^{t-1}}\right) = \sum_{t=1,2,\ldots 18}^{t} \left(\frac{C_t * p_t}{(1+d)^{t-1}}\right)$$

The expected present values of future CIP expenditures will be compared against the one-time costs of relocation and buyout for different years over the course of flooding, which as one-time costs do not require discounting by probability or discount rate. This framework will allow for the comparison of the expected present value of future CIP costs at different times with the one-time costs of a relocation and buyout. We propose that the comparison of CIP with alternatives that provide the same benefit will inform the discount rate of Devils Lake decision-makers when choosing CIP over buyout/relocation. The magnitude of this discount rate will reflect the preference of decision-makers for short-term over long-term mitigation strategies, the latter, which despite greater short-term costs, ultimately prove to be more cost-effective when dealing with long-term climate hazards like Devils Lake flooding.

4.3 Major Variables and Implications

The two major variables in our model consist of the probability of CIP protection and discount rate. While the state of climate and earth system understanding is improving, it is still difficult to predict climate fluctuation to any reasonable degree of accuracy. There is also considerable debate over the 'correct' discount rate (as determined by potential environmental impacts and ethical assumptions regarding consumption and growth) to use in the case of social projects, especially over those designed to mitigate future damages from climate driven hazards like DL flooding, or, from the planetary perspective, climate change. In both cases, there is uncertainty surrounding the pertinent variables because they cannot be known until after a future event or action has occurred. This makes any BCA dependent upon the assumptions underlying the determination of probability and discount rate.

This case study is directly applicable to the current efforts to address the long-term impacts of climate-change in that it is a unique instance where the estimated impacts of a climate-driven hazard can be compared against the both the estimated and actual costs of mitigation. Further, because most large-scale climate problems have extensive wicked characteristics, Devils Lake is an ideal laboratory in which to assess the economic efficiency of our current economic value assessment paradigm.

CHAPTER V

RESULTS AND ANALYSIS

5.1 Overview

The results of our model are presented in several ways. The first illustrates the impact that lake level exceedance probability has on the expected present value (EPV) of future CIP costs. The second set of results consist of a comparison of the EPV of future CIP costs from two different starting points in time (1994 and 2001) against the one-time costs of a buyout and two relocation scenarios (Relocation A and Relocation B) . The third result will illustrate how the length of time between the present day and a future cost impacts the EPV of CIP over the course of flooding. The fourth set of results will illustrate the long-term comparison between the EPV of future CIP costs and a buyout and relocation scenarios taking into account previous mitigation costs. Finally, the chapter will end with an analysis of Devils Lake flooding from a wicked problem perspective, and a description of another instance of high risk, low probability flooding on the Red River of the North which led to a long-term flood mitigation strategy.

5.2 Description of Results

The first results ran the model from the starting point of 1994 and with exceedance probabilities of 100%, 90%, 50%, and 10% over the discount rate. These results are portrayed in Figure 7. In this figure, both the exceedance probability and discount rate act to decrease the EPV of future CIP costs. On the x-axis, an increasing discount rate decreases the EPV, while on the y-axis the higher the probability of exceedance the lower the EPV of CIP.

The impact of decreasing exceedance probability is most apparent at the 0.0 discount rate. At 0.0, the change in EPV of CIP between the Actual CIP Costs and 10%, 50% and 90% exceedance probabilities ranges from $86.4 million (10% exceedance) and $865 million (Actual

CIP Costs). In other words, the EPV of CIP at 100% exceedance probability is 10x greater than the EPV of CIP at 10% probability.

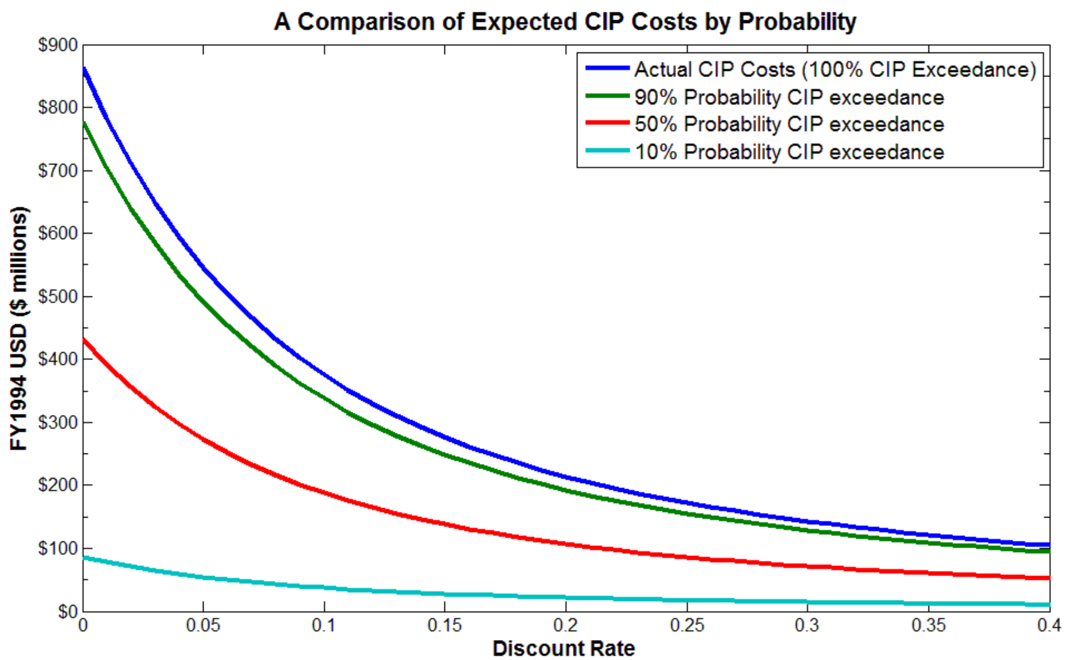

Figure 7. The Impact of Probability on the Expected Present Value of CIP Expenditures 1994-2011 (1994USD).

Due to the inconsistency of historical future lake level predictions, this model assumes that the annual exceedance probability over the course of flooding was between 90% and 100%. This assumption is based upon the relationship between the Lake surface elevation and the current level of CIP for any given feature in Devils Lake. In hindsight we know exactly how the Lake surface elevation fluctuated, giving it, and the corresponding CIP expenditures resulting from the Lake level fluctuation, a probability of 100%. Further, given that CIP increases occurred every year since 1994, we can assume that the likelihood that the CIP expenditures would be required is also very high.

Because of the constant CIP increases over the course of flooding, we assume a high exceedance probability of 90%. This is justified by the fact that, for all possible future lake level predictions, the observed lake level is greater than at least 1 ft. less than the 10% exceedance level. This means that the observed surface elevation was within 1 foot of surface elevations that were greater than at least 90% of all possible lake surface elevations as predicted by the USGS (Vecchia, 2002; Vecchia, 2008b; Wiche & Vecchia, 1995; Wiche & Vecchia, 1996a; Wiche & Vecchia, 1996b; Wiche & Vecchia, 1998; Wiche, Vecchia, Osborne, Wood et al., 2000). This assumption is significantly different than the assumptions utilized by the USGS, Barr Engineering, and the USACOE, who based BCA models on the future probability of DL surface elevation as predicted over 10,000 possible traces of future lake levels (Barr Engineering Co., 2003b; Barr Engineering Co., 2003d; Vecchia, 2002; Wiche & Vecchia, 1996a; Wiche & Vecchia, 1998; Wiche, Vecchia, Osborne, & Fay, 2000)

In this model, the 100% curve represents the actual cost of CIP, wherein the likelihood that the current elevation of CIP had a 100% chance of being inadequate and requiring incremental increases to its current level. The 90%, 50% and 10% represent hypothetical scenarios wherein the likelihood that the current level of CIP would be exceeded over the course of flooding is 90%, 50%, and 10%. Because the probability that a given level of infrastructural protection is directly related to its expected cost and is one of two variables within the model (represented by p_t), how it impacts the expected present value of CIP is critical to understanding the model's results.

The other major variable is the discount rate, or *d*. The discount rate illustrates the time preference, and as such, reflects how much decision-makers discount future costs because they are in the future. Within the model, regardless of the specific discount rate, the number of years between the starting point and a future cost determines how many time periods a discount rate will be compounded in order to reflect its present value. In our model, the discount rate is compounded annually by the number of the years between the initial year and the future year during which a given cost is incurred. The longer (shorter) the amount of time between the initial year and the final year, the greater (smaller) the order of magnitude by which the discount rate is compounded. The two starting points of 1994 and 2001 will illustrate how the discount rate impacts the expected value of future CIP expenditures at different points in time. 1994 is a logical choice for the first value as it is the year when officials began to address the growing problem of flooding. 2001 was chosen as the second starting point because it was at this point that CIP expenditures overtook the one-time 1994 cost of relocating the City of Devils Lake.

The most important results are those from the 1994 run, under the 100% and 90% probabilities, for discount rates between 0.0 and 1.0. The two curves produced by these parameters represent the most likely range of expected present value of CIP for 1994-2011. They are represented by figure 8. Figure 8 also illustrates how the *EPV* of future CIP costs from 1994 - 2011 compare with the estimates of relocation and buyout established by this study.

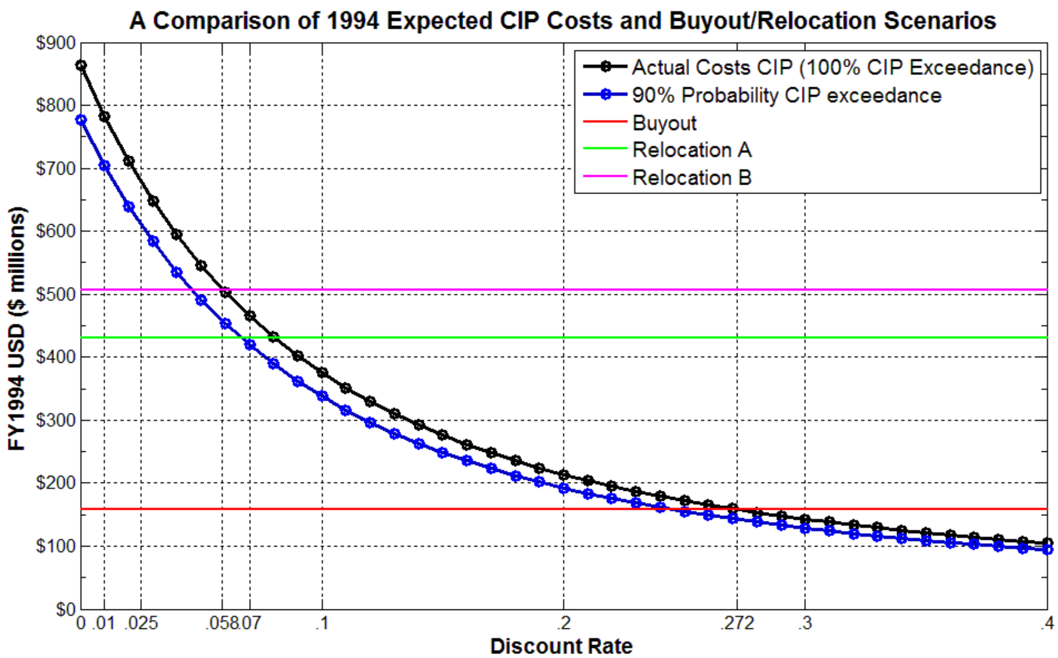

Figure 8. A Comparison of the Expected Present Value of Annual CIP Expenditures from 1994-2011 and DL Buyout and Relocation Alternatives (FY1994 USD).

In figure 8, the *EPV* is plotted on the y-axis, while the discount rate (*d*) is plotted on the x-axis. The Actual Costs CIP and 90% probability curve downward to the right away from origin because of the relationship between *d* and *EPV*. The rate at which the present values of future costs are discounted decreases the *EPV* of future CIP costs. Although the model computed results for rates between 0 and 1, the x-axis ends at a discount rate of 0.4 for the sake of clarity in order to illustrate the discount rate at which a buyout is equal to the Actual Cost CIP and 90%

probabilities. Not only does the curve flatten out considerably after this point, showing smaller rates of change between each discount rate, but likelihood of a discount rate higher than 0.4 is extremely unlikely regardless of which rationale for discounting is used.

If you assume that the discount rate should reflect the real growth in GDP, then it would be inappropriate to use a rate higher than 3%, given the average rate of growth in GDP between 1970 - 2010 was 2.82% and 1990-2010 was 2.49% (Shane, 2010). This rationale also assumes the rate at which costs increase in the future (or in this case the rate at which you need to discount future costs in order to achieve their true present value) correlates with the average rate of growth in domestic output. Given that the future costs increase with lake elevation, this would be an incorrect comparison.

If you assume the discount rate is best reflected by long-term private investment rates or long-term government securities, over the same time period than it is unlikely the discount rate would exceed 6%. Like GDP, this assumes that damages are correlated with private investment, which has no bearing on whether a given CIP expenditure will be incurred. Within the literature, there is no instance wherein a discount rate greater than 10% was used, and because this was the previous standard rate utilized by the OMB, it hasn't been used in BCA since 1992 (Tietenberg & Lewis, 2009).

The dotted lines represent key discount rate values. The 0.10 rate represents the former standard discount rate for BCA performed by government agencies, the 0.07 rate is the current rate as set in the 1992 circular by the Office of Management and Budget, under the Executive Office of the President (Office of Management and Budget, 1992), the 0.0587 rate represents the rate which the USACOE uses in its BCA, and 0.04 represents the approximate average of proposed social discount rates as reported in academic literature (Moore et al., 2004).

At the 0.0 discount rate, we see the total costs of buyout and relocation compared against the total costs of CIP in the long-term. This point represents the cost of CIP under the assumption of the perfect probability regarding the likelihood that CIP would protect priority infrastructure for all possible future lake levels. Relocation A (a scenario wherein major transportation routes are relocated along with the city), Relocation B (wherein major transportation routes remain in their current location), and Buyout are represented by straight lines at their nominal 1994 value because they are one-time costs that require no future expenditures, and thus, do not need to be discounted. The distance between Relocation A and Relocation B represent the likely range of possible relocation costs for Devils Lake and the surrounding areas. The point of intersection between the 90% Probability and Actual Costs CIP curves, and relocation and buyout scenarios illustrates the discount rate at which CIP was equivalent in monetary terms over the course of flooding. The rates at which the actual CIP costs cross the relocation A, relocation B, and buyout lines occurs at 5.9%, 8.1%, and 27.2% respectively. The 90% probability curve intersects at approximately 4.5%, 6.8%, and 24.5% respectively.

The model assumes each of the alternatives produces equal benefits. From the point of intersection between two alternatives, where the CIP curve is higher (lower) than the straight buyout/relocation lines, the expected present value of future CIP costs are higher (lower) than the one-time costs of buyout/relocations. When comparing CIP with the other alternatives, because CIP was chosen over the other alternatives, the rate must be greater than the rate at the point where CIP and any of the other alternatives intersect.

Figure 8 represents the comparison of alternatives from 1994 through 2011 perspective. Because the discount rate compounds over time, changing the year in which CIP, relocation, and buyout are compared affects the rate at which the alternatives intersect with CIP. Figure 9 illustrates the expected value of future CIP costs from 2001-2011 against the one-time costs of a relocation and buyout, as well as the total costs of CIP over the course of flooding.

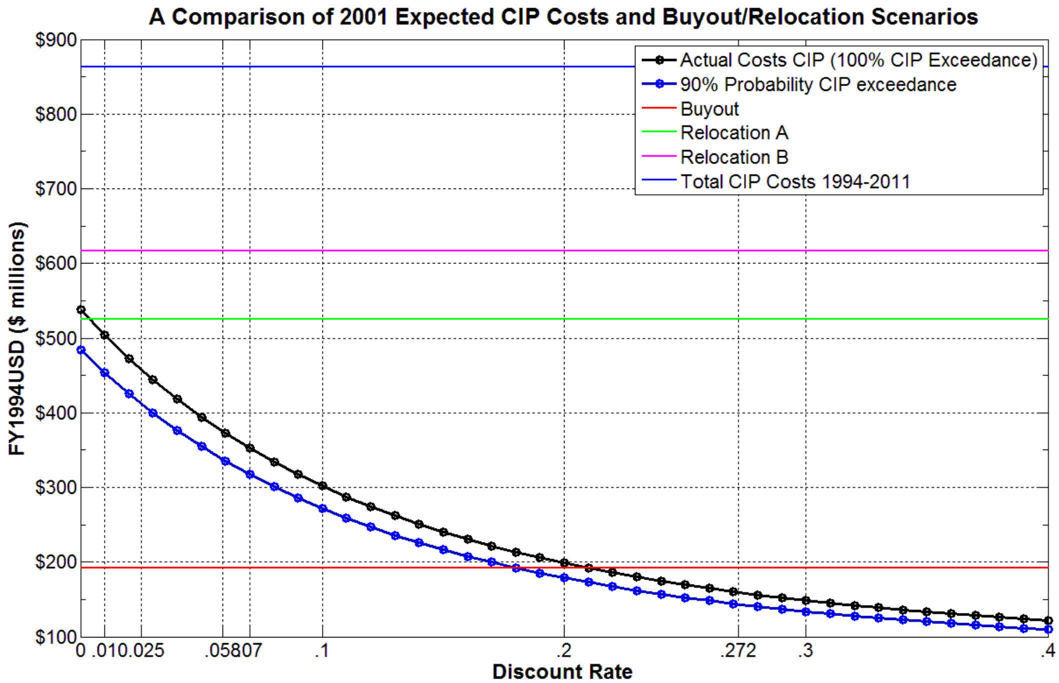

Figure 9. A Comparison of the Expected Present Value of Annual CIP Expenditures from 2001-2011 and DL Buyout and Relocation Alternatives (1994 USD).

Figure 9 illustrates the effect that changing the starting year can have. In this figure only the Actual Costs CIP curve intersects with Relocation B (at approximately .5% discount rate). While both the Actual Cost and 90% probability exceedance curve intersect with the buyout alternative, they do so at a much lower rate than in the 1994 results, crossing at 21% and 18% respectively. While this set of results would suggest that CIP is likely to be cheaper than relocation in the future (at discount rates higher than approximately .5% both CIP curves are cheaper) it doesn't reflect the true costs of CIP. Because the model only provides the expected value of future CIP, it does not take into account previous costs of mitigation. This is demonstrated when one compares the relocation and buyout alternatives against the total CIP costs from 1994-2011. While the future expected value of CIP from 2001-2011 is less than the one-time costs of relocation, relocation is still less expensive than CIP as a whole.

These expected present value model provides snapshots of future costs but does not illustrate how the future costs are impacted by previous mitigation. Figure 10 shows the expected present value of future CIP costs at 5.87% discount rate and 100% and 90% probabilities on an annual basis from 1994-2011.

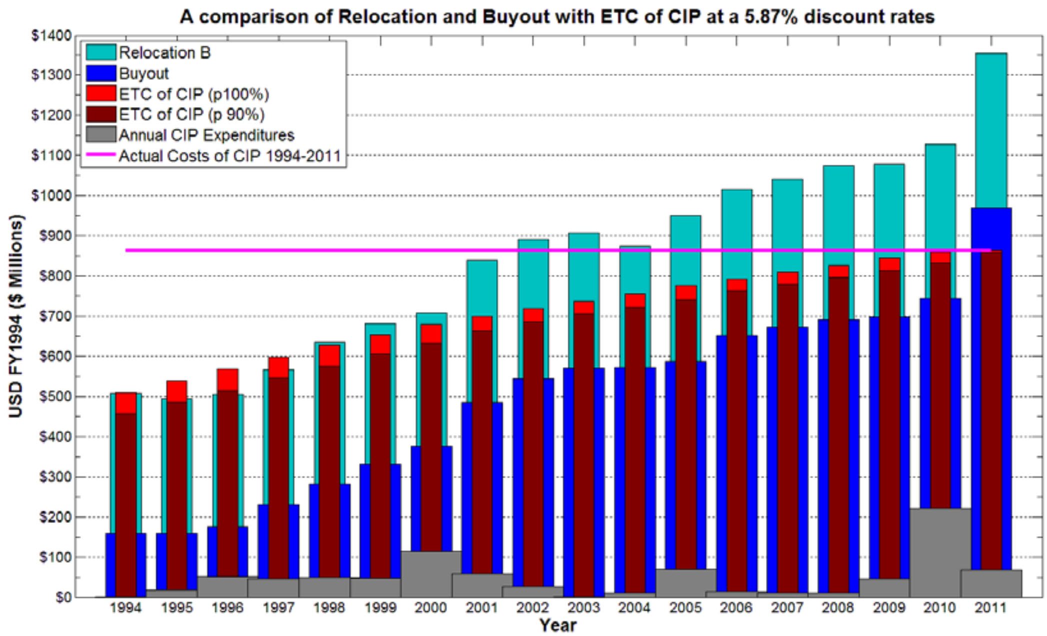

Figure 10. A comparison of the expected total cost of CIP (EPV of future CIP costs at 5.875% + previous CIP expenditures) with DL Buyout and Relocation Alternatives from 1994-2011 (FY1994 USD).

In this figure, the year of flooding is represented on the x-axis and the cost in 1994 fiscal dollars on the y-axis. It illustrates five sets of data, consisting of the total yearly cost of relocation B, buyout, and the annual EPV of CIP at 100% and 90% probabilities. The previous costs of mitigation (or sunk CIP costs) have been added to each of the totals to represent how the sunk costs impact the model comparisons. This figure also includes the annual costs of CIP. This figure shows more clearly the expected future cost of CIP and how it compares to a relocation or buyout. From this figure, we can draw three conclusions. The first is that the point at which the one-time costs of relocation surpassed the future total expected value of CIP was in 2001 assuming the standard USACOE discount rate. The second conclusion is that the point at which CIP became cheaper over the current course of flooding was in 2002. Finally, the cost of buyout didn't exceed the total expected cost of CIP or total CIP until 2011.

These results depend critically on the assumed discount rate. When the model is altered to reflect the observed discount rate of a buyout in figure 8 (e.g. 27.2%) the results change considerably. Figure 11 illustrates the impact that the larger discount rate has on the annual EPV of future CIP and how that changes the expected total costs (EPV + sunk CIP) over the course of flooding.

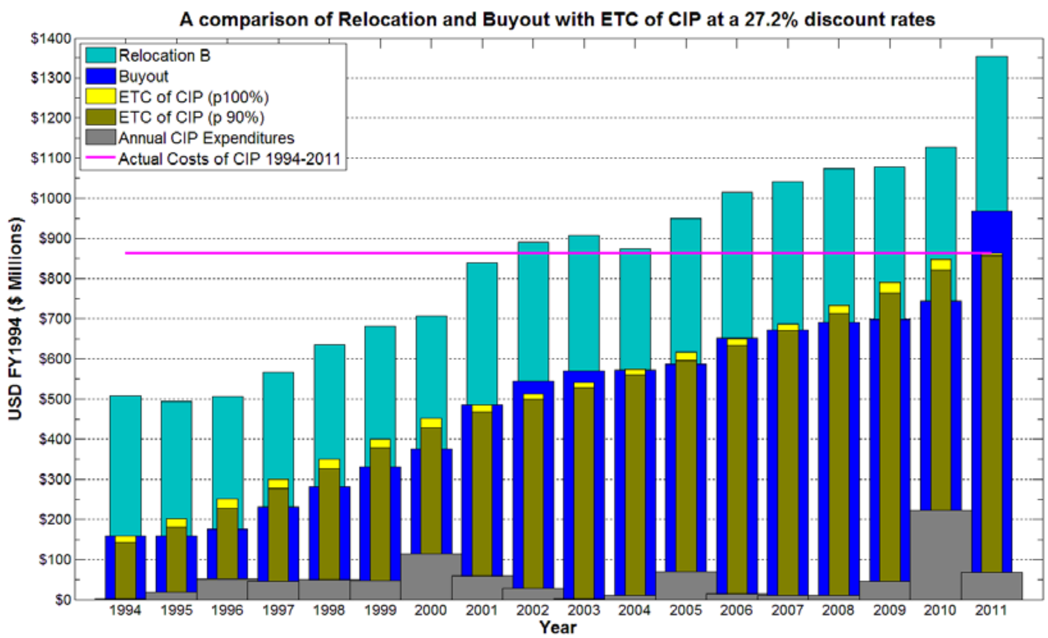

Figure 11. A comparison of the expected total cost of CIP (EPV of future CIP costs at 27.2% + previous CIP expenditures) with DL Buyout and Relocation Alternatives from 1994-2011 (FY1994 USD).

Similar to the previous figure, figure 11 compares the cost of relocation, buyout and EPV of future CIP costs in addition to sunk CIP costs and annual CIP expenditures. It differs only in the discount rate, which is 27.2% annually. In this iteration of the model, the future total expected costs of CIP are at no point greater than the estimated cost of relocation. Further, the one-time cost of a buyout is not uniformly less expensive as under the previous discount rate. A buyout is cheaper until 2001, at which point it becomes equal to or more expensive than CIP through 2005. While CIP is more expensive than a buyout in 2005, the two alternatives are nearly equal in monetary value until 2008, at which point a buyout becomes cheaper until 2011. In both figures

10 and 11 the one-time costs of buyout and relocation are much larger than the annual CIP expenditures.

These results are wholly dependent upon the discount rate and probability. The assumed discount rate of 27.2% is dependent on the comparison between the EPV of future CIP costs and the one-time cost of a buyout in 1994. The method of estimating this cost was described in chapter 2, and is based upon the known costs of residential, commercial and agricultural land and property, as well as the known input costs of road and necessary infrastructure construction. It was derived from the same sources that previous studies utilized and can be assumed to be accurate. Moreover, the assumed range of probability is justified by previous future lake level analysis and historical lake level and climate data.

Given these assumptions, the resulting discount rate of Devils Lake policymakers is at least 27.2%. The impact this discount rate had in decision-making is that it prevented alternatives that were economically more efficient, given equal benefits of each alternative, and the total costs of CIP over the course of flooding. Taking into account sunk costs, the cost of relocation in 2001 was approximately $747 million in 1994 USD. This would have been $117 million cheaper than the total cost of CIP from 1994-2011. However, at a discount rate of 27.2% the EPV of CIP plus the previous CIP expenditures totaled between $490 million and $474 million over the same time period. This is a difference of approximately 35%.

5.3 Wicked Problems and Decision-Making

That Devils Lake is a wicked problem is clear. As described in the literature review, wicked problems are characterized by their unique nature, lack of clear end point, high social complexity, varying problem definition, difficulty to model and test, and tendency to foster solutions that cause ancillary and highly complex problems. As the only multidecadal terminal lake flood in the history of U.S., Devils Lake is certainly unique, while the conflict over the various outlet alternatives that drain into the Sheyenne River, including the controversy over the water quality of Devils Lake from both Canada and the EPA, shows the lack of a comprehensive problem definition and the presence of alternative solutions that pose ancillary problems. Finally, the sheer number of government agencies and competing actors speaks to the social complexity of the issue.

The literature is clear that Wicked-Problems are not generally well-solved by traditional responses (Allan, 2008; Churchman, 1967; Conklin, 2006; Lazarus, 2009; Palmer et al., 2007; Van Bueren et al., 2003; E. P. Weber & Khademian, 2008). Further, it is not difficult to see how the characteristics of Wicked Problems would complicate a situation like Devils Lake; specifically, alternatives with a predicted positive benefit-cost ratio ultimately had a negative or equal benefit-cost ratio. The unique nature and lack of clear solutions and end points arguably increases the likelihood that traditional project costs will be greater than expected, especially when those costs are incremental in nature like CIP.

Despite the fact that many characteristics of wicked problems suggest that traditional responses would prove to be less than cost-effective it does not necessarily make them so. While the combination of characteristics likely contributed to the less than effective response, nothing within the model's results provides any indication that this is the case. Defining Devils Lake as a wicked problem is useful insofar that it distinguishes it from a normative policy problem that is relatively easy to address and all too often serves as an excuse for reckless decision-making. For someone familiar with the terminology, this designation likely causes policymakers to examine their possible actions and consequences more closely. But for those unfamiliar with wicked problems the difference is largely qualitative.

This certainly is not without its uses, as it allows especially complex policy problems to be identified very early within the policy-making process. Yet, the sole prescription for wicked problems involves selecting solutions that eliminate wicked characteristics, which is not a major criterion in any governmental decision-making paradigm. Nothing in the results or the Devils Lake literature suggests that defining Devils Lake as a wicked problem early in the course of flooding would have caused policymakers to act any differently. While defining Devils Lake as a wicked problem would have likely broadened the potential scope of possible alternatives, it would not have changed the outcome of historical BCA's by giving "wicked solutions" a positive predicted benefit-cost ratio. The ultimate cost-effectiveness of "wicked solutions" like relocation/buyout over much of the course of flooding notwithstanding, changing how many solutions are considered does not change the methods through which solutions are assessed, nor how diligently the methods are applied.

The causal mechanism in this case is clear. Although the defining Devils Lake as a wicked problem might lead to more in-depth analysis and/or information gathering, it does not change the outcomes chosen. Within the standard problem-solving paradigm of the USACOE (and in government in general), it is the information and analysis that leads to different decisions, not qualitative conceptual definitions of the problem. This thesis provides a clear example. While the novel nature of defining Devils Lake as a wicked problem led to the examination of the cost-effectiveness of the decision-making response, it is the economic analysis that primarily drives the recommendations and changes in policy; analysis that could have been performed outside of the conceptual framework of wicked problems with the exact same effect.

5.4 Policy Analysis

An examination of the results in comparison to previous benefit-cost and cost-effective analysis makes clear the impact that discount rate and probability have in determining the BCR for a given project, and the EPV of a project in hindsight. That these variables must be considered is undisputed, but in instances involving climate driven hazards with unique characteristics like Devils Lake, the results suggested that more precaution should be taken to eliminate long-term risk when determining the best mitigation option.

The policy formulation and selection criteria also lack an emphasis on risk reduction when applied to wicked problems. The plan formulation is focused on four criteria consisting of completeness, effectiveness, efficiency, and acceptability with the "appropriate mitigation of adverse effects…" playing an integral part of any proposed solution (Watt, 1983). After formulating a number of plans consistent with Section 102(2)(C) of the National Environmental Policy Act (which requires Federal agencies to "study, develop, and describe appropriate alternatives to recommend courses of actions in any proposal which involves unresolved conflicts concerning alternative uses of available resources." (Pearson et al., 2003)), the final plan selected is the one that has the greatest proposed net economic benefit consistent with protecting the nation's environment (Watt, 1983). This emphasis on formulating and selecting plans based upon the determination of net economic benefit makes the elimination of risk a secondary consideration.

This thesis does not suggest that these guidelines are not effective in most instances. However, in response to a wicked problem like Devils Lake, the focus on net economic benefit relies too greatly upon the likelihood of future events that, like all wicked problems, are difficult to model, test and predict. This difficulty produces a great deal of uncertainty surrounding the predicted economic benefit of a project or policy that the nature of wicked problems prevents from being adequately quantified. In response to the uncertainty and magnitude of risk that are hallmarks of wicked problems like Devils Lake and other climate driven hazards, the America's Climate Choices (ACC) final report (2011) recommends the adoption of an 'iterative risk management framework'. This framework is illustrated in Figure 12.

The benefit of this type of decision-making framework in Devils Lake is that it allows for decisions to be evaluated from a much more diverse set of criteria, like risk-reduction potential, feasibility, effectiveness, fairness, and robustness to uncertainty when determining an appropriate course of action (Arnell, 2011). This allows for a much broader information base for determining the potential impacts, costs, and consequences of action because it examines the issue from a multidisciplinary perspective. Further, by explicitly incorporating uncertainty into nearly aspect of the process, the impacts of uncertainty are much more likely to be understood and dealt with. This process also benefits because its emphasis on uncertainty within a multiple criteria framework eliminates the single criterion net economic benefit focus of traditional benefit-cost methodologies (Arnell, 2011).

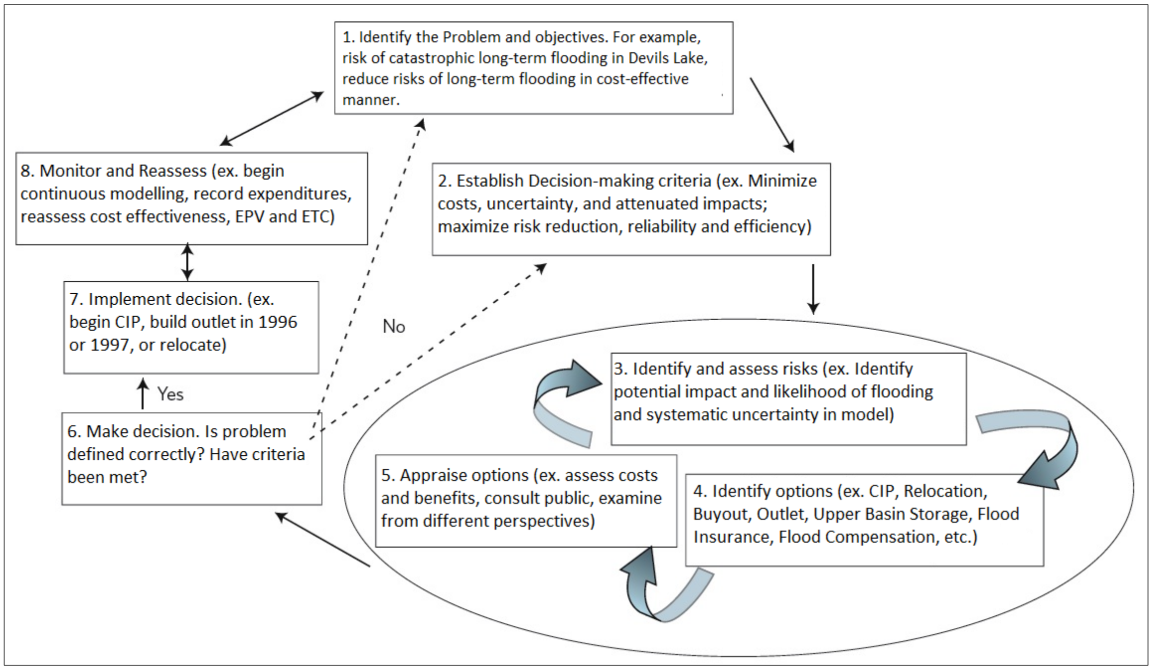

Figure 12. A Diagram of an 'Iterative Risk-Management Framework'. The steps of an 'iterative risk-management approach' to policy formation in response to Devils Lake flooding (copyright National Acadamies Press © 2011). This is a framework developed for addressing climate change (National Research Council, 2011) at a national level as adapted for dealing with Devils Lake (Arnell, 2011).

There are problems associated with implementing this type of framework, not the least of which result from the difficulty associated with the interpretation of information regarding the future effects of wicked problems (Arnell, 2011). This however, is not a problem that is exclusive to an 'iterative risk-management approach' as the interpretation of information regarding wicked problems is a point of concern within the current decision-making frameworks utilized by the USACOE and other agencies. This is clearly demonstrated by the effects of probability and discount rate on the expected present value and expected total cost of CIP over time. The determinations of both are the key determinants in assessing the expected value of future costs.

This is why the concepts of present and expected value are at the core of this analysis. One relies upon the probability of an outcome, out of the sum of the total outcomes to determine value, while the other requires the subjective assumption of how the value of money will change in the future. Starting with the concept of expected value, for instances where the total probability is known, like in a game of poker, the value is easily estimable. In Devils Lake, the sum of outcomes is equal to the 10,000 traces the USGS ran simulating the full range of potential outcomes for a given lake elevation and inflow.

Yet, it is a logical fallacy to assume that the likelihood of a given lake level in the model is equal to the actual likelihood of a given lake level occurring in the lake. Although the model is useful for predicting possible ranges and their potential likelihoods, it is not absolute, and as such, the probability that any given lake level will occur is unknown and entirely unpredictable. This unpredictability increases the farther into the future the model looks. In the short-term, it is possible to predict fairly accurately predict the future lake levels (usually for time periods less than 12 months). However, over the long-term, the uncertainty of the model prevents accurate determinations of the likely future level. Further, because the lake rises incrementally over many years, the level of protection is fundamentally viewed against the likelihood it will be needed, not against the likelihood that it could be needed.

This is a stark difference between river flood protection and Devils Lake flood protection. Rivers can achieve a small probability level in a very short time. The fact that a small river flood happens as fast as a massive flood prevents an incremental approach because the time needed to implement such solutions is not available. This tends to support massive, long-term, high-cost projects that are completed over the course of a short period of time. In the case of Devils Lake, catastrophic levels take far longer to achieve, prompting policymakers to postpone their response until it is clear that action is needed. This prevented the consideration of long-term solutions designed to eliminate uncertainty associated with flooding because CIP was implemented as necessary, protecting priority structures up to the most likely near-term level; additional funds were not considered for solutions that mitigated a flood risk that was years in the future and had an unlikely chance of occurring.

This leads to situations where despite lake levels that greatly exceeded predictions, even large increases were not so great as to threaten the entire priority infrastructure being protected. For example, even though the observed maximum lake level in 2004 was nearly 0.61m (2 ft.) higher than levels the lake was predicted to have a 1% of exceeding in 10,000 traces over the next 10 years (based upon 1994 levels)(Wiche & Vecchia, 1995), the average increase was only 1.6 ft. per year. This produces a much different approach to decision-making because not only is a given increase likely small (in the case of Devils Lake between 6 inches and 5 ft.) but it is also uncertain. CIP as a long-term decision is the type of response you would expect from a hazard that is slow-moving and dependent upon continual and uncertain increases. To put it in a different perspective, decision-makers would respond much differently if they were told in 1994 that the lake had a 9.7% chance of rising 30.6 ft. (the difference between pre-flood elevation in 1992 and current elevation July 4th, 2011) by 1995. But the chance this would happen in 1994 was so small as to be unimaginable. In the face of such odds, a high one-time cost alternative like relocation/buyout would never prove to be more cost-effective when predicting the BCR of alternative mitigation strategies.

That policymakers considered the possibility of a catastrophic flood event, but considered the long-term risk to be low is strongly supported within the literature and by the history of decision-making (Anfang & Loss, 2003c; Conner & Noone, 2006 Devils Lake Basin Water Management Plan; Cox, 2007; Pearson et al., 2003; Vecchia, 2008a; Vecchia, 2008b; Wiche & Vecchia, 1995; Wiche & Vecchia, 1996b; Wiche & Vecchia, 1998). This perception likely contributed to the rate at which policymakers discounted CIP over long-term solutions, like relocation/buyout, by increasing the perceived risk that would be involved in such large-scale decisions. Combined with the other likely rationales for discounting, including a preference for the present over the future, the current location of the community, and the perceptions of high opportunity costs of relocation/buyout, the preference of policymakers for short-term solutions like CIP fundamentally prevented an accurate economic assessment of the possible alternatives.

The discount rate of decision-making, indicated by the model in this study, of 27.2% suggests a strong preference against alternatives that mitigate long-term risk and require drastic adaptation in the short-term. This is contradictory to a high level of precaution, which would suggest that alternatives with a high probability to eliminate a problem are better in the long-term. In the case of Devils Lake, the small short-term magnitude of flooding and low probability of catastrophic flooding made policymakers cautious of alternatives whose short-term impact and cost weren't warranted by short-term risk. The results suggest a preference for solutions that prevented high probability near-future damages over low probability long-term damages. This is the exact opposite type of caution that policymakers should be exercising in planning the long-term mitigation of climate driven hazards.

The results suggest that a greater level of caution for the potential effects of uncertainty should be used by policymakers when responding to long-term climate driven hazards. Although broad in scope, this suggestion has specific impacts on policymaking, and avoids the risks associated with making recommendations in hindsight. To criticize decision-makers in 1994 for making decisions that the preponderance of information suggested were the best decisions to make would be disingenuous. The fact that relocation/buyout is more cost-effective than CIP over the course of flooding is only knowable after the fact. The literature makes clear that by the time the cost of an incremental relocation was first estimated in 2002, it was already four years too late to change course[4].

The problem in making a recommendation in this instance is one of causation. The only way to change the decisions of policymakers in 1994 is to provide them with the information we know today. The reason we know as much about the Lake as we do today, is a direct result of the fact that the Lake has flooded for 18 years. If the Lake does not flood, there is no perceived problem to investigate, and no need to develop the in-depth understanding of Devils Lake.

[4] The cost of relocation/buyout exceeded the expected total cost of CIP at a 27.2% discount rate in 1998. A comparison of the actual costs reveals that the cost of relocation in 2002 was equivalent to the total actual cost of CIP.

With the bounded rationality of decision-makers in mind, the results suggest that policymakers examine future wicked problems similar to Devils Lake with a more long-term perspective less focused on the present costs and more focused on the potential savings. An example of this type of perspective can be seen in the different impacts of the Red River of the North flood of 1997. In 1997, the City of Grand Forks North Dakota suffered the worst flood in over 100 years (Perry, 2005). After experiencing some of the heaviest snowfalls and one of the worst blizzards on record (recorded snowfall was between 96 and 117 inches) the Red River crested on April 17, at 52.04 feet, 1.84 feet higher than the previous record set in 1897 (Perry, 2005). At this point it had a flow of 137,000 cubic feet per second, and had overtopped the dikes forcing a city-wide evacuation. In all, the flooding and severe weather resulted in over $5 billion in damages to the region (Perry, 2005).

Although Grand Forks and Fargo ND had built levees, they were not sufficient to withstand the magnitude of the flooding that occurred. In Winnipeg, Manitoba the situation was much different. Winnipeg is downstream of Grand Forks, ND approximately two hours south of where the Red River of the North enters Lake Winnipeg. Because Winnipeg was founded much earlier than Grand Forks, it had a longer institutional memory of severe flooding, which prior to the construction of the Red River Floodway in 1962, it had experienced cyclically for 150 years (Passfield, 2002). 71 years before the former highest flood on record for Grand Forks (1897), Winnipeg suffered a catastrophic flood that covered the future site of the city with 15 ft. of water, creating a lake 25 miles wide and inundating 900 square miles of land (Passfield, 2002). Additional severe floods struck the city in 1882, 1904, 1916, and 1948.

Concerned by the possibility of another severe flood, the City of Winnipeg and the Manitoba Provincial Government began to explore flood protection strategies that would protect the city in the event of a severe flood. In assessing the effectiveness of a mitigation policy the Manitoba government focused on the cost-effectiveness of alternatives in terms of how they would perform in the event of another 1826 flood (Passfield, 2002). By focusing on the damages associated with an absolute worst case scenario, the provincial Royal Commission on Flood Cost-Benefits recommended the construction of a $72 million floodway that could withstand 169,000 cfs, which occurred once every 165 years (Passfield, 2002). In 2011 dollars, this is $536.6 million dollars.

The newly elected premier of Manitoba, Dufferin (Duff) Roblin, championed the project spending the years between 1958 and 1962 organizing resources, convincing policymakers, and planning construction. Yet, his efforts to push the floodway were the source of considerable criticism from opponents, who viewed the plan as "approximating the building of the pyramids of Egypt in terms of usefulness" (Passfield, 2002). After three years of planning and six years of construction, "Duff's Ditch" (as it was called by his opponents) consisted of 100 million cubic yards of earth excavated to form a ditch 29.4 miles long, 700 to 1,000 feet wide, and between 30 to 40 feet deep. It was completed in 1968.

Despite constant and severe criticism, Roblin managed to finish the project, but ended up losing his bid for re-election in 1968 by a very wide margin, largely due to the unpopular sales tax his government introduced to pay for the extremely expensive floodway (Passfield, 2002). Ironically, the Floodway would have an immediate and substantial impact, preventing significant flood damage to Winnipeg in 1969, 1970, 1974, and 1979. In 1997, after leaving some 35,000 North Dakota Residents homeless, the Red River was approximately 18 miles wide with a velocity greater than the Mississippi River at New Orleans, temporarily making it the largest river in North America at the time (Passfield, 2002). Whereas Grand Forks was nearly destroyed, Winnipeg was saved by Duff's Ditch. Approximately 66,000 cfs was diverted around the city by the Floodway, saving 99% of all the homes and property in Winnipeg, and preventing what would have been one of the largest natural disasters in the history of Canada (Passfield, 2002). The same flood that resulted in $5 billion in damages to cities just two hours to the south, and would have caused an estimated $4 billion damages to Winnipeg and the surrounding areas, caused only $400 million damages (Passfield, 2002; Perry, 2005).

Following the flood, the City of Grand Forks, in coordination with the State of North Dakota and the U.S. Federal Government, constructed a $409 million flood protection project designed to protect against a 250 year flood event, which could be adapted to fight a 500 year flood with a 10 foot clay cap (Sturner, 2007). Fargo, ND (the only other remaining significant city on the Red River of the North) has yet to implement a similar long-term flood protection plan, though there has been significant pressure to do so since the completion of the Grand Forks plan (Halliday, 2009). Currently the City of Fargo has begun examining the feasibility of several alternatives, including floodways and levees, but is currently focused on a diversion around the city (Lunday, 2010).

There are differences between the various Red River flood mitigation projects that have been implemented in Fargo and Grand Forks, ND, and Winnipeg, MB. Beginning with the most basic, they all involve river flooding, which both countries have a great deal of experience dealing with. The affected communities are also much larger than those affected by Devils Lake flooding, with a total combined population of approximately 1.2 million people (City of Winnipeg, 2011; U.S. Census Bureau, 2011; U.S. Census Bureau). The fact that the population of the immediate Devils Lake area is 1.76% of the size of these three cities (pop. 22,745) (U.S. Army Corps of Engineers St. Paul District, 2002) is a significant factor that should not be overlooked, but will be discussed later within this section. Finally, the nature of the flooding is much different in that it is transitory and cumulative unlike Devils Lake. Despite these differences, the proximity of the two basins (the Devils Lake Basin is a sub-basin of the Red River Basin), similarity of their demographics, differences in flood mitigation policy, and nearly identical climatic conditions make the flood experiences of Winnipeg, Grand Forks, and Devils Lake ideal analogues for comparing differences in perceived risk and risk mitigation strategies.

Where Winnipeg represents a long-term risk aversion perspective to flood mitigation in response to cyclical flooding, Devils Lake represents a short-term risk aversion perspective to cyclical flood mitigation. Grand Forks and Fargo represent components of each. The key distinction between the two perspectives is how each dealt with uncertainty. In the case of Winnipeg, the long history of settlement in the area allowed for a much longer time period of observation of the Red River. As a result, Winnipeg had experienced floods more than three-quarters of a century before major settlement occurred in North Dakota (City of Grand Forks, 2011; Perry, 2005). This provided a much longer perspective and greater understanding of the variability of Red River flooding.

Although the City of Devils Lake was not formally incorporated until 1884, Europeans had been exploring and conducting trade in the region since the 1815 (Ramsey County North Dakota, 2011). Historical lake levels prior to 1830 are infrequent, but there were reports of Devils Lake overflowing into Stump Lake, which only occurs at elevations greater than 1446 ft. (United States Geological Survey, 2010c), while numerous accounts from early explorers describe areas as having been altered by recent flooding, which could only have occurred at lake levels higher than 1447 ft. (Bray & Bray, 1976).

This is consistent with the initial hydrological and geological studies of the region, as well as sediment analysis conducted in the 1950's and 1960's, that predict lake level fluctuations from 1400 ft. to 1458 ft. over the history of the lake. The literature on the subject over the last 100 years makes clear that the Lake could and has achieved levels as high as current day (Bray & Bray, 1976; United States Geological Survey, 2010b; United States Geological Survey, 2010d). When viewed in combination with the known historical data, the severe decrease in lake surface elevation from 1900-1950 also evidences the extreme variability of the Lake surface elevation.

Based on this knowledge, Devils Lake policymakers could have realistically examined the issue from a long-term perspective, similar to the one used in Winnipeg. When determining the benefit-cost of the proposed floodway in Winnipeg, the Royal Commission on Flood Cost-Benefit found that the BCR of the floodway was 2.72:1 (Perry, 2005). This is significant in that the BCA performed on the floodway did not discount the costs of the project by the likelihood that a significant flood would occur, but rather, compared the estimated costs of construction of alternatives against the damages that the alternatives would prevent (Perry, 2005). This differs in the case of DL, wherein the USACOE similarly compared the costs of an alternative against the damage it would prevent, but also adjusted the expected value of the costs by the long-term likelihood that the lake would achieve a given lake level over a give time period (Anfang & Loss, 2003c).

In order to reflect the uncertainty surrounding the predictions, the USACOE examined the BCR of projects under four scenarios describing various potential future lake level rises (based on the likelihood of lake level rise as determined in 10,000 model traces). These scenarios described two likely moderate futures, one unlikely wet future, and one dry future. Similar to the case of Winnipeg, these scenarios allow for the reflection of the BCR of alternatives in what was considered a likely "worst case scenario". In the case of Winnipeg, a 165 year flood probability does not mean that they planned to fight a massive flood once in the next 165 years, but rather that a flood of the given magnitude had a 1 out of 165 chance of occurring any given year. The key difference between the two cases is that the comparison of scenarios in Devils Lake reflected the likelihood of each scenario occurring over the next 50 years, inherently focusing the discussion around the likelihood that a given level of mitigation would be needed.

Fundamentally, the Winnipeg perspective was based on the knowledge that massive and severe floods occurred in the past and would occur again, thus it also does not have the challenges of being a wicked problem. As a result, they focused on implementing a flood protection strategy that would prevent the worst regardless of when it came. In the case of Devils Lake, despite acknowledging the extreme potential for lake fluctuation and the potential impact of the worst case scenario, decision-makers put too much emphasis on the likelihood that the worst case scenario would happen within a given time period. This likely prevented a more long-term mitigation strategy from being implemented.

It can be argued that such a long-term perspective or iterative risk-management framework is less appropriate for Devils Lake than Winnipeg, whose greater size and worth allow it an increased ability to justify more expensive alternatives. This argument belies the reality of the Devils Lake situation and Red River flooding in general. However, if a long-term perspective is inherently justified by a community's size and value, it stands to reason that Grand Forks and Fargo would have long ago implemented much more sustainable long-term flood protection strategies. This is not the case. Grand Forks, the smaller of the two cities did not build its massive levee system until after it was more or less destroyed in 1997. Even after a $409 million protection plan was put in place in Grand Forks, Fargo, whose population is more than double that of Grand Forks, has yet to receive similar long-term protection, despite the city's efforts to obtain federal support to do so.

Further, the current cost of CIP seems directly contradictory to the idea that a long-term perspective similar to Winnipeg's is only appropriate for communities of large size and value. In 1994 USD, the Grand Forks flood protection plan cost $347.5 million. This is less than half the $863.6 million total actual cost of Devils Lake CIP from 1994 -2011 in 1994 dollars. In fact in 1994 USD, the actual cost of CIP are 20% greater than the total cost of the long-term flood mitigation strategies implemented in Grand Forks and Winnipeg combined[5].

Compared to the cities of Grand Forks and Fargo, ND and Winnipeg Manitoba, even the smallest of the three (Grand Forks) has a population six times greater than combined population of all the communities at risk from Devils Lake flooding (U.S. Census Bureau, 2011). As of 2010, the combined population of these communities was only 1.14% of Grand Forks and Winnipeg Combined, and only 1.01% of Grand Forks, Fargo, and Winnipeg altogether. This is an important comparison because despite a population that is approximately 100 times smaller, the actual cost of CIP through 2011 is greater than the combined cost of protection for Grand Forks and Winnipeg combined, and equivalent to the cost of protection in Fargo. This fact does not

[5] The 1994 USD of the Winnipeg floodway is $369.6 million. In total, the cost to protect Winnipeg and Grand Forks from 250 to 500 year flood levels was $717.15 million (1994 USD). The 2010 estimated cost of the proposed Fargo diversion of the Red River on the North Dakota or Minnesota side is $1.3 billion and $1.14 billion respectively. Compared to the actual cost of CIP (in 2010 USD) of $1.31 billion, a North Dakota diversion has an equivalent and the Minnesota diversion would be $186 million cheaper.

support the argument that a long-term perspective or an iterative risk-management framework is only practical when utilized for larger cities and populations.

Like CIP in Devils Lake, the BCR for the various flood protection strategies in Grand Forks, Fargo and Winnipeg was positive. Unlike its river neighbors, the only reason Devils Lake CIP had a positive BCR is because of the low long-term risk of a natural overflow when the BCA was performed. In hindsight, the actual BCR of the Winnipeg floodway was 40.0 in 1997 alone, the current BCR of Devils Lake CIP (the value of the damage avoided to property/cost of mitigation) is 0.69 given the property estimates in this thesis, and 0.77 given the USACOE's estimate for relocation as reported in the Final EIS (Anfang & Loss, 2003c). The difference is clearly in the priority each placed on mitigation risk over time. Winnipeg clearly placed a high value on long-term risk mitigation, and Devils Lake did not.

A possible explanation for the difference in the priority placed on risk elimination in each of these cases is the respective perception of risk. According to E.U. Weber (2006), recent personal experience strongly influences the evaluation of a given event's risk, with low-probability events generating less concern than they statistically merit on average, but more concern in those instances when the decision-maker has had recent experience with a low probability event. This is especially important in regards to the difference between the experience of respective policymakers prior to both the construction of the Red River Floodway and the onset of Devils Lake flooding.

Although construction of the Floodway did not begin until 1962 (Passfield, 2002) the recent Red River flood of 1950 weighed heavily on the minds of policymakers (Passfield, 2002). Prior to 1950, the Red River at Winnipeg had not experienced a flood comparable to the flood 1950 since 1861, and more importantly, flooding was largely regarded as a purely local problem to be addressed at the discretion of the affected municipalities (Passfield, 2002). As a result, Winnipeg began expanding in 1916, building new neighborhoods near the River that were only minimally protected from potential flooding (Passfield, 2002).

When the 1950 flood struck, it was considered one of the greatest natural disasters in Canadian history. At the time, it was the most catastrophic natural disaster in terms of flood damage, dislocated population, and economic impact, resulting in $22 million in aid ($329.3 million 1994 USD) and approximately $126 million in damages ($1.89 billion 1994 USD) (Passfield, 2002). In response to the severity of this flood, the federal and provincial authorities collaboratively constructed a dike and levee system and began investigating a long-term flood mitigation options, ultimately deciding upon the Red River Floodway (Passfield, 2002).

In stark contrast, Devils Lake had not surpassed 439.2 m (1441 ft.) in elevation since prior to 1830. Since that time, the lake slowly receding over the next 110 years, reaching its most recent low point of 427 m (1400.9 ft.) in 1940 (United States Geological Survey, 2010b). It was at this time that proposals were developed to stabilize the Lake's level, cumulating in the passage of the Flood Control Act of 1944. This act authorized the Bureau of Reclamation to construct the Missouri-Souris Diversion Unit for the purpose of diverting water from the Missouri River for irrigation and Devils Lake stabilization (Pearson et al., 2003). This authorization also included an outlet from Devils Lake into the Sheyenne River. Although the project was abandoned because the much of the land in the Missouri-Souris Diversion was not irrigable, the Federal and State Governments continued to authorize proposals for a Missouri-Souris inlet into Devils Lake (and outlet into the Sheyenne River) in 1965, 1974, and 1986 (Pearson et al., 2003). The USACOE was still examining potential infrastructural solutions for Devils Lake stabilization as late as 1992, less than one year before the Lake rose 1.25 m (4.10 ft.) (Pearson et al., 2003; United States Geological Survey, 2007).

In both instances, the worst case, long-term potential impacts were known. However, the difference in recent experience and subsequent difference in mitigation policy, supports the claim of Weber that negative affects (i.e. emotions like fear or worry), and not the consideration of statistical likelihoods and/or mental simulation of adverse consequences typically provided by domain experts, is the primary motivator of action (E. U. Weber, 2006). This is not to say that human beings do not use their logical capacities in decision-making, but rather that decision-making is motivated more by the visceral responses produced by the recent experience of low-probability events than it is by the statistical understanding of the likelihood of a low-probability event. This would explain the discrepancy between the policy decisions in the contrasting cases of Winnipeg and Devils Lake. It would also support the differences in policy between Devils Lake and Grand Forks.

The policy implication behind this argument is based upon uncertainty. Because the perception of risk and statistical probability of risk are not consistent, it implies that the uncertainty involved in assessing potential impacts and associated costs is greater than current methods would suggest. This perception of risk is one of the basic rationales behind discounting, and thus immediately impacts the estimated present value of the alternatives, which is supported by the results of the model.

In both Grand Forks and Winnipeg, policymakers were keenly aware of the potential damages and impacts of the low-probability event, as in both cases major long-term flood protection was completed shortly after the a low-probability event occurred. In Grand Forks, the $400 million flood protection system was completed less than 10 years after the flood of 1997 (Sturner, 2007). In the case of Winnipeg, the perceived threat of another 1950 flood was one of the primary factors that brought Duffer "Duff" Robelin into power as the Manitoba Premier, who began project planning almost immediately after being elected to office (Passfield, 2002). This directly contrasts with the case of Devils Lake, which policymakers had been attempting to fill for much of the past 40 years prior to flooding.

In both cases, it can be argued that the perception of risk, based upon the recent experiences with a low-probability event, motivated the priority decision-makers placed on long-term risk elimination. In Winnipeg, Duff Robelin's promises to implement a long-term flood mitigation project saw him elected Premier of Manitoba eight years after the 1950 flood. However, by 1969, the sales taxes Robelin instituted to pay for the Red River Floodway, were credited with costing him his campaign, suggesting that in a span of 19 years the priority of risk elimination had decreased to the point that it was trumped by a 4% sales tax (Passfield, 2002). In Devils Lake, the statistical data, literature, and results of the cost effectiveness economic model suggest that policymakers preferred the short-term, incremental CIP strategy over the much longer-term solution of relocation.

These results are further supported by significant anecdotal evidence that suggests the recent experience of those most highly impacted by Devils Lake flooding has made them overestimate the risk of catastrophic flooding. This has caused local level policymakers to dramatically push for solutions that seek to eliminate long-term risk, but in a short-term fashion. This was most evident at the Tolna Coulee rally organized by Nelson County Commission Dan Marquart, which was held on Monday, May 16th, 2011 to protest the lack of direct action to relieve the impacts of Devils Lake flooding, especially on agricultural land. Specifically, the Rally was to consist of meeting at the Tolna Coulee (the natural outlet of Devils Lake and Stump Lake into the Sheyenne River) with a shovel and every attendee shoveling 1 ft. from the outlet (Heitkamp & Marquart, 2011a).

Although normally the opinions of one individual cannot generally be considered to express the views of the larger population, Marquart's assertions that a natural overflow was "inevitable", accompanied by his call to dig a simple outlet into the Sheyenne River, drew nearly 2,000 people, or almost 1/5 of the immediate lake area population to his rally. When taken in context with his status as a county elected official, the clear overestimation of the likelihood of a natural overflow[6] and support for an outlet through the Tolna Coulee (which despite eliminating long-term risk, was viewed as immediately necessary from a short-term perspective) suggests that the same recent experience that prevented an emphasis on the elimination of long-term risk in Devils Lake, is now fostering an over-emphasis on long-term risk elimination.

[6] At the time of this show's recording there was less than a 5% chance that the lake would exceed the natural overflow elevation of 444.4 m (1458 ft.) by 2015 (Vecchia, 2008a).

The statements of Commissioner Marquart, and the number of individuals who attended the rally he organized, illustrate both the impact that perceived risk has in motivating action and decisions as well as the short-term policy preference suggested by the results of the model. That Marquart (and radio host Joel Heitkamp, as well as the numerous callers on his show) were firmly in support of the outlet in order to ease the impact on adjacent agricultural lands is unquestionable. Although their concern is admirable, the content of the radio show (and the subsequent follow-up show (Heitkamp & Marquart, 2011b)) make clear the lack of consideration given to the potential downstream impacts. A simple outlet like the one proposed by Marquart would likely violate the Boundary Waters Treaty of 1909 (constituting a violation of U.S. Federal Law), pose significant risk of flooding Valley City, ND and have unknown environmental impacts on the Sheyenne River, and Red River ecosystems. Heitkamp, however, dismissed these issues saying, "If you believe Canada's going to sue us, you think they weren't gonna before? Let's get to the lawsuit. Let's go find the lawyers and see who wins. But at least let's get to the punching, because once you know you're going to get in a fight, you best start swinging early (Heitkamp & Marquart, 2011a)."

This is significant because it suggests that the perception of risk based upon recent experience, when combined with the short-term preference suggested by the results, likely supported CIP (which was economically inefficient) in 1994, and likely supports the simple outlet advocated by Marquart and Heitkamp, which has unknown and potentially disastrous downstream and long-term impacts. When these alternatives are examined in the context of Devils Lake as a wicked problem, neither solves all of the immediate or long-term problems posed by flooding and both cause significant ancillary problems. CIP assumes agricultural flood damages are lost, and consequently governmental remuneration of losses has been inconsistent. Further, a simple outlet poses significant environmental and flood risks to downstream communities and ecosystem and potentially violates federal law.

This combination of factors supports the implementation of an ‘iterative risk-management framework’ for dealing with long-term climate driven hazards as described by the *America’s Climate Choices* report (National Research Council, 2011). This framework would combine a continual assessment of the statistical likelihood and potential impact of long-term risk with the ability for negative recent experience to effect significant policy action. This is consistent with Weber’s call for the expression of potential wicked problem impacts in visceral ways in order to promote more sustainable and effective long-term strategy (2006). Based upon the evidence, this type of decision-making framework might have resulted in more holistic and cost effective long-term decision-making, not only in Devils Lake, but in long-term climate driven wicked problems on all levels.

In the case of Devils Lake, an ‘iterative risk-management framework’ would involve a much more extensive emphasis on intelligence gathering, and a continual reassessment of both potential options and the effectiveness of chosen options. In Devils Lake, this would have involved continuous lake level analysis. This would have provided much more timely comparison of future lake levels as well as an almost continual reassessment of long-term catastrophic risk. Such a continuous assessment of risk would have illustrated the changing (decreasing) nature of the BCR of CIP, and likely driven a more in-depth assessment of all alternatives. From 2001 to 2003 the BCR of CIP decreased from 2.72 to 1.07 (Barr Engineering Co., 2003c), it is likely that a continual annual assessment of BCR of alternatives after the 1.25 m (4.1 ft.) increase that occurred in 1993 would have illustrated this trend at a much earlier point.

The continual assessment of BCR and prediction of future lake levels would have provided an additional benefit when combined with an annual assessment of expenditures and policies. A continual cost-effective analysis of CIP would have illustrated the sharp divide between the predicted an actual costs of CIP, and the actual costs of CIP and relocation/buyout. By 1999, the current cost of CIP was already $212.3 million (1994 USD), or 24.6% of the total actual cost through 2011 and 49.3% of the cost of relocation in 1994. Such comparisons would have likely cast CIP in a different light. Combined with a direct emphasis on uncertainty an 'iterative risk-management framework' might have produced, if not a different outcome, than a more cost-effective version of CIP.

Finally, such a framework would work well within a standard "wicked problem" definition from a governmental framework. Wicked Problems have been clearly defined in the business and public administration literature (and more recently in the environmental hazard and climate change literature) since the late 1960's (Churchman, 1967). Yet, this is not true from a governmental perspective. While the basic priority setting process utilized by government agencies is not inappropriate, as agencies are confronted with more long-term climate driven wicked problems of increasing scopes (and correspondingly large costs), they would benefit immensely from an institutional emphasis on wicked problems. This seems simple, but such a distinction at the beginning of the problem-solving process allows for the quick differentiation between normative and wicked policy problems. The qualitative definition of characteristics can be easily codified and rigorously applied with very little administrative cost and minimal effort. This will allow for potential wicked problems to be dealt with at a much earlier point in the problem-solving process.

The prioritization of wicked and normative problems is essential to dealing with one of the chief drawbacks of an 'iterative risk-management framework' and the most common issue affecting government agencies since the invention of government. This framework attempts to reduce the effects of time preference, probabilistic uncertainty, and inappropriate risk perception with more rigorous information gathering, risk assessment, and clarification of uncertainty. It does this at an increased cost of information gathering and analysis. Because government agencies are perpetually balancing the cost of achieving their political priorities and carrying out their congressionally mandated responsibilities, the political capital needed to achieve even small expenditures can be costly[7].

Using a wicked problem theory to prioritize departmental priorities would allow for more resources to expend on wicked problems from their onset, and would free up long-term budgetary pressure caused by wicked problems run amok. Using Devils Lake as an example, the amount spent on information gathering and study comprised only a small percentage of the total cost ($4.8 million in 1994 dollars, or 0.56% of total actual CIP cost). The small proportion of research to overall costs, suggests that an increased emphasis on information gathering would result in beneficial savings in the long run. Moreover, the costs of research are so small compared to the whole, investments in information gathering would only need to result in a small level of overall savings to justify their expenditure (for example, a 300% increase in Devils Lake research would be economically justifiable at savings no less than 1.5% of the total).

[7] In 2002 Senator Kent Conrad (D-ND) employed a senatorial privilege to hold up departmental appointments, as well as his position on the Senate Finance Committee to place pressure on U.S. Army Corps of Engineers to examine a Devils Lake outlet, telling former Secretary of State Colin Powell "…he could listen better if Powell would get word to the U.S. Army Corps of Engineers that a Devils Lake outlet is critical to North Dakota."(Pearson et al., 2003)

CHAPTER VI

DISCUSSION

6.1 Overview

This discussion is divided into two sections. The first section discusses the results of the economic model used in this research and what they imply about the effectiveness of decision-making in response to Devils Lake flooding; the effect of the discount and probability variables on the results of the model; the accuracy of the underlying data used in the model; and the potential reasons why such a high discount rate was observed in this Devils Lake case study. The second section consists of a sensitivity analysis of the model and how it affects the models results.

6.2 Model Results

To justify CIP over relocation/buyout, the discounted rate has to be equal to or greater than 24.5% and 27.2% for the exceedance probability between 90% and 100%. This is not to say that the discount rate is dependent upon the exceedance probability as both are separate variables within the model. Neither value can be known exactly. However, because exceedance probability is based upon the likelihood that the lake level would exceed the action level of a given feature, which can be estimated fairly accurately in the near-term, it is easier to estimate than the discount rate. Further, the fact that CIP costs were incurred every year proves, in hindsight, that policymakers considered it more likely that the lake would increase rather than decrease. Thus, given the model's assumed range of probability and a policy goal of preventing flooding in the most cost-effective manner possible, then the estimated discount rate had to be greater than the aforementioned 24.5% or 27.2% rates. At lower rates, CIP would not have been the most cost-effective solution.

We cannot say exactly what the rate was, because the intersection point between a relocation/buyout only describes the rate at which the alternatives are equal in monetary value. If we assume that the choice facing policymakers was between a relocation/buyout and CIP, given the discrepancy between the actual costs of CIP and the estimated cost of relocation/buyout observed in hindsight, the only way CIP could be predicted to be more cost-effective in the long-run is if policymakers were discounting CIP by a minimum rate of 27.2% annually. This was not a conscious choice on the part of policymakers however; it is simply a product of how they viewed the risk of catastrophic overflow, the exceedance probability, and the preference they placed on the present and near-term over the long-term future.

When compared to the standard rate of 5.875% used by the USACOE, 7% used by OMB, or 2.5%[8] used by the Environmental Protection Agency (EPA), the estimated rate at which relocation/buyout was actually discounted is much higher. The impact this difference has between the observed rate and the predicted rate is correspondingly large. When the EPV of CIP at the observed rate is compared with the rates used by the EPA, USACOE, and OMB, the corresponding difference in EPV of future CIP expenditures in 1994 is approximately $584 million, $392 million, and $238 million respectively. The smallest of which is still only 33.7% of the total actual cost of CIP from 1994-2011.

The observed rate for discounting relocation/buyout in Devils Lake is nearly twice as large as current real discount rates from different countries across the globe, the largest being Philippines and India, which utilize real discount rates in practice of 15% and 12% respectively (Harrison, 2010). Most developed countries have utilized rates between 2% and 10% since the late 1970's (Harrison, 2010). Of course, when dealing with projects that have long-term benefits and/or cost (like relocation/buyout or CIP) there is considerable debate surrounding the most appropriate rate to use when performing BCA. This debate has been articulated at great length by

[8] This rate is an approximate value. The EPA recommends using rates between 2%-4% when performing CBA's and cites a number of different rates as representative of the literature. The mean of these rates is approximately 2.5% which is validated by the reported rates described in the literature used in this thesis (Boardman, Greenberg, Vining, & Weimer, 1996; National Center for Environmental Economics, 2010; Newell & Pizer, 2003; Nordhaus, 1999)(Baumol, 1968; Henderson & Langford, 1998; Horowitz, 1996; Lind, 1995; Moore, Boardman, Vining, Weimer, & Greenberg, 2004; Stern, 2008; Weitzman, 1998).

Nordhaus (2007) and Stern (2007) over the potential long-term costs and damages of climate change (CC).

On one side of the debate, environmental economists like Nicholas Stern (author of the Stern Review on Climate Change (2007) argue that the increasing clarity of scientific understanding of climate change and its economic impacts (which suggest the worst case climate impacts are more likely to occur with a greater probability than previous scientific methods), along with the intergenerational nature of CC costs/damages support much lower discount rates than those used in federal BCA or even normative measures of investment (Stern & Taylor, 2007). The biggest reason is based upon the consumption of resources, which in the long-term, even low normative discount rates produce drastic inequalities in terms of the benefit received from shared natural resources. On the other side of the debate are economists like William Nordhaus who argue that the Stern Review, in calculating the potential economic impacts of climate change, used a discount rate that suffers from parameterization; that is by using a low time discount rate, Stern's assumptions produce damages and policy costs that are not consistent with actual market data.

Stern argues that it is imperative for policymakers to use low time-discount rates because the increasing risk and likelihood of irreversible environmental damages with potentially drastic costs of remediation in the future result in future scenarios that carry unacceptable economic, environmental, and ethical costs for society(Stern, 2008). In contrast, Nordhaus criticizes Stern for choosing a low discount that inherently supports present action over future action in order to avoid environmental damages on future generations (Norhaus, 2007). His criticism is based upon Stern's discount rate of 0.0001 yr^{-1} which is far below the market based rates generally used to establish standard government discount rates (Norhaus, 2007). Stern counters this argument by asserting that the private savings and investment rates to which Nordhaus refers to are not indicative of the actual discount rate for the long-term decision making perspective needed when addressing complicated long-term hazards like climate change (Stern & Taylor, 2007).

Without supporting either argument, the results of the model in this thesis suggest that the estimated discount rate policymakers used in Devils Lake case could be far higher than any standard rate used in government BCA or the rates proposed by Stern or Nordhaus, regardless of which set of ethical assumptions are used to determine the rate. The estimated discount rate is also much higher than any standard or private rate which should be used for discounting according to Nordhaus. Using a lower rate, in accordance with Stern, would have changed how the EPV of CIP compared against a relocation/buyout, but it is not known how much. Remember, in both cases policymakers assumed that they were only discounting the future costs of CIP by the standard USACOE rate. At this rate, even if one assumes a full knowledge of the total costs of each alternative, the standard USACOE rate still produces a discounted CIP cost that is less than the actual CIP cost total by $311 million or 36.1%. Even the EPA discount rate of approximately 2.5% is $117 million less (13.6%) than the actual cost of CIP from 1994-2001.

This rate fluctuates with the estimated total cost of CIP. While the actual costs of CIP from 1994-2011 are close to the estimated total costs of CIP[9] from 441 m (1447 ft.) to 445.9 m (1463 ft.), assuming a current CIP level between 443.5 m (1458 ft.) and 445 m (1460 ft.), based on Barr Engineering definition of CIP level (see footnote 2) the total estimated actual cost of CIP is between 26.4% and 46.7% greater than the most recent estimated total cost of CIP as predicted

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[9] The total cost of CIP was estimated at $1.15 billion (FY2002) in 2001, which decreased to $1.089 billion (FY2002) in 2002 as part of the Final Devils Lake, North Dakota Integrated Planning Report and Environmental Impact Statement (Anfang & Loss, 2003c). The estimated cost decreased further to $912 million (FY2002) in the 2003 Barr Engineering assessment of DL alternatives (Barr Engineering Co., 2003b). These estimates consist of the total CIP costs per foot of elevation from 441 m (1447 ft) through 445.9 m (1463 ft) and put the estimated total costs of CIP between $757 million and $954 million in fisal year 1994 dollars. Using a starting point of 435.9 m (1430 ft) (as of the initial estimates the costs of CIP up to an elevation of 441 m (1447 ft) were known) the estimated per foot cost of CIP through 445.9 m (1463 ft) was between $22.9 million and $28.9 million. Assuming a CIP level equal to the designed level of protection (DLP) between 1.5 m – 3 m (5 ft. – 10 ft) minus the .304 m (1 ft) action level as described by Barr Engineering) the current CIP level is between 443.5 m (1455 ft) and 445 m (1460 ft). Assuming a current CIP level of 443.5 m (1458 ft) (the average CIP for all features rounded up to the nearest foot), then the per foot elevation cost of actual CIP expenditures from 1994-2011 is $30.8 million. This makes the estimated actual cost of CIP (actual CIP costs 1994-2011 $30.8 million per foot through 445.9 m (1463 ft)) $1.11 billion (FY1994). This makes the estimated actual cost of CIP through 445.9 m (1463 ft) between 16.4% and 46.7% greater than the predicted total cost of CIP as reported by Barr Engineering and the USACOE from 2001-2003.

by Barr Engineering (Barr Engineering Co., 2003b). This is notable because as the estimated total cost of CIP decreases, so does the discount rate at which it has an equivalent monetary value with relocation/buyout. Although initial estimates were higher, even than the USACOE's estimate of relocation (approx. $1 billion), the fact that future CIP costs were incremental and located in the long-term future means that the short-term cost was smaller each year and had the potential of not being incurred, causing policymakers to discount CIP over relocation/buyout. That the actual cost of CIP through 445.9 m (1463 ft.) will likely be higher simply means that the discount rate for CIP over a relocation/buyout was higher than the 27.2% indicated by the results.

From an economic perspective, a discount rate of 27.2% is not only inconsistent with the standard governmental discount rates used across developed nations in governmental BCA, it is also inconsistent with discount rates used in evaluating private financial decision-making, which was between 7.8% and 11% from 1950-2000 (Aschauer, 1990; Chapman, 1999; Tietenberg & Lewis, 2009). Such a high rate of discount limits the number of choices available to policy-makers and complicates decision-making, drastically under-estimating the present value of future costs of mitigation. This is best expressed by the change in expected total costs of CIP (ETC) from 1994-2011. These results indicate that the point at which the ETC of CIP was surpassed by the sum of the cost of relocation/buyout and previous CIP expenditures under the observed discount rate was in 2001 for a buyout. The cost of relocation was never less than the ETC of CIP through 2011. If the discount rate is assumed to be equivalent to the USACOE standard of 5.875% then the point of no return for relocation was 1998 and for buyout it was 2011. Even though the total cost of relocation and previous CIP expenditures was less than the total cost of CIP from 1994-2011 until 2002 (and approximately equal until 2005), because the total cost of CIP was not known, it could only be known after the fact.

Even when dealing with high short-term probabilities like those utilized in the model, the ETC of CIP does not reach 90% of the actual cost until 2007. The effect that this has on Devils Lake is one wherein it limits the discussion to alternatives that can take advantage of short-term certainty and smaller incremental costs, regardless of whether those alternatives are more cost-effective in the long-term. The nature of the governmental BCA inherently biases decisions against alternatives with higher short-term costs in favor of short-term costs with more certain probabilities of occurrence. In cases like Devils Lake where the short-term increase in lake elevation can be reasonably predicted, the high discount rate disproportionately biased decision makers against a relocation/buyout.

There are many reasons why the estimated discount rate might be high. Generally, the discount rate reflects an individual decision-maker's risk assessment of a project, time-preference (the value they place on the present over the future), opportunity cost, and social attitudes concerning the "correct" way to deal with a problem (National Center for Environmental Economics, 2010). In Devils Lake, it is likely that all of these factors played some part in discounting CIP to the extent observed. Initially, the perceived risk that the lake would achieve the observed surface elevations over the course of flooding was low. Based upon the stochastic analysis performed by the USGS, the USACOE reported in 2002, eight years after the onset of flooding, there was only a 9.4% chance of a natural overflow within the next 50 years (Pearson et al., 2003). This probability shall be referred to as the catastrophic flood risk, which as opposed to exceedance probability of the model, was low. This is not contradictory, because the catastrophic flood risk is the stochastic probability of a natural overflow (elevation > 1458 ft.), while the exceedance probability is the likelihood that the current CIP level of a given feature would be exceeded by surface elevation in a given year. The former is a long-term probability, while the latter is a short-term probability.

This distinction is critically important because while it is possible to predict the future lake level accurately for the next 6 months, given recent inflow data, predicting the future lake level many years into the future is extremely difficult and highly uncertain. The exceedance probability is the likelihood that the current CIP level will be exceeded by surface elevation within the time period designated for a feature's CIP increase (usually less than a year). Because the CIP level is much lower, the likelihood that the lake surface elevation will exceed it within the next 12 months is much higher, generally between 90% -100% as assumed in this thesis. The catastrophic flood risk is equal to the probability that the lake will exceed surface elevations of 44.4 m (1458 ft.) or higher sometime between 1994 and 2044. The exceedance probability does not have an effect, and is a completely separate variable from the discount rate, as opposed to the catastrophic flood risk which would have affected the rate at which policymakers discounted CIP over relocation/buyout.

It is logical to assume that had the risk of a natural overflow been higher, a much longer term plan of action would have been implemented. This is not the case. The low level of long-term risk likely had an impact on the other factors that determine discount rate. A low long-term risk would have driven up the opportunity cost of relocation/buyout and would have delayed a thorough discussion of possible alternatives. The actions of policymakers in response to DL flooding are consistent with a perceived low long-term risk of catastrophic flooding. While there is some anecdotal evidence to suggest that early in the course of flooding (1994-1998) relocation/buyout of the urban areas was suggested, the same sources say this suggestion was dismissed. Anecdotal evidence aside, the first estimates for an "incremental relocation[10]" were produced in 2001, and were not examined again until 2003(Barr Engineering Co., 2003b). This is further supported by the fact that when the actual CIP costs exceeded the 1994 cost of relocation in 2002, the sum of the cost of relocation and previous costs of CIP had already exceeded the total cost of CIP through 2011, making CIP a more efficient alternative over the next nine years.

[10] The first estimates of incremental relocation were produced in 2001 by Barr Engineering did not consist of the first instance when relocation was considered as an option. Relocation was identified as an option in 1996 in the USACOE's *Devils Lake, North Dakota Contingency Plan* but no cost of relocation was estimated in this report (Pearson et al., 2003). The only options that included estimates for construction and operational cost were those describing a number of potential outlets into the Sheyenne River, and later that year the Corps was directed to develop an emergency action plan selected from one of the previously identified Sheyenne River Outlet alternatives (Pearson et al., 2003). If one assumes a 5.875% discount rate, which suggested that the sum of previous CIP expenditures and relocation would exceed the ETC of CIP through 2011 in 1998, by the time the estimated cost of relocation was determined in 2001, it was already expected to cost more than CIP based upon its ETC at this rate.

Policymakers operating under an assumed high long-term risk would likely have reacted much differently, and would have considered and possibly implemented a relocation/buyout option much sooner after the onset of flooding. This is supported by the results, which indicate that had the discount rate been equivalent to the standard USACOE rate of 5.875%, the EPV of future CIP costs would have been $552 million. At this discount rate, the EPV of CIP is greater than relocation by approximately $90 million and buyout by $400 million.

That neither option was considered until 2001 suggests the perceived opportunity cost of relocation/buyout and time preference of decision-makers also resulted in the high observed discount rate. Economic theory has illustrated a preference for the present over the future in a many instances (Council on Environmental Quality, 2010; National Center for Environmental Economics, 2010; Norhwest Power and Conservation Council, 2010; Tietenberg & Lewis, 2009), while the concept of opportunity cost (i.e. the cost of any activity is measured in terms of the next best alternative) is a long established principle in economic theory as well (Chapman, 1999). Using the year of 1994 as an example, the cost of relocation was 347x greater than the yearly CIP cost in that same year, even though it was cheaper by $432 million than CIP through 2011. Given a low long-term risk, it is entirely logical that policymakers would prefer the annual cost of CIP over the cost of a relocation/buyout as a mitigation strategy.

6.3 Sensitivity Analysis

The model examines decision-making from the perspective of federal policymakers. Because the lion's share of expenditures were federal in nature (>75% of total expenditures), this perspective is the most logical to examine. However, it prevents the model from representing the decision-making preferences of North Dakota State and Local officials. This is an important distinction because the preferences of these decision-makers might be, and likely are, drastically different from those of federal decision-makers.

An example of this would be illustrated by a comparison between relocation/buyout and CIP from a local official perspective. From this perspective, the one-time cost of a relocation/buyout is so expensive, not to mention psychologically traumatic, that the rate of discount for CIP over relocation/buyout would likely be much higher. Although CIP is still prohibitively expensive for the City of Devils Lake in later years, early on it was cheap enough to be covered by the City, where relocation/buyout was not.

A significant issue in the sensitivity of our model involves the lack of transaction costs considered in estimating the costs of a relocation/buyout. These are costs incurred in the process of making an economic exchange, and would likely be considerable for a relocation/buyout. Because of the nature of this alternative, each individual property owner would have to be contacted by the government and offered the terms of a relocation/buyout. This would involve significant expenditures of time and involve potentially large expenditures for salaries, legal proceedings, lawsuits, and other similar costs on top of the costs already delineated as part of a relocation/buyout. These costs were not included in the estimates because the number, exact nature, and potential value of each of the possible transaction costs were impossible to determine.

Similarly, the model does not taken into account the economic benefits that would accrue by the increased area of wetlands resulting from a relocation/buyout of the adjacent communities. The value of these environmental benefits would have decreased the estimated cost of a relocation/buyout. Unlike the transaction costs, these costs are likely very minor. The area of the city which would effectively be under the Lake is little less than the entire area of the city limits, an area of less than 2,600 ha (6400 acres). Like transaction costs, the benefits accruing from the increased lake area resulting from a relocation/buyout are impossible to estimate.

Despite the inability to estimate these costs, it is not likely that they would dramatically alter the results of the model. The minor benefits provided by the increased lake area would likely result in a very small increase in the estimated discount rate, while the transaction costs would decrease the estimated discount rate. While the transaction costs would likely decrease the estimated discount rate of our model, the transaction costs would have to increase the estimated cost of a relocation/buyout between $300 and $400 million in order to produce a discount rate that was equivalent to the rates used by the USACOE or OMB. The power of the government to relocate or buyout private property under threat of flooding has been well established in numerous cases (Lindell, Prater, & Perry, 2006; Rose et al., 2007). Further, a government buyout of private property has a precedent in the case of Devils Lake, which bought the community of Churches Ferry under the auspices of the emergency authority vested in FEMA. While the transaction costs could be considerable, it is not likely that they would achieve the aforementioned magnitude. As a result, while they would likely decrease the discount rate estimated by the model, they would not decrease it enough to change implications of the analysis.

CHAPTER VII

CONCLUSIONS

Devils Lake has been flooding since 1992 and will continue flooding into the foreseeable future. Since the Lake surface exceeded 435.9 m (1430 ft.) in 1994, $864 million (1994 USD) has been spent implementing CIP. While CIP was initially predicted to have a positive benefit cost ratio, it has since proven to cost more than the infrastructure it was designed to protect. Upon initial examination this appears to be an economically inefficient solution. Yet, a closer inspection of the qualitative and quantitative characteristics of Devils Lake reveals a much more intricate and complex situation than a superficial examination would imply.

From a qualitative perspective, Devils Lake is a wicked problem because it exhibits a number of discrete traits including: the unique nature of the lake and flooding caused by climatic fluctuations; the socio-political complexity resulting from the sheer number of policy actors involved in the policy solution and the contention between them; the uncertainty surrounding future lake level rise and the impact mitigation would have on downstream communities; the lack of clear "good" solutions; and the lack of any distinct endpoint. This is a useful conceptualization of Devils Lake because it allows us to easily define the multiple levels of complexity characterizing the policy setting and problem-solving processes enacted in response to flooding. Further, it distinguishes Devils Lake flooding from normative problems that are much easier to solve, and if confused with wicked problems, can lead to reckless and/or ineffective policy solutions.

Although the qualitative elements of the problem are useful in focusing more attention to the scope and magnitude of the Devils Lake flooding, it is the quantitative factors which drive the in-depth analysis that is ultimately useful within traditional governmental decision-making paradigms. These paradigms are primarily focused on the cost-effectiveness of proposed responses to an identified problem. With that in mind, this thesis utilized a cost-effective analysis to compare the incremental government policy of Continuing Infrastructural Protection (CIP) with the estimate one-time cost of a relocation/buyout of the at-risk communities. The model used to determine the Expected Present Value[11] (EPV) and Expected Total Cost[12] (ETC) of CIP over time took into account both the likely exceedance probability of the lake for a given, as well as, the likely range of potential discount rates.

The results indicated that the rate at which policymakers discounted CIP over the more long-term strategy of relocation/buyout was greater than or equal to 27.2%, assuming an exceedance probability of 100%. This result is highly sensitive to the assumed exceedance probability. However, assuming a likely range of exceedance probability between 90% and 100%, the rate of discount was likely between 27.2% and 24.5%. This thesis focused on the high discount rate based upon the fact that the CIP expenditures were 100% likely once the lake surpassed the action level of the designed protection level for a given feature at risk from flooding. Further justification comes from the fact that the observed lake levels over the course of flooding were within 1 ft. of all the lake levels predicted by the USGS to have at least a 10% or smaller probability of occurring. This means that the observed maximum lake level was greater than or equal to approximately 90% of possible predicted lake elevations.

This thesis also described the most common rationales for discounting future costs in a CEA. Regardless of rationale, the results suggest the rate of discount of CIP over relocation/buyout was the reason the ETC of CIP differed from the actual total cost of CIP over the course of flooding. The observed rate was compared to standard rates used by developed nations in BCA and CEA. Even the highest of these rates was only half of the observed rate in Devils Lake. The estimated discount rate determined by the model suggests that decisions of

[11] EPV is the total cost of CIP as adjusted by the exceedance probability and discount rate. In the model it is determined annually from 1994-2011.
[12] ETC is the EPV of CIP for a given year from 1994-2011.

policymakers were potentially characterized by a potential underestimation of CIP costs, a strong preference for short-term solutions over long-term ones, and/or a misperception of the statistical likelihood and risk of long-term flooding. It is not known which factor had the biggest impact on decision-making, and given the assumptions of the model it is likely that all three played a part in producing the high estimated discount rate reported in this thesis. What is clear is that a great deal more caution should have been used when assessing the costs, probabilities, and risk involved in Devils Lake flooding.

This type of caution is exemplified by the perspective of policymakers in Manitoba when determining the flood protection plan for Winnipeg and the surrounding areas. The key difference between the two situations was in how decision-makers valued uncertainty. In Devils Lake, the high rate of discount suggests that perceived risk of catastrophic flooding was low. This caused policymakers to focus on solutions that addressed the most likely short-term risk rather than than the low long-term risk. In Winnipeg, policymakers very clearly focused their efforts on the elimination of long-term flood risk when dealing with uncertainty in their estimates.

The difference in how each group dealt with uncertainty determined the long-term effectiveness of each group's flood protection. In Devils Lake, policymakers focused on an alternative that traded long-term risk elimination for small short-term investments. Winnipeg, on the other hand, focused on the elimination of long-term risk and built a floodway that was so expensive the Province had to amortize the costs over the next 50 years. The results of each groups' perspective could not have been more disparate and show why features of wicked problems (i.e. Devils Lake has many more decision-making entities involved) prevent effective solution alternatives from being implemented.

In the case of Devils Lake, the actual cost of CIP surpassed the cost of relocation in 2004, only 10 years after the onset of flooding. 18 years after implementing the incremental policy of CIP, the ratio of the actual costs of CIP as compared to relocation (Cost of CIP/Cost of Relocation), assuming an equal benefit from each alternative, is 0.91. In contrast, Winnipeg's cautious emphasis on the elimination of risk prevented four severe floods between 1969 and 1979 (Passfield, 2002). However, even if the Red River at Winnipeg experienced no flooding between the floodways completion and 1997, the estimated damages prevented by the Red River Floodway in the aftermath of the 250 year flood that occurred in 1997 were nearly 40 times greater than the cost of the floodway. In both cases, the initial predicted benefit-cost ratio was approximately the same, with the BCR of CIP over 50 years estimated to be 2.27 (Barr Engineering Co., 2003b) and the BCR of the Floodway estimated to be 2.73 (Passfield, 2002). The key difference is based on the fact that Winnipeg's cautious approach viewed the BCR in terms of the damages avoided in a low probability catastrophic flood and Devils Lake viewed the BCR of CIP in terms of the damages avoided in the most likely lake flooding scenario over the 50 year planning period (Anfang & Loss, 2003b).

In an ideal world, the results of the model would lead to an easily identifiable prescription for improving the past and future response to Devils Lake flooding. In an ideal world policymakers would have chosen to build a Pelican Lake outlet in 1998 that, given a very likely reduction of 15.24 cm (6 inches) per year, would have removed 1.98 m (6.5 ft.) from the Lake. Regardless of the fact that such an outlet was not economically justifiable, it was still chosen as the preferred alternative by the U.S. Army Corps of Engineers (Anfang & Loss, 2003c). At an estimated cost of $169 million (1994 USD), it was three times more expensive than the West-End outlet that was constructed in 2005. Given the assumed reductions, it would likely have prevented $371 million (1994 USD) in CIP costs since 1998. But this is not an ideal world. In this world the likelihood that the Lake would reach its current surface elevation and/or cost was so small that it was not even considered. Such is the state of uncertainty in Devils Lake.

Economic theory has long known that the treatment of uncertainty ultimately determines whether a given decision will have future economic benefits or costs. That wicked problems like Climate Change are characterized by social, technical, and political complexities that make Devils Lake seem insignificant is also not a novel idea. Although certainly not on the same scale, it is not logical to dismiss the lessons that an examination of Devils Lake can teach us. Ultimately, what the results of this thesis tell us is the cost of uncertainty in a specific case study. Yet, in the same way that a no-action scenario (wherein Devils Lake would be allowed to flood) was never considered, no one is seriously considering "do-nothing" approaches to long-term climate hazard mitigation. However, the preference of policymakers for decisions that mitigate short-term over long-term risks ultimately cost more than the decisions that eliminated long-term risk.

In Devils Lake, the extra costs of this preference for what can be considered as "wait and see" alternatives can be borne by society at large. However, whether society at large can bear the extra costs of waiting to respond to wicked problems on a global scale is a different question altogether, and one that is entirely outside the scope of this thesis. It is however, directly relevant. The case of Devils Lake suggests that alternatives which eliminated catastrophic long-term risk were more cost-effective over the long-term. While the likelihood of catastrophic impacts from climate change and other climate driven hazards is fraught with uncertainty, the enormity of the potential impacts should make us extremely cautious about waiting to respond to them. There is certainly a risk that they might not be as bad as we think, but there is an equal risk that they might be worse than we could have imagined. And like Devils Lake, how we choose to respond to that risk will make all the difference.

CHAPTER VIII

FUTURE RESEARCH RECOMMENDATIONS

The avenues for future research consist of: a refinement of the estimated cost of one-time relocation/buyout for the various Devils Lake communities in question and priority infrastructure; the creation of an elevation-based assessment for relocation in the region; the amortization of the costs of relocation/buyout as per the methodologies used by Barr Engineering and USACOE; a refinement of probability of future lake levels; and estimates of the maximum infrastructure and total deconstruction costs of CIP.

The first area of research involves refining the estimated cost of relocation/buyout. This is necessary to accurately take into account the full likely cost of relocating all of the structures in all of the communities. While the current estimate reported in this paper is accurate, because relocation/buyout as it is considered in this thesis has no analogues in previous relocation estimates, it is essential that the respective methodologies for determining the cost of relocation be compared, and the most justifiable method be established. Where the USACOE uses the average structure cost to determine relocation for an incremental buyout option, this thesis uses the true and full assessed property value for the city.

Each method has its strength and drawbacks. The Army Corps' method estimates the cost by building and property type, regardless of ownership type, and for unique or central buildings, uses the specific cost as reported by the owner. This method is suspected to overestimate the value of property because of the variability of property value in the area. The methodology used in this thesis prevents overestimating by using the True and Full value of all property used for tax purposes. However, this relies upon an estimate of public and non-taxable property from the city assessor. The accuracy of this estimate is not only difficult to determine, but it combines non-taxed and public buildings into the same amount. As a result of this, the cost of buyout is likely underestimated because it does not take into the cost of buying out non-taxed private property (i.e. churches, non-profit organization property, etc.) which could potentially drive up the price of a buyout.

An additional benefit to refining the estimated cost of relocation is the ability to parse out more specifically the infrastructure being relocated. In addition to producing a much more fine-tuned estimate of all the adjacent properties (i.e. Ft. Totten, Minnewaukan, and St. Michael), it would allow for the relocation estimate of these communities to be cross-referenced with their relocation cost as reported by the USACOE. Although this thesis used the USACOE relocation cost for these three communities, it is likely that the cost of relocation for these cities would increase were they determined to the same degree as the relocation cost for Devils Lake, because the cost would include the cost of infrastructure which was not considered in the Barr Engineering report.

The second area of research would tie the relocation/buyout cost to the elevation map of the region. This would require the creation of a digital elevation map that was classified by per foot increase in elevation. Such a map would require a fine spatial resolution (1 meter or smaller) and location and value data for the region. This data is available for Devils Lake and Minnewaukan, but it is not known if it is available for St. Michael and Ft. Totten. It would also require, for the pre-1994 elevation, all transportation to be identified and subsequently modified within the map to accurately reflect the elevation and cost of the roads relocation. A further component of this area of research would involve tracking down more accurate records of the cost of road raises and relocations. Current data has the transportation expenditures listed by year, but not by project. This would allow for the comparison of the road raising component of CIP (which comprise approximately 50% of total CIP costs) to be compared against the estimated cost of relocating roads around the Lake. This would also allow for a more accurate understanding of the relative long-term risk of catastrophic flooding to property value at a given elevation.

The third area for further research would use the refined estimates of relocation, as described by their relative spatial location and elevation, to compare an incremental relocation with CIP. This would use the same expected present value model described in this thesis and would more closely compare CIP with relocation as it was considered by policymakers. This would also allow for a comparison of incremental relocation, which is essentially a cross between a buyout and relocation as it is defined in this thesis (it only proposes to relocate structures below a given action level, and does not attempt to provide a new location or maintain community integrity).

The fourth area of research would tie the costs of CIP more closely to their given action and CIP level. This would allow for a refined assumption of the exceedance probability and also allow for the EPV of individual features to be determined. This would produce a much more nuanced understanding of the rate of discount used in decision-making and shed insight on the relative preference of decision-makers for CIP or relocation by feature. This provide for a range of likely discount rates, which could be used to produce a more robust sensitivity analysis.

The fifth area of research involves comparing the CIP Cost/elevation data previously described in terms of their expected present value as amortized over the 50 year planning period for USACOE water projects. This would allow for CIP as it was described in previous BCA analysis to be compared against its actual implementation over time. This would show the difference between the predicted BCR of CIP and the actual BCR of CIP.

The sixth area for further research involves developing cost estimates for future CIP up to the maximum elevation level, and the eventual deconstruction of CIP when the lake level recedes. If the lake were to revert to 1992-1993 levels, much of the transportation infrastructure would prove to be incredibly unsafe. It is also not known how stable the current levee protection would be, as it would be nearly 50 ft. higher than the lake surface in some places. The best example of this is Highway 57 which, if the lake were to recede to 1992 levels or lower, would be nearly 40 feet higher than lake. The cost of adapting current infrastructural levels to a decreased lake has never been considered. Estimating this cost would allow for the total cost of relocation to be compared against the total cost of CIP over the long run and would provide insight into the possible magnitude of intergenerational costs associated with short-term mitigation strategies used in Devils Lake.

The final area of future research involves estimating the financial impact of flooding in the Devils Lake basin. This would require the use of a regional economic model of the region, and the estimated loss from agriculture and property. Such a model is operated by Randall Coon at North Dakota State University, and could be done collaboratively with him. Most significantly this would require a determination of the area of land that is inundated each year and its potential use. These results could be obtained using the Farm Financial Database net production statistics recorded by the University of Minnesota. It would also require a basic land classification methodology to differentiate between cropland, grazing land, and urban residential land. The value of these different types of properties would be determined using a standard crop mix for each year and combined with a 1 ft. contour map to determine the lost value. This would be useful because, as one component of CIP, the compensation provided for flood losses in the region has never been compared with the flood losses that have occurred.

One additional area of research with an attenuated link to this thesis is the economic effectiveness of the policy responses to wicked problems. In the academic literature there are many examples of wicked problems, however, it is not known how much analysis has been done on the cost-effectiveness of the solutions, regardless of whether a solution was traditional or "wicked" in its response. Such research might lead to more comprehensive BCA or CEA methods that would be better equipped to more accurately predict the economic impact of complex policy responses.

Pursuing these areas of research would refine the results of this model and shed light on decision-making in response to long-term climate hazards like Devils Lake. It could also potentially identify potential strategies that could be used to ensure that the mitigation strategies in response to larger climate-driven problems don't have the same long-term economic inefficiencies that characterize Devils Lake. It would also contribute to our understanding of how to assess the cost effectiveness of alternative mitigation measures in response to wicked problems in the future.

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